Duration of the Snow Cover and the Need for Artificial Snow—A Challenge for Management in Ski-Centres of Serbia

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Abstract The production and use of artificial snow has become necessary in most ski centres in Europe. The lack of snow creates problems in ski centres that were built without the prior valuation of natural factors. The survey covered winter tourist centres in Serbia, which are facing problems due to the shortening of the tourist season caused by the lack of snow cover on the ski slopes. The duration of the snow cover is the result of several factors. Air temperature changes were analysed in mountain tourist centres in Serbia, as well as at undeveloped destinations with a potential for snow sports. On the basis of the quantitative indicators of the air temperature and the methodology by means of which snowmaking is carried out, the time periods during the year for making artificial snow are presented. Due to the forecast rise in air temperature, the issue of profitability of artificial snow in the ski centres of Serbia remains open.

Keywords Snow cover · Air temperature · Duration · Correlation Index · Serbia

In the last 40 years, winter tourist centres have faced a number of problems due to climate change. According to importance for the development of winter sports tourism in the mountains, climatic elements are indexed and ranked as follows: precipitation—index 6.04, thermal component (temperature and humidity) 5.84, insolation 5.55 and wind speed 5.41 (Scott and Lemieux 2010). Depending on climatic factors, the problems are different, but they are reduced to the lack of snow cover. Since 1966, higher air temperature and uneven precipitation have affected the 10% shorter retention of snow cover on the northern hemisphere (Folland 2001). Observations show significant reductions in the North Hemisphere's (NH) snow cover extent over the past 90 years, with most of the reduction occurring in the 1980s. Because of earlier spring snowmelt, the duration of the NH snow season has declined by 5.3 days per decade since the 1972/1973 winter (Stocker 2013). By the end of the 20th century, Alpine tourist centres rarely faced the lack of snow. However, for three years in a row

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W. Leal Filho et al. (eds.), *Climate Change Adaptation in Eastern Europe*, Climate Change Management, https://doi.org/10.1007/978-3-030-03383-5_10

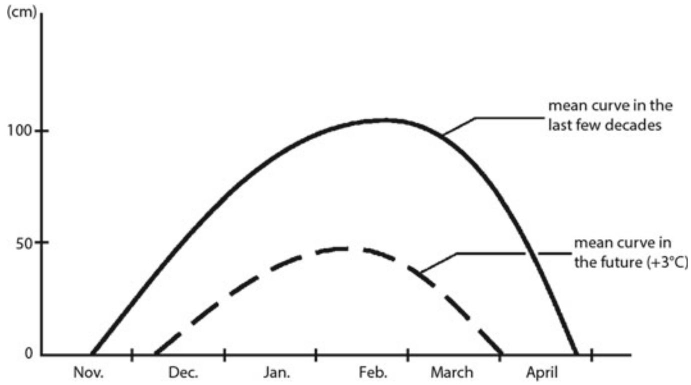

Fig. 1 Descriptive presentation of snow depth during snow cover period at the altitude of 1500 meters during the last few decades and a future scenario (Foehn 1990)

from 1987 to 1990, winters were unusually warm, affecting destinations by reducing the number of overnight stays and profits of resorts, transport companies and retail chains. A smaller number of tourists affected negatively the vulnerable rural areas in which tourism is the main economic sector, but also a reason for the survival of local population. The lack of snow cover was most expressed in lower altitude centres, with poor orientation of ski trails and sensitive ecosystems. During the winter season with the lack of snow in most visited centres, ski centres located at high altitudes (close to or above snow line) have benefited. According to most climate change scenarios in the Alps's winter tourist regions, the temperature of the air will be increasing, while the pattern of the future distribution of precipitation varies (Koenig and Abegg 1997; Moen and Fredman 2007; Wilcke et al. 2012). As a result of an increase in the air temperature in the Alps, the rising of the snow line, a delayed beginning of the tourist season and the shortening of the season by one month are expected. New strategies and plans for tourism development have been announced in order to adapt to climate change. So far, dozens of papers have been published on the effects of climate change on winter sports tourism. In relation to the methods of adaptation to climate change since then, various aspects have been studied: winter tourism adaptation to climate change (Abegg et al. 2007; Scott and McBoyle 2007; Wall and Badke 1994) stakeholder views and risk management (Trawöger 2014), costs of snow making (Hahn 2004) and the effects of artificial snow making (Caravello et al. 2006; de Jong and Barth 2007; Rixen et al. 2003) (Fig. 1).

Although most papers on the impact of climate change on ski tourism in Europe focus on Western and Northern Europe, some recent studies suggest that ski tourism is threatened by climate change in the countries of Central Europe and the Balkan Peninsula, such as Poland (Bil 2018), Slovakia (Mikloš et al. 2015), Slovenia (Ogrin et al. 2011; Vrtačnik Garbas 2009), Romania (Micu 2009), Bulgaria (Demiroglu 2016; Grunewald et al. 2009), and Serbia (Djordjevic et al. 2016; Stojsavljević et al. 2016). On the Bulgarian mountain Musala (period 1973–2006) the main changes are: a general decrease of days with temperatures below 0 °C, a significant longer vegetative period (>5 °C), and the tendency to shorter winters and longer summers (Grunewald et al. 2009). Some Romanian mountain areas (particularly in the Southern Carpathians) are supposed to experience more rainy than snow days, during winter ski season (December–March) and a rise of temperature by over 1.0 °C until 2050 (Micu 2009). Econometric studies for Romania (Dincă et al. 2014; Surugiu et al. 2010, 2011), Slovakia (Demiroglu et al. 2015), Slovenia (Vrtačnik Garbas 2007) and Bulgaria (Mochurova et al. 2010) confirm that observed climatic changes in the ski resorts could lead to losses in tourist business. Demiroglu et al (2015) predict that due to the anticipated temperature increases, sales in Slovak ski resorts in the 21st century will drop by 6.6–19.2%. Slovenian ski resorts are even more vulnerable in comparison to other ski resorts in the Alps, since they lie at lower elevations. Furthermore, this means that winter tourism will need to focus on other activities; they will also need to focus on the summer season and on transitional periods as well (Ogrin et al. 2011). Damm et al. (2016) predict that in the period 2035–2065 the ski season in Slovakia and Slovenia will be shorter compared to the period 1971–2000; in some resorts it will be shortened by more than 30 days.

Adaptation to the winter season with a shorter retention of snow cover includes several strategies: 1. relocation or construction of ski centres at higher altitudes, 2. development of special interest tourism, 3. artificial snow making and 4. cooperation between companies.

At the latitudes between 40 and 45° N, due to the theoretical height of the modern snow line (of about 3000 m), the *first strategy* is possible in mountains where there are spaces (e.g over 2500 m where ski runs and installations are not yet built) (Grunewald and Schiethauer 2010; Milivojević et al. 2008). Spaces above 2500 m in Serbia are negligible. They are located on Šara mountain and on Prokletije, so this strategy is not a solution. In addition, there are numerous works in which negative effects of mass construction in already existing ski centres with over 1200 m are proved (Bjedov et al. 2011; EJR 2018; Potić et al. 2015; Ristić et al. 2008a, b, c, d, 2009; Šušić and Đorđević 2013). Ski resorts of individual centres are located in fragile reserves within national parks (Kopaonik, Shar Planina) and nature parks (Zlatibor, Stara planina).

A good example of the *second strategy* is the Romanian mountain resort of Sinaia, whose profile is more for business, weekend and recreational tourism and not only for winter sports tourism. Research indicates that the Sinaia resort is not very vulnerable to climate change. Reduction in snow cover depth and increase in mean air temperature attract tourists and increase the number of overnights in Sinaia. Thus, climate change expressed through increase in temperature does not necessarily bring only negative effects, but depending on the profile of the resorts, it can also bring positive effects (Surugiu et al. 2011). In Serbia, the second strategy has a tradition of 10 years in the mountains like Kopaonik, Zlatibor, Zlatar, Stara planina, Suva planina and Maljen. There is an offer of special interest tourism where tourist activities take place during the spring, summer and autumn. This is a part of the year in which snow cover is not a critical climatic element (Joksimović et al. 2015; Vujadinović et al. 2013).

Consequently, the climate is not a limiting factor of tourism, but, depending on the nature of the changes, stimulates one and limits other forms of tourism.

The rising trend in air temperature in Serbia is in line with trend in Europe. Analysis of the time series of the North Atlantic Oscillation (NAO) and EA index showed that both factors influenced the increase in air temperature in Serbia. In the period during the winter, an increase in air temperature was recorded from 0.02 to 1.82 °C (Bajat et al. 2015; Unkašević and Tošić 2013). The increase in air temperature is influenced by modifiers such as altitude, terrain morphology, aspects, slope angle, vegetation, hydrographic objects and settlements. The *third* and *fourth strategies* have been implemented for 20 years in mountain centres. However, in the action plans and master plans of winter tourism, climate data are not analyzed in the context of climate change (ECOSIGN 2007; HTL 2009). Since climate change does not affect all destinations equally, research at the regional level is one of the ways that can effectively respond to the needs of winter sports centres. Regional climate models have been identified as the best solutions for climate change and impact scenarios (Wilcke et al. 2012). Among the climate change scenarios, the warm and dry climate scenarios, as well as the humid and cold climate for the periods 1961–2000 and 2001–2050, are used equally. The most widespread climate change strategy is investing in building a system for artificial snow making (Wolfsegger et al. 2008). Snow making has become the method most used to overcome immediate impacts of climate change in ski resorts worldwide (Demiroglu 2016). It often creates a conflict between investors and communities advocating environmental protection (environmentalists). Creation of artificial snow leads to permanent environmental impact which requires great energy and huge amounts of water. By building up the accompanying infrastructure, the ecosystems and the aesthetic properties of the area are disturbed. The most common problems arising from the unplanned construction of ski resorts and artificial snow systems are: deforestation, erosion processes, increased floods and torrents, and aesthetically degraded area without vegetation, unattractive outside the ski season.

Production of artificial snow was developed in North America in the fifties and sixties of the 20th century. It occurred in Europe during the seventies (Hahn 2004). The basic factors that influence production of artificial snow are: water, energy, air temperature and humidity. Water is dispersed during the day or night when the air temperature is below 0 °C and falls on the surface as snow. With the current technology, air temperatures ≤ -1 °C and air humidity of more than 40% are required to make artificial snow. On a wet thermometer, the air temperature is ≤ -5.1 °C. With the use of certain additives, the required air temperature can be higher. Resulting artificial snow differs from the natural one due to the different appearance of snowflakes. Water used for artificial snow is extracted from rivers, springs or lakes. Its composition is different from rainwater, which makes snow different (Rixen et al. 2003). For the production of artificial snow 30 cm thick, on an area of one hectare, 1000 m^3 of water is needed (Hahn 2004). Snow making systems are used mostly at night. Accordingly, the reference is air humidity after 21 h and the mean daily air temperature below 0 °C. The use of water from rivers, springs, underground water and water supply reduces the water level in the lower areas, which causes ecological

Table 1 Wet bulb temperature as a factor for artificial snow production

Air humidity (%)	Air temperature (°C)								
	3	2	1	0	−1	−2	−3	−4	−5
100	3	2	1	0	**−1**	**−2**	**−3**	**−4**	**−5**
80	1.7	0.7	−0.2	**−**1.1	**−2.1**	**−3**	**−4**	**−4.9**	**−5.9**
60	0.3	−0.5	−1.4	−2.3	**−3.2**	**−4.1**	**−5**	**−5.8**	**−6.7**
40	−1	−1.8	−2.6	−3.5	**−4.3**	**−5.1**	**−5.9**	**−6.8**	**−7.6**
20	−2.5	−3.3	−4.1	−4.8	**−5.6**	**−6.4**	**−7.2**	**−8**	**−8.4**

Source Lang 2009

consequences. The costs of snow making have been investigated in several papers (Abegg et al. 2007; Hahn 2004) (Table 1).

The objectives of artificial snow making are:

1. Artificial snow production should respond to the demands of the skiers—to match the lack of snow cover and to respond to the demands of a large number of tourists;
2. Production of artificial snow should bring profit to investing companies;
3. Providing the image of sports destinations where skiing competitions are held;
4. It should provide a framework for training, recreational ride and sporting competitions.

In addition to these, we emphasize that the construction of a snowmaking system should be in accordance with the environmental conditions and resources in order to avoid adverse effects on relief, water and habitats.

1 Climate Conditions as a Factor of Development of Winter Sports Tourism in Serbia

The development of winter sports tourism has a tradition of 90 years. Initially, the development of winter sports was related to mountains near major cities. In Avala near Belgrade, in 1929, a cross-country skiing competition was held at 8 km. With the opening of the first mountain hut on Kopaonik in 1935, the tourist stage of skiing in Serbia began. This also started the phase of valorization of climate indicators (air temperature, snow cover) for the purpose of opening ski centres. The number of competitors, recreationalists, trails and infrastructure facilities increased. The first competition in alpine disciplines in Serbia was held at Kopaonik in 1936 (Mišović and Nišavić 1951). Today, winter sports tourism in Serbia is developing on several mountains. Due to climate change, investments in ski tourism are becoming more risky. In the 1991–2016 period, on Kopaonik, there were 31% days with a snow cover of less than 30 cm, which led to the production of artificial snow. The duration of a snow cover suitable for skiing influences the tourist demand and the hosts of the offer are forced to produce artificial snow.

Winter sports tourism includes sports that take place on the snow cover or in relation to the snow cover: alpine skiing, cross-country skiing, ski jumping, climbing, sledding, curling, skating etc. In Serbia, artificial snow systems are developed in five ski centres: Kopaonik, Stara Planina, Zlatibor, Brezovica and Tara. The systems are used to provide ski trails with artificial snow in periods when there is no natural snow. This ensures the stability of the ski season, i.e a response to the demand of the skiers as well as the profit of the stakeholders.

The systems were built successively, with the extension of the cableway and the construction of new tracks. For the needs of snow making, mini accumulations were made, followed by pumping plants, piping installations of water and air, compression plant and snow machines. On Kopaonik, since 2008, the old system for regeneration has been revitalized and a new one has been set up in four phases: 2008, 2009, 2010, 2012. System management is regulated by software. In this way, relative to the current temperature, humidity and wind direction can be controlled by the process of snowmaking to obtain the desired quantity and quality of snow. For the production of artificial snow, natural, unprocessed water is collected in accumulation lakes without chemical additives. Kopaonik resort is equipped with 300 fixed and 15 mobile snowmaking devices (Infokop 2014).

On the basis of climatic indicators, the aim of our work was to underline regions with comparative advantages as well as a time frame for artificial snowmaking in Serbia. We believe that in our work the original methodology for allocating regions with comparative advantages for artificial snow making has been applied. Our standpoint is that it is necessary to use the natural conditions for skiing in the less valued ski centres in order to reduce tourist pressure on main ski centres developed in fragile areas. This would probably reduce the need for snowmaking and prevent further degradation of the environment.

2 Method and Observational Data

In order to determine climate potential for skiing in different regions of Serbia, the Kopaonik ski resort was selected as the basic model of research. The aforesaid centre has the longest tradition of winter tourism development and a complete database of climate data as compared with other stations. The determined indicators are the duration of the snow cover, the number of days with the average daily temperature below zero, the relative humidity, the average height of the snow cover by months at the daily level and the average number of tourist nights by months. Based on the Kopaonik model, the correlations of climate indicators were analysed and the need for artificial snowmaking was determined for other stations. At the regional level, ski resorts (ski runs and infrastructure for skiing without accompanying accommodation facilities) and ski centres (ski resorts with built accommodation facilities and a number of services) were allocated. Among ski centres, there are complex resorts, weekend resorts, city resorts and spa resorts. Based on the Kopaonik model, a regional climate model for the other existing 16 ski resorts and ski runs has been given.

These models required data at a different spatial level and are based on a different time series—the statistical data of the Republic Hydrometeorological Service of Serbia (RHSS 2017), the Statistical Office of the Republic of Serbia (SORS 2017), unpublished data of the Ski Resort of Serbia (Infokop 2014, the data obtained by field research and created by GIS software. The data related to the 1991–2016 period and a special focus was put on the winter tourist season (December 1–April 15). On DEM (digital elevation map) we determined regions with 900 m of altitude and higher, where the largest number of ski resorts is concentrated. Those regions are located mainly in the southern part of Serbia. Numerous valleys, mountains and plateaus are part of the Dinaric, Carpathian, Balkan, Šara-Pindus systems and the Serbian-Macedonian mass. A limit in the survey was the fact that in 10 of the 18 ski resorts climate station do not exist (Table 2). Due to the lack of climatological stations, we used informal sources of data on the number of days with snow cover (Stara planina, Golija) and data from near stations that do not represent ski resorts but are at a similar altitude (e.g. RC Kamenički vis for Bojanine vode – Suva planina).

We used the correlation method to determine the connection between the average values of the number of days with snow cover, the average number of days with the average air temperature below 0 °C and the number of overnight stays in individual centres. To determine the correlation (Correl) of the time series of these indicators, equation was used:

$$Correl(X,Y) = \frac{\Sigma\left(x - \bar{x}\right)\left(y - \bar{y}\right)}{\surd\Sigma\left(x - \bar{x}\right)^2\left(y - \bar{y}\right)^2}$$

where x and y are the average values of given variables (climatic elements and indicators of tourism) of time series x and time series y. If the obtained value is closer to number 1, the correlation is higher, and vice versa, if it is further than the number one, the correlation is lower.

In order to determine the ratio of snow cover and air temperature as a factor determining the need for artificial snowmaking, we suggest a new index of artificial snow (IAS) with the proposed equation:

$$I_{as} = \frac{N_{ds}}{T_{\ avg<0\,°C}}$$

where N_{ds} is the average number of days with snow cover over the year and $T_{\text{avg}<0\,°\text{C}}$—number of days with average daily air temperature below 0 °C. If the index is closer to number 1, climatic conditions are more suitable for artificial snowmaking.

For the mapping of the results, we used tools in the Global Mapper v15.2—points styles based on attributed values (temperature data) and Voronoi diagram (average

Table 2 Basic data of ski resorts and ski runs in Serbia

	Ski resort/ski run	NUTS 3 region	Climate station/ski run altitude (m)	Climate data time series	Type of winter sports destination	Snowmaking (number of ski runs of total)
1	Kopaonik	Raška, Rasina	1710	1991–2016	Complex resort	27/37
2	Babin Zub—Stara planina	Zaječar, Pirot	1758	n/a	Complex resort	2/8
3	Tornik—Zlatibor	Zlatibor	1028	1991–2016	Complex resort	4/5
4	Brezovica—Šar Planina	Prizren	915	1991–2008	Complex resort	1/8
5	Crni Vrh—Divčibare	Kolubara	980	n/a	Complex resort	1/2
6	Golijska reka—Golija	Moravica	1420	n/a	Ski-run	0/1
7	Odvraćenica—Golija	Raška	1620	n/a	Weekend resort	0/4
8	Goč	Raška, Pomoravlje	990	1991–2016	Weekend resort	0/1
9	Iver-Tara	Zlatibor	1250	n/a	Complex resort	2/4
10	Vlasina	Pčinja	1190	1991–2016	Weekend resort	0/1
11	Sjenica	Zlatibor	1038	1991–2016	Ski-run	0/1
12	Crni Vrh	Bor	1037	1991–2016	Ski-run	0/2
13	Nova Varoš—Zlatar	Zlatibor	985	n/a	Town resort	0/1
14	Lukovska Banja	Toplica	770	n/a	Spa resort	0/1
15	Bojanine vode—Suva Planina	Nišava	864	n/a	Ski-run	0/1
16	Kraljevica—Zaječar	Zaječar	144	1991–2016	Ski-run	0/1
17	Besna Kobila	Pčinja	1480	n/a	Weekend resort	0/1
18	Rajkovo—Majdanpek	Bor	750	n/a	Ski-run	0/1

Source field survey taken from 2013 to 2018

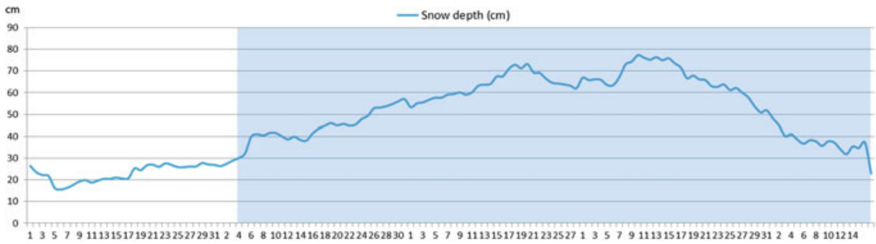

Fig. 2 Average natural snow cover depth on Kopaonik ski resort (1710 m) (season 1 Dec–15 Apr) in period 1991–2016. *Source* RHSS 2017

number of days with show cover) were used. The equation for the Voronoi diagram is:

$$reg(p) = \bigcap_{q \in S - \{p\}} dom(p, q)$$

where the area of region (*reg*) is the proportion dominated by point *p*, *p* and *q* are two adjacent centres/stations, *S* is a series of *n* points (climatological stations) and *dom* (*p*, *q*) domination of *p* over *q*.

3 Results

During the second half of the 20th century, modern ski centres in the northern hemisphere were considered destinations of winter sports if in 7 of 10 winters a snow cover 30–50 cm deep appears at least 100 days between 1 December and 15 April (Abegg 1996). According to that criterion, as well as the available data, in Serbia, over the last 20 years, it is only Kopaonik that stands out as there the natural snow cover with an average depth of more than 30 cm lasts on average from January 4 to April 15 (101 days) (Fig. 2). The number of days with an average daily air temperature below 0 °C is 67, adding the number of days with the air temperature below 0 °C at 21 h. With the average air humidity of 85% from December to April, the air temperature forms the basis of a high-quality tourist season. Compared with other mountain centres in Serbia, Kopaonik has the highest number of overnight stays in the winter season—an average of 66% of annual overnights. Because of this, this centre is the most sensitive to climate change.

In the 2008–2016 period, on Kopaonik there were five winter seasons with an average of 43 days of snow cover and with a minimum depth of 30 cm. Therefore, the justification for the construction of an artificial snow system is encouraged. During the winter season 2013/2014, the depth of the natural snow cover exceeded 30 cm only for a few days (Fig. 3). With systems for artificial snow, the depth was held at a relatively uniform level of 15–30 cm because the air temperature did not have a

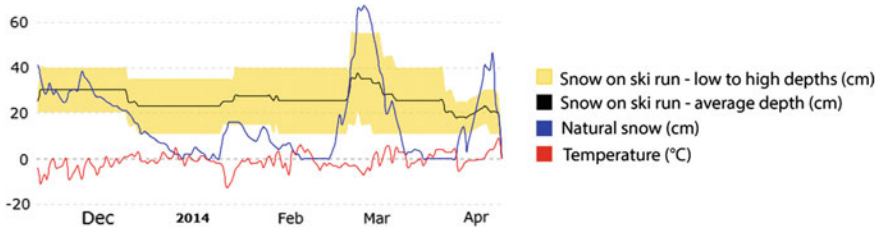

Fig. 3 Snow cover on Kopaonik during winter season 2013/2014. *Source* Infokop 2014

continuity of rise, that is, it allowed for snow making. The production of 1 m^3 of snow on Kopaonik costs 20 dinars (0.15 euro cents), which is significantly less than the price in Alpine centres, where it ranges from 2 to 5 euros per 1 m^3 (Badre et al. 2009; Hinnerth 2012). In addition to other factors, this is due to lower electricity prices and the use of natural water that is not paid. For example, 1 kWh of electricity in Germany costs 30.5 cent, in Italy 21, in Austria 19.5, in France 16.9, in Slovenia 16.1 while in Serbia it costs 5 euro cents. It is interesting that a one-day ski pass in these countries, depending on the ski centre, costs from 30 to 40 euros, while on Kopaonik, in the 2016/2017 season, it cost 26.8 euros. The price of a one-day ski pass during the 2010/2011 season, which was only 18 days with a snow cover of 30 cm deep, was 19.6 euros. The price of a ski pass during the 2013/2014 season, in which there were only 21 days with a natural snow cover above 30 cm, reached 28 euros.

It is obvious that the costs of snow production are not correlated with the price of a ski pass in Serbia, i.e. that the price is unrealistically high in relation to the cost of artificial snow production. The price of a ski pass determines the tourist demand and, vice versa, the price of a ski pass is stimulated by the tourist demand. If one compares this with the prices of ski passes in other ski resorts in Serbia, the price in Kopaonik winter resort is twice as high.

In other ski resorts and ski runs in Serbia, the number of snow-covered days ranged from 41 (Zaječar) to 123 (Crni vrh). The number of days with the age daily air temperatures below 0 °C was from 15 (Zaječar) to 58 (Crni vrh). Among the stations where there are no ski runs, as a potential, we can point out the mountain Kukavica (1442 m) in the Jablanica District, where there were 130 days with snow cover and 52 days with daily air temperature below 0 °C. The average monthly relative air humidity at 21 pm was above 80% at all stations, which at 0 °C allowed −1.1 °C and, thus, the production of artificial snow.

Correlation of N_{ds}—average number of days with the snow cover and number of days with $T_{avg<0\,°C}$ for the selected stations is high, but the difference between stations is not significant (Table 3). This indicates that low air temperatures are important for the maintenance of snow cover in ski centres. Correlation $T_{avg<0\,°C}$ and H_{avg}—average humidity by month (at 21 pm) indicated a relatively significant correlation between air temperature and air humidity. Among the stations, only Kopaonik, as the highest station, recorded a minor correlation between humidity and frosty days. This can be

Table 3 Correlation between climate and tourism data

	Correl (N_{ds}, T_{avg} < 0 °C)	Correl (T_{avg} < 0 °C, H_{avg})	Correl (N_{ds}, N_o)	IAS
Kopaonik	0.96	0.30	**0.75**	2.46
Brezovica	0.94	0.77	n/a	3.48
Zlatibor	0.94	**0.81**	-0.30	3.00
Goč	0.96	0.77	0.03	2.41
Vlasina	0.93	n/a	n/a	2.91
Crni vrh	**0.97**	0.71	n/a	2.12
Dragaš	–	–	–	3.20
Kamenički vis	–	–	–	**1.82**
Kar. bunari	–	–	–	2.58
Kučevo	–	–	–	2.64
Kukavica	–	–	–	2.50
Sjenica	–	–	–	2.86
Zaječar	–	–	–	2.73

Explanation: N_{ds}—average number of days with snow cover by month, T_{avg} < 0 °C—average number of days with average temperature bellow 0 °C by month, H_{avg}—average humidity by month, N_o—average number of tourist overnights

attributed to the altitude and the micro-climate of a climatological station located in a forest environment. The correlation of N_{ds} and the number of tourist overnights indicates the affirmation of tourist centres for snow sports. Kopaonik had a significant correlation and it was primarily the snow cover that attracted tourists. The high correlation of the number of days with snow and the number of overnight stays indicates the sensitivity of the tourist season in relation to the snow cover. Therefore, Kopaonik on one side and other potential centres of winter sports tourism on the other can be identified as a priority for the construction of a system for artificial snow. On Zlatibor and Goč, the correlation between N_{ds} and N_o was not significant, which points to orientation towards other forms of tourism (Fig. 4).

The results of the artificial snow index calculation (IAS) indicate the different potentials for artificial snow. The Kamenički vis station near Niš had the most favourable index—1.82, which could refer to the Bojanina voda ski run on Suva planina, due to a similar altitude and relative proximity. The Brezovica station had the most unfavourable snow index—3.48 due to a small number of days with $T_{avg<0\ °C}$. That can be explained with specific location and southern latitude compared to other stations. According to the snow index, among the built ski centres and ski runs the order is following: 1. Crni vrh, 2. Goč, 3. Kopaonik, 4. Zaječar, 5. Sjenica, 6. Vlasina, 7. Zlatibor and 8. Brezovica. Among the explored mountains, according to the snow index, the biggest potential for the construction of ski resorts is on Kukavica and Carpathian Mountains around Majdanpek. In addition to these results, we note that climatological data are missing for some developed ski runs and ski resorts

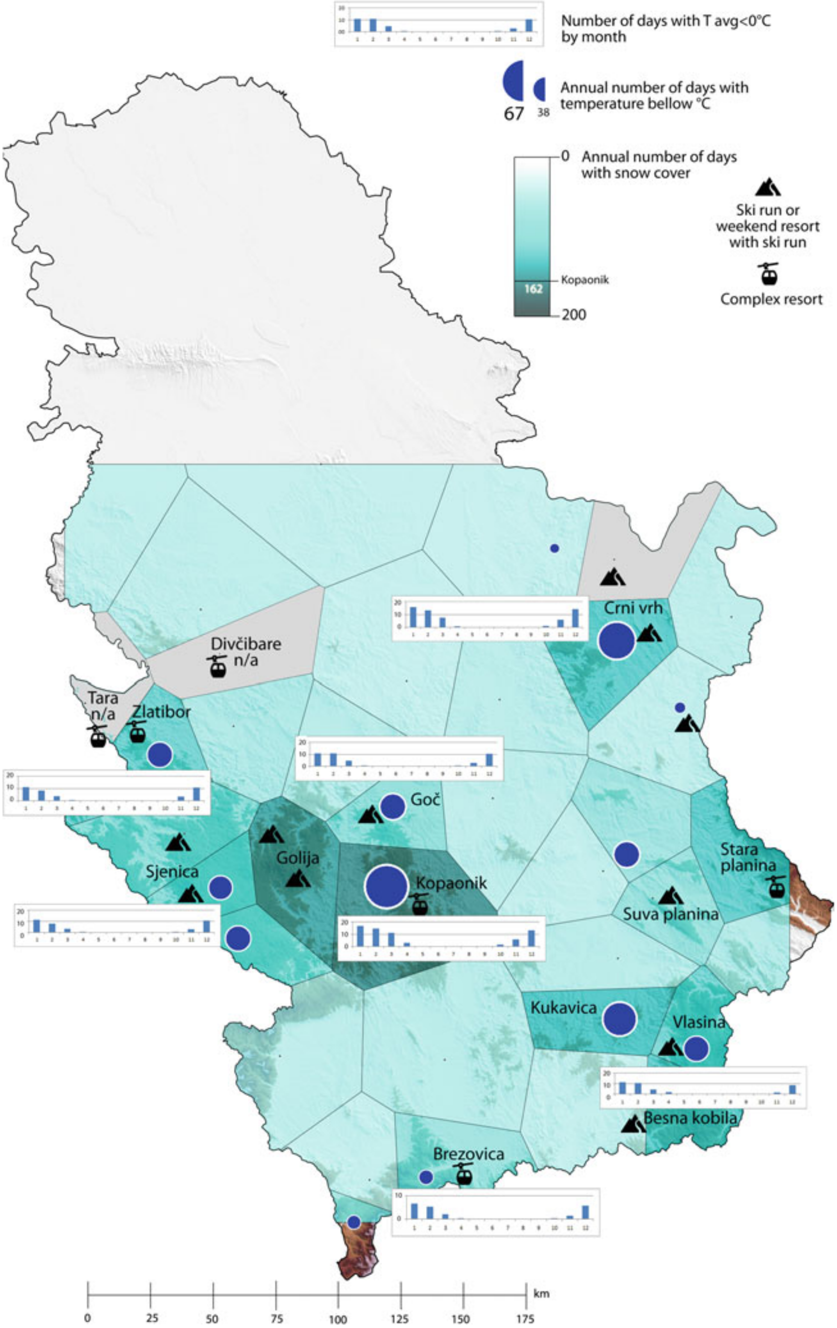

Fig. 4 Climate conditions for artificial snow production in Serbia

(Divčibare, Stara planina, Golija, Tara and Besna kobila) where de facto there is a potential for snowmaking and ski season maintenance.

4 Conclusion

Research on the snow cover as a factor for the development of winter tourism in Serbia is based on the fact that this niche of tourism provides much more than recreation for tourists. The pragmatism of applied regional climatology lies in the natural conditions that enable winter tourism and affect the area in which it develops. Experiences from ski centres in the Alps indicate that climate change is subject to all but the most vulnerable ski centres in rural areas where tourism is the main industry. Among the modes of adaptation to climate change applied in European ski centres, the only one known in Serbia is the practice of artificial snowmaking with the constant monitoring of environmental indicators. Stakeholders in all winter destinations should consider the type of adaptation to further warming and less frosty days.

Among the limitations in our research, we point out the small number of relevant climatological stations in Serbia, because of which the climatic data base is incomplete. Also, we point out the lack of data about snow cover created by snowmaking in developed ski centres (except Kopaonik). We believe that, allowing for limitations and methodological imperfections, the contribution of this work lies in determining natural conditions for the existence of a quality season for winter sports. The paper presents ski centres, ski resorts and mountains where there are qualitative advantages for lowering tourist pressure on ski resorts of mass winter tourism. Reducing number of tourists, stopping the construction of new paths and infrastructure in ecologically sensitive areas guarantees the preservation of ecosystems and the value of the landscape of mountain areas in Serbia. The monopolistic impact of the leading stakeholders in winter tourism would be dropped and would open a path for projects of local self-governments and districts on whose territory there are mountains with comparative climate benefits. The results show comparative advantages in terms of climatic conditions for the duration of the ski season as well as possibilities for artificial snowing as a necessary form of adaptation to warmer winters with less natural snow.

By means of further research, the climatic conditions of importance for the duration and quality of snow cover at the daily level for the complete network of climatological stations in Serbia remain to be investigated. Also, we believe that our research could encourage the creation of prognostic models for the duration of the snow cover and thus the responsible planning of a snow making system.

Acknowledgments This paper presents the result of the research projects 176008, funded by the Ministry of Education, Science, and Technological Development of Republic of Serbia.

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