Review

Jie Deng et al., *Suitability Analysis of Ski Areas in China: An Integrated Study Based on Natural and Socioeconomic Conditions*, The Cryosphere Discuss., https://doi.org/10.5194/tc-2019-43

Reviewer: C. M. Carmagnola

This study presents a method to evaluate the suitability of existing and future ski areas in China based on a combination of natural and socioeconomic conditions. Blending geographic information system spatial analysis, remotely-sensed observations, online and field data, the authors were able to define an integrated index to identify the best suited locations for ski-resorts in the country. This index was evaluated using the locations of already existing resorts and more detailed information from a field survey of a panel of 35 resorts. Results show that 92% of the existing ski-resorts are currently located in areas with medium-to-high suitability indexes. As for future ski-resorts, this analysis framework could help driving new investments in the ski market at the national scale, by defining objective indicators to identify regions potentially interesting for developing ski-related activities. To this aim, the authors also suggest some broad strategies to guide the next steps of ski tourism industry in China.

The main novelty of this work lies in the method used for aggregating the different natural (snow cover, air temperature, topography, groundwater, vegetation) and socioeconomic (welfare, accessibility of transportation, distance to tourist attractions, distance to cities) conditions. Applying a linear weighting method allowed the authors to compute the relative contributions of each condition to the integrated suitability index. However, this part of the work also represents the weakest section of the paper in its current form. Indeed, the approach followed to compute and then aggregate the weight coefficients starting from a data sample of 128 ski-resorts is not presented clearly. In particular, it appears that the same dataset has been used for informing the aggregation method and to evaluate its results. Moreover, and perhaps more importantly, the computation of individual indexes, namely those for snow cover and air temperature, raises some concerns. In this regard, for example, is it not clear how the snow depth and snow cover days have been estimated and there seems to be some confusion between air temperature and wet bulb temperature, which is the main parameter for snowmaking. More generally, I would not overstate the importance of the main results of this study for a direct application. Even if the method can be seen as a first attempt to identify the main ski area's suitability pattens in China, a more detailed and refined analysis based on local data will be necessary before deciding to invest (or not) in a new ski-resort. In other words, the results of this study provide interesting guidelines for the ski market at the national scale,

but do not tell whether a specific resort will be, in fact, viable.

Overall the paper is easy to follow and well written, beside some small mistakes and sentences that need to be rephrased. In light of the novel approach and the great effort put by the authors in combining and homogenizing data coming from various sources in a consistent and coherent way, I support publication in The Cryosphere. However, several points should be considered to improve the presentation and some major issues should be addressed before publication can be recommended.

P.1 - L.19: "To evaluate" → "Therefore, evaluating".

P.1 - L.20: "has since become" → "has become".

P.1 - L.21: "using linear" → "using a linear".

P.1 - L.22: "information systems" → "information system".

P.1 - L.25-28: I would reverse the order of two sentences and rephrase them as follows: "As such, a metrics ranging from 0 to 1 considering both natural and socioeconomic conditions is used to define a suitability threshold for each candidate region for ski area development. A ski area is considered to be a dismal prospect when the locational integrated index is less than 0.5. The results show that 92% of existing ski areas are located in areas with an integrated index greater than 0.5".

P.2 - L.19: "freshwater resource" → "resource".

P.2 - L.22: On the effect of climate change on future snow conditions, you could also make reference to this recent work: Verfaillie et al. (2018).

P.2 - L.25: "particularly in lower elevation and mid-latitude ski areas" → "particularly at lower elevations and in mid-latitude ski areas".

P.2 - L.25-26: I do not entirely agree with this statement. In some cases, even at medium-to-long term, snowmwaking could prove to be useful for keeping ski areas reliable, compensating for the scarcity of natural snow (Spandre et al., 2018). While stressing very well the environmental impact related to snowmaking installations, this section does not focus enough on the added-value of machine-made snow production as a necessary complement to natural snow for ski-resorts. In this regard, you could see for example Steiger (2010), Hanzer et al. (2014) and Damm et al. (2014, 2017).

P.2 - L.30-31: These figures are a bit low. One ha of slope, covered with 30 cm of artificial snow having a density of 500 kg m^{-3}, will necessitate a water consumption of 1.5 million litres. However, snowmaking efficiency in converting water into snow is less than 80%. This is mainly determined by wind conditions, according to, for instance, Spandre et al. (2017). Therefore, in practice at least 2 million liters of water are needed to cover 1 ha with a 30 cm thick snowpack. As for the electric consumption, it is usually accepted that the current snow-gun generation requires 2 to 3 kWh to produce 1 m^3 of snow.

P.2 - L.34: "became critical since inappropriate selections" → "is critical since inappropriate choices".

P.3 - L.1: "To evaluate" → "Evaluating".

P.3 - L.5: An important reference that could be used to provide more information on the state of the Chinese ski market is Vanat (2019), in particular for the number of skier visits. This recent book updates some figures of the previous "China ski industry white book 2017".

P.3 - L.6: "public to" → "public in China to".

P.3 - L.25: "Systems" → "System".

P.3 - L.26: "linear weighted" → "a linear weighted".

P.3 - L.29: In the introduction, it is worth mentioning the work of Demiroglu et al. (2019) and Demiroglu (2019), who have defined a Ski Climate Index (SCI) to estimate the overall suitability of Turkey for ski tourism. This index has been designed as a combination of several factors, among which snow reliability, land cover, aesthetics, market accessibility, comfort (sunshine, wind and temperature conditions) and even security. There are several similarities between your approach and Demiroglu's.

P.3 - L.30-33: I would rephrase this section to improve clarity: "This paper is organized as follows: in Sect. 2, we provide a description of the data and method. Sect. 3 presents the results. Section 4 evaluates the method, discuss its limitations and proposes suggestions for the development strategy. The final section contains a brief conclusion and discusses future work."

P.4 - L.13: Please consider adding a table listing the values of each natural and socioeconomic index, along with their normalization (this has been done only for air temperature, in Table 2). Having a complete table summarizing all the indexes will greatly improve the readability of this section.

P.4 - L.17: "both as supplement and attractions". This is not clear, please rephrase.

P.4 - L.23: "rule as the most" → "rule and is the most".

P.5 - L.3: This entire "Snow cover" section should be revisited, since several vital points are quite obscure. What is the period considered to define the winter season? What is the minimum snow depth used to define a snow cover day? What do you mean when saying "snow depth is only taken as a reference for the index of snow cover"? When applying the 100-day-rule, did you consider consecutive or non-consecutive days? What MODIS bands and what products did you use to retrieve the snow cover fraction? How were the SD and SCD indexes normalized? You should also highlight the fact that these

observations are for natural snow only and the possibility to add some machine-made snow is taken into account by the next index, that for air temperature.

P.5 - L.17: The clarity of this section needs to be improved. First, it is not clear how you have computed daily mean and maximum air temperatures starting from a dataset of daily observations. Second, you do not explain what period you have considered to rule out high-temperature regions and if you require the 90 days with temperature greater than 10°C to be consecutive. Third, you should clearly distinguish between air temperature and wet bulb temperature. The latter is what really matters for snowmaking, and in this case the colder is the temperature, the better is the snowmaking efficiency. For this reason, you should explain that the 11 temperature regimes and their corresponding scores are designed as a trade-off between colder temperatures needed to preserve the snowpack and to produce machine-made snow and warmer temperatures needed by skiers. Finally, the effect of wind, which is not at all considered in this study, should be at least briefly discussed, since it can have a significant impact on both the attractivity of a site and its potential to sustain snowmaking.

P.5 - L.21-24: Usually, the slope classification goes like this: very easy = 15% = ∼9°; easy = 20% = ∼11°; hard = 30% = ∼17°; very hard = 40% = ∼22°. Therefore, I would not exclude slopes between 10° and 20°. Please comment on that.

P.5 - L.27: What minimum and maximum values did you use to normalize the slope gradient?

P.5 - L.33: Why did you consider only rivers and not, for example, lakes?

P.6 - L.2: Could you give a few more details on the cost distance method you allude to?

P.6 - L.5: "Vegetation is a representative of an ideal environment and an important" → "Vegetation contributes to creating an ideal environment and is an important".

P.6 - L.7: About wind conditions, please see comment on P.5 - L.17.

P.6 - L.14: Please explain briefly how the "geometrical interval classification" has been applied in this case.

P.6 - L.28: "relative values". Relative to what?

P.6 - L.28: "without an estimation" → "without a direct estimation".

P.6 - L.30: Please explain briefly how the "kernel density analysis" has been applied in this case.

P.7 - L.2: Please explain briefly how the "distance decay theory" has been applied in this case.

P.7 - L.4: Did you apply any selection criterion regarding the size of the cities?

P.7 - L.12: Would it be possible to consider, in addition to the road network, also the distance to airports?

P.7 - L.21: How do you define a ski area? For instance, Vanat (2019), distinguishing between ski areas (designated place where one skis and that may not have lifts) and ski resorts (an organized ski area with more than four lifts), reports a total of 703 Chinese ski areas.

P.7 - L.25: It is not at all clear how the dataset coming from the 128 ski areas has been used to calculate the weight coefficients. See comment on Section 2.3.

P.7 - L.27: "five grades, of which 1S to 5S represent" → "five grades from 1S to 5S, representing".

P.8 - L.1-3: This sentence is not clear. Do you mean that only 27 areas out of 35 have been ranked, since the others are already listed in the Xinjiang Government Tourist Office? If it is the case, you could rephrase as follows: "According to the feedbacks from our field surveys, ski areas were roughly ranked into different grades, except for the 8 ski areas whose grades were already defined in the Xinjiang Government Tourist Office."

P.8 - L.4: Section 2.3 needs to be improved in several aspects.
- In Eq.1 and Eq.2, you introduce the weighting factors W, while in Eq.11 you compute the weight coefficients w. Are they not the same?
- In Eq.1 and Eq.2, i and j are used for the natural and socioeconomic conditions, respectively. Starting from Eq.4, however, the same indexes are used for the number of optional schemes and the number of evaluating indexes. This generates some confusion.
- In Eq.4, you should say what the optional schemes and the evaluating indexes are in your case. If n is equal to 128 and m is equal to 9, this has to be stated clearly.
- In Eq.5, the reason why you have to normalize is not presented clearly.
- In Eq.6 and Eq.7, what does r stand for? Should it not be x instead? And $x_{j,max}$ instead of x_{max}?
- In Eq.10, why should P_{ij} be equal to 0?
More generally, the main missing point is the description of how the dataset coming from 128 ski areas has been used to compute w, a and b. In particular, it seems that the same dataset has been used to compute the coefficients and then to evaluate them. Please clarify this point.

P.10 - L.2: "led" → "lead". Sometimes you use the past tense, other times you use the present simple. Please standardize this throughout the text.

P.10 - L.5: "that evaluates" → "by evaluating".

P.10 - L.10: "China, which differs" → "China. This patterns differs".

P.10 - L.16: You say that the suitability index allows to identify 7 regions, but then you list 8, and in Fig.5 they are 10. Please check this out.

P.10 - L.16: "have greatest" → "have the greatest".

P.10 - L.22-23: Reference to Fig.6 should be made at the end of the previous sentence (after "gradient colors").

P.10 - L.24: I would replace "dark-shaded" with "black-shades" and "light-shaded" with "yellow-shaded".

P.10 - L.31: These surface areas in ha seem to be out by a factor of 10. Please check them again.

P.11 - L.3: "Moreover" → "Finally".

P.11 - L.5: Adding up the 4 areas, you get less than half the total area of China. Do the excluded areas account for the rest? Please comment on that.

P.11 - L.7: The low suitability here appears to be mostly due to poor natural conditions.

P.11 - L.8-9: "In contrast, the integrated suitability of eastern China was enhanced; thus, Shandong province, the Yangtze River Delta and the Beijing-Tianjin-Hebei region were more pronounced (Fig. 5)." → "In contrast, the integrated suitability of eastern China has benefited from better socioeconomic conditions, as in the Shandong province, the Yangtze River Delta and the Beijing-Tianjin-Hebei region (Fig. 5)."

P.11 - L.11: "verify the evaluation method" → "evaluate".

P.11 - L.13: "Verification" → "Evaluation".

P.11 - L.17: "0.5. However" → "0.5, while".

P.11 - L.27: "selected" → "can consider".

P.11 - L.30: "high" → "medium-to-high".

P.12 - L.10: What do you mean by "product homogeneity"?

P.12 - L.15: "find" → "found". Verb tenses should be carefully checked to ensure consistency (see comment on P.10 - L.2).

P.12 - L.16: "result" → "results".

P.12 - L.22: According to Vanat (2019), there are currently about 12 million skiers in China. Is the goal of having 300 million skiers in 3 years realistic? Please comment.

P.12 - L.24: "Thus, in less developed northwestern China" → "Thus, in this less developed area".

P.12 - L.31: "number" → "few number".

P.12 - L.31: See comment on P.12 - L.10.

P.13 - L.18: In the Conclusion, you could say that this study can pave the way to more detailed and refined analyses based on local data and other sources of information, which represents the next, necessary step to help driving investments in new ski-resorts.

P.13 - L.26: "base" → "based".

P.13 - L.27-28: "the rationality of our suitability evaluation methods was verified based" → "our method to estimate the suitability was evaluated based".

P.14 - L.2: Please consider adding some references on future snow conditions in China.

P.14 - L.3: "may become better" → "may increase".

P.14 - L.4: "become central" → "central".

Figure 1: In all figures, you used Rainbow palettes, which are known to have several drawbacks (https://betterfigures.org/2015/06/23/picking-a-colour-scale-for-scientific-graphics/). I strongly suggest you to use different color-bars to improve readability.

Figure 4: It looks like there are other regions showing high socioeconomic suitability in Northern and North-Eastern China. Why did you neglect them?

Figure 6: You could reverse the y-axis of the color-bar to be consistent with Fig.8. See also comment on P.10 - L.24. Finally, you could maybe swap Fig.6 and Fig.7.

Figure 8: Please consider using the same symbols as those used in Fig.7. It seems that several ski areas established before 2012 (red triangles) match recent ski areas (blue circles): did you count the same areas twice? You should also remind that natural and socioeconomic suitabilities have different weight coefficients (0.52 and 0.48, respectively), that is why the shaded regions and the green line do not intercept the x and y axes at the same point. Finally, in the label: "less" → "lower", "dotted" → "dashed".

Table 3: Why is the sum of natural suitability coefficients equal to 1.01, and not 1? You should comment on the fact that the total weight of natural suitability (0.52) is higher than that of socioeconomic suitability (0.48). How was this result obtained? See comment on P.8 - L.4.

Table 4: "The areas of four zones by different driving factors." → "Surface areas and

driving factors for four zones of suitability."

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