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Suitability Analysis of Ski Areas in China: An Integrated Study Based on Natural and Socioeconomic Conditions

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Abstract. The successful bidding of the 2022 Winter Olympics (Beijing 2022, officially known as the XXIV Olympic Winter Games) has greatly stimulated Chinese enthusiasm to participate in winter sports. Consequently, the Chinese ski industry is rapidly booming driven by enormous market demand and government support. However, investing in ski area at an unreasonable location will cause problems both from economic perspective (in terms of operation and management) as well as geographical concerns (such as environmental degradation). To evaluate the suitability of a ski area based on scientific metrics has since become a prerequisite to the sustainable development of ski industry. In this study, we evaluate the locational suitability of ski areas in China by integrating their natural and socioeconomic conditions using linear weighted method based on geographic information systems (GIS) spatial analysis combined with remote sensing, online and field survey data. Key indexes for evaluating the natural suitability include snow cover, air temperature, topographic conditions, groundwater, and vegetation, whereas socioeconomic suitability is evaluated based on economic conditions, accessibility of transportation, distance to tourist attractions, and distance to cities. As such, an integrated metrics considering both natural and socioeconomic suitability is defined to be a threshold and used to identify the suitability of a candidate region for ski area development. The results show that 92% of existing ski areas are located in areas with an integrated index greater than 0.5. In contrary, a ski area is considered to be a dismal prospect when the locational integrated index is less than 0.5. Finally, corresponding development strategies for decision-makers are proposed based on the multi-criteria metrics, which will be extended to incorporate potential influences from future climate change and socioeconomic development.

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1 Introduction

Ski tourism, as a major component in winter sports and tourism, creates great opportunities for business and promote regional economic development (Eadington and Redman, 1991). In many countries, ski tourism has brought in additional revenues compared to traditional agricultural and industrial practices (Lasanta et al., 2007). Especially in mountainous regions, the development of ski tourism has opened new doors for employment, which would boost the local economy, and lead to a recovery of the local population (Silberman and Rees, 2010).

As known, rapidly-developing economics often scarifies the environmental sustainability, which, in turn, hampers future business opportunities. The operation of ski areas is generally accompanied by environmental degradation such as deforestation, vegetation destruction and soil erosion (Burt, 2012). The construction and maintenance of ski slopes have been found to cause disturbances in mountainous regions, which have significant impacts on the ecosystem and the environment (Burt and Rice, 2009). With the expansion of such infrastructure into the nature, this kind of human-induced disturbance compels animals to leave their original habitat, leading to habitat loss and fragmentation (Sato et al., 2014; Brambilla et al., 2016). The enlargement of ski runs and the use of artificial snow are particularly prone to causing changes in plant species and declines in biodiversity (Wipf et al., 2005; Delgado et al., 2007), which may further increase surface runoff and soil erosion, and ultimately lead to land degradation (Ristić et al., 2012). Furthermore, constrained sediments and chloride have been found in streams near ski areas (Wemple et al., 2007). Extensive studies of lakes in northern Finland have shown that ski area operations have resulted in water contamination such as eutrophication (Tolvanen and Kangas, 2016).

For sustainable development of ski areas, the impact of climate change has to be considered because 1) snow is the most important freshwater resource that supplies the ski area and 2) locally-increased temperature may shorten the duration of the ski season (Steiger and Abegg, 2018; Gilaberte-Búrdalo et al., 2017). Previous studies have established national or regional climate-driven snow models under different climate change scenarios to investigate how future climate change will affect snow conditions (Hennessy et al., 2008; Rutty et al., 2017; Steiger and Abegg, 2018), with the conclusions that global warming will lead to a decline in the snowpack and a shortening of the length of the ski season. In addition, winter sports are vulnerable to climate variability, particularly in lower elevation and mid-latitude ski areas, because poor snow conditions are shown to result in a decline in the number of tourists (Scott, 2017). Snowmaking is usually preferred for individual ski area as a supplementary strategy in a short term, however, not suitable for long-term operations (Hennessy et al., 2008; Pons-pons et al., 2012). In addition, snowmaking results in greater water and energy consumption, which contradicts the well-acknowledged consensus regarding the emissions reduction of greenhouse gases to mitigate the effects of climate change (Steiger and Stötter, 2013). As a quantitative measure and clear evidence, the Commission Internationale pour la Protection des Alpes (CIPRA) has reported that the production of one hectare of artificial snow (with a thickness of 30 cm) requires between 0.6 and 1.5 million liters of water and between 5000 and 27,000 kWh of electricity (Duglio and Beltramo, 2016). Therefore, intense snowmaking would pose a critical threat to ski areas in two main ways, economically and environmentally, which might lead to their permanent closure (Tervo-kankare et al., 2017). In summary, the location of ski areas became critical since inappropriate selections may

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contaminate, degrade or even damage the environment (Tsuyuzaki, 1994). To evaluate of the location of ski areas based on scientific metrics is prerequisite to help reduce the inevitable consequences caused by the construction and operation (Spulerova et al., 2016; Cai et al., 2019).

Recently, in major skiing countries, the number of skiers has been declining, and the number of ski resorts has become relatively saturated (Wang et al., 2017). In contrast, the successful bidding of the 2022 Winter Olympics (Beijing 2022, officially known as the XXIV Olympic Winter Games) has motivated the general public to participate in ice and snow sports. As a competitive sport with potential business opportunities, skiing is strongly supported by the Chinese government, which has created a good atmosphere for the associated promotion and training. With a series of initiatives and future plans proposed by the Chinese government, it is expected that 300 million citizens will invest in winter sports activities before 2022. In 2010, there were only 270 ski areas in China. However, driven by enormous market demand and government support, the number of ski areas has been rapidly increasing in recent years. Seventy-eight new ski areas were opened in 2016, bringing the total number of ski areas in China to 646 (Wu and Wei, 2017), and this is only the start for an even longer growth in ski tourism. According to the strategic plan proposed by the China National Tourism Administration, the number of ski areas is expected to reach 800 by 2022. This booming industry raises the following question: how can we mitigate the environmental problems and avoid unnecessary economic losses caused by the unreasonable location of ski areas?

The operation of ski areas mainly relies on suitable natural environment and local socioeconomic conditions (Morey, 1985). On the one hand, ski areas are highly controlled by natural conditions, such as the terrain and climate conditions (Morey, 1984; Gilaberte-Búrdalo et al., 2017). On the other hand, local socioeconomic conditions are key indicators supporting the operation of ski areas since the market for most ski areas is mainly composed of local tourists (Silberman and Rees, 2010). Thus, both natural and socioeconomic conditions should be considered to determine the location of ski areas (Fukushima et al., 2002). Despite the pivotal role that ski areas have played in the social economy and environment, only a few studies have focused on locational suitability for ski area development (e.g., Geneletti, 2008; Silberman and Rees, 2010; Dezsi et al., 2015; Cai et al., 2019). Silberman and Rees (2010), for example, evaluated alternative but currently undeveloped sites based on the standard measures of existing areas, with conclusions for industry decision-making. It is also noted that the previous studies are mostly limited to small scales (i.e., local or regional scale). In this study, using Geographic Information Systems (GIS) spatial analysis combined with remote sensing, online and field survey data, linear weighted method is employed to evaluate the locational suitability of ski areas in China based on both natural and socioeconomic conditions. This work can provide scientific metrics for decision-makers to avoid unreasonable economic investment and environmental problems and thus promote the sustainable development of Chinese ski tourism.

This paper is organized as follows: in Sect. 2, we provide a description of the data and method. Once the data have been preprocessed and analyzed, Sect. 3 details the evaluation results. Section 4 demonstrates the validation of the method and the existing problem and proposes the development strategy. The final section contains a brief conclusion and discusses future work.

2 Data and Methodology

2.1 Data collection

In this study, the locational suitability of ski areas is evaluated based on two components: the natural conditions (from supply perspective) and the socioeconomic conditions (from demand perspective). Note that regions where the elevation is higher than 4000 m are unsuitable for skiing due to the lack of oxygen, nor are areas where the maximum air temperature is higher than 10 ℃ for more than 90 days during the ski season (November 1 to March 31) (Scott, McBoyle, and Mills, 2003). Areas with high elevations are mainly distributed in western China, including most of the Tibetan Plateau, while areas with higher temperatures are mainly distributed in southern China and the Sichuan Basin (see Fig. 1a). All factors were analyzed using GIS spatial analysis based on data from multi-sources with a spatial resolution of 1 km combined with online and field survey data. Table 1 summaries all of the data used in this study. Normalization processing was implemented to make the data dimensionless and mutually comparable (Geneletti, 2008). This work was conducted for the entirety of China, except for Taiwan, Macao and Hong Kong due to the lack of data.

2.1.1 Natural conditions

Variables serving as indexes of natural conditions that could impact the development of ski areas include snow cover, air temperature, topographic conditions, groundwater and vegetation, as shown in Fig. 1.

Snow cover

Natural snow cover is a crucial resource for ski areas, both as supplement and attractions, e.g., skiers may cancel trips when there are poor snow conditions (Scott et al., 2003; Steiger and Abegg, 2018). The snow depth (SD) and number of snow cover days (SCD) represent the average snow depth and total number of days with snow cover in an area during the ski season, respectively, which determine the duration of the ski season as the minimum requirement for ski areas (Silberman and Rees, 2010). Tervo (2008) analyzed the viability of nature-based winter tourism enterprises and declared a "90–120-day-long winter season to be adequate for making a profit". In fact, a ski area is profitable if the snow reliability period is greater than 100 days per season, which is known as the 100-day rule as the most common indicator of snow reliability (Steiger, 2012). Therefore, in this study, an SCD larger than 100 days is taken as the optimal value. Scott, McBoyle, and Mills (2003) defined a skiable day as a day with an SD greater than 30 cm. However, the SD in China is much lower than that in North America and Europe (Mudryk et al., 2015). Additionally, small-scale snow properties (~1 km) cannot be obtained due to the low resolution of passive microwave products (Che et al., 2008). Therefore, SD is only taken as a reference for the index of snow cover.

With a spatial resolution of 500 m, the moderate-resolution imaging spectroradiometer (MODIS) snow cover products used in this study were downloaded from the National Snow Ice Data Center (NSIDC, https://nsidc.org/) then resampled to 1 km. The SD products were downloaded from the Cold and Arid Regions Sciences Data Center at Lanzhou (http://westdc.westgis.ac.cn). The SD products derived from passive microwave remote-sensing data in China were developed by Che et al. (2008), with a spatial resolution of 25 km. Based on the MODIS cloud removal algorithm and downscaling algorithm developed by Huang

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et al. (2016), the daily cloud-free snow cover and 1 km daily SD data for the 2010-2014 ski seasons were produced. The snow cover index is defined as the sum of the average SD and SCD values from 2010 to 2014, each normalized to a range of [0-1] and assigned a weight of 0.5 (Fig. 1b).

Air temperature

Low temperature is a prerequisite for skiing. Scott et al. (2003) have also pointed out that ski areas are supposed to be closed if the maximum temperature is greater than 10 ℃ for 2 consecutive days and accompanied by liquid precipitation. Additionally, skiers may also choose not to ski in extremely low temperatures (~below -25 ℃) (Tervo, 2008; Rutty and Andrey, 2014). Since snowmaking has been used as an adaptive strategy to compensate for the loss of snow reliability worldwide, temperatures between -2 ℃ and -5 ℃ are taken as optimal conditions in regard to efficient snowmaking (Tervo, 2008).

Based on the daily air temperature generated from more than 2400 meteorological stations in China, a gridded daily observation dataset with a spatial resolution of 25 km was developed by Wu and Gao (2013). In this study, using an extrapolated method with a lapse rate of 0.6 ℃ per 100 m in relation to elevation (Steiger and Stötter, 2013), the temperature dataset was resampled to a 1 km spatial resolution for the 2010-2014 ski seasons. The daily maximum air temperature dataset was used to obtain the high-temperature regions that are unsuitable for ski area development (more than 90 days with a maximum air temperature greater than 10 ℃). Following previous studies (Scott et al., 2003; Tervo, 2008; Rutty and Andrey, 2014), the daily mean temperature is reclassified into 11 regimes with corresponding scores (Table 2), and the index of air temperature is the mean score for the 2010-2014 ski seasons (Fig. 1c).

Topographic conditions

The topographic conditions are essential for identifying suitable locations for ski areas. Ski runs require a certain topographic slope (Dezsi et al., 2015). In 2014, the China National Tourism Administration announced the Rank Division for the Quality of Mountain Ski Resorts, which requires that the average slope gradient of advanced slopes should not be less than 20° and that the average slope gradient of intermediate slopes should be greater than 15°. Unfortunately, information loss is inevitable when using the slope values extracted from remote-sensing images during averaging. Accordingly, slope gradients of 20° to 25° are considered to be the best topographic conditions.

Slope gradient data were derived from the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) (V004) with a spatial resolution of 90 m (National Map Seamless Data Distribution Systems, http://seamless.usgs.gov). The topographic conditions index was produced by a normalized slop gradient (Fig. 1d).

Groundwater

To reduce the vulnerability of ski areas caused by climate change, snowmaking has been increasingly adopted as an adaptive strategy to compensate for the scarcity of natural snow (Hennessy et al., 2008; Pons-pons et al., 2012). In fact, snowmaking requires large amounts of water. The high water consumption of snowmaking not only increases the operating cost of ski areas but also poses stress on local water resources, especially in arid regions (Duglio and Beltramo, 2016; Wilson et al., 2018). Consequently, an area with abundant water resources is more suitable for ski area development. River spatial distribution data were taken from the Data Center for Resources and Environmental Sciences (RESDC, http://www.resdc.cn) of the Chinese

Academy of Sciences (CAS) and generated by an automatic extraction method based on the DEM. The groundwater index was estimated by calculating the shortest cost distance between any pixel in the study area and rivers using the cost distance method (Fig. 1e).

Vegetation

Vegetation is a representative of an ideal environment and an important indicator for evaluating destination attractiveness. Vegetation, especially trees, can define the edges of ski runs and prevent skiers from being hit by strong winds (e.g., skiable days include the requirement of winds less than 6.5 m s^{-1}; Crowe et al., 1973). The vegetation index for 2015 was derived based on the annual normalized difference vegetation index (NDVI) spatial distribution dataset covering the Chinese region (Fig. 1f). With a spatial resolution of 1 km, this dataset integrated SPOT NDVI data and MODIS vegetation data, which were sourced from the RESDC (http://www.resdc.cn).

2.1.2 Socioeconomic conditions

Socioeconomic conditions highlight a favorable level of economic development and infrastructure conditions by integrating four indexes: economic conditions, distance to cities, accessibility of transportation, and distance to tourist attractions. All indexes were reclassified into 10 regimes by geometrical interval classification (see Fig 2).

Economic conditions

Skiing is a luxury activity for skiers; therefore, the development of ski areas should consider the balance between investment and revenue. Economic census data are sometimes difficult to acquire on a larger scale, and currently, reliable economic data in China are mainly reported at the provincial level (Zhao et al., 2017). With the development of remote-sensing technology, nighttime light images have become an efficient means of mapping national economic activities (Rybnikova and Portnov, 2015). Visible infrared imaging radiometer suite (VIIRS) day/night band (DNB) nighttime light data are considered as a new generation of nighttime light imagery. The annual average radiance composite images were produced by the Earth Observations Group (EOG) at the National Oceanic and Atmospheric Administration's National Geophysical Data Center (NOAA/NGDC) using VIIRS DNB nighttime data; the spatial resolution is 500 m. Prior to averaging, the DNB data are filtered to exclude data impacted by stray light, lightning, lunar illumination, and cloud cover. The data are available at https://www.ngdc.noaa.gov/eog/viirs/download_dnb_composites.html.

Many studies report that there is a strong correlation between an administrative unit's total gross domestic product (GDP) and the digital number (DN) value of the pixel of nighttime light imagery (Doll et al., 2000; Zhao et al., 2011). In this study, the relative values in different areas were needed to measure the economic development level. Thus, without an estimation of the GDP values, the nighttime light pixel value is used as a surrogate index. The economic conditions index was generated by kernel density analysis based on the annual average radiance composite images for 2015 (Fig. 2a).

Distance to cities

The customer plays a major role in the ski tourism industry. Except for a few ski areas in China that can attract both national and international visitors, the skiers in most ski areas are local visitors. The farther a ski area is from a major metropolitan area, the less likely it is to draw a large crowd to its mountainous area (Fukushima et al., 2002). As analyzed using the distance decay theory, the number of visitors declines exponentially as the distance from a source increases, although the impact of distance on visitors is not a deterministic construct in its own right (Mckercher, 2018). Here, the distance to cities index was estimated by calculating the shortest cost distance between any points in the study area and cities (Fig. 2b). Information on the location of cities was taken from the National Geomatics Center of China (NGCC, http://www.ngcc.cn/).

Accessibility of transportation

The transportation network is the foundation of accessibility. Kaenzig et al. (2016) surveyed a former ski slope, and their results show that easy access to a summit is a key factor in its renewed attraction for visitors. Convenient transportation, which provides easy access to a ski destination, will bring more visitors. In this study, the accessibility of transportation index was acquired by calculating the shortest cost distance from any point to roads (Fig. 2c). The road network is obtained from OpenStreetMap (https://www.openstreetmap.org/#map), which was assembled using a manual survey, global positioning system (GPS) devices, aerial photography, and other free sources.

Distance to tourist attractions

Many enterprises are aware of the potential benefits of regional cooperation (Buhalis, 2000; Young, 2002). To reduce costs, maximize tourist attraction, and improve enterprise competitiveness, many ski areas, especially small ski areas, should be located within tourist attractions with necessary facilities, such as hotels and restaurants as well as shops (Lasanta et al., 2007; Dezsi et al., 2015; Spulerova et al., 2016). Additionally, visitors would like to enjoy beautiful views while skiing. The distance to tourist attractions index was determined by measuring the cost distance from any point in the study area to tourist attractions (Fig. 2d). The tourist attractions were manually extracted from an online map (https://maps.baidu.com).

2.2 Ski area information and field survey

To verify the results of the evaluation, the location information of 598 ski areas was manually collected from an online map (https://maps.baidu.com). Unfortunately, limited information could be found online for lower-class ski areas, although there are 646 ski areas in China according to a white paper on China's ski industry in 2016 (Wu and Wei, 2017). Based on the year of establishment, the location information of 128 operating ski areas that have been in operation for more than 5 years was collected as suitable sample data, which were used to calculate the weight coefficients of different indexes.

Additionally, field surveys on ski areas were conducted during the 2018 ski season. The ski areas investigated were distributed in 13 provinces, spatially representing highly different natural and socioeconomic conditions (see Fig. 7). The managers or staff of 35 ski areas were interviewed with a questionnaire and through conversations. The questions mainly involved location information, the quality of the ski area, its operating state, and its market competition situation. The questions concerning the quality of the ski area were designed to collect the characteristics of the ski area, including the number and slope of ski runs, equipment, facilities, and accessibility of transportation. According to the Rank Division for the Quality of Mountain Ski Resorts promulgated by the China National Tourism Administration in 2014, the quality of ski areas is divided into five grades, of which 1S to 5S represent the lowest- to the highest-grade standard. It is a comprehensive assessment that integrates 10 aspects, such as equipment, facilities, accessibility of transportation, and the reception scale. Notably, ski areas are roughly divided into different grades referring to the field survey information, except for the 8 ski areas that was already defined by the Xinjiang Government Tourist Office.

2.3 Methodology

In this study, the linear weighting method was used for synthetic evaluation. The natural suitability for ski area development (NS) is expressed as

$$NS = \sum_{i=1}^{i} W_i NC_i \quad (1)$$

where i is the number of natural conditions indexes, W_i is the weighting factor that represents the importance of the natural condition indexes, and NC_i represents the natural index.

The socioeconomic suitability for ski area development (SS) is expressed as

$$SS = \sum_{j=1}^{j} W_j SC_j \quad (2)$$

where j is the number of the socioeconomic condition indexes, W_j is the weighting factor that represents the importance of the socioeconomic indexes, and SC_j is the socioeconomic index.

The integrated suitability for ski area development (CS) is expressed as

$$CS = aNS + bSS \quad (3)$$

where SS is the index of socioeconomic suitability, NS is the index of natural suitability, a is the weight coefficient that represents the importance of NS, b is the weight coefficient that represents the importance of SS. The weight coefficients in Eq. (3) (a and b) are given by the entropy method in the following paragraph. Finally, NS, SS and CS are rescaled to 0-1.

The weight coefficients are calculated by an objective method based on entropy weight theory (Bian et al., 2018). The sample data are the 128 existing ski areas established before 2012. Suppose that there are n optional schemes and that each scheme has m evaluating indexes. The data matrix is established as follows.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}_{n\times m} \quad (4)$$

where x_{ij} is the value of the jth index in the ith scheme, i = 1, 2, ..., n; j = 1, 2, ..., m.

First, normalization processing is performed because the difference in different quantity grades in X may produce inaccurate results in the decision-making process. The value after normalization (Z_{ij}) is expressed as

$$Z_{ij} = \frac{x_{max} - x_{ij}}{x_{max} - x_{min}} \quad (5)$$

where

$$x_{max} = max\{r_{1j}, \dots r_{nj}\} \quad (6)$$

$$x_{min} = min\{r_{1j}, \dots r_{nj}\} \quad (7)$$

The information entropy e_j of the jth index is defined as

$$e_j = -k \sum_{i=1}^{n} P_{ij} \ln(P_{ij}) \quad (8)$$

where

$$k = \frac{1}{\ln n} \quad (9)$$

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{n} z_{ij}} \quad (10)$$

where $P_{ij} = 0$, $P_{ij} \ln(P_{ij}) = 0$.

The entropy weight w_j of the *j*th index is expressed as

$$w_j = \frac{1-e_j}{\sum_{j=1}^{m}(1-e_j)} \quad (11)$$

The calculation results of the weight coefficients for the evaluation indexes are shown in Table 3.

3 Results

This section presents the evaluation results of the locational suitability for ski area development in China. The first part of the analysis focuses on the natural conditions for ski area development. Natural suitability was evaluated based on the linear weighting of five natural indexes: snow cover, air temperature, topographic conditions, groundwater, and vegetation. The second part describes the analysis of the socioeconomic conditions for ski area development. Socioeconomic suitability was evaluated based on the linear weighting of four socioeconomic indexes: economic conditions, distance to cities, accessibility of transportation, and distance to tourist attractions. Subsequently, the spatial distribution of the natural suitability and socioeconomic suitability indexes were used to obtain the integrated suitability index, which identifies the areas with greatest potential for ski area development. Finally, we analyzed the fundamental driving factors of ski area development based on natural and socioeconomic conditions.

3.1 Natural suitability

For ski area development, natural suitability shapes ski areas from the supply side (Fig. 3). In general, areas with high scores were characterized by an excellent natural endowment, including abundant snow resources, favorable temperature, suitable terrain, beautiful natural landscape, and adequate water resources. The areas with high scores were widely distributed, mainly including the Changbai Mountains (northeast China), the Daxing'an Mountains (Inner Mongolia province), the Tianshan Mountains and Altai Mountains (Xinjiang province), the Qilian Mountains (Gansu province and Qinghai province), the Yanshan Mountains and Taihang Mountains (Beijing-Tianjin-Hebei region), the southeastern Tibetan Plateau (Sichuan province), and the Qinling Mountains (Shaanxi province).

Areas with high scores were always located in mountains, particularly in northwestern and northern China. Additionally, as mentioned in Sect. 2, most areas of the Tibetan Plateau were unsuitable for ski area development because the elevation is too high. There was also a large area covering the Gobi Desert in the middle region of northwestern China with low natural suitability values. With the increase in temperature from north to south, ski areas need to be built in mountains with higher elevations. High temperatures led to the low natural suitability values of southern China. In the eastern part of China, the low values are due to poor topographic conditions (flat terrain).

3.2 Socioeconomic suitability

For ski area development, socioeconomic suitability plays a crucial role that evaluates ski areas from the demand side (Fig. 4). The regions given high scores in this figure had favorable socioeconomic conditions. For instance, they were usually close to well-developed regions, markets, roads and tourist attractions with better economics and infrastructure. Ski areas near regions with high socioeconomic suitability values would give enterprises a more advantageous environment.

Figure 4 shows the significantly imbalanced socioeconomic development between eastern and western China. The socioeconomic suitability of western China lags far behind that of eastern China, which differs from the spatial distribution of natural suitability. The regions with high socioeconomic suitability values were mainly distributed in the eastern coastal areas, including the Yangtze River Delta, the belt encircling the Bohai Sea (including the Beijing-Tianjin-Hebei region), followed by the urban agglomerations of the Central Plains Economic Zone and the Northeast Economic Zone.

3.3 Integrated suitability

For ski area development, integrated suitability was evaluated based on the spatial distribution of natural and socioeconomic suitability (Fig. 5). The integrated suitability results identified seven regions that have greatest potential for ski area development, which are the Changbai Mountains (northeast China), the Yanshan Mountains and Taihang Mountains (Beijing-Tianjin-Hebei region), the Tianshan Mountains (central Xinjiang province), the Qilian Mountains (Qinghai province and Gansu province), the Qinling Mountains (Shaanxi province), the area surrounding Mount Tai (Shandong province), the Wuyi Mountains (Yangtze River Delta), and the southeastern Tibetan Plateau (Sichuan province).

We further classified each of the natural suitability (Fig. 3) and socioeconomic suitability (Fig. 4) domains into deciles and then cross-tabulated them to generate 100 unique combinations marked with gradient colors. In this scheme, the red-shaded areas are where socioeconomic suitability is high but natural suitability is modest (Fig. 6). In contrast, the green-shaded areas have high natural suitability values but low socioeconomic suitability values. The black and dark-shaded areas have high values for both types of suitability, whereas the yellow and light-shaded areas have low values for both types of suitability.

Figure 6 illustrates the fundamental driving factors of ski area development in China. The analysis identified four zones. The first zone consists of “natural-driven areas” with favorable natural conditions but relatively poor socioeconomic status. The second zone consists of “socioeconomic-driven areas”, which are characterized by a good socioeconomic status but relatively modest natural conditions. The third zone consists of “ideal areas”, which feature both favorable natural conditions and advantageous socioeconomic conditions. Finally, the fourth zone consists of “unfavorable areas”, which have poor natural and socioeconomic conditions. In total, 4.75 million hectares (12.6% of the analyzed area) were categorized as natural-driven areas (Table 4), mainly distributed in the mountains of northwestern China and Inner Mongolia province. A total of 18.91 million hectares (49.9% of the analyzed area) were classified as socioeconomic-driven areas, including expanses of eastern and central China. A total of 5.55 million hectares (14.6% of the analyzed area) were determined as ideal areas, particularly distributed in the Beijing-Tianjin-Hebei region, the eastern part of northeast China and central Xinjiang province. Moreover, 8.66 million hectares of land (22.9% of the analyzed area) were found to be unfavorable areas, which were mainly distributed in regions of northwestern and southern China.

Influenced by socioeconomic conditions, the integrated suitability in most regions of northwestern and northern China was weakened; thus, the areas of the Altai Mountains, the Daxing'an Mountains and the marginal zone of the Tibetan Plateau were rendered in a light shade. 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).

4 Discussion

This section first uses the information on existing ski areas to verify the evaluation method. Second, according to the evaluation and verification results, a series of development strategies are proposed.

4.1 Verification

The existing 598 ski areas are illustrated in the spatial distribution map of integrated suitability for ski area development (Fig. 7). Additionally, Fig. 8 presents a detailed analysis of the natural suitability, socioeconomic suitability and integrated suitability of the existing ski areas, including ski areas established before 2012 and still in operation. In total, 92% of ski areas are located in areas with an integrated suitability value greater than 0.5. However, 8% of ski areas are located in areas with integrated suitability values less than 0.5, with most being scattered in the mountainous areas of southern China (Fig. 7 and Fig. 8).

As shown in Fig. 8, the areas are categorized as having low, medium and high suitability. A total of 74.68% of ski areas are distributed in medium suitability areas, whereas 25.32% of ski areas are located in high suitability areas. There are no ski areas in low suitability areas. Additionally, 39.2% of ski areas fall into ideal areas; 58.62% of ski areas are situated in socioeconomic-driven areas; 1.45% of ski areas are located in natural-driven areas; and only 4 ski areas are distributed in unfavorable areas. The ski areas established before 2012 are mainly located in socioeconomic-driven areas and ideal areas. After 2012, many ski areas were built in areas with an integrated suitability value less than 0.5, which are almost distributed in socioeconomic-driven areas. Notably, the ski areas in socioeconomic-driven areas are more prone to causing environmental problems due to lower natural suitability, and these enterprises will soon face the challenges of dismal prospects.

It can be assumed that successful and suitable ski areas can operate for longer periods of time. We selected ski areas established before 2012 and still in operation as successful and suitable ski areas. Before 2012, ski areas were mainly distributed in northern, northeastern and northwestern China, and there were no ski areas in southern China. These ski areas are mainly located in areas with high integrated suitability values, indirectly proving the validity of our integrated evaluation method (Fig. 7).

To further verify the suitability evaluation method, we analyzed the 35 ski areas that were investigated in the field (Fig. 7). The results show that the 5S-graded (highest grade) ski areas are clustered in areas with high integrated suitability values (ideal area), which are mainly distributed in higher latitude regions, such as northeast China, the Beijing-Tianjin-Hebei region and Xinjiang province; the 4S-graded and 3S-graded (medium grades) ski areas are distributed around Beijing and the marginal zone of the Tibetan Plateau; and the 2S-graded and 1S-graded (lowest grades) ski areas are mainly located in southern China, the North China Plain and western Xinjiang province. In general, the higher the grade of the ski area is, the better its locational suitability. In most natural-driven areas, such as western Xinjiang province, small ski areas are established rather than large resorts due to their low socioeconomic suitability. There are a large number of lower-grade ski areas with poor facilities in lower elevation and mid-latitude regions, such as the North China Plain (socioeconomic-driven areas). In such areas, according to the interviews with ski area managers, the vicious competition between enterprises resulting from product homogeneity is so serious that it is difficult for some small ski areas to continue operations and they are threatened with closure. Therefore, in socioeconomic-driven areas, the number of ski areas should be limited, and enterprises should enhance their competitiveness by improving the quality of the ski area. In southern China, selected ski areas are operated by the government to promote winter sports and sometimes run without profit.

Collecting location information online and conducting a field survey on existing ski areas, we find that the suitability results well-reflect the actual conditions for ski area development. Additionally, the verification result indicate that some small ski areas have been built in areas with lower integrated suitability values, with most being distributed in socioeconomic-driven areas.

4.2 Development strategy

To meet the goal of having 300 million Chinese citizens involved in winter sports by 2022, China is making an enormous effort to popularize winter sports by improving the accessibility of facilities and training for beginners. According to China's General Sports Administration's "13th Five-Year Plan", a roadmap for development from 2016 to 2020, snow and ice sports should be vigorously promoted, especially in southern and northwestern China.

In fact, northwestern China has abundant snow and ice resources. Thus, in less developed northwestern China, the vigorous development of ski tourism is an opportunity to promote regional economic development. In contrast, southern China can provide favorable economic conditions for ski tourism development. The expansion of snow and ice sports in southern China will make winter sports more accessible for citizens living in warmer climates, which will bring a large number of new amateurs to skiing.

However, the poorer economic conditions in northwest China and the lower natural suitability in southern China, which can restrict the development of ski areas, should be considered. Especially in southern China, as noted in Sect. 4.1, there are a number of small ski areas due to low natural suitability, and enterprises face a situation of product homogeneity and fierce competition (Wang et al., 2017). Under global warming, increased winter temperatures and decreased snowfall will severely affect these ski areas (Fukushima et al., 2002; Dawson et al., 2009), causing economic losses, resource waste and environmental damage.

To stimulate the sustainable development of the ski industry, the location of ski areas should carefully be determined according to the results of the suitability evaluation. Based on our analysis, corresponding development strategies for the development of the Chinese ski tourism industry are proposed:

(1) In natural-driven areas, upscaled ski areas mainly used for competition and training are suggested to be built, which can improve the popularity of ski area by hosting sporting events. A number of small and medium-sized ski areas with good snow quality are also welcomed to be appropriately planned around cities.

(2) In socioeconomic-driven areas, ski area markets are determined by local visitors. According to the situation of local socioeconomic development, an appropriate number of small ski areas are advised to be built for recreational sports to expand the influence of snow sports.

(3) In ideal areas, a number of high-end ski resorts with complete support facilities are feasible to attract national and international visitors by holding major international sporting events.

(4) Unfavorable areas with both poor natural and socioeconomic conditions are unsuitable for skiing.

In addition, in economically developed southern China, the snow resources are insufficient because of high temperatures; thus, to popularize snow recreation, indoor ski slopes can be considered. Furthermore, in the less developed and oxygen-deficient Tibet Plateau, commercial ski areas are difficult to operate.

5 Conclusion

This study integrated natural and socioeconomic conditions from the supply and demand perspectives to quantitatively evaluate the locational suitability for ski area development in China. Five corresponding evaluation indexes of natural conditions were proposed: snow cover, air temperature, topographic conditions, groundwater, and vegetation. The socioeconomic conditions contained four indexes: economic conditions, accessibility of transportation, distance to tourist attractions and distance to cities. Using GIS spatial analysis technology combined with remote sensing, online and field survey data, we presented a linear weighted method for synthetic evaluation in which the weight coefficients were calculated using an objective method based on entropy weight theory. The results showed the spatial distribution of the locational suitability of ski areas and identified the areas with the greatest potential for ski area development. Four zones were also identified by analyzing driving factors base on natural conditions and socioeconomic conditions. Additionally, the rationality of our suitability evaluation methods was verified based on the collection of location information and field surveys on ski areas. Finally, corresponding development strategies for decision-makers were proposed.

The results of the weight coefficients indicate that concerning natural conditions, snow resources, air temperature and topographic conditions are major factors influencing ski area development. In the context of global warming, with the increase in winter temperatures and the decrease in snowfall in the next few decades, the natural suitability values for southern and eastern China will drop, and small mid-latitude and low-elevation ski areas will be the first to close due to poor snow conditions (Bark and Colby, 2010; Gilaberte-Búrdalo et al., 2017). Additionally, with social and economic development, people's living standards will greatly improve. Thus, the socioeconomic suitability in northwestern and northeastern China may become better. As a result, northwestern and northeastern China may become popular markets and become central places for ski tourism. To more thoroughly study the future of ski tourism in China, future research is needed to evaluate the locational suitability for ski areas in relation to climate change and socioeconomic development.

Author contributions: TC and JD conceived this study with input from CX, LD and AM. SW led the field surveys on ski areas. The manuscript was written by JD and TC. All authors contributed to editing and revision.

Competing interests: The authors declare no conflict of interest.

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Figure 2. The spatial distribution of the socioeconomic conditions indexes: (a) economic conditions; (b) distance to cities; (c) accessibility of transportation; (d) and distance to tourist attractions.

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Figure 4. The spatial distribution of socioeconomic suitability for ski area development based on economic conditions, distance to cities, accessibility of transportation, and distance to tourist attractions: I: Yangtze River Delta; II: belt encircling the Bohai Sea (including the Beijing-Tianjin-Hebei region); III: Central Plains Economic Zone; and IV: Northeast Economic Zone.

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Figure 6. Spatial distribution of the driving factors of ski area development.

Figure 7. The distribution of existing ski areas in China.

Figure 8. The suitability values of existing ski areas.

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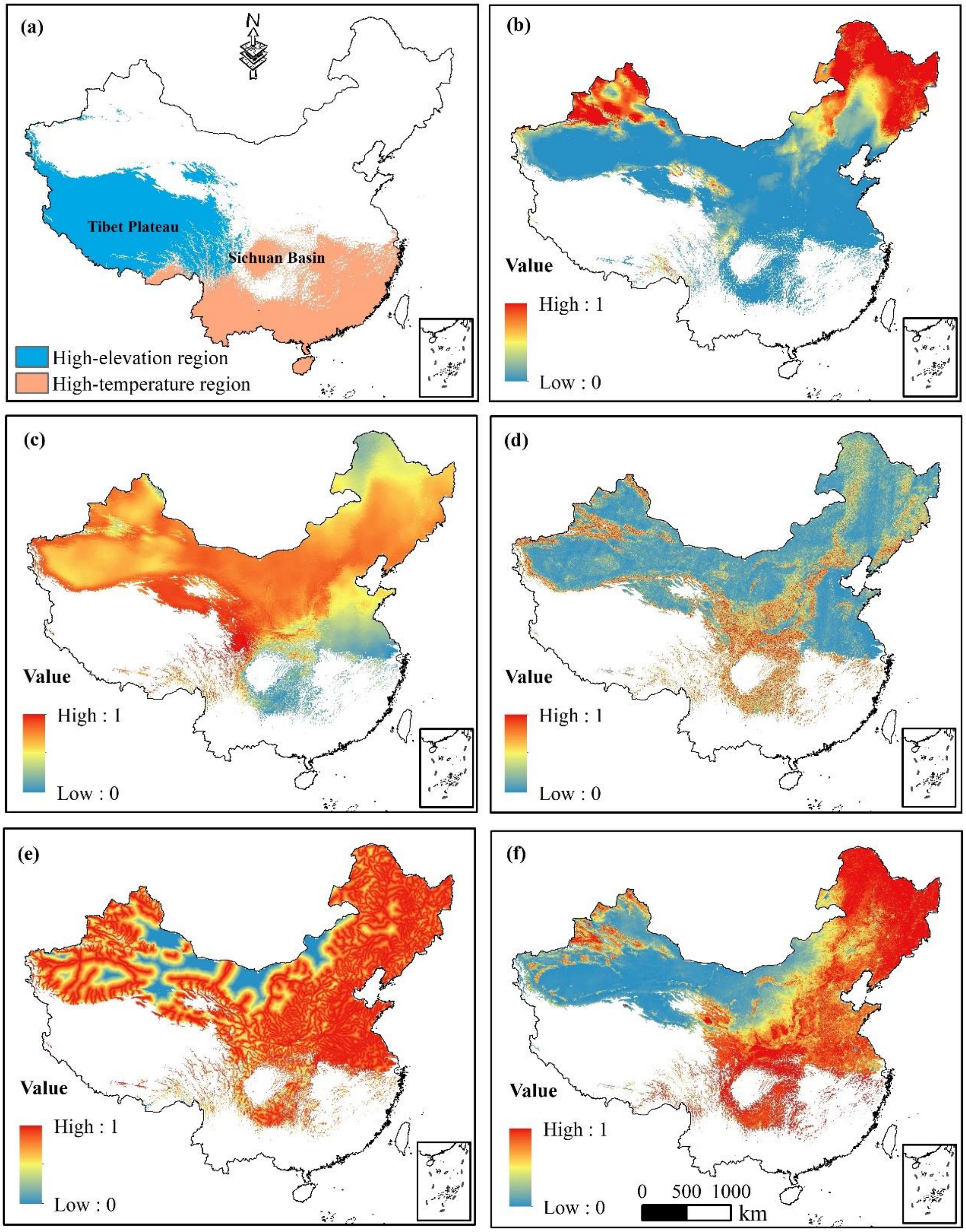

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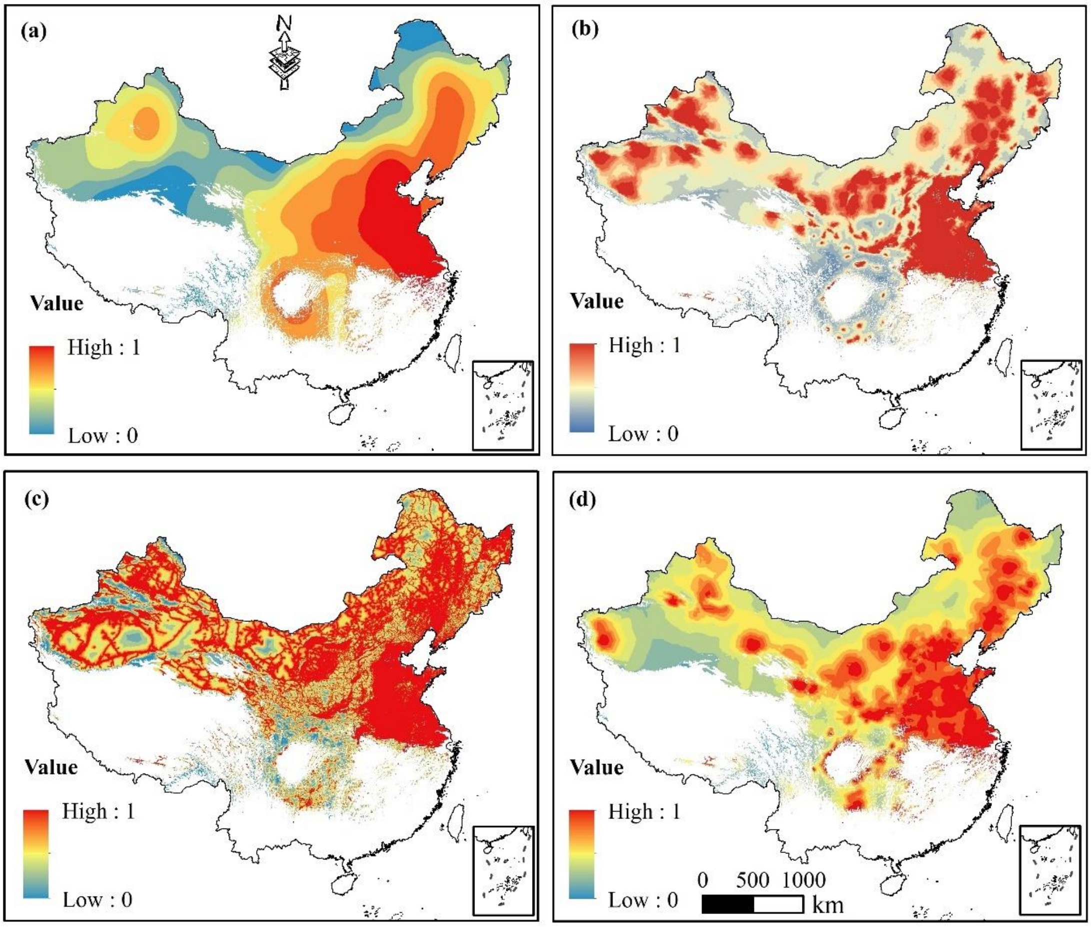

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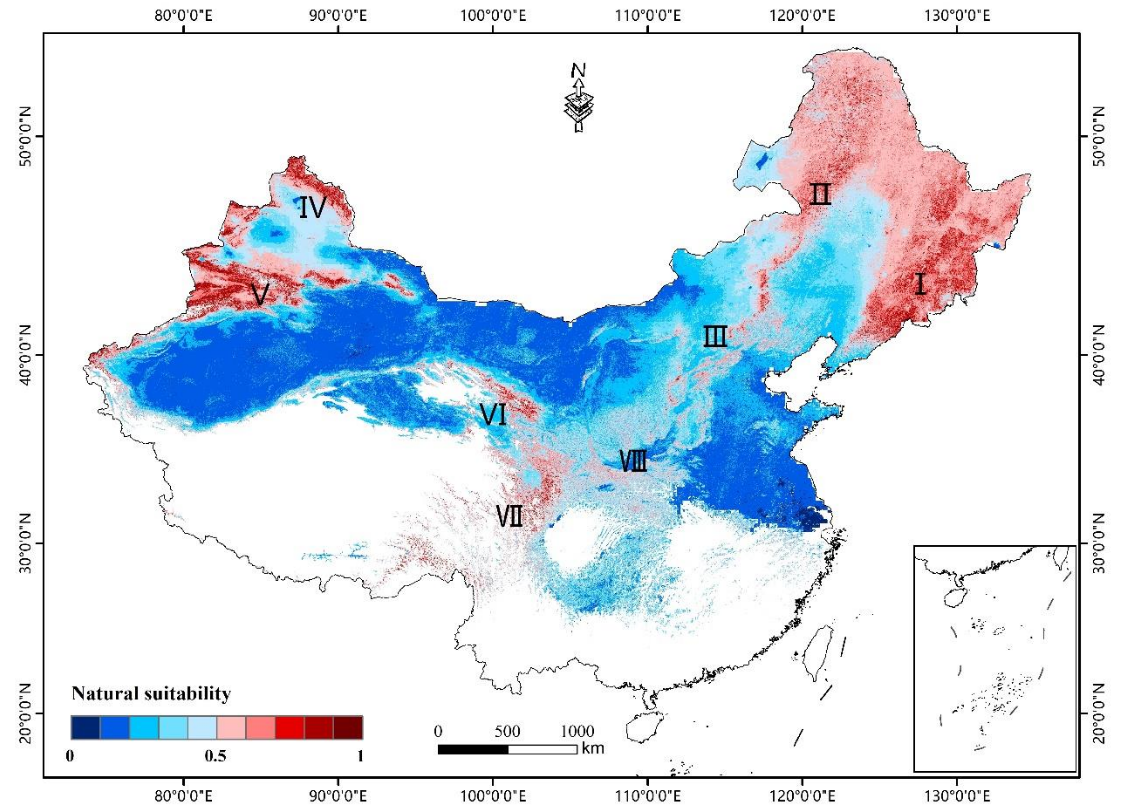

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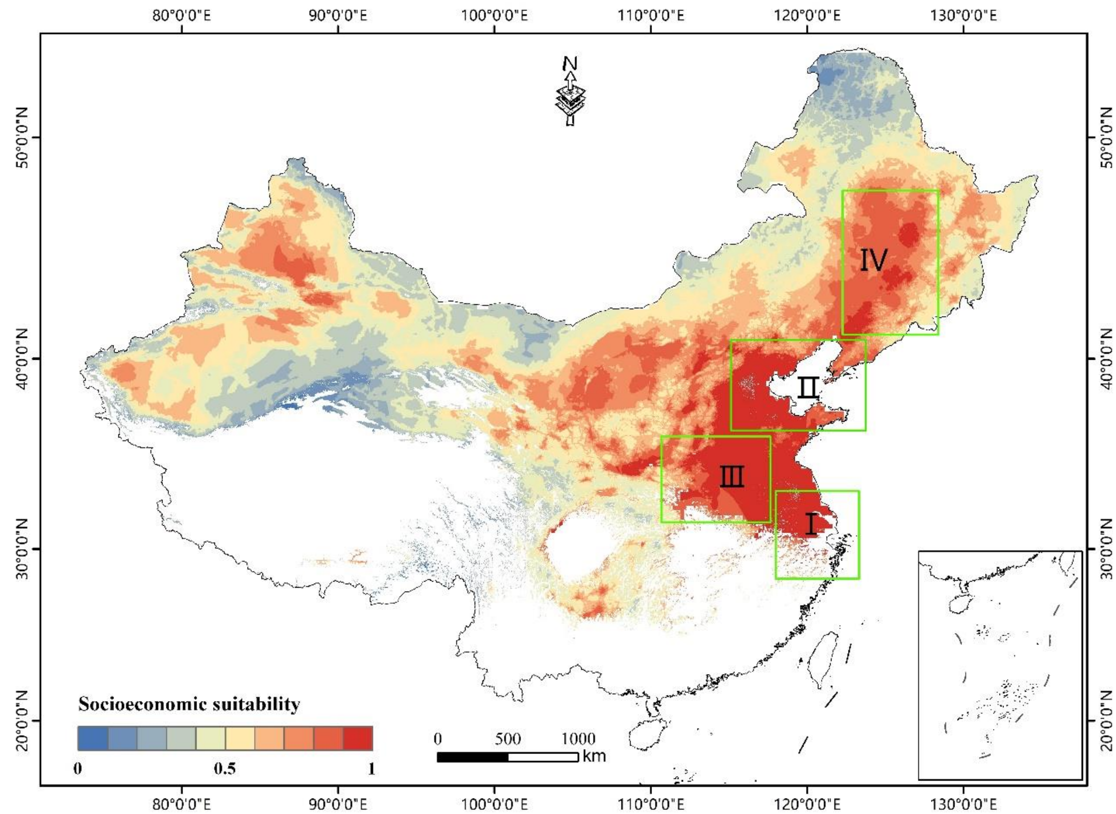

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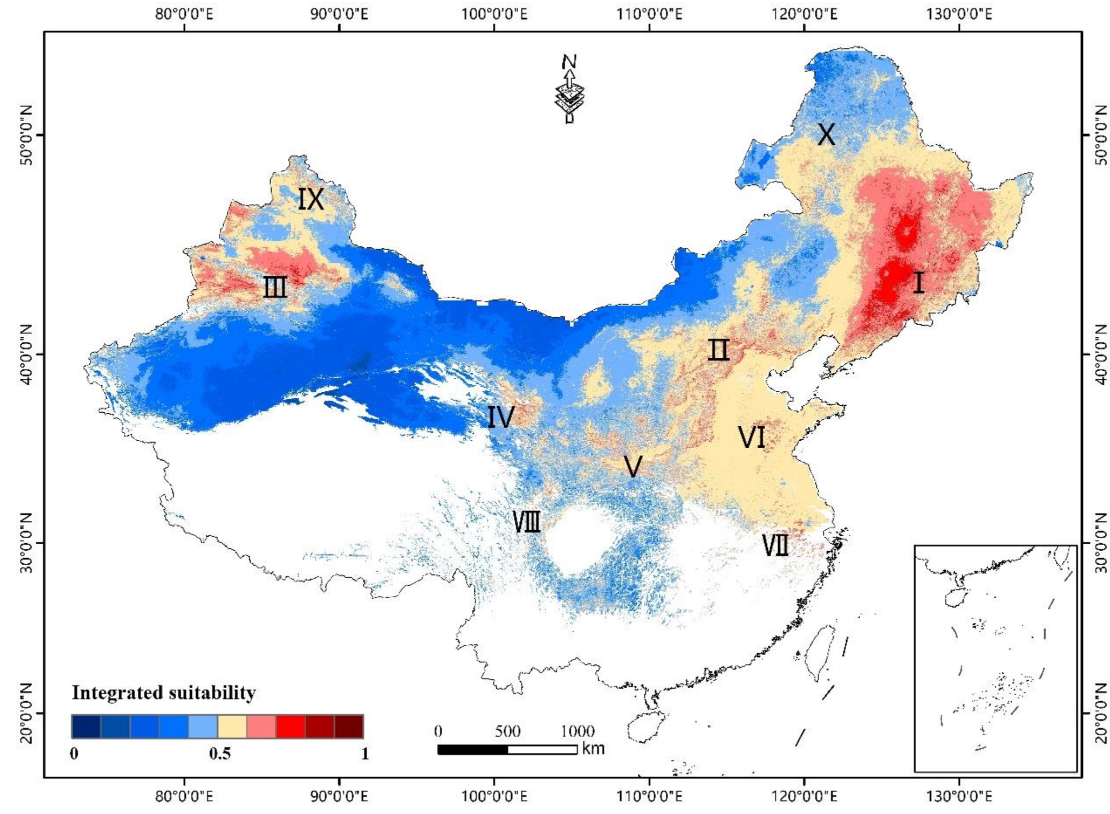

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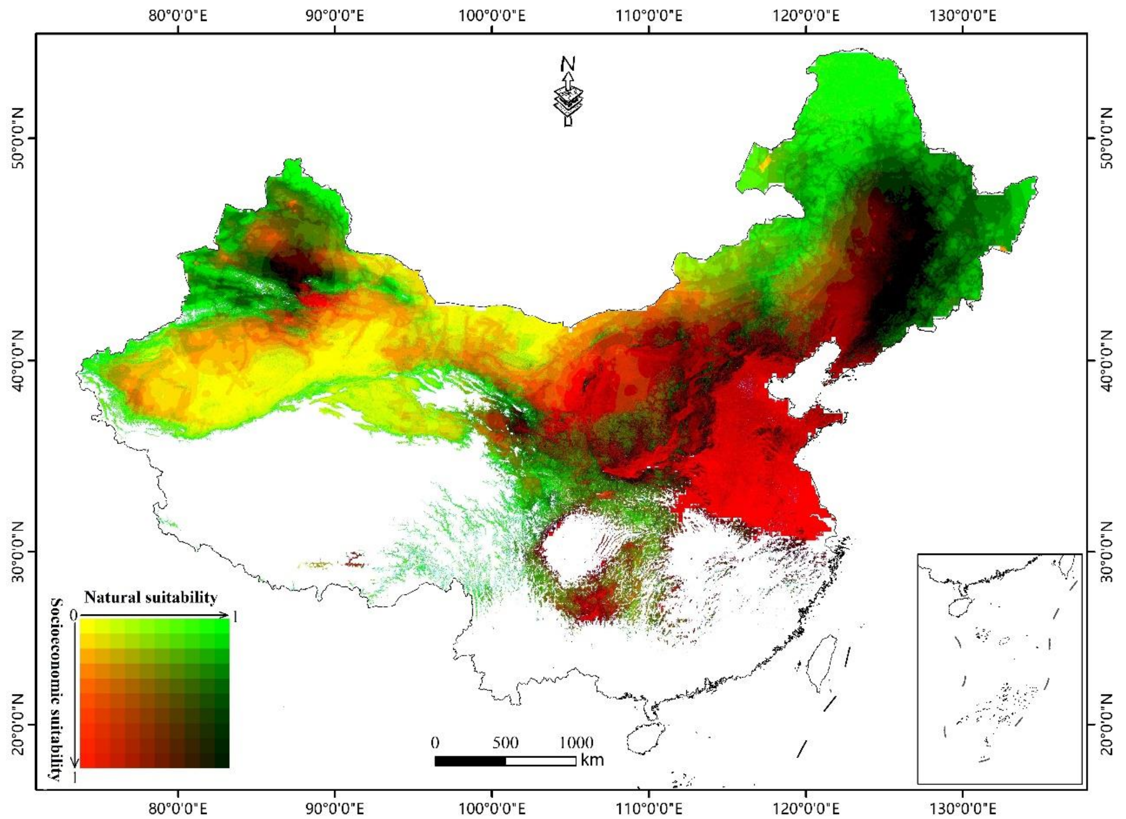

Figure 6. Spatial distribution of the driving factors of ski area development. The natural suitability and socioeconomic suitability values are classified into deciles, generating 100 unique color combinations. Socioeconomic-driven areas are shown with red shades, natural-driven areas with green shades, ideal areas with dark shades, and unfavorable areas with light shades.

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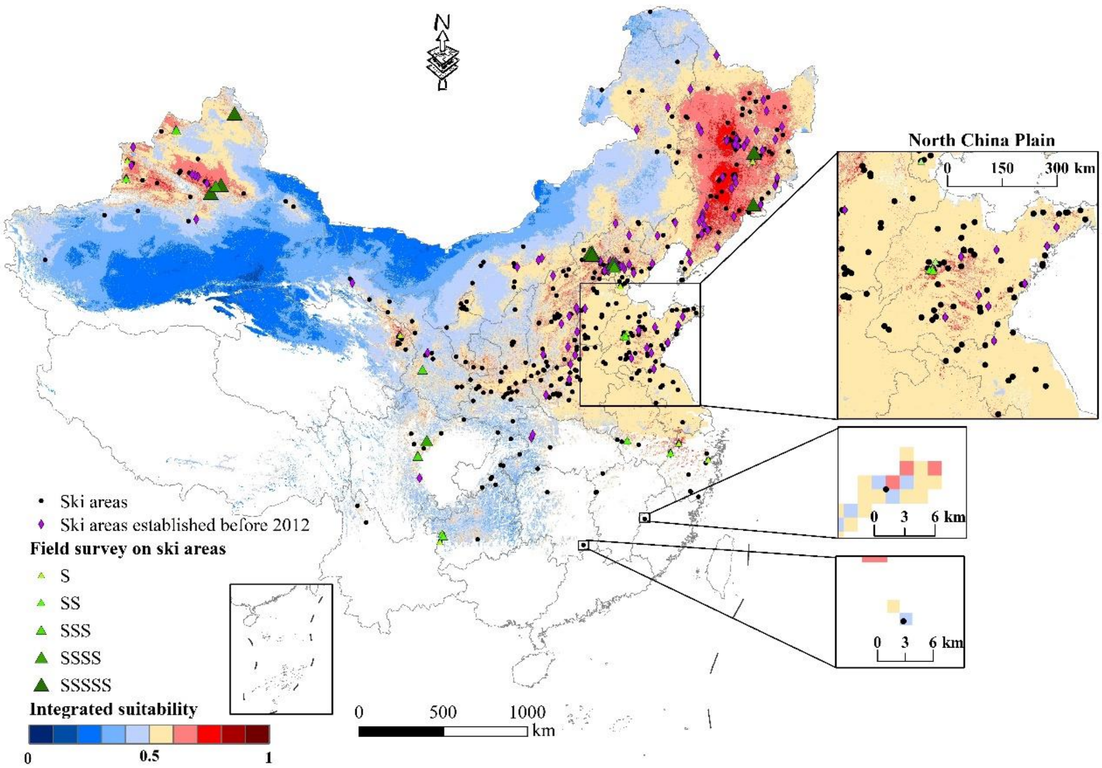
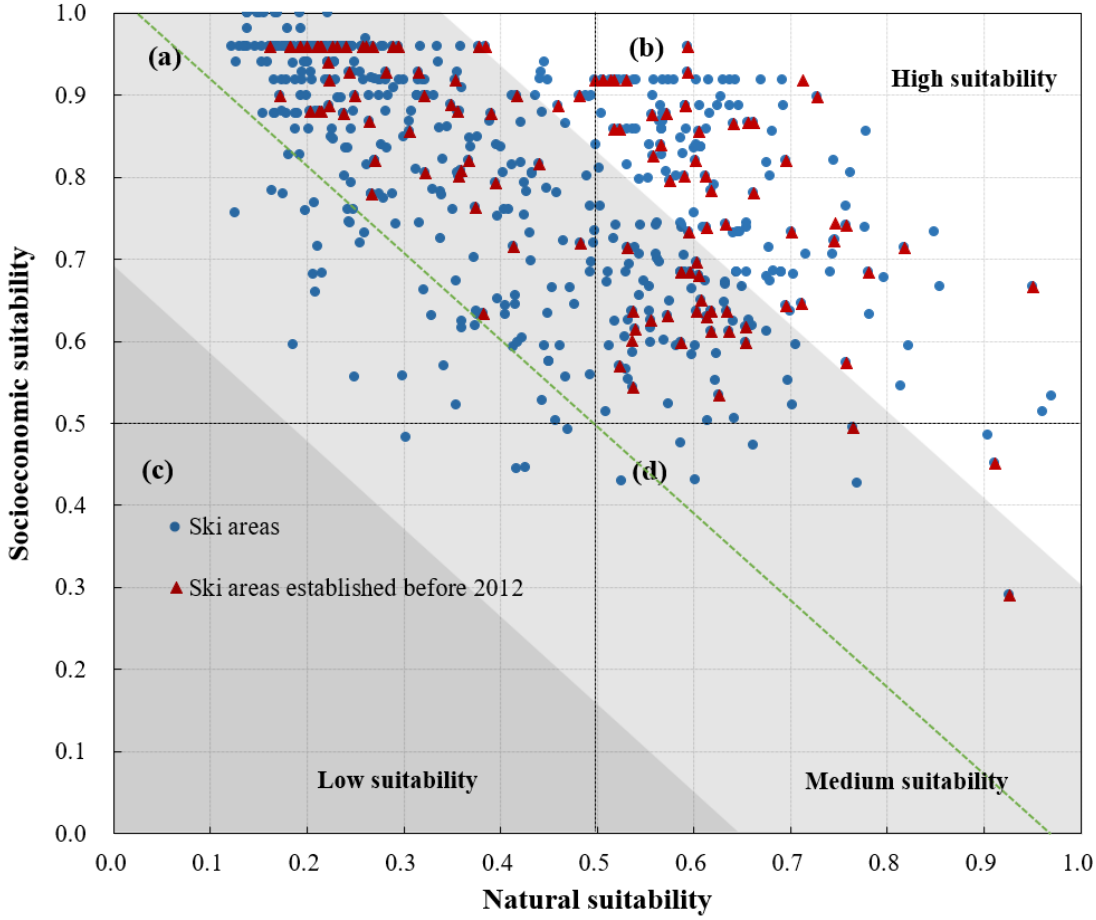


Figure 7. The distribution of existing ski areas in China. The ski areas established before 2012 are marked with rhombuses. The ski areas that were investigated in the field are marked with triangles, and the larger the triangle is, the higher the grade of the ski area. Details on the North China Plain and southern China are shown in the black insets (right).



5 **Figure 8. The suitability values of existing ski areas. (a) Socioeconomic-driven areas; (b) ideal areas; (c) unfavorable areas; (d) natural-driven areas. The deeply shaded region has integrated suitability less than 1/3 (low suitability); the lightly shaded region has integrated suitability greater than 1/3 and less than 2/3 (medium suitability); and the white region has integrated suitability greater than 2/3 (high suitability). The green dotted line is the demarcation line with an integrated suitability of 0.5.**

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Table 1. Descriptions of the data used in this study.

Data	Period	Spatial attribution	Source
Moderate-resolution imaging spectroradiometer (MODIS) snow cover products	2010-2015	500 m	National Snow Ice Data Center, https://nsidc.org/
Snow depth (SD) products	2010-2015	25 km	Cold and Arid Regions Sciences Data Center, http://westdc.westgis.ac.cn
Gridded daily observation dataset	2010-2015	25 km	Wu and Gao (2013)
Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) (V004)	2000	90 m	National Map Seamless Data Distribution Systems, http://seamless.usgs.gov
Annual normalized difference vegetation index (NDVI) spatial distribution dataset	2015	1 km	Data Center for Resources and Environmental Sciences, http://www.resdc.cn
Annual average radiance composite images	2015	500 m	National Oceanic and Atmospheric Administration's National Geophysical Data Center, https://www.ngdc.noaa.gov/eog/viirs/download_dnb_composites.html
River spatial distribution data	1999	line	Data Center for Resources and Environmental Sciences, http://www.resdc.cn
Cities spatial distribution data	2009	point	Geographic Data Sharing Infrastructure, College of Urban and Environmental Science, Peking University, http://geodata.pku.edu.cn
Road network	2015	line	OpenStreetMap, https://www.openstreetmap.org/#map
Tourist attractions	2018	point	Online map, https://maps.baidu.com
Existing (598) ski areas	2018	point	Online map, https://maps.baidu.com
35 ski areas	2018	document	Field surveys

Table 2. Different daily air temperature regimes and corresponding scores.

Daily mean temperature (℃)	Score
-2 ~ -5	7
-5 ~ -10 or -2 ~ 0	6
-10 ~ -15	5
-15 ~ -20 or 0 ~ 5	4
-20 ~ -25	3
-25 ~ -30 or 5 ~ 10	2
< -30	1
> 10	0

Table 3. Weight coefficients for the evaluation indexes.

Indexes	Weight coefficients
Natural suitability	0.52
Snow cover	0.32
Air temperature	0.19
Topographic conditions	0.34
Groundwater	0.05
Vegetation	0.11
Socioeconomic suitability	0.48
Economic conditions	0.37
Distance to cities	0.28
Accessibility of transportation	0.18
Distance to tourist attractions	0.17

Table 4. The areas of four zones by different driving factors.

Zones	Natural suitability	Socioeconomic suitability	Area (km^2×10^3)	Percentage (%)
Natural-driven areas	0.5~1	0~0.5	475	12.6
Socioeconomic-driven areas	0~0.5	0.5~1	1891	49.9
Ideal areas	0.5~1	0.5~1	555	14.6
Unfavorable areas	0~0.5	0~0.5	866	22.9