Journal of Destination Marketing & Management 18 (2020) 100506

Contents lists available at ScienceDirect

Journal of Destination Marketing & Management

journal homepage: www.elsevier.com/locate/jdmm

China's glacier tourism: Potential evaluation and spatial planning

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ARTICLE INFO

Keywords:
Glacier tourism
Potential evaluation
Spatial planning
China

ABSTRACT

To investigate the advantages of glacier tourism resources in China and evaluate their potentials, a spatial assessment system based on an analytic hierarchy process (AHP) is established here and takes into account some of the key impacting factors on China's glacial tourism, such as location and transportation, resources and environment potential, infrastructure and development level, and socio-economic conditions. The system also evaluates glacier tourism potential based on the administrative-district level in western China using a weighted integrated method. The results show that regions with higher integrated potential indices include better traffic conditions, richer glacier resources, more robust economic and social bases, closer tourist markets, and better accessibility to glacier areas, and richer tourist resources. Regional development strategies with higher and lower potentials are also discussed in order to improve tourism competitiveness and spatial attractions. The rich, unique glacier tourism resources, accompanying with the implementation of inter-provincial cooperation projects (for example, the Silk Road Tourist Belt, the Qing-Tibet Rail Tourist Belt, and the Shangri-la Ecotourism Zone), will lead to a stronger appeal for China's glacier tourism, for both domestic and foreign tourists.

1. Introduction

The status of glaciers is a sensitive indicator of climate change and an important component of the world ecosystem (Carey, 2005; Cecil, Green, & Thompson, 2004; Jurt, Brugger, Dunbar, Milch, & Orlove, 2015). In particular, mountain glaciers play a crucial role in maintaining biological diversity, protecting the natural environment, adjusting the local climate, shaping mountain landscapes, stabilizing water supply and ecological integrity, and supporting regional tourism products in alpine areas (Grêt-Regamey, Walz, & Bebi, 2008). At the same time, mountain glaciers can offer extraordinary scenic and aesthetic attractions, such as the various landforms (seracs, ice-falls, ice-crevasses, glacier streams, and neve basins), ancient glacier relics (U-shaped valleys, V-shaped valleys, cirques, pothole, horn peaks, forelands, and moraines) as well as spectacular glacier collapsing and calving phenomena, beautiful and fascinating geological landscapes and elegant attractions in mountainous areas (Labhart, 2007). Owing to their magnificent landscape, diverse scenes, and elegantly quiet retreats, some well-known glaciers around the world have become the important tourist attractions for mountaineering, expedition, sightseeing, leisure activities, and adventures.

China has one of the richest mountain-glacier resources in the world, and its modern glacier tourism originated from mountaineering and scientific expeditions in the early 1900s. In 1984, its first glacier attraction, the Qiyi glacier in the Qilian Mountains became the forerunner of China's modern glacier tourism. Since then, two glacier-distributed areas, "Three Parallel Rivers of Yunnan" and "Gonggashan Hailuogou" have been designed as National Parks, stimulating rapid development of tourism at glaciers in the two parks. Since the 1990s, the glacier resources around the Xuebaoding, Baishui, Midui, Laigu, Rongbuk, and Toumingmengke glaciers have been gradually utilized and developed and have been operating as important tourist attractions (Fig. 1). In 2013, the glacier groups of West Tianshan Tuomuer in the Aksu Prefecture and of the Bogda-Tianchi scenic area, East Tianshan in the Changji Prefecture, Xinjiang have been involved in World Heritage because of their popularity and geographic significance. Among all glacier destinations, Yulong Snow Mountain has gradually been developing to the most mature glacier tourist attraction in China since 1996. The number of tourists has increased from 100 000 in 1995 to 3.84 million in 2016. Direct tourism income exceeded CNY 500 m (~US$71 m) in 2016, increasing over 2000 times since 1994 (Wang & Zhou, 2019). Yuan and Wang (2018) calculated that the total recreational

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https://doi.org/10.1016/j.jdmm.2020.100506
Received 1 August 2019; Received in revised form 7 October 2020; Accepted 11 October 2020
Available online 19 October 2020

production of glacier tourism in Yulong Snow Mountain ranged from 1.97 to 8.17 billion CNY.

In contrast to some mountainous countries in Europe and America (Dilsaver & Wyckoff, 1999; Diolaiuti et al., 2006; Koenig & Abegg, 1997), however, the level of development of glacier tourism in China is relatively low. Most glacier tourism programs in China focus only on sightseeing, while a few higher-level programs have introduced glacier science expeditions, hiking and skiing, glacier adventuring by snowmobile, glacier sightseeing by express (e.g. train or tracked car) and helicopter, ice-cave touring, ice climbing, glacier and geology museums, and outreach education. Because most glaciers in China are located at high altitudes in the western hinterland, traffic conditions are poor and ecologies are fragile. Moreover, due to the less-developed economic conditions in these areas, a short tourist season, and significant distance from the main tourist markets, most glacier resources have not been effectively exploited as tourist attractions. The development of glacier tourism in China is thus still in the primitive stage, and the glacier resources have not completely been transformed to fully exploit their economic advantages. At present, only around ten glacier attractions in China are available for tourism, with a relatively low level (Zhou, Wang, & Sun, 2020).

From the scientific and management perspectives, assessment of potential of glacier -tourism can help tourism managers and operators make sensible plan for tourism. Because glacier tourism is affected by many factors, two prerequisites must be acquired for its potential evaluation, establishing an evaluation system and selecting an evaluation method. Obtaining necessary weights objectively using an analytical hierarchy process (AHP), the integrated evaluation system in this study selects a total of 26 individual impacting factors based on location and transportation, resources and environment, development levels and market, as well as socio-economic potentials. A weighted integrated method (WCM) is used to evaluate the development potentials of glacier tourism in 32 administrative districts in China.

In order to objectively evaluate the potential of glacier tourism services in various areas and thus ensure the rational future development of glacier tourism, the spatial development strategies in different potential areas are presented and guarantee mechanisms (e.g. traffic conditions, infrastructures and related tourism policies) are also proposed. In addition, the study also provides a new development idea for the conversion of China's glacial resources to achieve competitive economic advantage. These conversions are a promising way to mitigate the hardship during the off-season (winter and spring) periods in western China and for promoting the stepwise and leap-forward development of China's glacial tourism.

2. Background

Many glaciers worldwide have become popular tourism destinations. Glacier tourism, which has mountain glaciers and ancient glacier relics as its main attractions, includes the tourist activities of glacier sightseeing by cableway, aircraft and express (e.g. train or tracked car) glacier hiking, photography, and skiing, as well as scientific exploring and surveying for education, etc. (Wang, He, & Song, 2010; Welling, Árnason, & Ólafsdottír, 2015). Glacier tourism originated from early pilgrimage, mountaineering and expedition activities in Switzerland and Norway in the early 1800s (Alean, 2010; Ritter, Fiebig, & Muhar, 2012; Zumbühl & Iken, 1981) and developed into as a touring activity for professionals in the 1900s, then becoming globally popular after the 1980s. Nowadays, glacier tourism, as an tourism attraction, has been successfully developed and operated, gaining economic benefits in many places of the world. In addition, the impacts of climate change is also expected to lead to a gradual shift of tourist destinations towards the

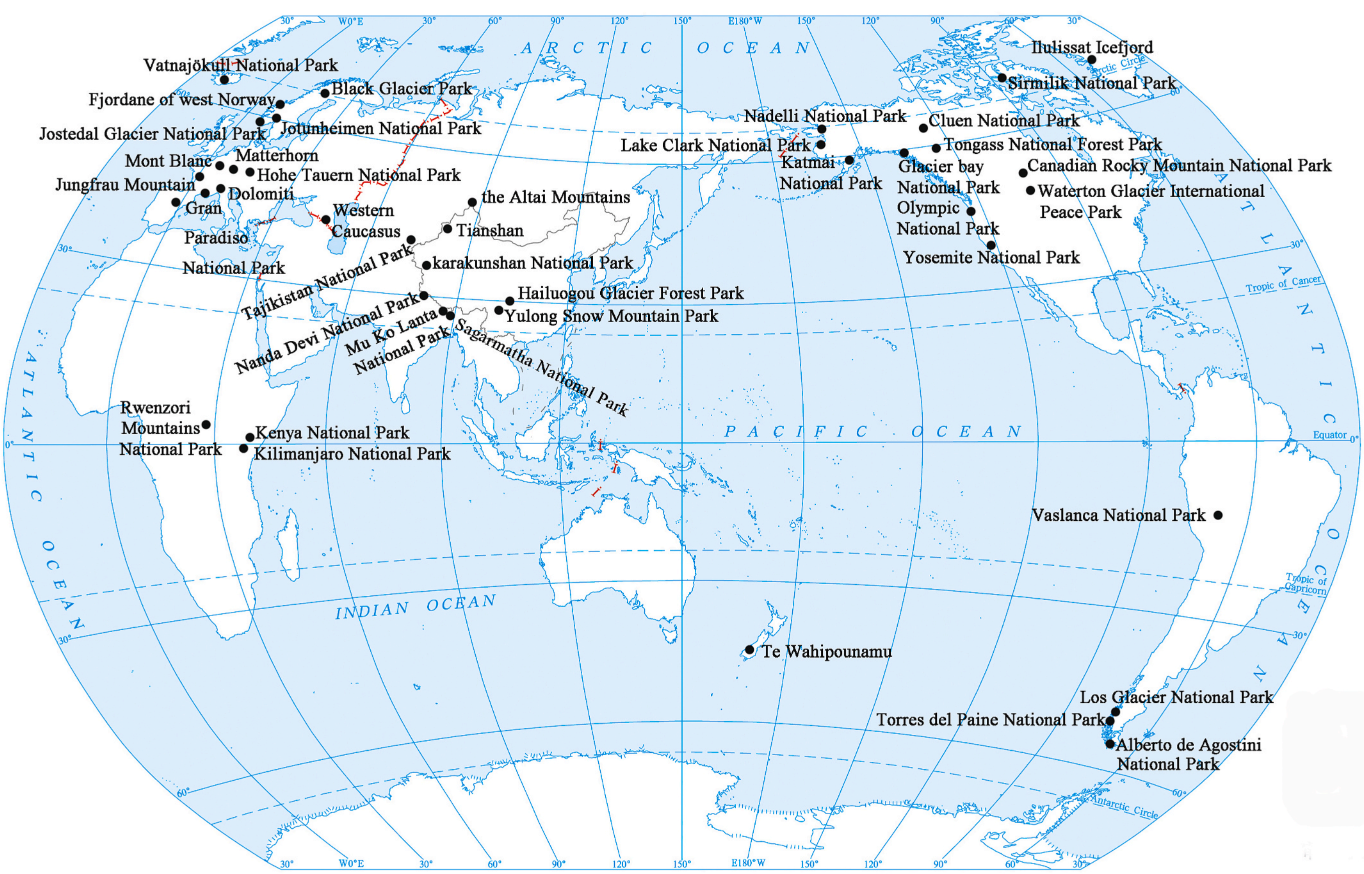

Fig. 1. Distribution of the world's glacier tourism destinations (Zhou et al., 2020).

regions at higher latitudes and altitudes (Hamilton, Maddison, & Tol, 2005). Along with improvements in infrastructure and increased leisure time, glacier tourism is becoming more and more popular and mature, and tourists around the world are willing to enjoy and appreciate different glacial landscapes by train, ship, cableway, helicopter, and any other transportations. There are more than 100 well-known mountain glacier resorts in the world that operate as special natural attractions (Wang, Zhao, & He, 2012), among which some have been listed as World Heritage Sites and World Biosphere Reserves because of their unique and spectacular landscapes and the educational significance with respect to climate change (Wang & Jiao, 2012). Examples include, the Perito Moreno and Upsala glaciers of the Los Glaciares National Park (NP) in Santa Cruz, Argentina, the Jostedal Glacier of the Jostedal Glacier National ParkP in Sogn og Fjordane, Norway, the Sermeq Kujalleq Glacier of the Ilulissat Icefjord in Western Greenland, the Aletsch and Fiescher glaciers of the Jungfrau-Aletsch-Bietschhorn in Valais, Switzerland, and the Athabasca Glacier in the Canadian Rocky Mountain National Parks (see Fig. 1 and Table 1).

With the rapid growth of the global economy, the accessibility of transportation, public leisure time and expanding consumer demands in the tourism industry have been greatly improved and increased. Many glacier-related studies demonstrate the basis for the rational exploitation and preservation of global glacier resources for developing glacier tourism. However, climate change has certainly affected the sustainability of glacier tourism to some extent.

Glacier tourism is inevitably impacted by many aspects of climate change, both positive or negative, which also affects local communities and the environment. Previous glacier tourism researches have mainly focused on the climate's influence on glacial landscapes and on climate change to the interests of glacier tourists and tourism-industry operator's (Bollati, Smiraglia, & Pelfini, 2013; Furunes & Mykletun, 2012; Garavaglia, Diolaiuti, Smiraglia, Pasquale, & Pelfini, 2012). Comparative analysis of existing or potential impacts on adaptation and measures of glacier tourism have been discussed in Carey, Huggel, Bury, Portocarrero, and Haeberli (2012), Espiner and Becken (2014), Furunes and Mykletun (2012), Purdie (2013), Purdie et al. (2014), Wang and Zhou (2019), and Wang, Che, Pang, and Du (2020). The disasters of glacier destinations, and the impact of glacier tourism on local communities and natural environment have been summarized by Bollati et al. (2013), Carey et al. (2012), Espiner and Becken (2014), Purdie, Gomez, and Espiner (2015), and Zhou et al. (2020). However, because few researches have gone on to evaluate the potential, spatial planning and layout of the glacier tourism on a national scale, there is an urgent need to strengthen the spatial planning of glacier tourism in order to maximize its benefits and mitigate the impact of climate change upon it.

Table 1
Some glaciers as popular tourist destinations.

Park name and location	Glacial attraction (s)	Number of visitors per year	Tourist activities provided
Banff NP, Canada	Columbia Ice Fields Athabasca Glacier	600,000	Glacier coach tours, glacier hiking, exhibitions
Banff NP, Canada	Columbia Ice Fields, Athabasca Glacier	600,000	Glacier coach tours, glacier hiking, exhibitions
Glacier Bay NP, Alaska	Margerie Glacier Grand Pacific and Ferris Glacier	400,000	Glacier cruise, boat tours, heli-hiking on glacier
Los Glacier NP, Argentina	Perito Moreno Glacier Lake Argentino	167,000	Glacier hiking, ice-climbing, ice cave tours, glacier boat tours
Huascar an NP, Peru	Pastoruri Glacier	109,000	Sightseeing, hiking
Westland Tai Poutini NP, New Zealand	Franz Jozef Glacier Fox Glacier	346,000	Glacier walking, ice-climbing, heli-hiking
Ilulissat Icefjord, Greenland	Sermeq Kujalleq Glacier	12,000	Cross-country skiing, dogsled tours, cruise ships, heli-hiking
Jostedal glacier NP, Norway	Brikdals Glacier	40,000	Glacier hiking, glacier lake kayak/boat, skiing, cross country skiing, exhibition
Vatnajökull NP, Iceland	Vatnajökull Glacier	343,000	Glacier hiking, ice-climbing, ice cave tours, glacier boat tours, snowmobiling, super jeep tours

Source: IUCN & UNEP-WCMC (2014), Purdie (2013), (Pirhalla, Gende, & Lders (2014)), Wang and Zhou (2019) and Welling et al., 2015

3. Study area

Glaciers in China account for 30% of those in the world's middle-low latitudes, and include the largest glacier area of all countries in this region. The Second Glacier Inventory of China reported there to be 48,571 glaciers, with a total area of 5.8×10^4 km^2 and glacier volume of somewhere between 4.3 and 4.7×10^3 km^3 (Liu et al., 2015). Glaciers in China account for 7.1% of the total glacier area in the world (~72.6×10^4 km^2 in total excluding the Antarctica and Greenland ice sheets). China's glacier resources are widely distributed from the Altay Mountains (49°10′N) of the Xinjiang in the north to the Yulong Snow Mountain in the south (27°40′N), and from Xuebaoding (103° 45′E) in northwestern Sichuan Province in the east to the international boundary (74° 30′E) between China and Tajikistan in the west (Fig. 2).

In China, the Qinghai-Tibetan Plateau holds the world's greatest reserve of mountain glaciers in the Tibet and Qinghai Province. The glaciers reach to 28,600 km^2 in area and produces around 32.5 billion m^3 of water from glacial runoff per year. Tibet has the largest number and area of glaciers. There are 28 glaciers, each of which has an area larger than 100 km^2 in Tibet; and 21 (75%) glaciers with area greater than 100 km^2 are in Xinjiang (Shi, Liu, Ye, Liu, & Wang, 2008), where the largest glacier volume is hosted. In the Qinghai province, glaciers are concentrated in the western Kunlun Mountains, southern Tanggula and northern Qilian Mountains, and their number and area rank the third in China. In the Gansu Province, glaciers are located on the northern slopes of the Qilian Mountains, and their number and area are smaller than Xinjiang, Tibet, and Qianhai. In the Sichuan and Yunnan provinces, glaciers are sparsely distributed on the Meili Snow Mountain, Yulong Snow Mountain, and Gongga Mountain, with minor numbers and areas (Liu et al., 2015). In this paper, the study area covers 32 administrative districts developed with modern glaciers (i.e. excluding glacier relics) in western China, among which 12 administrative districts are in Xinjiang, four in Qinghai Province, two in Sichuan Province, seven in Tibet, three in Yunnan, and four in Gansu Province, respectively.

4. Data and methods

4.1. Data obtaining and processing

The data used in this study include regional glacier richness, length of typical glaciers, locations, traffic conditions of glacier scenic area, and socio-economic and tourism data. 'Typical glaciers' refer specifically to glaciers developed as scenic sites or close to tourism cities. The data are mainly in the form of statistics, the number and area of regional glaciers and length of typical glaciers being sourced from the "Concise Glacier Inventory of China" (Guo et al., 2015; Shi et al., 2008). The data of regional traffic and location came from the "Map of glaciers and lakes on the Tibetan Plateau and adjoining regions" (Yao, 2008) and the "Atlas of China Traffic", available at https://www.openstreetmap.org/#map=2/59.4/-73.8&layers=T (last accessed: 9 May 2018). The data on tourism resources were provided by the *Yearbook of China*

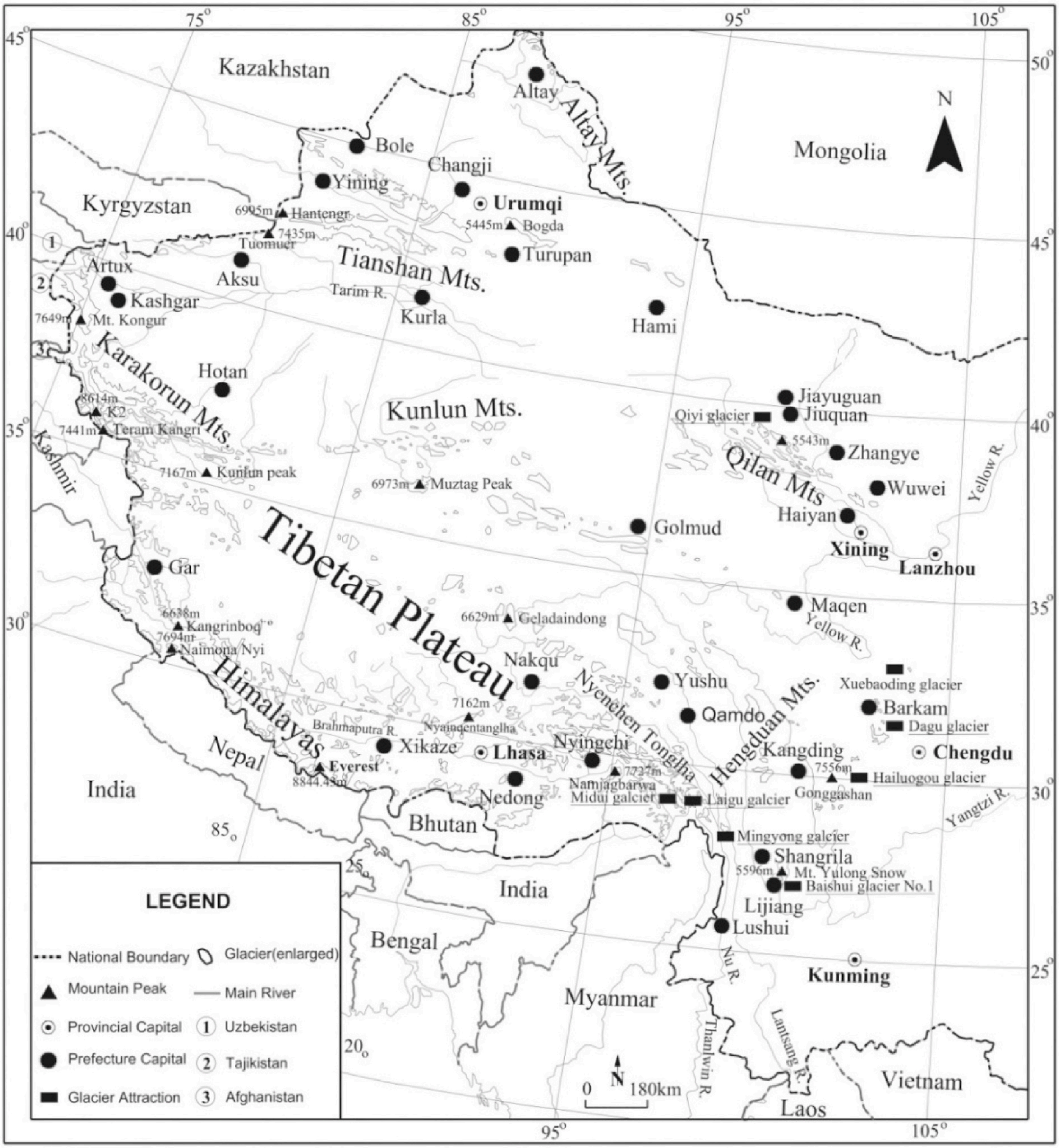

Fig. 2. Distribution of the glaciers in China (Wang, 2015).

Tourism Statistics (2017, 2018) and the online official data released by the websites of China National Tourism Administration, Tibet Tourism Bureau, Qinghai Tourism Bureau, Xinjiang Tourism Bureau, China National Park, State Administration of Cultural Heritage, and Intangible Cultural Heritage in China.

In addition, some descriptive indicators were adopted in the study. They are quantified to reflect the impact or significance on a five-point scale (Likert scale), ranging from 5 (strongly agree/very high) to 1 (strongly disagree/very low), reflecting its degree or significance (Cevat, 2002; Guo, Liu, Zhang, Yu, & Lu, 2006; Likert, 1932). For example, the integration potential of a glacier and the surrounding landscapes (*D7* in Table 1) can be classified into five classes: very high (5 points), high (4 points), moderate (3 points), low (2 points), and very low integration potential (1 point). In this study, the scores of all descriptive indicators were determined by 40 respondents including 10 geographers, 10 tourism scholars, 10 glaciologists, and 10 local government officials. The survey was conducted via e-mail correspondence.

Because the above data are quantified with different metrics and could not be used for comparison directly. The original evaluation factor data were normalized to be dimensionless by range transformation. Following the method by a previous study (Wang, Qin, & Xiao, 2015), we apply the z-score normalization to standardizing the data from various sources.

4.2. Establishment of the hierarchy-potential evaluation

The potential of glacier tourism resources is not only determined by glacier scale, size, shape, attractions, scenic quality, and scenic value but also by regional conditions, ecological environment, and socio-economic systems. The glacier tourism is largely dependent on its geographic location and natural aesthetics, and socio-economic support and infrastructure (Espiner & Becken, 2014) can also enhance the tourists' experience. (Keeney and Raiffa (1976)) suggested five criteria should be considered when indices are integrated, i.e. being complete, operational, decomposable, non-redundant, and (Purdie et al., 2015) at a minimum size. Considering into these conditions, as well as the comprehensibility and applicability of the indicator system (Wang et al., 2010), this study defines a potential evaluation system of glacier tourism with four hierarchy structures, total goal hierarchy (*A*) (integrated potential index), goal hierarchy (*B*) (four main factors, B_1, B_2, B_3, B_4), criterion hierarchy (*C*) (specific indicators, C_1-C_{10}), and factor hierarchy (*D*) (specific indicators, D_1-D_{26}) (Table 2).

In the goal hierarchy, location and transportation conditions (B_1) are further divided into location of tourism destination (C_1) and regional location (C_2) factors. Resource and environment potential (B_2) includes the richness of glacier tourism resources (C_3), the value of sightseeing ($C4$), the value of science and culture (C_5), and tourism environment (C_6) factors. Infrastructure and development potential ($B3$) and socio-economic condition potential (B_4) consists of development conditions (C_7) and market potential (C_8) factors, and economic support ability (C_9) and social support ability (C_{10}) factors, respectively. Additionally, the details of 10 indices in criterion hierarchy and 26 indices in factor hierarchy are shown in Table 1. In the study, the data selection, such as glacier scenic account or area, the length of the glacier, and gross domestic production (GDP), was based on expert judgments and tourist surveys on the significance of indices. These indices were cross-checked by statistical analysis, including normalization, weights, and AHP. This procedure ensures the retention of those indices shown have necessary interconnections with other indicators (Dowling, 1993; Wolfslehner & Vacik, 2008).

Location and transportation conditions (B_1) determine the degree of accessibility of tourists to the glacier destinations. Low accessibility is a major weakness in the development of glacier tourism. Accessibility relates to the ease with which destinations can be reached physically, as well as the ease with which the destination can be enjoyed itself as a tourism activity (Gunn, 1988). In this study, accessibility (D_1) was assessed using the distance from the glacier destination to major cities or towns in western China, and the geographical advantage of glacial area (D_2) was represented by the numbers of neighboring countries. A glacier close to more neighboring countries thus yielded a greater geographical advantage. The convenience of regional traffic (D_3) (e.g. accessibility to aviation, highway, railway, and provincial highways) and the distance from a nearby tourism market (provincial capital) (D_4) reflects its relation to the geography and location of the glacial area.

Resources and environment potential (B_2) represents the development basis of glacier tourism and evaluated by the following ten indices. The length of a typical glacier (D_5) directly determines its aesthetic value and scale, and the relevant tourism activities on the glacier surface. The scale and richness of a regional glacier (D_6) (glaciers area of per 100 km^2 regional land area) are directly related to the development potential of the regional glacier tourism. The comprehensive potential of glaciers and the surrounding landscapes (D_7) represents the scenic diversity (e.g. springs, forests, meadows, lakes, oases, and religious and cultural landscapes). Conversely, cleanness and morphology of a typical glacier (D_8) indicate its landscape quality. Suitable travel period (D_9) and tour conditions in a glacier scenic area (D_{10}) directly influence the development potential of a tourist resort. The functions of scientific survey, science popularization, and environmental education (D_{11}), religious, historical and cultural richness in the glacier scenic area (D_{12}), diversity of ethnic culture (D_{13}), highlight scientific, environmental, and cultural values of the glacier destination. The number of scenic locations (D_{14}) is mainly represented by national scenic sites of 4A level and higher. Environmental condition (D_{15}) refers to the tourism environment, including natural ecology, cultural-human environments, and hygienic conditions in a glacier destination. D_{15} requires a scientific analysis in details. Risk of glacier hazards (D_{16}) is used to reflect the security of a

Table 2
Potential evaluation system and indicator weight of glacier tourism.

Total Goal (A)	Goal Hierarchy (B)	Criterion Hierarchy (C)	Factor Hierarchy (D)	Weight
Integrated potential index (A)	Location and transportation potential index (B_1, 0.37)	Location of tourism destination (C_1, 0.14)	The accessibility of glacier scenic area (D_1)	0.124
			Geographical advantage in glacier area (D_2)	0.061
		Regional location (C_2, 0.28)	The convenience of regional traffic (D_3)	0.093
			Geographic conditions in glacier area (D_4)	0.093
	Resources and environment potential index (B_2, 0.28)	Richness of glacier tourism resource (C_3, 0.087)	The length of typical glacier (D_5)	0.053
			The scale and richness of regional glacier (D_6)	0.033
			Integration potential of glaciers and the surrounding landscapes (D_7)	0.043
		Value of sightseeing and leisure (C_4, 0.053)	Cleanliness and morphology of typical glacier (D_8)	0.023
			Suitable travel period in glacier scenic area (D_9)	0.042
			Leisure and tour conditions in glacier scenic area (D_{10})	0.013
		Value of science and culture (C_5, 0.027)	The function of scientific survey, science popularization and environmental education (D_{11})	0.010
			Historical religious and cultural richness in glacier scenic area (D_{12})	0.010
			Diversity of regional nationality culture (D_{13})	0.020
		Tourism environment (C_6, 0.023)	The number of regional tourism resources (D_{14})	0.013
			Environmental condition of glacier destination (D_{15})	0.011
			Risk of glacier hazards (D_{16})	0.010
	Infrastructure and development potential index (B_3, 0.15)	Infrastructure condition (C_7, 0.08)	Current situation of glacier tourism development (D_{17})	0.019
			The grade of scenic area typical glacier is attached (D_{18})	0.016
			Technology and facilities of glacier utilization (D_{19})	0.014
				0.041

(*continued on next page*)

Table 2 (*continued*)

Total Goal (A)	Goal Hierarchy (B)	Criterion Hierarchy (C)	Factor Hierarchy (D)	Weight
		Market potential (C_8, 0.04)	Tourism market conditions in glacier scenic area (D_{20})	
			Regional popularity and influence power (D_{21})	0.026
			Market value of glacier scenic area (D_{22})	0.033
	Socio-economic condition potential index (B_4, 0.20)	Economic support ability (C_9, 0.18)	Regional GDP (D_{23})	0.090
			The tourism industry share of GDP (D_{24})	0.044
		Social support ability (C_{10}, 0.09)	The strength of tourism policy support (D_{25})	0.033
			Cooperation condition of regional tourism (D_{26})	0.033

glacier destination.

Infrastructure and development potential (B_3) reflects the development status of glacier attraction and its surrounding area. Although glacier tourism is largely dependent on the natural beauty of glacial resources, the development of infrastructure can enhance visitors' demand for tourism consumption and this development potential is evaluated by following 6 indicators. Current development situation of glacier tourism (D_{17}) refers to the developed and developing status. The scenic areas to which the typical glacier is attached (D_{18}) is divided into three grades using global, national, and provincial standards. The betterment of technology and facilities in a glacier area, such as cableways and ski lifts, comprise (D_{19}) will make tourists easier to reach the upper part of a glacier and further enhance the natural attraction for them. Tourism market condition (D_{20}) is expressed as the distance from tourist market to glacier scenic area. Higher regional popularity and influence power (D_{21}) will increase market value of glacier attractions (D_{22}), which is represented by the degree for tourist satisfaction with the developed glacier attractions and by tourists' attractive force to the developing glacier attractions.

Socio-economic condition (B_4) is one of most important support system of glacier tourism development. Regional GDP (D_{23}) and tourism industry's share in GDP (D_{24}) are the economic motivation of glacier tourism development, and strength of tourism policy support (D_{25}) is a crucial external factor. Regional tourism collaboration (D_{26}) will also promote the regional potential and competence for facilitating the development of the glacier tourism.

4.3. Determination of the index weight

The index weight is determined by the AHP, which was originally proposed by Saaty (1987). It is a decision analysis method that combines both quantitative and qualitative criteria (Jinyang, Brian, & Thomas, 2002). An expert questionnaire was used to obtain the weights for complex factors and this process included following five steps: (1) the design of the questionnaires; (2) the calculation of a pairwise comparison matrix; (3) the estimation of relative weights (a scale from one to nine was used to compare the pairs of components); (4) examination of the consistency; and (5) aggregate of the weights to determine a ranking of decision alternatives (Erkut & Moran, 1991; (Wang & Zhao, 2011)).

The absolute weights of all indices relative to the overall goal are shown in Table 2. The weights of factors B_1, B_2, B_3, and B_4 are 0.37, 0.28, 0.15, and 0.20, respectively. Their differences show that the development potentials of location, transportation, resources and environment are more important than those of socio-economic and infrastructure. The main (top four) indices of criterion hierarchy C are arranged as follows: regional location (C_1), richness of glacier tourism resource (C_3), infrastructure conditions (C_7) and economic support ability (C_9). For the factor hierarchy D, the accessibility of glacier scenic area D_1 was a most vital factor, accounting for 12% of the total weight. The convenience of regional traffic D_3, geographic conditions in the glacier area D_4, and regional GDP (D_{23}) ranked second, explaining 9% of the total weight. Geographical advantage in glacier areas D_2 (0.06), the length of typical glacier D_5 (0.05), and D_7, D_9, D_{20}, D_{24} (0.04) also have relatively high weights. The above results from the questionnaire survey are consistent with the general concept of tourism development in China. Thus, it is essential to further improve location and transportation conditions, strengthen glacier attraction and tourism environment, and then promote socio-economic development for increasing the potentials of glacier tourism.

4.4. Integrated potential index (IPI)

Each index in the potential evaluation system reflects the potential level of glacier tourism. To fully reflect glacier tourism potential, an integrated evaluation is necessary. In this study, the integrated potential of glacier tourism development in 32 administrative districts is calculated by the weighted integrated method (WCM) from (1):

$$IPI = \sum_{i=1}^{26} X_k \times W_k \tag{1}$$

where IPI is the integrated potential index of glacier tourism development; X_k is the standardized kth indicator of factor hierarchy D; W_k is the weight of the kth indicator of factor hierarchy D relative to total hierarchy (A) (Table 1). $IPI > 0$ means that the potential index of glacier tourism is above the average level in 32 administrative districts, while $IPI < 0$ indicates that the potential index is below the average level. The calculations of B_1, B_2, B_3, and B_4 potential indexes also follow formula (1).

5. Results and analysis

5.1. Assessment and regionalization of overall glacier tourism potential

As shown by Fig. 4, *IPIs* varied between −0.95 and 0.73 in the 32 investigated districts. Urumqi, Changji, Aba, Ganzi, Aksu, Nyingchi, Ili, Xikaze, and Lijiang have high *IPIs* of 0.72, 0.55, 0.50, 0.50, 0.47, 0.45, 0.42, 0.41, and 0.40, respectively. However, other districts, such as Nakqu, Yushu, and Nagri have relatively low *IPIs*. The districts with higher *IPIs* have better traffic conditions, richer glacier resources, higher economic and social bases, closer tourist markets, easier accessibility to glacier areas, and more scenic sites. Among the 32 districts, Urumqi has the highest *IPI* of 0.726 owing to its rich glacier resources, excellent geographic conditions and strong economic base. Comparatively, Ngari located in the hinterland of Tibet Plateau, had the lowest *IPI* of −0.947 (Fig. 3) because of its weak economic base.

Fig. 3 shows that the districts with relatively high *IPIs* ranked from 1 to 18 (IPI > 0) and obviously higher than the average level (−0.11), indicating their better accessibility and socio-economic support, such as Urumqi, Changji, Bayingolin, Lhasa, and Jiayuguan. For example, Aba, Ganzi with Chengdu and Chongqing and Haibei with Xining and Lanzhou all have large tourist markets; and Lijiang, Diqin, Altay, Aksu, Ili and Kashgar, Lyingchi, Xikaze, and Shannan have rich tourism resources and better accessibility to typical glaciers. In contrast, poor accessibility to glacier landscapes in some regions, such as Hami, Turupan, Hotan, Nujiang, Jiuquan, Wuwei, Zhangye, and Qamdo, leads to consequently lower *IPIs*. Due to weak economic bases, poor transportation conditions, and distant tourist markets (Figs. 2 and 3), some regions have similarly

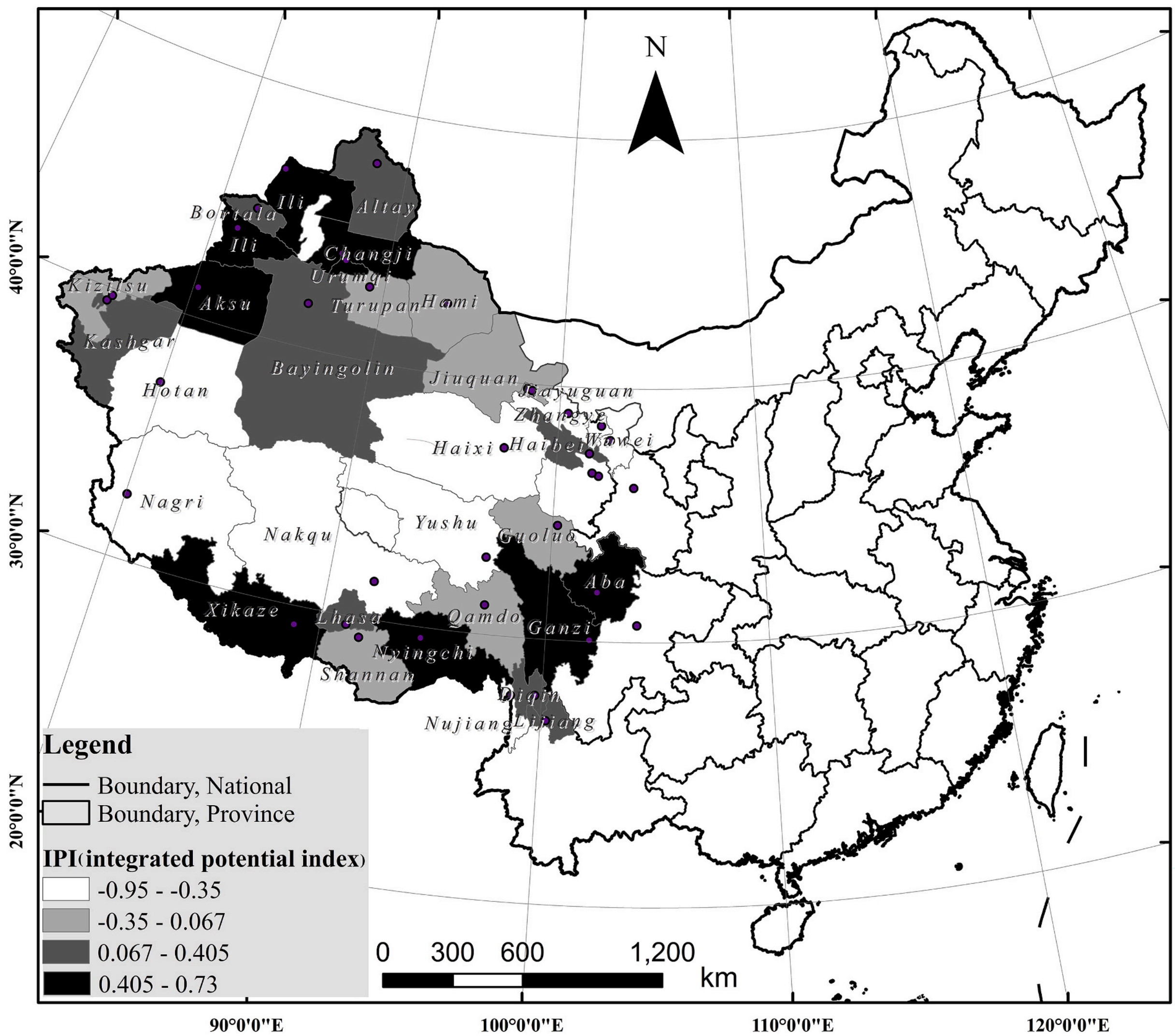

Fig. 3. The potential of glacier tourism development in 32 cities in China.

lower *IPIs*, like Kizilsu, Guoluo, Haixi, Yushu, Nakqu and Nagri, The above results integrating potential evaluation are in accordance with the current development situation of China's glaciers tourism. For example, some districts (Urumqi, Changji, Ganzi, Aba, Aksu, Nyingchi, Lijiang, Diqing, Jiayuguan, Ili, Altay, Haibei, and Xikaze) with relatively high *IPIs* display a developed level of glacier tourism. On the contrary, there are some districts with relatively low *IPIs* in Qinghai-Tibet Plateau, such as Nakqu, Yushu, and Ngari, because of the inconvenience in transportation. The districts with transportation advantages, as well as rich glacier and tourism resources, have relatively high *IPI*s, suggesting that the integrated potential evaluation system, has a robust scientific significance in explaining the distribution of areas with different IPIs (Figs. 2 and 3).

5.2. Strategies for developing glacier tourism

5.2.1. Development strategies in regions with higher potential

The districts with a high *IPI* on the scale of 1–18 own abundant scenic sites and easy accessibility to glacier landscapes in western China (Fig. 3). In particular, there are good location and traffic conditions, high economic development level, rich glacier tourism resources, and abundant near-field tourist markets in these districts, such as Urumqi, Changji, Lhasa, Baingolin, Haibei, and Shannan. Therefore, they have the highest *IPI*s for glacier tourism development among the 32 studied regions. Similarly, some districts with higher *IPI,* like Aksu, Ili, Xikaze, Altay, Kagshar, and Bortala, also have higher development potential because of their rich glacier resources, better access to glacier attractions and obvious geographic advantages. Some regions with suitable climate and high combination conditions of glacier, forest, meadow and regional cultural landscapes, such as Aba, Ganzi, Lyingchi and Diqin, are in Hengduan Mountains in southern China. Among them, Aba, Ganzi, Lijiang, Lyingchi, and Diqin have successfully developed Dagu Glacier, Hailuogou Glacier and Baishui Glacier No. 1, Midui Glacier and Mingyong Glacier as popular glacier attractions (Figs. 3 and 4). Thus, they will be attracting more tourists and getting better development prospect.

Based on the above analysis, the regions with higher potential, like Urumqi, Changji, Aksu, Yining, Kashgar Tashituer, Artux, Lhasa, Xikaze, Lyingchi, Lijiang, Jiayuguan and Haibei should fully take their advantages of the favorable location, better development conditions and promising tourist markets, highly combined value of glacier and surrounding resources to design and develop a variety of glacier tourism products and improve their service with environment protection (Liu, Yang, & Xie, 2006). This paper suggests meeting the demands from various tourists in the light of local conditions and the characteristics of glacier areas (for example, Tianshan, Karakorun, Himalayas, Nyenchen Tonglha, Hengduan and Qilian Mountains) (Table 3, Figs. 2 and 4). In addition, these regions should make further use of their stronger social and economic basis, large tourist market and high tourist reputation to

Fig. 4. Several popular glacier attractions in China (Dagu Glacier, Hailuogou Glacier, Baishui River Glacier No. 1, Midui Glacier and Mingyong Glacier, respectively).

Table 3
Glacier tourism type in main potential region, China.

Main potential region	Glacier area	The type of glacier tourism
Urumqi, Changji, Aksu, Yining	Tianshan Mountains	Mountaineering, expedition, ice climbing, glacier sightseeing, glacier photography, walking on glacier, border tourism of glacier, glacier skiing, popularization tourism of glacier science
Kashgar, Tashituer, Artux	Karakorun Mountains	Mountaineering, expedition, ice climbing, scientific investigation, walking on glacier, glacier skiing, glacier documentary shooting, glacier photography, border tourism of glacier
Lhasa and Xikaze	Himalayas	Mountaineering, expedition, scientific investigation, ice climbing, glacier sightseeing, walking on glacier, glacier documentary shooting, glacier photography, border tourism of glacier
Lyingchi, Lijiang	Nyenchen Tonglha Hengduan Mountains	Glacier sightseeing, glacier photography, leisure and vacation, scientific investigation, popularization tourism of glacier science, experience tourism of glacier geological museum
Jiayuguan, Haibei	Qilian Mountains	Glacier sightseeing, glacier experience, scientific investigation, popularization tourism of glacier science, geo-science practice

improve the functions of existing glacier tourism products and establish several international glacier scenic area and tourism routes with high quality. They can therefore form some well-known leisurely destinations with cryosphere features and make "the first engine" of China's glacier tourism.

5.2.2. *Development strategies in the regions with lower potential*

The districts with relatively low *IPIs* on a scale from 19 to 32, Kizilsu, Jiuquan, Qamado, Hami, Turupan, Guoluo, Wuwei, Nujiang, Haixi, Hotan, Zhangye, Nakqu, Yushu, and Nagri (Table 3; Fig. 3), can be classified into three sub-regions. The first sub-region, including Kizilsu and Qamdo, have rich glacier resources, excellent traffic conditions, and stronger development foundations. However, they are far away from the tourist market and lack national-level scenic sites; therefore, Kizilsu and Qamdo should actively establish several glacier scenic sites at the national level to increase the popularity of regional tourism. Similarly, the two districts should also increase publicity of glacier tourism to attract more tourists.

The second sub-region is located in the national tourism belt of the Ancient Silk Road in northwestern China, including Jiuquan, Hami, Turupan, Wuwei, and Zhangye (Fig. 3). Compared with the other districts, they have better regional traffic and socio-economic conditions, richer cultural landscapes and more diverse ethnic customs, although they are short of convenient access to glacier attractions. We suggest that these districts should comprehend glacier resources, oasis environment, and Silk Road culture to establish several glacier attractions with western features (arid environment) for future development. The third sub-region, including Guoluo, Nujiang, Haixi, Hotan, Nakqu, Yushu, and Nagri in the western hinterland, are rich in harsh natural environments, poor transportation infrastructure, backward socio-economic development conditions, less regional scenic sites, and proximity lacking to tourist markets. However, abundant glacier resources in these areas are compelling (Table 3; Fig. 3).

There are normally fragile ecological environments in the regions with lower tourism potential in western China, but with substantial soil and water conservation as well as major ecological security significances. These regions should try to prevent ecological deterioration, utilize the existing infrastructure and actively carry out scientific expeditions and environmental education of glacial knowledge to maximize the value of glacier resources and minimize environment pollution in glacial areas. Meanwhile, with the implementation of national main functional area planning and ecological function regionalization, the regions in western China should select several glacier attractions as demonstration areas for glacier tourism and increase their popularity.

With rapid improvement of traffic conditions and tourism services in the hinterland of the Qinghai-Tibet Plateau, the potential of glacier tourism there will gradually increase. In the future, tourists are expected to pay more attention to the size of the glacier than the distance from their departures.

6. Conclusions

Generally, the districts with convenient location and sophisticated transportation are predominantly identified as provincial capitals and their neighboring cities, and other districts with obvious geographical advantages. The districts with richer glacier resource, larger glacier scale, or better combination between glaciers and the surrounding landscapes, possess a higher potential index of resources and environment. The districts for high-level development of glacier tourism, mainly for provincial capitals and their surrounding cities, must have the impeccable infrastructure, higher potential index of socio-economic development and better industrial base. Overall, the districts with higher comprehensive potential index should be qualified with convenient traffic conditions, richer glacier resources, better economic and social base, closer tourist market, easily accessible to glacier area, and richer regional tourism resources. Currently, established glacier tourism destinations are mainly distributed in the Hengduan Mountains with more comfortable climate, easier accessibility, and a close tourist market (Fig. 2).

The development of glacier tourism is mainly confined by traffic conditions and other infrastructures as well as related tourism policies. Among them, road network construction can improve the accessibility of glacier tourism destinations, while tourism policies may influence the conversion from social capital to glacier tourism industry. With the construction and development of the double-track project of the Qinghai-Tibet Railway, the planning and design of Sichuan-Tibet and Yunnan-Tibet Railway, the transportation condition and infrastructure in Western China will be greatly improved in further. At the same time, inter-provincial cooperation projects along Silk Road National Tourist Belt, Qing-Tibet Rail National Tourist Belt, and Shangri-la National Ecotourism Function Zone have become more mature and feasible. Currently, China is nurturing tourism as a strategic pillar industry of the national economy and modern service industry which people are more satisfied with. Especially in March 2016, China's President Xi Jinping pointed out the scientific concept of "lucid waters and lush mountains are invaluable assets, while the ice frozen areas have a lot of opportunities to gain the fortune". These driving factors will attract more and more domestic and foreign tourists to visit, experience and explore the glacier attractions in Western China.

Author statement

Wang Shijin: Research design, literature review, data collection, data formal analysis, manuscript writing; Xie Jia: Data collection and data formal analysis; Zhou Lanyue: Methodology and plotted the figures.

Declaration of competing interest

None.

Acknowledgments

This research was supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA19070503), the Major Program of the National Natural Science Foundation of China (41690143), the State Key Laboratory of Cryospheric Science (SKLCS-ZZ-2020), National Social Science Foundation of China (19FGLB061) and Applied Technology Research and Development Fund Project of Aba Prefecture, China (20YYJSYJ0076). We also thank the anonymous reviewers, Professor He Yuanqing and Mr. Huang Shihai for helpful comments and suggestions, which considerably improved the final manuscript.

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