Evaluating the supply and demand of cultural ecosystem services in the Tibetan Plateau of China

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Abstract

Context In the Tibetan Plateau (TP), the supply of cultural ecosystem services (CESs) is unique, and the demand for CESs is gradually increasing with rapid urbanization. Evaluating the relationship between the supply and demand for CESs is critical for guiding regional sustainable development. However, due to the difficulty in obtaining empirical data in the high altitude and complex topography of the TP, relevant research is still lacking.

Objectives The objective of this study was to develop an approach to address the difficulties of obtaining the empirical data on the TP and to evaluate the relationship between the supply and demand for CESs.

Methods Taking the Qinghaihu-Huangshui basin as an example, we combined the SolVES model and social media big data to evaluate the supply and demand for CESs in the TP.

Results Our results showed that the combined method can effectively evaluate the supply and demand for CESs in the basin, and can be used for other remote regions. The supply and demand for CESs in the basin exhibited obvious spatial mismatch. Among the two types of mismatch, in the areas of high supply and low demand of CESs, residents' subjective well-being (SWB) were substantially lower. Being far away from central city was an important reason for the high supply and low demand of CESs.

Conclusions Establishing and improving the transportation system connecting central cities with other counties is encouraged to utilize the rich cultural and tourism resources of the TP, as well as enhance the SWB and promote regional sustainable development.

1. Introduction

Cultural ecosystem services (CESs) refers to the nonmaterial benefits that people obtain from the ecosystems through spiritual fulfillment, recreation and aesthetic experiences (Millennium Ecosystem Assessment, 2005., which has an important contribution to human well-being (de Groot et al., 2010). Compared to other ecosystem services, CESs are subjective and intangible. This makes evaluating CESs not only difficult but also often overlooked (Martín-López et al., 2009; Tilliger et al., 2015). The supply of CESs refers to the potential cultural services from an ecosystem to beneficiaries (Caputo and Butler, 2017). Demand for CESs refers to the CESs that are currently realized or used by people in a certain area at a certain time (Meng et al., 2020). In recent years, the supply of and demand for CESs have been closely linked to sustainable development. According to the 17 UN Sustainable Development Goals (SDGs), CESs are not only closely related to climate action (SDG 13), life below water (SDG 14) and life on land (SDG 15), but also contribute to other SDGs, such as poverty alleviation in SDG 1.1 (Geijzendorffer et al., 2017; Wood et al., 2018).

Research on the supply and demand for CESs in the Tibetan Plateau (TP) is very important. First, the supply of CESs in the TP is unique. On the one hand, the TP is the highest plateau in the world. The unique plateau climate characterized by low temperature, low atmospheric pressure and strong solar

radiation has formed a unique plateau landscape (Yang et al., 2014; Zhang and Zhang, 2019). On the other hand, the TP supports a multiethnic settlement dominated by Tibetans, and its culture presents unique multiethnic characteristics dominated by Tibetan culture (Liu, 2017). Second, the demand for CESs in the TP is gradually increasing. With the advancement of urbanization, transport links have gradually improved, e.g., the opening of the Qinghai-Tibet Railway in 2006, which has greatly increased demand for CESs in the TP (Wang et al., 2017). According to statistics, from 2006 to 2019, the number of tourists traveling to Qinghai Province and the Tibet Autonomous Region annually increased by 15.1% and 23.8%, respectively, and tourism revenues on average increased 23.6% and 26.7% annually, respectively (Bureau of Statistics of Qinghai Province and Tibet Autonomous Region, 2006-2019). Currently, the TP is an internationally acclaimed tourism destination. Therefore, under the background of urbanization, research on the supply and demand for CESs in the TP is of great significance to regional sustainable development.

Recently, some scholars have evaluated the supply and demand of CESs. For instance, Liu et al. (2020) evaluated the supply and demand of recreation services in the coastal city of Guangzhou, China. Yoshimura and Hiura (2017) assessed the supply and demand of aesthetic services in Hokkaido, a coastal region of Japan. Deng et al. (2020) evaluated the supply and demand of leisure services in Beijing on the North China Plain. Phillips et al. (2021) assessed the supply and demand of CESs provided by urban green space in Brussels on the Flanders Plain, Belgium. However, previous studies mainly focused on developed areas of low altitudes, and little attention has been given to the TP. In the TP, relevant progress has been made in assessing the monetary value of CESs based on land use/cover data (Jiang et al., 2020; Li et al., 2021). However, a comprehensive understanding of CESs from the perspective of supply and demand is still lacking. This is mainly due to the region's high altitude, with an average altitude of more than 4000 m, complex topography and inconvenient transportation routes, making it difficult to obtain empirical data.

The combination of the SolVES (Social Values for Ecosystem Services) model and social media big data provides an effective means to study the supply and demand of CESs in the TP. On the one hand, the SolVES model, which is based on questionnaire survey and Maxent maximum entropy, is capable of mapping multiple CESs to quantify the supply of CESs in the TP (Sherrouse and Semmens, 2015). This model has been successfully used for evaluating CESs in various national parks (Zhou et al. 2020; Sherrouse et al., 2014). On the other hand, social media big data can help us get access to empirical data in the TP, and can be used to quantify the demand for CESs (Yoshimura and Hiura, 2017). For instance, Meng et al. (2020) quantified the demand for three CESs in the Guanting Reservoir basin in China based on geotagged review data from Dianping.com.

This study evaluates the supply and demand for CESs in the TP. First, the Qinghaihu-Huangshui basin is used as an example, and we quantify the supply of three CESs, i.e., aesthetic service, historical and cultural service, and recreational and therapeutic service, using the SolVES model. Then, we collect social media big data and quantify the demand for the three CESs. The relationship between the supply and demand of CESs is further analysed using the matrix method. Finally, the association between the

mismatch of the supply and demand of CESs and the residents' subjective well-being is discussed. The findings provide a scientific basis for understanding the CESs in the TP.

2. Study Area And Data

2.1 Study area

The Qinghaihu-Huangshui basin is located northeast of the TP with a geographic location between 97°50'-103°15' E and 36°15'-38°25' N and covering an area of $6.25 \times 10^4 \text{ km}^2$. The basin includes two subbasins, i.e., the Qinghaihu and Huangshui subbasins (Fig. 1). The topography of the basin is high in the northwest and low in the southeast, and altitudes range between 1548 m and 5241 m. The basin is characterised by a semiarid, alpine, continental climate with low temperatures, low atmospheric pressure and strong solar radiation, similar to the climate of the TP (Fang et al., 2020, Yang et al., 2014). In the basin, the multiyear average temperature and precipitation levels are 1.4°C and 405.05 mm, respectively. The basin mainly includes the Buha River, Shaliu River, Huangshui River, and Datong River.

The basin includes 14 major cities, including Xining, the largest city in the TP. In 2019, the total population and GDP were approximately 4.3 million and 204 billion RMB, respectively, accounting for 31.7% and 33.2% of the total values for the TP. In other words, the basin is the main population and economic region of the TP. In addition, the population of the basin includes 52 ethnic groups, including all ethnic groups in the TP, indicating that the basin can reflect the characteristics of multiethnic settlement in the TP. In 2010, the Han, Hui, and Tibetan ethnic group populations in the basin accounted for 73.0%, 15.0%, and 6.2% of the total population, respectively.

The basin is characterised by a combination of farming and nomadic culture with rich natural landscapes and cultural heritage. For example, Qinghai Lake and Kumbum Monastery in the basin are rated as leading tourist attractions by the Ministry of Culture and Tourism of China, attracting many tourists for sightseeing (<https://zwfw.mct.gov.cn/>). Additionally, Xining is an ancient city in the basin where multiple civilizations and nations have met and harmonized throughout history (Luo et al., 2013). Therefore, Xining includes many major historical and cultural sites protected at the national level. For example, the relics of Shenna are the cultural heritage of ancient human beings from the Neolithic Age to the Bronze Age. Moreover, Xining is a multiethnic settlement, and its folk culture is very diverse, mainly in terms of material (such as clothing and diet) and spiritual folk culture (such as religion and art).

2.2 Data

We used the following three types of data for the case study. First, social media big data from Ctrip.com were obtained on November 10th, 2020 to quantify the demand for CESs. Second, environmental data, including land use and cover data, a digital elevation model (DEM), and the routes of rivers and roads, were used to quantify the supply of CESs. Land use and cover data were downloaded from the National Geomatics Center of China at a resolution of 30 m (<http://www.globallandcover.com/>). The DEM was downloaded from the Geospatial Data Cloud at a resolution of 30 m (<http://www.gscloud.cn/>). River and

road routes were downloaded from the National Geomatics Center of China (<http://www.ngcc.cn/ngcc/>). Third, statistical data, including statistical yearbook and census data for Qinghai Province and Gansu Province, were derived from the Economic and Social Big Data Platform of China (<https://data.cnki.net/NewHome/Index>) and used for further analysis and discussion.

3. Methods

3.1 Quantifying the supply of cultural ecosystem services

Our method involved three steps. First, we quantified the supply of CESs in the basin using the SolVES model. Second, we adopted the kernel density method to quantify the demand for CESs based on social media big data. Finally, we used the bivariate matrix method to evaluate the supply and demand of CESs (Fig. 2).

Referring to the work of Sherrouse et al. (2014) and the cultural characteristics of the basin, i.e., rich natural landscapes, a multiethnic culture, and a long history, we designed a questionnaire. The questionnaire contained two parts. First, the basic socioeconomic characteristics of the respondents in terms of gender, ethnic group, age, level of education, occupation and income were recorded. Second, the respondents' attitudes and preferences regarding CESs (e.g., aesthetic, historical, cultural, recreational, and therapeutic services) were recorded. In the survey, respondents were first asked to hypothetically allocate 100 RMB among the CESs based on their preferences. The higher the value assigned, the more important a CES was considered by a respondent. Then, the respondents were asked to list 1-3 locations in the basin providing the CESs they valued. Previous studies have shown that some types of CESs are provided simultaneously and cannot be distinguished, especially in terms of historical and cultural services as well as recreational and therapeutic services (Meng et al., 2020). Hence, we combined these services. Thus, aesthetic, historical and cultural, and recreational and therapeutic services were used to represent the characteristics of CESs in the basin.

In July 2020, we carried out on-site surveys in two locations and collected paper-based questionnaires through face-to-face interviews (Fig. 3). We conducted on-site surveys in all cities in the basin, and the number of questionnaires administered was proportional to the population. Additionally, in some tourist attractions, i.e., Qinghai Lake and Kumbum Monastery, we also conducted on-site surveys.

To ensure the representativeness of the survey data, we had to collect at least 204 questionnaires (Yamane, 1967). A total of 315 valid questionnaires were obtained after eliminating incomplete questionnaires, resulting in a response rate of 94.0%. In addition, to obtain a full account of the surveys and potential bias, we compared the demographic characteristics of the respondents to those of local residents. The results showed that the demographic characteristics of the respondents were generally consistent with those of residents in the basin (Table 1).

Table 1
Demographic characteristics of respondents and residents in the basin

	Respondents		Residents	
	Category	Number	Category	Number $\times 10^4$
Gender	Male	163(51.7%)	Male	217.06(50.5%)
	Female	152(48.3%)	Female	212.66(49.5%)
Age	<20 years old	56(17.8%)	<20 years old	109.22(26.7%)
	20-50 years old	209(66.3%)	20-49 years old	213.26(52.1%)
	>50 years old	50(15.9%)	>49 years old	86.93(21.2%)
Ethnic group	Han	238(75.6%)	Han	298.99(73.0%)
	Minority	77(24.4%)	Minority	110.42(27.0%)

After collecting the questionnaires, we adopted the SolVES model to quantify the supply of CESs in the basin (Sherrouse and Semmens, 2015). Specifically, we first obtained the spatial layer of locations providing the CESs identified by the surveys. Then, we processed the environmental data. Based on ArcGIS10.6 software, on the one hand, the slope was calculated. On the other hand, distance to water (DTW) and distance to roads (DTR) were calculated by the Euclidean Distance Tool. Finally, we ran the SolVES model. The model produced unitless value maps with values ranging from 0 to 10 for each CES based on the survey and environmental data. The greater the value is, the higher the CES supply is.

To represent differences in CES supply, we further calculated the average value of CES supply at the county level and divided the counties on four levels with the top 25% representing high supply areas, 25-50% representing relatively high supply areas, 50-75% representing relatively low supply areas, and the bottom 25% representing low supply areas.

3.2 Quantifying the demand for cultural ecosystem services

Following the work of Meng et al. (2020), geotagged review data from Ctrip.com were used in kernel density estimation to quantify the demand for CESs. Ctrip, founded in 1999, is China's largest travel website with 200 million active users in China. Consumers can not only obtain detailed information about tourist attractions but also voluntarily post ratings and comments on tourist attractions on the website. We crawled the website and collected all comments on tourist attractions of counties in the basin, resulting in a total of 26841 comments.

To control the quality of the social media big data, we applied four steps to process the collected data: (1) sites not located within the basin were removed; (2) sites not relevant to natural ecosystems, such as museums, were removed; (3) sites sharing similar names, such as "Langshidang Scenic Spot" and "Langshidang Scenic Spot in Beishan National Forest Park", were combined; and (4) sites receiving fewer than five comments were removed. After data processing, the final numbers of sites and comments were

139 and 15160, respectively. Then, we conducted a text analysis to divide the sites into three categories of CESs based on the keywords shown in Table 2. When users’ comments on one site included multiple keywords characterizing multiple CESs, the information was used to quantify each type of CES. Finally, we used kernel density estimation to generate a raster layer of rating-weighted CES demand applying the following formula:

$$D_i=10\times R_i(1)$$

where D_i is the CES demand of site i , R_i is the rating of the site on Ctrip.com where ratings vary from 0 to 5.

Table 2
Description of the cultural ecosystem services from the survey and geo-tagged data.

Type	Description	Representative keywords included in the geotagged comment data
Aesthetic	The ecosystems provide beautiful scenery.	scenery, photography, sightseeing, field of flowers, snowy mountain, grass, sunrise, sunset
Historical and cultural	The ecosystems record various historical events and preserve many folk customs.	history, culture, heritage, relic, ancient city, ancient road, ancient building, folklore, religion, rock cave, hole
Recreational and therapeutic	The ecosystems provide people with sites for outdoor leisure activities, supporting people’s physical and/or mental well-being.	recreation, exercise, walking, running, cycling, boating, fishing, mountain climbing, hiking, camping, barbecue, sand skiing, skating, bird watching, sketching

To represent differences in CES demand, we calculated the average value of CES demand at the county level and divided the counties on four levels, with the top 25% denoting high demand areas, the middle 25-50% denoting relatively high demand areas, the middle 50-75% denoting relatively low demand areas, and the bottom 25% denoting low demand areas.

3.3 Evaluating the supply and demand of cultural ecosystem services

Based on the work of Wang et al. (2020), taking the county-level administrative unit as our basic unit, we used the median to evaluate the matches between CES supply and demand. Specifically, through the classification of CES supply and demand, we combined the leading 25% and 25-50% of the counties as high-value areas. Simultaneously, we combined the leading 50-75% of the counties and the bottom 25% of the counties as low-value areas. Thus, four types of supply and demand were obtained, namely, high supply and high demand, low supply and high demand, high supply and low demand, and low supply and low demand combinations.

Due to the rich CESs in the basin, some regions have the supply capacity of multiple CESs. Therefore, we further assessed the supply and demand of multiple CESs. Four results were obtained. We first found

aesthetic and historical and cultural services to belong to the same type of supply and demand. Second, aesthetic and recreational and therapeutic services belonged to the same type of supply and demand. Third, historical and cultural, and recreational and therapeutic services belonged to the same type of supply and demand. Fourth, aesthetic, historical and cultural, and recreational and therapeutic services belonged to the same type of supply and demand.

4. Results

4.1 Supply and demand of aesthetic services

The areas with high and relatively high supply of aesthetic services spanned 7,300 km² and 13,700 km², respectively, accounting for 11.7% and 21.9% of the basin's total area, respectively. Spatially, the high supply area was mainly distributed in Xining and around Qinghai Lake, and the relatively high supply area was mainly located around Xining (Fig. 4a, b). In addition, the areas of relatively low and low supply accounted for 14.7% and 51.7% of the total area of the basin, respectively. Among them, the relatively low supply areas included Menyuan, Huangzhong and Honggu. The low supply area was distributed across Tianjun and Gangcha in the northwest and across Ledu and Yongdeng in the southeast of the basin.

The areas of high and relatively high demand for aesthetic services spanned 6,200 km² and 13,100 km², respectively, accounting for 9.9% and 21.0% of the total area of the basin, respectively. Spatially, the high demand area fulfilling people's demands for aesthetic services was located in Xining and its surrounding counties, namely, Huangzhong and Huzhu. The relatively high demand area was concentrated around the high demand area (Fig. 4c, d). Additionally, the relatively low demand area was mainly distributed in Gangcha, Haiyan and Yongdeng, accounting for 37.4% of the total area of the basin. The low demand area was mostly distributed in Tianjun in the northwest and in Honggu and Minhe in the southeast of the basin. The low demand area accounted for 31.7% of the basin's total area.

The relationship between the supply and demand of aesthetic services was dominated by the low supply and low demand and high supply and low demand combinations. The areas of low supply and low demand and high supply and low demand spanned 31,500 km² and 11,800 km², respectively, accounting for 50.4% and 18.9% of the total area of the basin, respectively. Specifically, low supply and low demand areas were mainly distributed in Tianjun and Gangcha in the northwest and in Yongdeng and Honggu in the southeast of the basin. High supply and low demand areas were mainly located in Haiyan and Minhe (Fig. 4e, f). In addition, areas of low supply and high demand and high supply and high demand accounted for 16.0% and 14.7% of the basin's total area, respectively.

4.2 Supply and demand of historical and cultural services

For the supply of historical and cultural services, the areas of high and relatively high supply spanned 2,500 km² and 10,900 km², respectively, accounting for 4.0% and 17.4% of the total area of the basin, respectively. Specifically, the high supply area was mainly located in Xining, and the relatively high supply area was mainly distributed around Xining (Fig. 5a, b). In contrast, the areas with relatively low and low

supply accounted for 17.6% and 61.0% of the total area of the basin, respectively. Spatially, the relatively low supply areas included Menyuan, Ledu and Yongdeng, and the low supply areas were concentrated in the northwestern part of the basin.

Regarding the demand for historical and cultural services, the areas of high and relatively high demand spanned 4,600 km² and 13,900 km², respectively, accounting for 7.4% and 22.2% of the basin's total area, respectively. Among them, the high demand area was located in Xining and its surrounding counties, namely, Huzhu and Pingan. The relatively high demand area was concentrated around the high demand area (Fig. 5c, d). In addition, the relatively low demand area mainly included Gangcha and Minhe and accounted for 27.4% of the total area of the basin. The low demand area covered Tianjun, Menyuan, Yongdeng and Honggu, accounting for 43.0% of the total area of the basin.

For historical and cultural services, the relationship between supply and demand was dominated by low supply and low demand and high supply and high demand combinations. The areas of low supply and low demand and high supply and high demand spanned 42,200 km² and 11,500 km², respectively, accounting for 67.5% and 18.4% of the total area of the basin, respectively. Among them, low supply and low demand areas were mainly distributed in the northwest of the basin. High supply and high demand areas were concentrated in Xining and its surrounding counties (Fig. 5e, f). Moreover, areas of low supply and high demand and high supply and low demand only accounted for 11.2% and 2.9% of the basin's total area, respectively.

4.3 Supply and demand of recreational and therapeutic services

The areas of high and relatively high supply of recreational and therapeutic services spanned 2,500 km² and 10,400 km², respectively, accounting for 4.0% and 16.6% of the basin's total area, respectively. Concretely, the high supply area was mainly located in Xining. The relatively high supply included counties around Xining, namely, Datong and Huzhu, as well as Ledu (Fig. 6a, b). Furthermore, the relatively low supply area included Menyuan, Huangyuan, Huangzhong and Yongdeng, which together account for 18.4% of the total area of the basin. The low supply area was concentrated in the northwestern part of the basin, accounting for 61.0% of the total area.

The areas of high and relatively high demand for recreational and therapeutic services spanned 6,200 km² and 15,000 km², respectively, accounting for 9.9% and 24.0% of the basin's total area, respectively. Spatially, the high demand area was distributed in Xining and its vicinity, namely in Huzhu and Huangzhong. The relatively high demand area was distributed near the high demand area (Fig. 6c, d). Additionally, the relatively low demand area included Gangcha, Ledu and Yongdeng, accounting for 34.4% of the total area of the basin. The low demand area was located in Tianjun in the northwest and in Honggu and Minhe in the southeast of the basin, and the area encompassed as much as 31.7% of the basin's total area.

The relationship between supply and demand of recreational and therapeutic services was mainly low supply and low demand and low supply and high demand combinations. The areas of low supply and low demand and low supply and high demand spanned 36,100 km² and 13,500 km² respectively, accounting for 57.8% and 21.6% of the total area of the basin, respectively. Among them, low supply and low demand areas were located in Tianjun and Gangcha in the northwest and in Yongdeng in the southeast of the basin. Low supply and high demand areas included Menyuan, Haiyan, Huangyuan and Huangzhong in the middle of the basin (Fig. 6e, f). In addition, areas of high supply and high demand and high supply and low demand accounted for only 12.3% and 8.3% of the basin's total area, respectively.

4.4 Supply and demand of multiple CESs

For multiple CESs, the relationship between supply and demand is dominated by low supply and low demand combinations. Low supply and low demand areas are mainly distributed in Tianjun and Gangcha in the northwest and in Yongdeng in the southeast of the basin, comprising 59.5% of the basin area (Fig. 7). Moreover, low supply and high demand areas include Haiyan, Menyuan, Huangzhong and Ledu, accounting for 23.2% of the total area of the basin. High supply and high demand areas are clustered in Xining and its surrounding counties, namely, Datong, Huzhu, Pingan and Huangyuan, accounting for 14.7% of the basin's total area. High supply and low demand areas are located in Minhe and Honggu in the southeastern part of the basin, accounting for 2.6% of the basin's total area.

5. Discussion

5.1 Effectiveness of evaluating CESs supply and demand

To date, existing representative methods have difficulty evaluating the supply and demand of CESs in the TP. For example, the expert-based rating approach usually involves experts scoring the supply and demand of CESs for different land use/cover types on the basis of land use/cover data (Burkhard et al., 2012). Although this approach is simple and fast, it is highly subjective and uncertain. Especially in the TP, due to the low accuracy of land use/cover data and the unique CESs present, this approach can further aggravate the uncertainty of CESs supply and demand assessment (Liu et al., 2019; Zhang et al., 2019). Another approach is to use proxy indicators to measure the supply and demand of CESs. For example, the average fraction of urban greenspace and the greenspace per capita have been used to quantify the supply and demand of CESs, respectively (Chen et al., 2019). This approach is relatively simple, but relies heavily on socioeconomic indicators based on administrative units. Thus, it is difficult to apply this approach to the TP, for which socioeconomic indicators are incomplete. Again, survey-based analysis are adopted to collect the perspectives of residents of various demographic backgrounds on the supply and demand of CESs (Kaltenborn et al., 2020). This approach is not applicable to the TP, mainly due to the region's high altitude, complex topography, inconvenient transportation routes and diverse demographic setting. In addition, some scholars have proposed using a mapping method for CESs supply and demand based on viewsheds. For example, Yoshimura and Hiura (2017) used geotagged photos posted on Flickr and the Maxent maximum entropy to map the supply and demand of aesthetic

services. However, this approach is only applicable for aesthetic service, and not suitable for the TP with various types of CESs.

The combination of the SolVES model and social media big data can effectively evaluate the supply and demand of CESs in the TP. First, the SolVES model based on questionnaire survey and Maxent maximum entropy can reliably assess the supply of CESs in the TP. Previous studies have shown that when the area under the curve (AUC) value of the Maxent model is greater than 0.7, the assessment is valid (Swets, 1988). In this study, the training AUC values of the three CESs were all greater than 0.9, and the test AUC values were all greater than 0.8 (Figs. 4, 5, 6), indicating that the model can effectively estimate the supply of CESs in the basin. For another thing, social media big data lays a sound foundation for effectively evaluating the demand of CESs (Zhai et al., 2015; Meng et al., 2020). Social media big data can not only fully reflect the public's attitudes and preferences regarding tourist attractions in the TP, but also provide rich information on different groups. More importantly, social media big data solve the difficulty of obtaining empirical data from the TP, and save time and effort.

The method of combining the SolVES model and social media big data can be applied for other remote regions. First, this method requires less empirical data. Although the SolVES model requires survey data to quantify the supply of CESs, social media big data provides an effective means to quantify the demand for CESs. This reduces the demand for empirical data in the supply and demand assessment of CESs to a certain extent. Second, this method is not limited by administrative units. Since the survey, environmental and social media big data used this method are not dependent on statistical data based on administrative units, this method can be widely used in the supply and demand assessment of CESs in natural boundary areas.

5.2 Residents' subjective well-being is lower in areas with “high supply and low demand” of CESs in the TP

The present case study of the Qinghaihu-Huangshui basin showed that the supply and demand of CESs in the TP exhibited an obvious pattern of spatial mismatch. More than a quarter of the basin exhibited spatial mismatch. Among the two types of mismatch, the area of low supply and high demand spanned 14,500 km² and was distributed across Haiyan, Menyuan and Huangzhong in the middle of the basin and Ledu in the southeast. The area of high supply and low demand spanned 1,600 km² and was located in Minhe and Honggu in the southeastern part of the basin (Fig. 7).

Previous studies have shown that humans satisfy and improve their well-being by consuming CESs such as aesthetic, recreational and historical services (Garcia Rodrigues et al., 2017; Santos-Martín et al., 2013; Kosanic and Petzold, 2020). When the supply and demand of CESs do not match, human well-being was affected (Gould et al., 2014; Pedersen et al., 2019; Willis et al., 2018).

To this end, we further analysed the association between the mismatch of the supply and demand of CESs and the residents' subjective well-being. From the collected questionnaires on human well-being

(Table 3), we found that residents' subjective well-being (SWB) in areas with high supply and low demand of CESs is significantly lower than that in low supply and high demand areas. Specifically, residents' average SWB values in areas with high supply and high demand, low supply and high demand, high supply and low demand, and low supply and low demand of CESs were 3.99, 3.98, 3.83, and 3.75, respectively. Among them, residents' average SWB in high supply and low demand areas was 4.0% lower than that of residents of high supply and high demand areas, while the residents' average SWB in low supply and high demand areas was only 0.3% lower than that of residents of high supply and high demand areas. Furthermore, the lower residents' SWB in areas with high supply and low demand was mainly reflected in the two essential elements of necessary materials for a good life and health. Compared to those of high supply and high demand areas, the average values for necessary materials for a good life and health in high supply and low demand areas were 5.4% and 7.0% lower, respectively, while values for other elements of human well-being were less than 2% (Fig. 8).

Table 3 Demographic characteristics of respondents and residents for human well-being in the basin

	Respondents		Residents	
	Category	Number	Category	Number × 10 ⁴
Gender	Male	340(50.3%)	Male	217.06(50.5%)
	Female	336(49.7%)	Female	212.66(49.5%)
Age	<20 years old	168(24.9%)	<20 years old	109.22(26.7%)
	20-50 years old	389(57.5%)	20-49 years old	213.26(52.1%)
	>50 years old	119(17.6%)	>49 years old	86.93(21.2%)
Ethnic group	Han	474(70.1%)	Han	298.99(73.0%)
	Minority	202(29.9%)	Minority	110.42(27.0%)

Note: (1) Based on the definition of human well-being in MA, we used six elements (necessary materials for a good life, health, security, good social relations, freedom and choice, and income) to represent human well-being. Among them, income was linked to actual conditions in the basin. (2) In July 2020, we collected paper-based questionnaires through face-to-face interviews in all cities in the basin, and the number of questionnaires was proportional to the population. (3) A total of 724 questionnaires were collected, and 676 were valid. (4) The demographic characteristics of the respondents were generally consistent with those of residents in the basin. (5) Referring to the work of Huang et al. (2020), we calculated the SWB.

5.3 The “high supply and low demand” of CESs in the TP and the distance to the central city

The relationship between the supply and demand of CESs is significantly affected by the process of urbanization. On the one hand, urbanization can promote regional economic development, thereby

changing the relationship between the supply and demand of CESs (Richards et al., 2020). On the other hand, urbanization changes the relationship between the supply and demand of CESs by improving road accessibility (Iniesta-Arandia et al., 2014).

We further compared the socioeconomic characteristics between areas with “ high supply and low demand ” and “ high supply and high demand ” of CESs in the basin, and found positioning far from a central city to be an important reason for high supply and low demand of CESs in the TP. In the basin, Xining is the central city and has remarkable radiation-driven effects on surrounding areas. Farther positioning from Xining results in a weaker radiation-driven effect and thus lower economic development (Fig. 9). This is consistent with previous findings (Peng et al., 2016) that, when the level of economic development is low, people’s demand for CESs is also low, and the relationship between the supply and demand of CESs readily reflects characteristics of high supply and low demand. For example, Minhe County is located more than 110 km away from Xining, and its GDP ranks below 40% of all counties in the basin (Fig. 9a). However, for counties located closer to Xining, the radiation-driven effect is stronger, the level of economic development is higher, and the relationship between supply and demand of CESs is more likely to show high supply and high demand characteristics. For example, Huzhu County is located only approximately 50 km away from Xining, and its GDP ranks in the top 40% of all counties in the basin. An alternative explanation may be that, most counties far away from Xining have sparse road networks, reducing opportunities for people to enjoy CESs, resulting in high supply and low demand for CESs. For example, Haiyan County and Ledu District are both more than 70 km away from Xining, and the density of local arterial highways ranks below 30% of all counties in the basin (Fig. 9b).

Therefore, optimizing the transportation network is an effective means to develop rich cultural and tourism resources and improve residents’ SWB. We make three specific suggestions. First, a modern, comprehensive transportation system with central cities in the TP at the core must be developed. Second, more central cities should be developed to support the traffic patterns in the TP. Third, tourism route planning in the TP should be integrated with central cities to facilitate access to tourist attractions.

5.4 Future perspectives

In our study, the SOLVES model and social media big data are used to evaluate the supply and demand of CESs. This method not only reduces the need for empirical data to some extent but is also not limited by administrative units. Thus, the approach can be widely applied in the supply and demand assessment of CESs in areas with limited access to empirical data or natural boundaries.

Our study has limitations. First, we only evaluated the relationship between supply and demand of CESs at the county level, ignoring the impact of spatial scale on CESs. Second, social media big data, which are mostly provided by younger users, may not reflect demand for CESs among the elderly and children (Zhai et al., 2015; Meng et al., 2020). In the future, we must further evaluate the relationship between supply and demand of CESs at different spatial scales. Moreover, we must also account for the views of the elderly and children in terms of demand for CESs through surveys.

6. Conclusions

The combination of the SolVES model with social media big data can be used to effectively evaluate the supply and demand of CESs in the TP. First, this approach can address the difficulties of obtaining the empirical data on the TP. Second, this approach can reflect the supply and demand of multiple CESs in the TP in a spatially explicit way. Finally, this approach is not limited by administrative boundaries and is applicable to other remote regions.

The supply and demand for CESs in the studied basin exhibited obvious signs of spatial mismatch with more than a quarter of the basin area presenting mismatch patterns. Among the two types of mismatch, residents' SWB in areas with high supply and low demand of CESs is significantly lower, mainly in terms of health and necessary materials for a good life.

Positioning far away from a central city was identified as an important cause of the high supply and low demand of CESs. In the TP, positioning far from a central city largely correlates with less regional economic development and road accessibility. Thus, building the transportation system with central cities at the core is an effective means to develop rich cultural and tourism resources, enhance SWB, and promote regional sustainable development.

Declarations

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

1. Caputo J, Butler B (2017), Ecosystem Service Supply and Capacity on U.S. Family Forestlands. *Forests* 8
2. Millennium Ecosystem Assessment, (2005.) *Ecosystems and Human Well-being*. Island Press,, Washington, DC., *Synthesis*.
3. Phillips A, Khan AZ, Canters F (2021), Use-Related and Socio-Demographic Variations in Urban Green Space Preferences. *Sustainability* 13

4. Sherrouse BC, Semmens DJ (2015) Social Values for Ecosystem Services, version 3. 0 (SOLVES 3.0): documentation and user manual. US Geological Survey
5. Wang L-e, Zeng Y, Zhong L (2017), Impact of Climate Change on Tourism on the Qinghai-Tibetan Plateau: Research Based on a Literature Review. Sustainability 9
6. Yamane T (1967), Statistics: An Introductory Analysis. 2nd Edition, Harper and Row, New York
7. Garcia Rodrigues, J., Conides, A., Rivero Rodriguez, S., Raicevich, S., Pita, P., Kleisner, K., Pita, C., Lopes, P., Alonso Roldán, V., Ramos, S., Klaoudatos, D., Outeiro, L., Armstrong, C., Teneva, L., Stefanski, S., Böhnke-Henrichs, A., Kruse, M., Lillebø, A., Bennett, E., Belgrano, A., Murillas, A., Sousa Pinto, I., Burkhard, B., Villasante, S., 2017. Marine and Coastal Cultural Ecosystem Services: knowledge gaps and research priorities. One Ecosystem 2.
8. Geijzendorffer, I.R., Cohen-Shacham, E., Cord, A.F., Cramer, W., Guerra, C., Martín-López, B., 2017. Ecosystem services in global sustainability policies. Environmental Science & Policy 74, 40-48.
9. Gould, R.K., Ardoin, N.M., Woodside, U., Satterfield, T., Hannahs, N., Daily, G.C., 2014. The forest has a story: cultural ecosystem services in Kona, Hawai'i. Ecology and Society 19.
10. Huang, Q., Yin, D., He, C., Yan, J., Liu, Z., Meng, S., Ren, Q., Zhao, R., Inostroza, L., 2020. Linking ecosystem services and subjective well-being in rapidly urbanizing watersheds: Insights from a multilevel linear model. Ecosystem Services 43.
11. Iniesta-Arandia, I., García-Llorente, M., Aguilera, P.A., Montes, C., Martín-López, B., 2014. Socio-cultural valuation of ecosystem services: uncovering the links between values, drivers of change, and human well-being. Ecological Economics 108, 36-48.
12. Jiang, W., Lü, Y., Liu, Y., Gao, W., 2020. Ecosystem service value of the Qinghai-Tibet Plateau significantly increased during 25 years. Ecosystem Services 44.
13. Kaltenborn, B.P., Linnell, J.D.C., Gómez-Baggethun, E., 2020. Can cultural ecosystem services contribute to satisfying basic human needs? A case study from the Lofoten archipelago, northern Norway. Applied Geography 120.
14. Kosanic, A., Petzold, J., 2020. A systematic review of cultural ecosystem services and human wellbeing. Ecosystem Services 45.
15. Li, M., Liu, S., Liu, Y., Sun, Y., Wang, F., Dong, S., An, Y., 2021. The cost-benefit evaluation based on ecosystem services under different ecological restoration scenarios. Environ Monit Assess 193, 398.
16. Liu, H., Remme, R.P., Hamel, P., Nong, H., Ren, H., 2020. Supply and demand assessment of urban recreation service and its implication for greenspace planning-A case study on Guangzhou. Landscape and Urban Planning 203.
17. Liu, Q., Zhang, Y., Liu, L., Li, L., Qi, W., 2019. The spatial local accuracy of land cover datasets over the Qiangtang Plateau, High Asia. Journal of Geographical Sciences 29, 1841-1858.
18. Liu, Z., 2017. Ethnic composition and cultural interaction on Qinghai-Tibet Plateau and its neighboring regions. Ethno-national Studies 2, 55-67.

19. Luo, S., Ju, K., Luo, Y., 2013. Analysis of the temporal variation in climatic comfortable period for tourism in Xining, 1954-2011. *Journal of Geocryology* 35(5), 1193-1201.
20. Martin-Lopez, B., Gomez-Baggethun, E., Lomas, P.L., Montes, C., 2009. Effects of spatial and temporal scales on cultural services valuation. *J Environ Manage* 90, 1050-1059.
21. Meng, S., Huang, Q., Zhang, L., He, C., Inostroza, L., Bai, Y., Yin, D., 2020. Matches and mismatches between the supply of and demand for cultural ecosystem services in rapidly urbanizing watersheds: A case study in the Guanting Reservoir basin, China. *Ecosystem Services* 45.
22. Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC.
23. Pedersen, E., Weisner, S.E.B., Johansson, M., 2019. Wetland areas' direct contributions to residents' well-being entitle them to high cultural ecosystem values. *Sci Total Environ* 646, 1315-1326.
24. Peng, J., Chen, Y., Hu, Z., 2016. Research progress and prospect on quantitative identification of urban hinterland area. *Progress in Geography* 35(1), 14-24.
25. Phillips, A., Khan, A.Z., Canters, F., 2021. Use-Related and Socio-Demographic Variations in Urban Green Space Preferences. *Sustainability* 13.
26. Richards, D.R., Law, A., Tan, C.S.Y., Shaikh, S.F.E.A., Carrasco, L.R., Jaung, W., Oh, R.R.Y., 2020. Rapid urbanisation in Singapore causes a shift from local provisioning and regulating to cultural ecosystem services use. *Ecosystem Services* 46.
27. Santos-Martin, F., Martin-Lopez, B., Garcia-Llorente, M., Aguado, M., Benayas, J., Montes, C., 2013. Unraveling the relationships between ecosystems and human wellbeing in Spain. *PLoS One* 8, e73249.
28. Sherrouse, B. C., Semmens, D. J., 2015. *Social Values for Ecosystem Services*, version 3. 0 (SOLVES 3.0): documentation and user manual, US Geological Survey.
29. Sherrouse, B.C., Semmens, D.J., Clement, J.M., 2014. An application of Social Values for Ecosystem Services (SOLVES) to three national forests in Colorado and Wyoming. *Ecological Indicators* 36, 68-79.
30. Swets, J.A., 1988. Measuring the accuracy of diagnostic systems. *Science* 240 (4857), 1285-1293.
31. Tilliger, B., Rodríguez-Labajos, B., Bustamante, J., Settele, J., 2015. Disentangling Values in the Interrelations between Cultural Ecosystem Services and Landscape Conservation—A Case Study of the Ifugao Rice Terraces in the Philippines. *Land* 4, 888-913.
32. Wang, B., Tang, H., Zhang, Q., Cui, F., 2020. Exploring Connections among Ecosystem Services Supply, Demand and Human Well-Being in a Mountain-Basin System, China. *Int J Environ Res Public Health* 17.
33. Wang, L.-e., Zeng, Y., Zhong, L., 2017. Impact of Climate Change on Tourism on the Qinghai-Tibetan Plateau: Research Based on a Literature Review. *Sustainability* 9.
34. Willis, C., Papathanasopoulou, E., Russel, D., Artioli, Y., 2018. Harmful algal blooms: the impacts on cultural ecosystem services and human well-being in a case study setting, Cornwall, UK. *Marine*

Policy 97, 232-238.

35. Wood, S.L.R., Jones, S.K., Johnson, J.A., Brauman, K.A., Chaplin-Kramer, R., Fremier, A., Girvetz, E., Gordon, L.J., Kappel, C.V., Mandle, L., Mulligan, M., O'Farrell, P., Smith, W.K., Willemsen, L., Zhang, W., DeClerck, F.A., 2018. Distilling the role of ecosystem services in the Sustainable Development Goals. *Ecosystem Services* 29, 70-82.
36. Yamane, T., 1967. *Statistics: An Introductory Analysis*. 2nd Edition, Harper and Row, New York.
37. Yang, K., Wu, H., Qin, J., Lin, C., Tang, W., Chen, Y., 2014. Recent climate changes over the Tibetan Plateau and their impacts on energy and water cycle: A review. *Global and Planetary Change* 112, 79-91.
38. Yoshimura, N., Hiura, T., 2017. Demand and supply of cultural ecosystem services: Use of geotagged photos to map the aesthetic value of landscapes in Hokkaido. *Ecosystem Services* 24, 68-78.
39. Zhai, S., Xu, X., Yang, L., Zhou, M., Zhang, L., Qiu, B., 2015. Mapping the popularity of urban restaurants using social media data. *Applied Geography* 63, 113-120.
40. Zhang, J., Zhang, Y., 2019. Trade-offs between sustainable tourism development goals: An analysis of Tibet (China). *Sustainable Development* 27, 109-117.
41. Zhang, Y., Liu, L., Wang, Z., 2019. Spatial and temporal characteristics of land use and cover changes in the Tibetan Plateau (in Chinese). *Chin Sci Bull* 64, 2865-2875.
42. Zhou, L., Guan, D., Huang, X., Yuan, X., Zhang, M., 2020. Evaluation of the cultural ecosystem services of wetland park. *Ecological Indicators* 114.

Figures

Figure 1

Figure 2

Flow chart

Figure 3

Survey points

Figure 4

Supply and demand of aesthetic services

Figure 5

Supply and demand of historical and cultural services

Figure 6

Supply and demand of recreational and therapeutic services

Figure 7

Supply and demand of multiple CESs

Figure 8

Comparison of subjective well-being between areas with “ high supply and high demand ” and “ high supply and low demand ” of CESs

Figure 9

Comparison of socioeconomic indicators between areas with “ high supply and high demand ” and “ high supply and low demand ” of CESs