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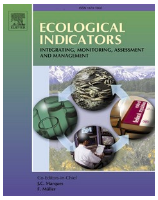

Spatial distribution of cultural ecosystem services demand and supply in urban and suburban areas: A case study from Shanghai, China

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ABSTRACT

In the urban ecosystem, the demand for cultural ecosystem services (CES) has greatly increased, and the imbalance of CES supply and demand has been prominent. This paper integrated multi-source data to analyze and visualize the spatial differences in CES demand and supply capacity between Shanghai urban center and suburbs. Based on the geo-tagged photo data, the spatial distribution differences of the four types of CES demand, Recreation & tourism services (RTS) demand, Aesthetic services (AS) demand, Heritage & cultural services (HCS) demand, and Spiritual & religious services (SRS) demand, were analyzed. Residents and tourists had a strong demand for recreation and tourism, and the spatial agglomeration effect was the most obvious. Overall, CES demand was more concentrated in urban center, while the spatial distribution of suburbs was relatively discrete. At the same time, there were under supply areas of CES near the Huangpu River in urban center and suburbs. Results from bivariate Moran's I method showed: 1) there was a significant positive spatial correlation between CES demand and CES supply capacity in urban center; 2) CES supply had a positive external impact on CES demand; and 3) the increase in CES supply capacity can promote the growth of CES demand.

1. Introduction

Ecosystem services are the conditions and processes by which natural ecosystems and their components sustain and fulfill human life (Daily, 1997).Most ecosystem services are not within the market system (such as flood control and climate regulation), so it is usually impossible to quantify their economic value except for certain services with real market value (such as food and wood supply) (Costanza et al., 1997; Seppelt et al., 2012). Due to the correlation between different ecosystem services, taking direct measures to increase the supply of market-oriented ecosystem services may reduce the quality of non-market-oriented services. Therefore, under the influence of social economy, attention should be paid to changes in service demand and supply (Gómez-Baggethun et al., 2010; Gutman, 2007). In the ecological environment affected by the economy, Cultural ecosystem services (CES) are critical components of urban ecosystem services (Liu et al., 2021), and are usually described as intangible, subjective and difficult to measure by biophysics or currency (MEA, 2005), which is why they are rarely included in decision-making process. However, CES are as important as any other ecosystem services in local communities, because recreation services can bring many important benefits (Castro et al., 2014; Zhen et al., 2010) and have a positive impact on the public's physical and mental health (Chan et al., 2012). The value of CES also provides opportunities for ecological conservation, as it is believed that maintaining CES could help protect habitats and species (Maes et al., 2012a). Moreover, the importance of CES to economic welfare and well-being (such as recreation or a sense of place) has inspired academic research on the connection between non-material benefits and natural landscape attributes (van Zanten et al., 2016). CES are not only the function or one-way flow provided by natural ecosystem for humans, but also the interaction between humans and the environment (Oteros-Rozas et al., 2017; Peña et al., 2015). In the urban ecosystem, the demand for ecosystem services has greatly increased, and there is an imbalance between the supply and demand of ecosystem services (Ko and Son, 2018; Wilkerson et al., 2018). As an important part of urban ecosystem services, CES are facing the challenge of rapid growth in demand in the process of rapid urbanization. This explains why we should pay attention to and explore the relationship between CES supply and demand. The supply of ecosystem services refers to the capacity of a particular area to provide a specific bundle of ecosystem goods and services within a given time period, while the demand for ecosystem services is the ecosystem services currently consumed, used, or valued in

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a particular area over a given time period (Burkhard et al., 2012). Regarding the spatial distribution of demand and supply of ecosystem services, the service heterogeneity is affected by the spatial heterogeneity of landscape (Zhao et al., 2018), which is manifested in the heterogeneity and complexity of the spatial distribution of different types and quantities of landscape components (Su and Fu, 2012). Among them, natural factors are the basis for determining the spatial distribution and supply of services, and human factors lead to the spatial differences in demand of services (Wu et al., 2013). Consequently, exploring the relationship between ecosystem and human social system based on the spatial distribution at the landscape level is more suitable for the research of relationship between supply and demand of CES.

For the valuation of CES, most studies focus on the supply side (Maria et al., 2014; Plieninger et al., 2013), while few comprehensive studies also considered the supply and demand relationship for CES (Berkel and Verburg, 2014; Liu et al., 2021). The CES supply is mainly evaluated by means of supply potential and supply opportunity (Peña et al., 2015). The mapping of ESs Supply based on land use data may ignore the spatial heterogeneity and interaction, leading to deviations in the spatial distribution (Eigenbrod et al., 2010). Based on land use data and combined with social and economic data, Burkhard et al. established a framework for evaluating the supply potential of different landscape types that provide ecosystem services (Burkhard et al., 2009). For mapping the recreation potential of a land, participatory mapping data based on public preference can be adopted to improve the method based on physical attributes (Scholte et al., 2018). The supply opportunity of CES is characterized by traffic, facility accessibility and population density (Maria et al., 2014; Peña et al., 2015; Scholte et al., 2018).

The demand for CES is the sum of cultural services and functions consumed or used by human society's (Burkhard et al., 2012). For demand assessment, interviews and questionnaire surveys are still important information sources (Oteros-Rozas et al., 2014), while PPGIS and other methods are employed in related research (Scholte et al., 2018), where the "local and region" dominates at the spatial scale (Hermes et al., 2018). There were still debates about the accuracy and reliability of value assessment in participatory mapping (van Berkel and Verburg, 2014). Due to the limitation of time and labor costs, it is difficult to obtain large data at multi-temporal scale, so the research on the dynamic spatial change of relationship between CES supply and demand is strictly restricted (Fu et al., 2011). Crowd-sourced photo data provides an opportunity to "mine the perception, cognition or activity ability of many people", online data shared through social media, especially geo-tagged photos, can reflect not only the relationship between landscape attributes and landscape preferences (Tieskens et al., 2018), but also the cultural and aesthetic perception of people on the landscape environment (Sinclair et al., 2018), which is becoming an increasingly attractive source of CES information (Oteros-Rozas et al., 2017). There is numerous evidence demonstrating that the higher the density of Flickr and Panoramio photos, the higher the visit rate, and the higher the landscape value (Tieskens et al., 2018). Scholars have begun to use social media data with geolocations to determine the visiting rate for recreation (Tenkanen et al., 2017). Some scholars have developed indicators to measure the use and value of cultural ecosystem services based on photo data obtained from sharing websites (Figueroa-Alfaro and Tang, 2017; Richards and Friess, 2015). The geotagged photos and the view of the photography location were used to map the demand and supply of CES (Yoshimura and Hiura, 2017), and the content analysis of photos can obtain effective CES demand and recreational preferences (Sinclair et al., 2018).

With the rapid development of urbanization, the assessment of urban ecosystem services has received more and more attention (Burkhard et al., 2014; Constant and Taylor, 2020; Marie et al., 2019; Peña et al., 2018). As scholars have discussed, all urban structures have the potential to provide ecosystem services (Shaw et al., 2016). The recreational aspects of all urban ecosystems, are perhaps the most valuable ecosystem service in cities, and all ecosystems provide aesthetic and cultural value for the city and provide structure for the landscape (Bertram and Rehdanz, 2015; Per and Sven, 1999). The spatial difference between the supply capacity and demand level of ecosystem services determines the distribution of hot and cold spots of urban CES (Liu et al., 2021). Therefore, the following questions are raised: (1) Are there differences in the preferences and agglomeration distribution of CES demand in urban center and suburban areas? (2) Is there an imbalance between supply and demand of CES? (3) Is there a spatial correlation between CES demand and CES supply capacity?

The purpose of this study is to interpret social media photos to determine CES demand preferences and spatial distribution; and analyze multi-source geospatial data to evaluate the CES supply potential and supply opportunities. We take Shanghai urban and suburban areas as examples for research, and analyze the spatial distribution characteristics and spatial correlation of CES supply and demand through Global Moran's I and bivariate Moran's I.

2. Materials and methods

2.1. Study area

Shanghai city is located in the east of China, Yangtze River estuary, and the east of Shanghai is near the East China Sea, while the north and west of Shanghai are connected with Jiangsu and Zhejiang provinces (Fig. 1). Shanghai has natural habitats for birds such as Dongtan National Nature Reserve, which has high ecological value. At the same time, as a well-known international tourist city, Shanghai has a high population density and a large number of international and domestic tourists. This fast-growing international city needs to start a forward-looking landscape planning on the basis of ecological protection in order to maintain the sustainable development of cultural ecosystem services.

There are obvious differences in land use types and landscape pattern between Shanghai urban center and the suburban areas (Fig. 1). In 2014, the urban center area was 275.04 square kilometers, with a permanent population of 7.16 million. The land use types were mainly built-up areas, and the landscape types were relatively simple. From 2004 to 2014, the built-up land area increased from 266.84 square kilometers to 269.40 square kilometers. The proportion of built-up land in the urban center area had increased by 0.93%. This area is equipped with sufficient entertainment infrastructure, and cultural landscapes are concentrated along the Huangpu River. The suburban area was 7703.95 square kilometers (including water area) and the permanent population in 2014 was 17.99 million. There were various types of land use in this area. The area of plain paddy fields is the largest, falling from 54.11% to 45.13% from 2004 to 2014. From 2004 to 2014, the water body dropped from 21.23% to 20.44%. Correspondingly, the area of built-up land continues to increase. Therefore, this paper assesses the spatial heterogeneity of CES supply and demand in these two regions.

2.2. Data collection

The previous methods of evaluating and mapping CES were reviewed (Castro et al., 2014; Maes et al., 2012a, 2012b; van Berkel and Verburg, 2014; Willemen et al., 2008), taking into account the characteristics of and available data within the study area. This research integrated multi-source geospatial data in GIS format, transformed a unified projection and coordinate system to evaluate the potential and opportunities of CES supply. The GIS software for geoprocessing was ArcGIS 10.7 ESRI Inc. Multi-source data was collected into a grid with a side length of 1km, and any zone whose marginal area less than 0.5 km^2 was eliminated. In the process of extracting the urban center and suburban areas of Shanghai, border grids with an area of less than 0.5 km^2 were retained to maintain the accuracy of the administrative scope. Then a database containing spatial reference and photos was created for picking out photo data that could represent the demand of CES through pre-

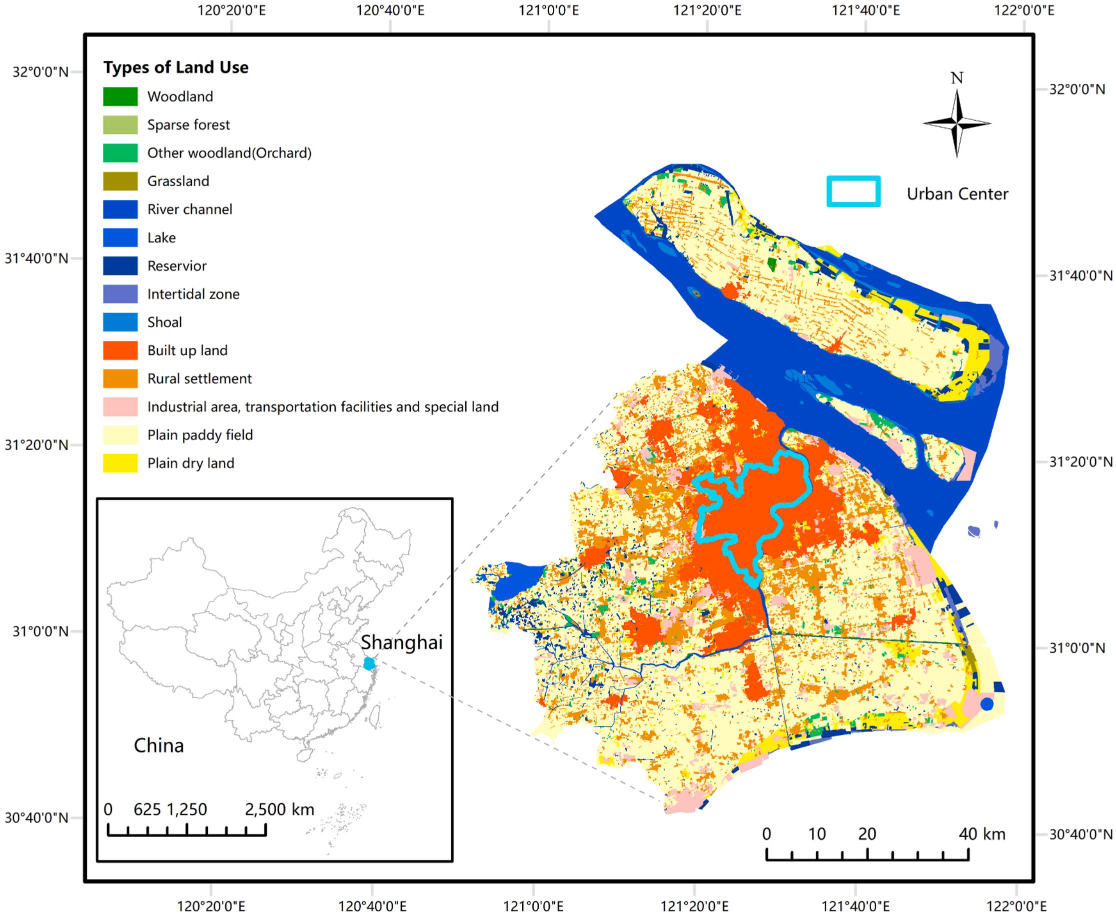

Fig. 1. Types of land use in Shanghai (2014)

operations (such as deleting repeated photos with same geographic coordinates).

2.2.1. *Supply capacity of CES*

In previous literature, the supply of CES is primarily evaluated by recreation potential supply (RPS) and recreation opportunity supply (ROS) (Maes et al., 2012b; Peña et al., 2015). Based on the land use type, this paper calculated the recreation potential of different landscape features, including (1) naturalness; (2) infrastructure; (3) water; (4) landscape diversity index (ILD); and (5) natural protected areas (NPA) (Peña et al., 2015; Tieskens et al., 2018). The recreation opportunity was assessed in terms of the distance to roads, the distance to natural landscape, and population density (Figueroa-Alfaro and Tang, 2017; Scholte et al., 2018). Compared with the natural landscape, the cultural landscape holds a larger proportion in the urban ecosystem of Shanghai. The cultural landscape presents the signs and relics of history and cultural civilization in a specific environment and landscape (Gulinck and Wagendorp, 2002). Today, the cultural landscape is seen as a necessary motivation for cities to attract tourists (Pajouh and Daneshpour, 2013). Therefore, in the analysis of recreation opportunity, this study listed the distance to cultural landscape as an indicator for evaluating the supply of CES. Spatial variability can be found across different regions of Shanghai in land use types and landscape pattern (Fig. 1). Thus, this study selected the water, infrastructure, distance to roads, population density (PD), distance to natural landscape and distance to cultural landscape to evaluate the CES supply in the urban center (Table1). The complexity of land use types and landscape features in suburban areas is high, with natural landscape coexisting with cultural landscape. This study selected the naturalness, water, index of landscape diversity (ILD), infrastructure, natural protected areas (NPA), distance to roads, population density (PD), distance to cultural landscape and distance to natural landscape to evaluate CES supply capacity in suburban areas.

The evaluation on CES supply capacity involved the index of proximity. The attraction and accessibility of landscapes decreased with the increase of distance. We determined the supply capacity of geographical units by the Euclidean distance from water, infrastructure, roads and landscapes, and set distance thresholds for those landscapes.

2.2.2. *CES demands*

This study collected 100 million pieces of photo data posted on Flickr platform in 2004–2014 through the open data from Yahoo webscope program (http://webscope.sandbox.yahoo.com) (Thomee et al., 2016), and picked out the photo data of Shanghai by virtue of geographic coordinates. The photo data has been identified by Yahoo artificial intelligence for content tags, which applied an off-the-shelf deep convolutional neural network (Krizhevsky et al., 2012), used Caffe (Jia et al., 2014) to train and tune 1570 classifier for 15 million photos taken from the entire Flickr corpus, achieved at least 90% precision on a held-out test set, including 23 types of information e.g. photo number, photographing time, title, description, deep learning label, longitude and latitude, in addition to the photo metadata. There were 125,327 photos selected from 2004 to 2014. In order to avoid the prejudice of highly active users, every grid contained only one randomly selected photo from each user. Furthermore, the photo dataset contained a large number of photos unrelated to landscape aesthetics and cultural recreation, so we deleted the photos with deep learning tags of "null", "indoor" and "people", as well as the photos that included "indoor" and "people", thereby preliminarily filtering out those unable to reflect CES demand.

According to the international classification standard of ecosystem

Table 1
CES supply and demand assessment indicators in the study area.

	Variable	Urban center	Suburban areas	Data source	Description	Evaluation
Recreation potential supply (RPS)						
	Land use/cover			RESDC	Habitat types classification	
1	Naturalness		√	RESDC	Index of degree of human influence on ecosystems. It comprises the damage or transformations caused by humans and how these ecosystems depend on human activity themselves (0-5) (Peña et al., 2015)	5: Natural forests, no continental habitats that can be absorbed; 4: Salt marshes, wetlands, coastal habitats; 3: Continental waters, shrubs, wastelands; 2: Grasslands-hedges, reservoirs, forest plantations; 1: Parks, crops, orchard, invasive species, quarry; 0: man-made buildings and land
2	Water	√	√	RESDC	Grid units within 2000 meters from water bodies have a certain supply capacity (0-2000) (Scholte et al., 2018)	Euclidean distance to water bodies
3	Index of landscape diversity (ILD)		√	RESDC	Index of landscape diversity (SHDI) for each grid (0-1) (Tieskens et al., 2018)	The Shannon's Diversity Index of each grid is calculated by the Fragstats 4.2.
4	Infrastructure	√	√	RESDC	Number of infrastructures for recreation (Recreational areas, ecological parks, theme parks) (0-44) (Tenerelli et al., 2016)	Number of infrastructures for recreation in each grid
5	Natural protected areas (NPA)		√	Shanghai Municipal Administration of Culture and Tourism	Presence of natural protected areas(0-2) (Scholte et al., 2018)	2: Protected biotopes, biosphere reserve, RAMSAR wetlands; 1: Sites of naturalistic interest, natural parks; 0: No protected areas or without naturalistic interest.
Recreation opportunity supply (ROS)						
6	Distance to roads	√	√	RESDC	Grid units within 500 meters from roads have a certain supply capacity (0-500) (Scholte et al., 2018)	Euclidean distance to roads
7	Population density (PD)	√	√	RESDC	Average population density per square kilometer in the study area (0-41416) (Figueroa-Alfaro and Tang, 2017)	Population in each grid
8	Distance to cultural landscape	√	√	RESDC	Grid units within 3000 meters from cultural landscapes have a certain supply capacity (0-3000)	Euclidean distance to cultural landscapes
9	Distance to natural landscape	√	√	RESDC	Grid units within 3000 meters from natural landscapes have a certain supply capacity (0-3000) (Scholte et al., 2018)	Euclidean distance to natural landscapes
CES demand						
10	Photo data	√	√	Flickr (Yahoo Webscope)	Social preferences of different ecosystems and landscapes for recreation (0-345) (Figueroa-Alfaro and Tang, 2017)	The number of photos in the grid

RESDC: Data center for resources and environmental sciences, Chinese academy of sciences.
Yahoo Webscope: http://webscope.sandbox.yahoo.com.

services (CICES v.4.3, 2013, https://cices.eu/), this study evaluated the following CES demands through the landscape features taken by photo data: Recreation & tourism services (RTS), Aesthetic services (AS), Heritage & cultural services (HCS), and Spiritual & religious services (SRS). Table 2 summarizes the key classification of CES demand based on photo, from related research in this area. This study screened the deep learning tags of photos based on different landscape features (Table 2). Only the deep learning tags with a confidence score of more than 0.95 were included in the statistics. This part of the work was completed through the python program, and a total of 6,534 photos were used to evaluate CES demands (there are some photos representing multiple CES demands). After that, this study randomly sampled 5% of the photos representing the different types of CES demand, and matched 785 photo primitives with the data screening results, which was 100% consistent. We imported the photo data table into ArcGIS after filtering, converted it into projection data, and mapped the photo data to the 1,000m grid to display the spatial distribution of photos.

2.3. General design of methodology

This study was conducted using a four-step method: (1) CES supply capacity measurement; (2) CES demands valuation; (3) comparison of the spatial distribution of CES demand and supply in urban center and suburban areas; (4) spatial correlations between CES demand and supply.

CES supply capacity is composed of ROS and RPS. RPS was quantified by indicators from five aspects: naturalness, water, ILD, infrastructure and NPA; ROS was quantified by indicators from four aspects: distance to roads, PD, distance to cultural landscape and distance to natural landscape. Among them, CES supply indicators have different value ranges. In order to ensure the comparability of the data, this study had calculated the raw data of the indicators in the urban center and suburban areas, normalized the CES supply indicators from 0 to 1 (Vigl et al., 2017). Positive indicators include naturalness, ILD, NPA, infrastructure and PD (Eq. (1)); negative indicators include water, distance to roads, distance to cultural landscape and distance to natural landscape (Eq. (2)). The mean values of supply variables were used for comprehensive evaluation on the CES supply capacity. All components were considered equally important, covering complementary aspects of recreation supply, therefore, they were given equal weights, within and among them (Paracchini et al., 2014). This study calculated the average value with the same weight to measure RPS and ROS in each grid, and take the average of the two to evaluate the supply capacity of CES. The calculation equations that we utilized are as follows:

Positive indicators:

$$X'_{i,j} = \frac{X_{i,j} - X_{i,min}}{X_{i,max} - X_{i,min}} \tag{1}$$

Negative indicators:

Table 2
Classification of CES demands based on photo landscape features

Cultural Ecosystem Services(CICES 4.3)	CES demands	Landscape feature	References
Experiential use of plants, animals and land-/seascapes in different environmental settings (Code 3.1.1.1)Physical use of land-/seascapes in different environmental settings (Code 3.1.1.2) Entertainment (Code 3.1.2.4)	Recreation & tourismServices (RTS)	Trees/Plant/ Grasslands/Lawn/ Lake/River/Sea/ Costal/Beach/ Dune/Mountain/ Harbor/Marina/ Amusement park	(Oteros-Rozas et al., 2017; Tenerelli et al., 2016)
Heritage, cultural (Code 3.1.2.3) Symbolic (Code 3.2.1.1)Scientific (Code 3.1.2.1) Educational (Code 3.1.2.2)	Heritage & cultural services (HCS)	Monuments/ Cenotaph/ Memorial/ Rampart/River/ Mountain	(Tieskens et al., 2018)
Aesthetic (Code 3.1.2.5)	Aesthetic services (AS)	Coastal/Beach/ River/Sea	(Oteros-Rozas et al., 2017)
Sacred and/or religious (Code 3.2.1.2)	Spiritual & religious services (SRS)	Temple/Alter/ Cathedral/ Church/ Pantheon	(Oteros-Rozas et al., 2017)

$$Y'_{i,j} = \frac{Y_{i,j} - Y_{i,min}}{Y_{i,max} - Y_{i,min}} \tag{2}$$

where $X'_{i,j}$ and $Y'_{i,j}$ are the standardized value of$X_{i,j}$ and $Y_{i,j}$, which are respectively the original value of the ith positive and negative indicators in the jth grid. $X_{i,max}$ and $Y_{i,max}$ are respectively the maximum values of the ith indicator across all grids. $X_{j,min}$ and $Y_{i,min}$ are respectively the minimum values of the ith indicator across all grids.

Most studies that used photo data to evaluate CES adopted the number of photos taken from a specific location as the representative of the CES intensity (Oteros-Rozas et al., 2017; Tenerelli et al., 2016). This study counted the number of valid photos in each grid to assess the CES demand and separately counted photo number containing different deep learning tags to evaluate the different CES demands (Figs. 4&5).

The spatial autocorrelation tool (Global Moran's I) was used to evaluate the spatial distribution of CES supply capacity and CES demands in the urban center and suburban areas. The cluster and outlier analysis tool (Anselin Local Moran's I) was used to identify the spatial clustering with high or low value elements, including High-High clusters, Low-Low clusters, Low-High outlier and High-Low outlier (Figs. 2&3). This tool is able to obtain the hot spot and cold spot zones of CES demands and supply capacity (Figueroa-Alfaro and Tang, 2017). Both of the above analysis tools can be completed in ArcGIS 10.7.

This study also normalized the CES demand level in each grid (Eq. (1)), and calculated the difference between the CES supply capacity and the CES demand in each grid. When the difference between CES supply capacity and demand is less than 0, it means that demand exceeds supply significantly (undersupply); when the difference is equal to 0, it means neutral balance; when the difference is greater than 0, it means supply exceeds demand significantly (oversupply) (Burkhard et al., 2012).

While analyzing the difference in the spatial distribution of CES supply and demand, analyzing the spatial correlation between CES supply capacity and demand is an important method to clarify the spatial dependence of the two. This study employed the bivariate Moran's I to explore the spatial clustering (positive spatial correlation) and spatial dispersion (negative spatial correlation) between CES demands and CES supply capacity (Table 3). The bivariate Moran's I was analyzed using GeoDa 1.12 (GeoDa Press LLC, Chicago, IL), whose statistical significance was evaluated via permutation test, statistically significant at 0.1% level (Anselin, 1995). This study exported the CES demand and CES supply capacity values of all grids obtained in ArcGIS software as vector data, and use them as the input data of the bivariate Moran's I in GeoDa, and choose a consistent spatial weight definition method. The spatial clustering analysis defined the spatial weights based on the Queen contiguity. The average value of all neighbors was used to evaluate the correlation between the X and Y values of a position.

3. Results

3.1. Spatial patterns of CES supply capacity

The CES supply capacity was reflected by recreation opportunity supply (ROS) and recreation potential supply (RPS) (Fig. 2). The ROS level in Shanghai's urban center was expressed by a normalized value from 0.254 to 0.975. The average ROS was 0.705, with a sharp gap of 0.721 between the maximum and the minimum, which demonstrated a spatial pattern of decreasing from center to periphery (Fig. 2a). At the same time, the spatial agglomeration effect of ROS was more obvious than that of RPS (ROS Moran's I value: 0.740 〉 RPS Moran's I value: 0.683), and the High-High clusters were primarily located in the central and eastern regions (Fig. 2d). The RPS level in Shanghai's urban center was denoted by a normalized value from 0 to 0.773, with an average RPS of 0.187, which demonstrated a spatial pattern of decreasing from the east to the west (Fig. 2b). The supply potential of this area was intensified by the clustering of both water body and infrastructures in the east, and some areas with high RPS appeared in the northwest. From the perspective of local clustering effect, these two regions were both shown as significant High-High clusters, while the northern, western and southwestern regions were apparently Low-Low clusters (Fig. 2e).

The supply capacity of CES was the average of ROS and RPS in each grid unit, which was expressed by a normalized value from 0.127 to 0.830 (Fig. 2c). The average CES supply capacity was 0.446, with a gap of 0.721 between the maximum and the minimum, while the spatial pattern also displayed a trend of higher in the east and lower in the west. The hot spot areas with local clustering were mostly located in the densely populated central and eastern regions, and the western and southern marginal areas were Low-Low clusters, reflecting the obvious disparity in the geographical location and supply capacity of urban center (Fig. 2f). At the same time, a Low-High outlier appears in the northeast, indicating that a high CES supply capacity value appears around the low CES supply value; a High-Low outlier distribution appears in the southern, indicating a low CES supply capacity value appear around the high CES supply value.

The ROS level was represented by a normalized value from 0 to 0.830 in suburban areas (Fig. 3a). The average ROS was 0.705, with a maximum-minimum gap sharper than that of urban center. The high values of ROS commonly appeared in the marginal areas of urban center, while Pudong District and other suburbs also showed discrete distribution. The spatial agglomeration of ROS was more obvious (ROS Moran I value: 0.703〉 RPS Moran I value: 0.482). High-high clusters were concentrated in the central region. The low-low clusters were mainly located in Chongming Island and the southern region, among them, some areas had high-low outlier distribution, which had large CES supply potential (Fig. 3d). The RPS level was denoted by the normalized value from 0 to 0.689. The average RPS was 0.17, with a gap between the maximum and the minimum slightly lower than that of urban center, and the high values were gathered around water areas and in the west (Fig. 3b). Overall, RPS in the suburban areas was relatively scattered compared to the urban center, which is related to the discrete distribution of population and landscape. The High-High clusters were distributed in the west (Qingpu District and Songjiang District), the surrounding areas of Huangpu River, the north of Chongming Island and the estuary (Fig. 3e). These areas are distributed with Shanghai's main

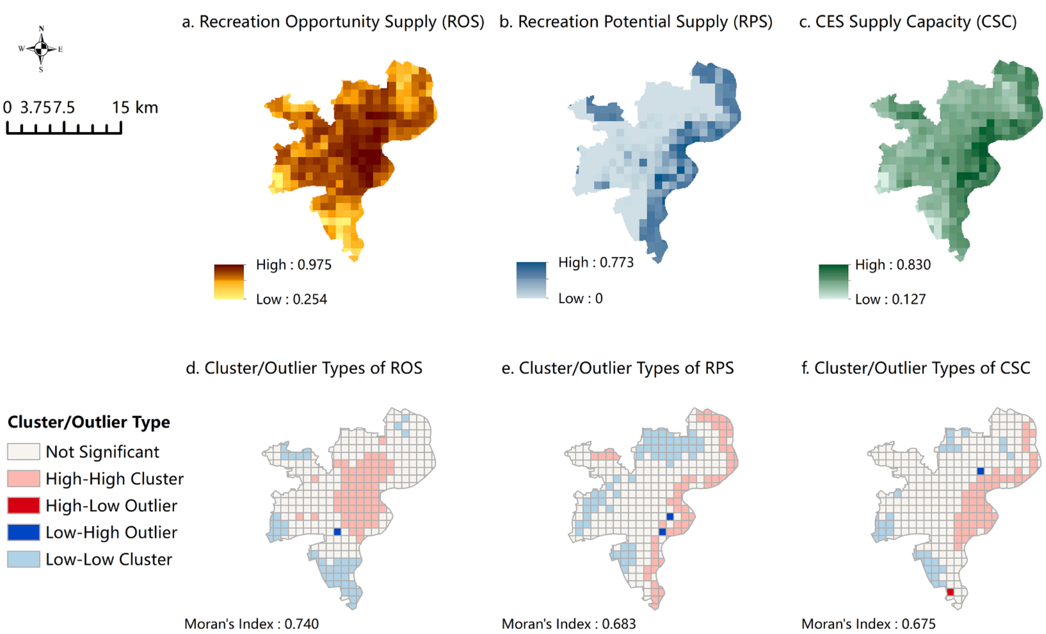

Fig. 2. Spatial pattern and cluster/outlier types of CES supply capacity (ROS & RPS) in urban center a. Spatial pattern of ROS value. b. Spatial pattern of RPS value. c. Spatial pattern of CES supply capacity value. d. Cluster map of ROS. e. Cluster map of RPS. f. Cluster map of CES supply capacity. The P values of Moran's Index in Fig. 2 are all less than 0.0001.

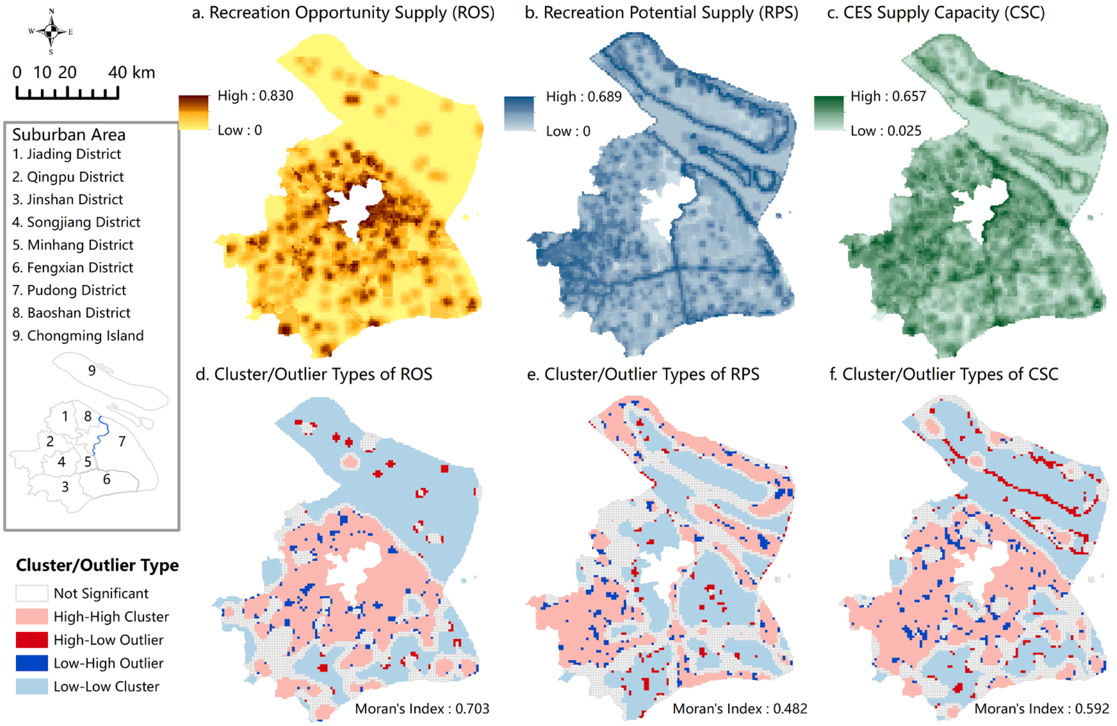

Fig. 3. Spatial pattern and cluster/outlier types of CES supply capacity (ROS & RPS) in suburban areas a. Spatial pattern of ROS value. b. Spatial pattern of RPS value. c. Spatial pattern of CES supply capacity value. d. Cluster map of ROS. e. Cluster map of RPS. f. Cluster map of CES supply capacity. The P values of Moran's Index in Fig. 3 are all less than 0.0001.

woodlands and well-known landscapes. The surrounding area had convenient transportation and strong landscape accessibility.

The CES supply capacity was expressed by a normalized value from 0.025 to 0.657 (Fig. 3c). The average supply capacity was 0.231, and lower than that of urban center. In terms of local clustering effect, the High-High clusters were commonly located in Jiading District, Songjiang District, Minhang District, Pudong District and Baoshan District around the urban center, while the Low-Low clusters mainly appeared in Chongming Island, Jinshan District, and Fengxian District (Fig. 3f).

3.2. *Spatial patterns of CES demands*

All CES demands showed uneven spatial distribution in urban center, including aesthetic services (AS) demand, Heritage & cultural services

(HCS) demand, Spiritual & religious services (SRS) demand and Recreation & tourism services (RTS) demand. The sum of all photos representing CES demand was between 0-345 (Fig. 4). RTS demand was strongest, photos representing RTS demand was between 0-260. As far as the spatial pattern was concerned, CES demands appeared strongest in the area around the Huangpu River in eastern urban center, and it tended to decline from this area as the center to the periphery, with the lowest demands in the west (Fig. 4d).

The demand for CES in urban center showed a significant positive spatial correlation (Moran's I value: 0.673) (Fig. 4e). The local clustering effect was obvious, represented by High-High clustering in the eastern region, the western and southern marginal areas showed Low-Low clusters (Fig. 4j). Among the CES demands, the RTS demand displayed the most distinct spatial clustering feature (Moran's I value: 0.687), which was the closest to the local clustering effect of the overall demands (Fig. 4i). The second were SRS demand and AS demand, and HCS demand had the weakest clustering (Fig. 4h, f & g). For these three CES demands, the High-High clusters were also gathered in the eastern urban center, with some High-Low and Low-High outliers, but free from any significant Low-Low cluster. AS demand and SRS demand had High-Low outlier distribution, and HCS demand and SRS demand had Low-High outlier distribution.

All CES demands (AS, HCS, SRS and RTS) also showed uneven spatial distribution in suburban areas, where the sum of all photos representing CES demand was between 0-313 (Fig. 5). RTS demand was also strongest, photos representing RTS demand was between 0-256 (Fig. 5d). As far as the spatial pattern was concerned, CES demands was only concentrated in some areas, and the CES demands reflected in the photos only appears in 583 grids (7.45% of 7829 grids), of which the intensity around the Huangpu River was the largest.

The spatial distribution of CES demand (Moran's I value: 0.208) in the suburbs is relatively scattered, and the degree of agglomeration is low (Fig. 5j). High-High clusters were concentrated in the west of Pudong District, north of Minhang District, and the central area of Songjiang District. Low-Low clusters were distributed in Chongming Island and southern Shanghai (Jiading District, Jinshan District and Fengxian District). The local agglomeration effect of the three types of demand of AS, HCS and SRS were similar, and no significant Low-Low clusters appeared (Fig. 5f, g & h).

3.3. CES supply-demand balance

We found weak overlap among Shanghai's CES supply capacity and CES demand, with only 2.25% of grids showing the same value for all components. CES supply capacity was generally higher than the demand, including the urban center and the suburban areas. There were 343 grids over supplied in the urban center (Fig. 6a), accounting for 99.13% of the total. There were 7,668 grids over supplied in the suburban areas (Fig. 6b), accounting for 97.94% of the total, mainly distributed in Qingpu District, Songjiang District, Baoshan District and northern Pudong District.

Compared with over-supply, this study pays more attention to the areas showed demand exceeds supply. Only 2% of the grids showed a high CES demand than CES supply capacity, which are mainly distributed on Songjiang district and both sides of the Huangpu River. This is consistent with the most demanding spatial distribution of CES (Figs. 4 & 5).

3.4. Spatial correlations between CES demands and supply capacity

The results of bivariate Moran's I showed the positive spatial correlation between CES supply capacity and demand was stronger in the urban center (Moran's I: 0.376) than that in the suburban areas (Moran's I: 0.125) (Table 3). In the urban center, the spatial correlation between RTS demand and CES supply capacity was the strongest, followed by AS and SRS demands, while the correlation between HCS demand and CES supply capacity was the poorest. The positive correlation was strongest between infrastructure and CES demand (Moran's I: 0.508), and the next was the population density (Moran's I: 0.247), while water has the weakest correlation (Moran's I: 0.063). This indicates that although water body had high entertainment potential, the spatial distribution of CES demands far away from water body was affected by more other indicators, thus the spatial correlation between them was not necessarily distinct. In the suburban areas, the spatial correlation between CES supply capacity and CES demand was weak. The bivariate Moran's I values of CES demand and CES supply capacity are statistically

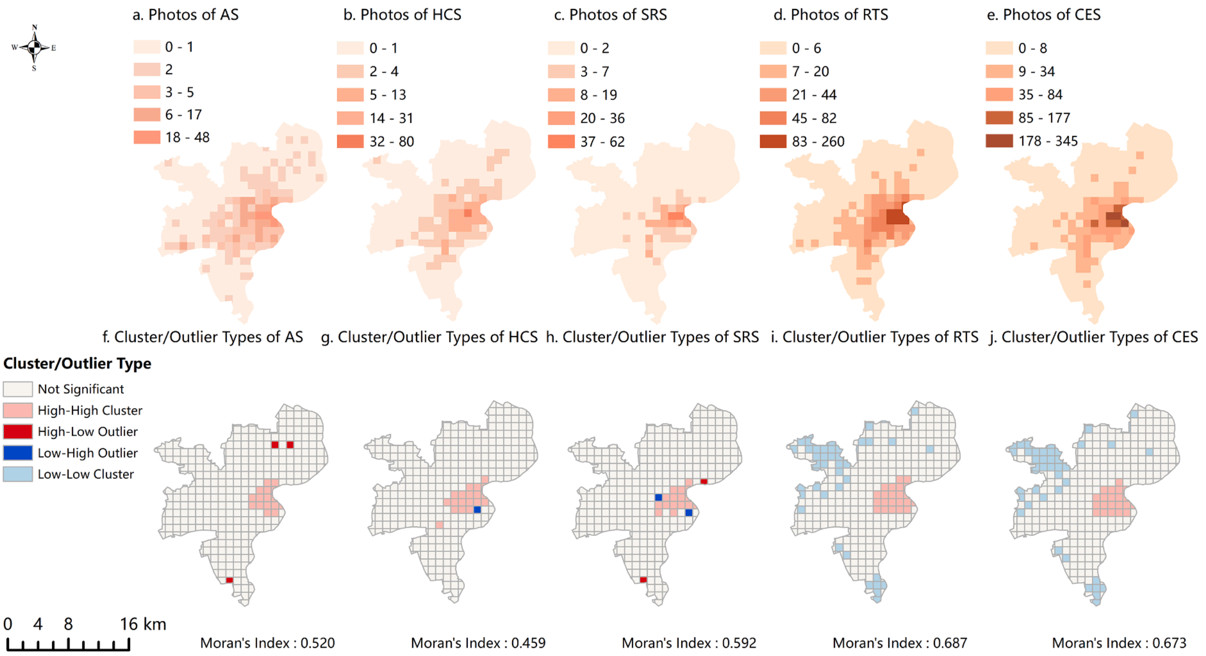

Fig. 4. Spatial pattern and cluster/outlier types of CES demands in urban center a. Spatial pattern of AS demand. b. Spatial pattern of HCS demand. c. Spatial pattern of SRS demand. d. Spatial pattern of RTS demand. e. Spatial pattern of CES demand f. Cluster map of AS demand. g. Cluster map of HCS demand. h. Cluster map of SRS demand. i. Cluster map of RTS demand. j. Cluster map of CES demand. The P values of Moran's Index in Fig. 4 are all less than 0.0001.

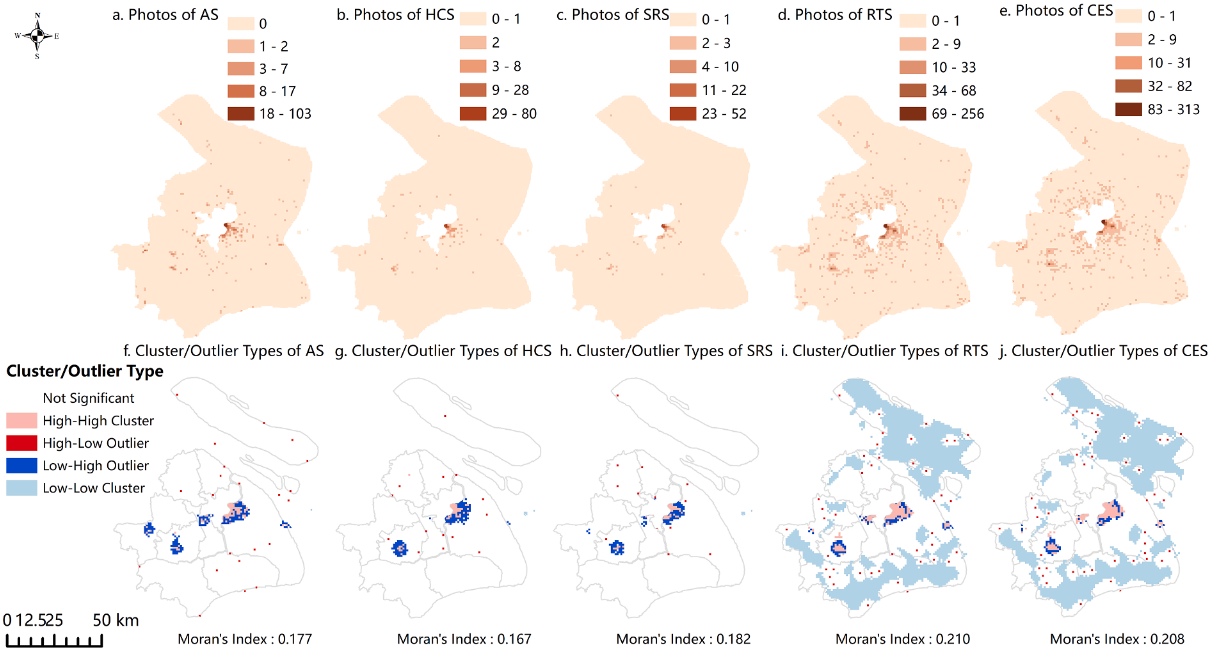

Fig. 5. Spatial pattern and cluster/outlier types of CES demands in suburban areas a. Spatial pattern of AS demand. b. Spatial pattern of HCS demand. c. Spatial pattern of SRS demand. d. Spatial pattern of RTS demand. e. Spatial pattern of CES demand f. Cluster map of AS demand. g. Cluster map of HCS demand. h. Cluster map of SRS demand. i. Cluster map of RTS demand. j. Cluster map of CES demand. The P values of Moran's Index in Fig. 5 are all less than 0.0001.

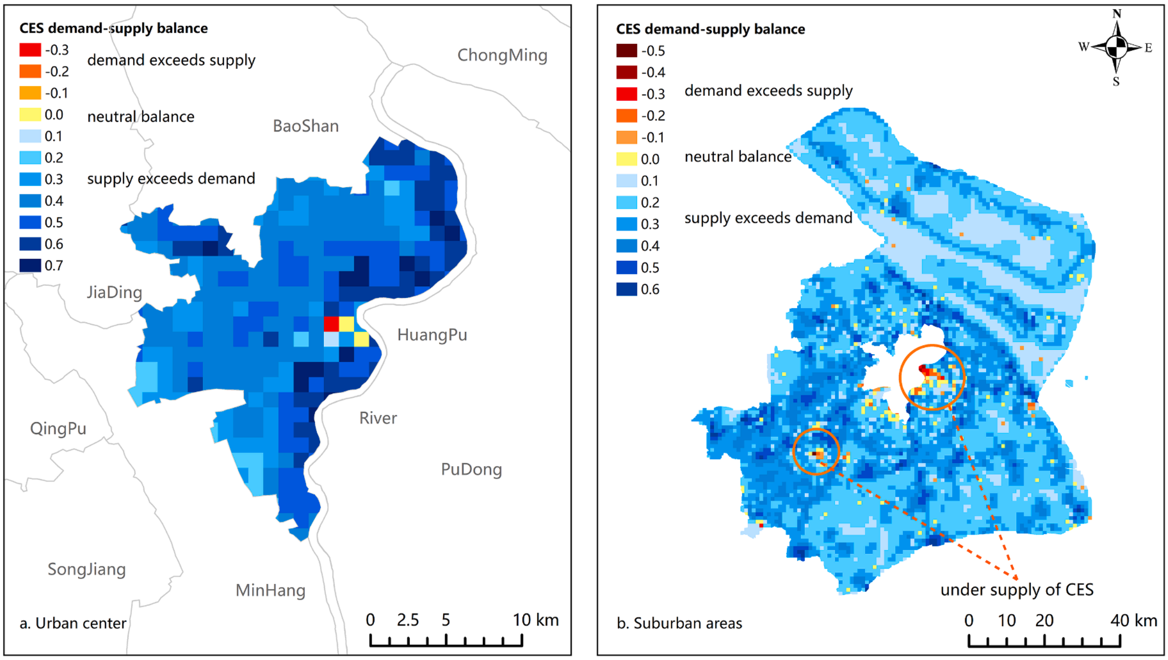

Fig. 6. CES demand-supply balance in Shanghai urban center and suburban areas a. CES demand-supply balance in Shanghai urban center. b. CES demand-supply balance in Shanghai suburban areas

significant, indicating that the two have spatial spillover effects (Zhang et al., 2018).

4. Discussion

4.1. Spatial distribution of CES supply and demand in urban center and suburban areas

In previous studies, CES demand assessment mainly used surveys and interviews (Casado-Arzuaga et al., 2013; Hermes et al., 2018; Peña et al., 2015; Scholte et al., 2018), which were very time-consuming and costly, and also difficult to replicate and transfer research results to other regions (Buchel and Frantzeskaki, 2015). Based on the landscape characteristics reflected by the online photo data (Yoshimura and Hiura, 2017), this study divided the CES demands into RTS, SRS, HCS and AS, and verified the spatial distribution differences of these CES demands. Compared with traditional field surveys, this method can cover different areas of the city and is very efficient. In addition, the spatially clear

Table 3

Bivariate Moran's I between CES demands and comprehensive supply capacity (RTS: recreation & tourism services, AS: aesthetic services, HCS: heritage & cultural services, SRS: spiritual & religious services.)

Variables	CES demands in urban center					CES demands in suburban areas				
		HCS demand	SRS demand	RTS demand	AS demand		HCS demand	SRS demand	RTS demand	AS demand
CES supply	**0.376***	0.279*	**0.320***	**0.388***	**0.340***	0.125*	0.105	0.097	0.129*	0.111
RPS	0.216*	0.152*	0.197*	0.224*	0.212*	0.033	0.032	0.031	0.033	0.033
Infrastructure	**0.508***	**0.403***	**0.440***	**0.518***	**0.434***	0.136*	0.110	0.115	0.140*	0.122*
Water	0.063	0.029	0.064	0.069	0.082	0.070	0.055	0.051	0.073	0.058
NPA	-	-	-	-	-	0.031	-0.002	-0.003	0.034	0.006
Naturalness	-	-	-	-	-	0.012	0.020	0.020	0.009	0.016
ILD	-	-	-	-	-	-0.016	-0.015	-0.015	-0.016	-0.013
ROS	**0.311***	0.242*	0.247*	**0.320***	0.258*	0.127	0.102	0.092	0.133*	0.110
Distance to roads	0.137*	0.110	0.113	0.139*	0.117	0.015	0.010	0.008	0.016	0.013
Distance to cultural landscape	0.231*	0.172*	0.183*	0.239*	0.205*	0.123	0.099	0.090	0.128	0.106
Distance to natural landscape	0.199*	0.146*	0.158*	0.206*	0.178*	0.091	0.070	0.063	0.095	0.078
PD	0.247*	0.208*	0.191*	0.251*	0.169*	0.163*	0.146*	0.130	0.166*	0.145*

* Statistically significant at 1% level. Statistically significant of other indicators is at 5% level.

mapping may introduce CES along with other ecosystem services that are easier to assess into the assessment of ecosystem services (Burkhard and Maes, 2017). In this study, the urban CES demand is more concentrated in the urban area, and the spatial distribution in the suburban area is more discrete, which is consistent with the conclusions of previous studies (Kabisch and Haase, 2014; Ko and Son, 2018; Rall et al., 2017).

The process of CES supply and benefit output differs from that of other ecosystem services. The output and benefit of cultural services are realized by completing the supply and consumption through the experience of residents and tourists (Rall et al., 2017). The supply of CES only indicates the ability and opportunity of an ecosystem to provide such function. CES arise from nature perception rather than from nature directly (Buchel and Frantzeskaki, 2015). This study analyzed the spatial distribution differences of the four types of CES demands in urban center and suburban areas of Shanghai, including RTS, AS, HCS and SRS, and improved the research on the relationship between CES supply and demand. Shanghai residents and tourists have a strong demand for RTS, while AS, HCS and SRS are significantly different from the former, although Shanghai has a dense historical and cultural landscape (Wei and Zhang, 2018). The Shanghai tourism management department is also focusing on the promotion of cultural tourism, which can be planned and deployed for the spatial dependence of SRS, HCS and AS demand.

In previous evaluations of ecosystem services, the supply capacity of CES has always been the focus of spatial analysis (Groot et al., 2010; Kienast et al., 2009). Factors such as land use type, population, and accessibility are the main factors in analyzing supply capacity (Casado-Arzuaga et al., 2013; Eigenbrod et al., 2010; Scholte et al., 2018). Many scholars are concerned about the difference in CES supply capacity in different areas of region and nation (Aalders and Stanik, 2019; Bertram and Rehdanz, 2015; Buchel and Frantzeskaki, 2015; Ko and Son, 2018; Liu et al., 2021; Nahuelhual et al., 2014; Plieninger et al., 2013), there is little in-depth discussion on the difference in CES supply capacity assessment between urban center and suburban areas. CES is described in terms of the non-material benefits that people receive from natural or semi-natural ecosystems (MEA, 2005). Under the influence of urbanization, the ecosystems in urban areas have shown the characteristics of semi-natural ecosystems, while natural ecosystems and semi-natural ecosystems coexist in many suburbs. Based on the differences in the ecosystems of Shanghai's urban center and suburban areas, this study adopts differentiated evaluation indicators to evaluate the supply potential of CES, although there might be disputes over the comparability of CES supply capacity in the two regions. The ROS of CES in Shanghai's urban center and suburban areas are greater than the RPS. This is related to the development of infrastructure construction in the process of rapid urbanization, while the proportion of natural landscapes such as nature reserves, water body and green spaces has decreased. Based on the premise of CES supply and demand balance, rational planning of urban parks and green spaces has become an important proposition for sustainable urban development (Bertram and Rehdanz, 2015).

4.2. CES demand and supply balance and spatial correlation

In the CES supply-demand relationship, it is a balance which has a certain direction, which is consistent with the conclusions of previous studies (Paracchini et al., 2014; Peña et al., 2015). The high demand for CES in urban center and suburbs is concentrated in several hotspots, while the demand for CES in other areas is significantly less than the supply, especially around the National Nature Reserve and other scenic spots. This result shows the importance of using both components, the supply and demand in analyzing CES.

In the evaluation of ecosystem services, many studies evaluated the spatial aggregation of ecosystem services (or biodiversity) values to delimit ecological protection areas (Bai et al., 2014; Li et al., 2015). Urbanization has brought about an increase in the intensity of human activities and the pressure of ecological protection needs to be considered (Zhang et al., 2018). The Areas of under supply of CES (CES demand exceeds supply) have appeared in Shanghai (Fig. 6). These areas are widely distributed in the suburban areas, which may be related to the accessibility and supporting facilities of some landscapes (Paracchini et al., 2014). At the same time, there are also areas of under supply of CES in the surrounding areas of the Huangpu River, which areas have high supply potential and opportunities of CES. The Huangpu River is an important natural landscape in Shanghai, and it is also a symbol of history and culture. Therefore, these areas cannot directly increase the entertainment potential and opportunities to achieve a balance between supply and demand. The key areas for ecological space protection, restoration and expansion should be urban center and suburbs in Shanghai, not just suburbs (Shi et al., 2020).

The imbalance between CES supply and demand throughout the study area was prominent. Nevertheless, simply raising or dropping the supply setting does not guarantee the corresponding adjustment of demand (Burkhard et al., 2012). Their sustainable planning and regulation need to be based on their spatial correlation and dependence. In the spatial correlation analysis of this research, there is a significant positive spatial correlation between CES demand and CES supply capacity in urban center, which provides a basis for urban landscape planning. Spatial spillover effect refers to the spatial externality caused by location-based proximity, that is, a unit obtains benefits or costs from its neighbors (Day and Lewis, 2013). This study shows that there is a spillover effect in the spatial relationship between CES demand and supply capacity (Table 3). Generally, the CES supply capacity applied a positive external impact on the CES demands (all bivariate Moran's I 〉0). The improvement of CES supply capacity in a certain area may lead to the growth of CES demands in surrounding areas. The improvement of CES supply capacity in the urban center can promote the increase of CES demand, but does not work for the suburban areas. The construction of urban tourism and recreation areas usually drives the enhancement of facilities in peripheral areas. The construction of road network can reinforce the accessibility of natural and cultural landscapes, thus promoting the growth of CES demands, which is applicable in both the urban center and the suburban areas.

4.3. Advance and deficiency in research design

By contrast with the previous research on the spatial relationship among different ecosystem services, this paper took CES as the research object, constructed a multi-source factor set to evaluate the CES supply capacity, classified the CES demands through the landscape features on online photos, and conducted analysis by mapping the spatial differentiation and balance of CES demands and supply capacity. The spatial differentiation of CES supply and demand manifests that the balance of ecosystem service needs to focus on the spatial differentiation of both supply and demand. This study considered the differences of ecosystem among regions in Shanghai, and investigated the spatial correlation between CES demands and supply capacity – a topic that was rarely discussed in existing literatures. On the one hand, data on demands are more difficult to collect than production or cost data (Ellis and Fisher, 1986), on the other hand, today's ecosystem service demand and consumption are far from being driven by actual supply (Burkhard et al., 2012). Previous research paid more attention to CES supply-side analysis, because most CES supply is related to specific landscape attributes (Brown, 2004). The visual mapping offered a method to link the CES demand with different landscapes (Peña et al., 2015). The correlation between landscape attributes and CES demand preferences have been evaluated (Ko and Son, 2018; Oteros-Rozas et al., 2017; Tieskens et al., 2018). The spatial correlation between CES demand and supply should also be analyzed accordingly. The bivariate Moran's I values verified the spillover effect in the spatial relationship between CES demand and supply.

As an international tourism destination, in addition to CES supply indicators, factors such as economy and demand psychology also affect CES demand. In this paper, the contents of photos were used to reflect the difference among CES demands, but the information of photo users has not been taken into account, such as the origin of travel, distance from origin of travel to photographing place, travel motivation, which would also exert non-negligible influence on CES demands. In particular, many local residents in cities do not have much incentive to take and share photos of cultural experiences and entertainment, which will affect the integrity of CES demands (Wood et al., 2013). Due to limited space, this paper did not perform a comparative study on CES demand and supply balance in years.

CRediT authorship contribution statement

Zhenhua Bing: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Writing - original draft, Writing - review & editing. **Yishu Qiu:** Conceptualization, Software, Writing - review & editing. **Heping Huang:** Funding acquisition, Methodology, Writing - original draft. **Tingzhen Chen:** Writing - review & editing. **Wei Zhong:** Funding acquisition, Writing - original draft. **Hong Jiang:** Supervision.

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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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