RESEARCH ARTICLE

Analysis of the relationship between supply–demand matching of selected ecosystem services and urban spatial governance: a case study of Suzhou, China

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Abstract
The mismatch between the supply and demand of ecosystem services has become a critical cause of the decline of urban ecological security. Studying the supply–demand matching of ecosystem services and exploring its association with urban spatial governance are imperative for ensuring sustainable urbanization. Taking Suzhou City as a case, the supply and demand values and matching degrees of five selected ecosystem services were assessed. Additionally, we explored the relationship between ecosystem services and urban spatial governance, with a focus on urban functional zoning. The findings indicate that first, the supply value of water production, food production, carbon sequestration, and tourism and leisure fall short of the demand value, while the supply value of air purification exceeds the demand value. The spatial matching of supply and demand shows a typical circular structure, with areas in short supply predominantly located in the downtown area and its vicinity. Second, the degree of coupling coordination between the supply–demand ratio of selected ecosystem services and the intensity of ecological control is low. Urban functional zoning can affect the supply–demand relationship of selected ecosystem services, and intensified development efforts can exacerbate the mismatch between supply and demand. Third, research on the supply–demand matching of selected ecosystem services can facilitate the assessment and regulation of urban functional zoning. Urban spatial governance can be regulated based on land use, industry, and population, with a focus on achieving a better supply–demand matching of ecosystem services. Through the analysis, this paper is aimed to provide reference for mitigating urban environmental problems and formulating sustainable urban development strategies.

Keywords Ecosystem service mismatch · Urban management · Assessment · Coupling coordination · Spatial analysis

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Introduction

The rapid growth of urbanization and industrialization has caused a significant influx of people migrating to cities. As of 2018, 55% of the world's population live in cities, which poses one of the biggest governance challenges of the twenty-first century (UN DESA 2019). With the increasing urban population, urban space expansion through land use changes is occurring simultaneously.

Human activities, including arable land occupation, deforestation, lake reclamation, and large-scale water conservation, have caused a considerable amount of agricultural and ecological lands to be converted to construction land, resulting in ecological imbalances at the regional level (Euliss et al. 2010; Haas and Ban 2014; Wang 2018). This has led to a rise in urban eco-environmental problems such

as air pollution, greenhouse effects, water resource shortages, disease outbreaks, and biodiversity loss (Chen et al. 2013; Li et al. 2017; Sakakibara and Owa 2005). The primary issue is that urbanization weakens the direct feedback between the ecosystem and social system (Cumming et al. 2014). To promote urban ecological security, the concepts of "resilient city" (Ribeiro and Pena Jardim Gonçalves 2019) and "livable city" (Zhan et al. 2018) have emerged, emphasizing the importance of coordinated development between the urban ecosystem and social system.

Ecosystem services act as a link between ecosystems and human well-being by providing the benefits that humans derive from them (MA 2005; Müller and Burkhard 2007). Ecosystem services play a crucial role in human well-being. For example, food and water supply services have a significant impact on the livelihoods of farmers in the Chinese Loess Plateau (Han et al. 2023), while the prevention of wind erosion service is critical for people living in the oasis-desert ecotone (Zhang et al. 2018). In addition, cultural services can enhance non-material well-being, such as spiritual satisfaction, entertainment, education, and aesthetic experiences for residents (Willis 2015). The loss of natural landscapes caused by urbanization can lead to a decline in residents' leisure and aesthetic experience (Meng et al. 2020). Unfortunately, human activities often contribute to ecological degradation and poverty intensification, resulting in a vicious circle (Duku et al. 2022). Thus, understanding the correlation between ecosystem services and human well-being is essential to achieve a win–win situation of protecting the ecosystem and improving human well-being.

The concept of ecosystem services can be categorized into four types: supply services, regulatory services, cultural services, and supporting services (MA 2003). This framework provides a pathway for restoring and enhancing direct feedback between ecosystems and social systems, which can promote sustainable urbanization. In earlier studies, the focus was on defining, classifying, and assessing ecosystem services, with an emphasis on understanding the structure, process, and function of ecosystems (Costanza et al. 1997; Daily 1997; Jim and Chen 2008; Wallace 2007). Numerous studies have been conducted by scholars to evaluate the quantity and value of ecosystem services and their response to land use and climate change across different scales (Rimal et al. 2019; Weiskopf et al. 2020; Yang et al. 2022b). However, the complicated relationship and driving mechanisms between ecosystem processes and human activities remained unclear (Huang et al. 2022). As research on the delivery process of ecosystem services advanced, a more systematic framework emerged due to the conceptualization of capacity, flow, and demand (Balzan et al. 2018; Baró et al. 2016). This framework shifted the research focus towards the interaction between human activities and ecosystem services (Costanza et al. 2017; Wu et al. 2019). Capacity refers to the potential

of ecosystem services, representing the maximum amount of services an ecosystem can provide (Baró et al. 2015). Flow refers to the actual amount of services that humans experience and can be seen as the supply of ecosystem services (Hein et al. 2006). Demand for ecosystem services is the expected amount of needs and wants that a society has for those services (Villamagna et al. 2013). Empirical studies have shown the positive role that ecosystem services play in urban development. However, a mismatch between the supply and demand of ecosystem services is a significant reason for the decline of urban ecological security (Lauf et al. 2014; Luederitz et al. 2015). Hence, investigating the supply and demand of urban ecosystem services holds both theoretical significance and practical value.

The identification, quantification, matching, regulation, and mapping of ecosystem service supply and demand under different temporal-spatial scales have become a research hotspot (Larondelle and Lauf 2016; Liu et al. 2019; Schulp et al. 2014). Researchers have used statistical data to quantify and map food, water, and energy services in the German region of Leipzig-Halle in 1990, 2000, and 2010, taking cultivated lands and forests as supply areas and urban and industrial lands as demand areas (Kroll et al. 2012). Nedkov and Burkhard studied the supply–demand relationship of flood regulation services by using land use, soil, population, terrain, and economic data in 2000 based on the hydrologic model KINEROS, which showed the highest demand for flood regulation services in densely populated areas and construction lands (Nedkov and Burkhard 2012). Serna-Chavez et al. quantified and mapped the supply and demand of services such as pollination, water production, and climate regulation in 2000 by overlaying various factors affecting the supply and demand of ecosystem services and using a threshold to limit the scope and degree of supply and demand (Serna-Chavez et al. 2014). Burkhard et al. assigned the service supply and service demand of different land use types using expert knowledge and constructed a supply–demand relationship matrix to explore the relationship between ecosystem services and land use in 1990 and 2007 (Burkhard et al. 2012). Using the ARIES model, Martinez-Lopez et al. conducted an assessment of the supply and demand of ecosystem services including flood regulation, carbon sequestration, and outdoor recreation in regions across three continents for the year 2010 (Martinez-Lopez et al. 2019). Spatializing the supply–demand relationship of ecosystem service can be achieved through several methods, including land use analysis (Chen et al. 2019a), ecological process simulation (Stürck et al. 2014), data space overlay (Sitch et al. 2003), expert judgement (Palomo et al. 2013), InVEST model (Boithias et al. 2014), and ARIES model (Bagstad et al. 2014). Despite occupying less than 2% of the earth's surface, cities are significant hubs of demand for ecosystem services and major contributors to global

environmental issues due to their high population density, consumption levels, and waste generation (Bai 2007). For example, cities are responsible for 78% of the world's energy consumption and more than 60% of greenhouse gas emissions (UN 2023). Urbanization has resulted in a range of environmental problems, such as air and water pollution, waste management, urban heat islands, land-use changes, and habitat destruction (Asabere et al. 2020; Cobbinah et al. 2017). However, it should be noted that not all cities are equal in terms of their environmental impacts, and the effective city management is crucial for mitigating their negative effects on the environment (Bulkeley 2010; Castán Broto and Bulkeley 2013). Many cities are implementing measures like promoting renewable energy, energy efficiency, waste reduction, and sustainable transportation to become more sustainable (Gallardo-Saavedra et al. 2022; Shadbahr et al. 2022).

As research on the topic deepened, scholars started exploring the impact of spatial planning and governance on ecosystem services, taking into account factors such as land use change, environmental policies, industrial development, and political systems.

For example, Estoque and Murayama used scenario analysis to examine the impact of land development intensity on urban ecosystem services in the Philippines based on land use/cover maps from 1988, 1998, and 2009 (Estoque and Murayama 2012). Chen et al. focused on the impact of land use change on ecosystem services at the county level in China from 1995 to 2015 (Chen et al. 2019b). Baró et al. evaluated the mismatches between ecosystem services supply and demand in five European cities according to the EU environmental quality standards in 2009 (Baró et al. 2015). Liu et al. proposed a sustainable development path for agriculture in arid areas by analyzing the relationship between different agricultural types and ecosystem services in 2019 (Liu et al. 2021). Yang et al. studied the positive significance of Payment for ecosystem services (PES) for promoting ecosystem services and regional well-being in backward areas based on the LULC data for 2000, 2010, and 2020 (Yang et al. 2022a). Chaudhary et al. (Chaudhary et al. 2018) and He et al. (He et al. 2021) analyzed the impact of local knowledge and political structures on ecosystem services in Nepal from 2014 to 2015 and China from 2012 to 2018, respectively, highlighting the significance of effective management systems in the application of ecosystem services.

The inadequate and unregulated use of land resources, ignoring their spatial attributes, is a widespread problem that harms the global environment and reduces social well-being (Cecilio Rebola et al. 2021; Xu et al. 2016). This is largely due to weak urban governance and an imperfect social governance system (Fan and Li 2009). Therefore, there is growing attention on top-down government regulation of land space protection and utilization (Koroso et al.

2020). Urban planning and governance play a significant role in regional land use change, which profoundly affects the spatial pattern of urban ecosystems, particularly the relationship between supply and demand for ecosystem services (Mooney et al. 2013; Watson 2005). Moreover, the supply–demand balance of ecosystem services, as a reflection of urban spatial governance, highlights the tension between the human-land relationship and environmental carrying capacity (Xu et al. 2022). This balance, in turn, impacts urban spatial governance, such as the delineation and adjustment of urban functional areas (Feng et al. 2021; Song et al. 2021; Zhai et al. 2021). Therefore, the relationship between the supply–demand balance of ecosystem services and urban spatial governance is interactive and interdependent, demonstrating a typical coupling coordination relationship.

In conclusion, current research on the relationship between ecosystem service supply and demand is mainly focused on a macro-level due to limited data accuracy at a micro-level. While using currency as an assessment tool has been seen as a critical trial (Kroll et al. 2012), studies on urban areas still predominantly use non-currency assessments, limiting the role of ecosystem services in improving social cognition and guiding urban land use planning (Costanza et al. 2014). Moreover, studies mostly focus on the association between supply–demand matching and environmental quality standards and land management policies, while the connection between matching results and various spatial governance approaches is overlooked. Therefore, it is crucial to explore the internal logic between ecosystem service supply–demand matching and urban planning.

Given the current context, this study focuses on Suzhou City to examine the connection between the supply–demand matching of selected ecosystem services and urban spatial governance. The research intends to address the following inquiries:

(1) What is the approach to evaluate the micro-level supply–demand value of selected ecosystem services and determine the matching degree?

(2) To what extent does urban functional zoning impact the supply–demand relationship of selected ecosystem services, and how does the matching degree differ across functional zones?

(3) Could the study on supply–demand matching of ecosystem services function as a theoretical foundation for urban spatial governance, and what regulations could be proposed?

Through exploring these questions and conducting a relevant analysis, this research aims to promote the coordinated development of ecological and social systems, as well as sustainable urban development.

Research design

Study area

Suzhou City is situated between 119° 54′ E ~ 120° 54′ E and 31° 33′ N ~ 30° 45′ N, falling under the tropical monsoon climate zone with an annual average temperature of 15.7 °C and 1063 mm of precipitation. The terrain is predominantly low, with an average elevation of 3.5–5 m (Suzhou Local Records Compilation Committee 2020). Suzhou City encompasses six municipal districts, namely Gusu, Wuzhong, Xiangcheng, Huqiu, the Industrial Park, and Wujiang District, comprising over 56 streets and towns, including Tai Lake. Its total area covers 4652.84 km² , with Taihu Lake accounting for 1486.75 km² (Fig. 1). Each district has its unique characteristics and functions. For instance, Gusu District serves as the central old town and regional hub for politics, culture, and tourism. Huqiu District is a national high-tech industrial and innovation base located to the west. Wuzhong District, situated in the south of the Yangtze River, is a center for traditional culture and eco-tourism. Xiangcheng District, located in the north, boasts rich water resources and cultural heritage, serving as an ecologically livable town. Wujiang District, located in the south, is a scenic area with a rich cultural heritage and well-developed rural private businesses.

Finally, the Industrial Park, situated in the east, functions as a national high-tech industrial, cultural, and art center, as well as an important business tourism district.

Suzhou is a focal point in the Yangtze River Delta and one of the earliest regions to experience urbanization in China. Between 2000 and 2018, Suzhou's GDP increased from 71.689 billion CNY to 835.671 billion CNY, with the urban population growing from 1.332 million to 4.550 million and the urbanization rate rising from 46.84% to 81.84% (Suzhou Statistics Bureau 2019). However, this urbanization model has led to agricultural land loss and serious ecological environmental problems (Min and Chaolin 2002). As such, Suzhou serves as an ideal case study for exploring the challenges of rapid urbanization and transitioning from rural landscapes to urban landscapes.

General design

In this study, the relationship between supply–demand matching of selected ecosystem services and urban spatial governance was analyzed through four steps (Fig. 2). Firstly, we identified five types of ecosystem services from the perspective of stakeholders and used remote sensing and GIS to obtain the spatial distribution of land use types in Suzhou City. Then, we measured the supply of selected ecosystem services based on land use and calculated the
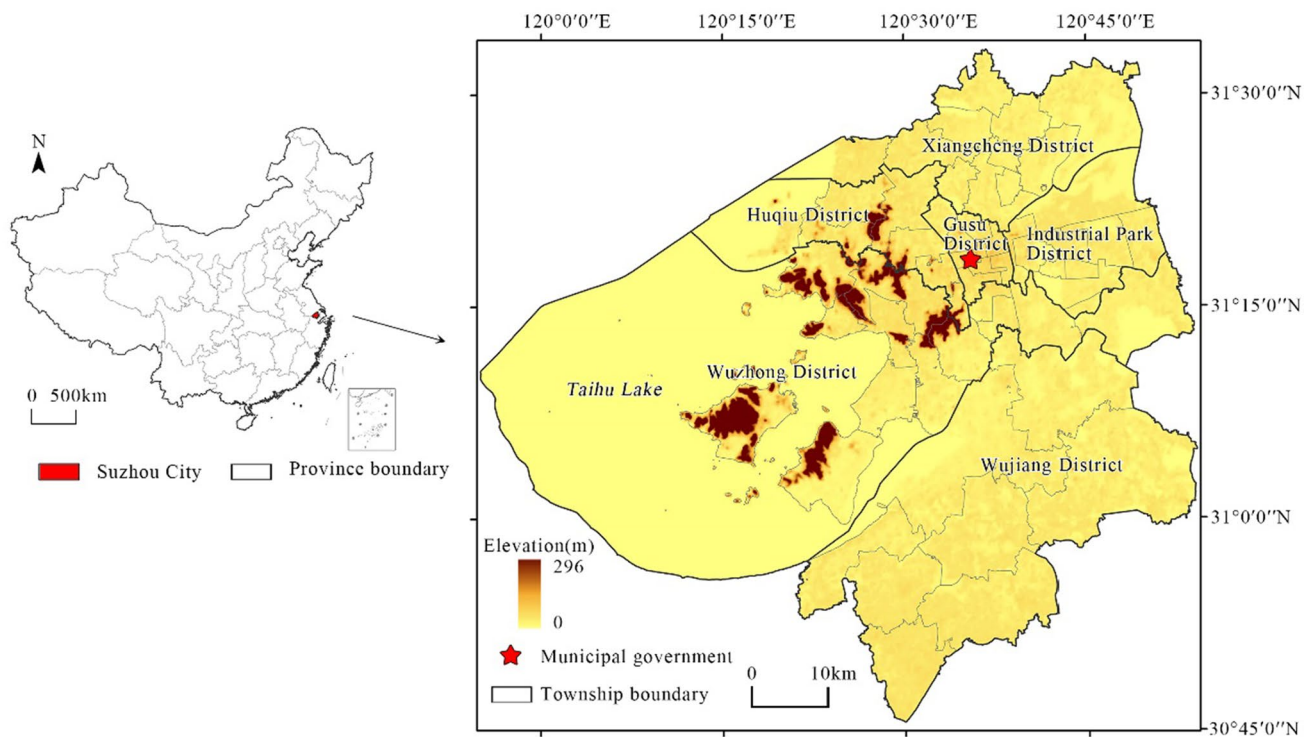

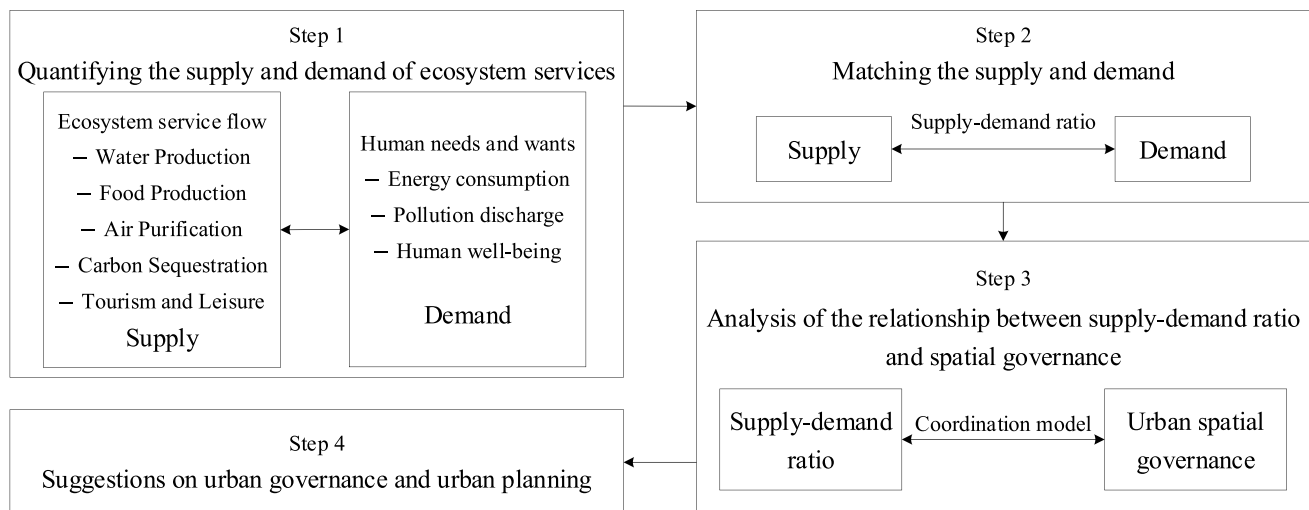**Fig. 1** Location and scope of Suzhou City

**Fig. 2** Overview for the overall methodology

demand of selected ecosystem services from human needs and wants. Secondly, we used the supply–demand ratio to assess the supply–demand matching of selected ecosystem services and identified surplus, balance, and deficit areas between supply and demand through spatial visualization. Thirdly, we explored the relationship between urban spatial governance and supply–demand matching of selected ecosystem services by taking main functional area planning as an example, using the coupling coordination model. Finally, we proposed relevant suggestions on spatial planning and spatial governance to achieve sustainable urban development in high-density population areas based on the above analysis.

Data sources and processing

Five datasets were used to calculate the value of five ecosystem services: land use/cover dataset, statistical dataset, consumption and pollution dataset, meteorological dataset, and point of interest dataset.

(1) Land use/cover dataset: land cover data of Suzhou City in 2017 are derived from the LandsatTM remote sensing data of the United States Geological Survey (USGS). Combined with the land change survey data and field survey of Suzhou City, the image was visually interpreted into 7 categories and 23 sub-categories of land use types, including cultivated land, woodland, garden land, grassland, water area, mudflat, and construction land (Fig. 3).

(2) Statistical dataset: population, GDP, food production, per capita food consumption, vehicle ownership, and industrial emissions of each street and township of Suzhou City in 2017, collected from statistical year-

books of Jiangsu Province, Suzhou, and the sub-municipal administrations. Water price in 2017 was derived from Suzhou Price Bureau (Suzhou Price Bureau 2017). Annual average food price was obtained from the Suzhou price monitoring center (Suzhou price monitoring center 2017). The number of tourists and per capita consumption in each municipal area are gained from Suzhou Municipal Bureau of Culture, Radio, Television, and Tourism (Suzhou Municipal Bureau of Tourism 2018). Main functional areas are from Suzhou Municipal People's Government (Suzhou Municipal People's Government 2014).

(3) Consumption and pollution dataset: water resources output and consumption in 2017 are from Suzhou Water Affairs Bureau (Suzhou Water Affairs Bureau 2018). Emission data of motor vehicle pollutants are from the Ministry of Ecological Environment of China (Ministry of Ecological Environment of China 2019). China's carbon emissions per capita in 2017 are from the International Energy Agency (IEA) (IEA 2018).

(4) Meteorological dataset: monthly statistical data of Suzhou weather and air quality index in 2017 are from the website of China air quality online monitoring and analysis platform (China Air Quality Online Monitoring and Analysis Platform 2018).

(5) Point of interest dataset: scenic spots, breeding farms, and residential areas in Suzhou City were collected from the point of interest (POI) of Gaode map platform in 2017 using geographic crawler software. After screening, cleaning, and spatial matching, the POI data were obtained: 2386 scenic spots, 86 breeding farms, and 11,411 residential areas.

Fig. 3 Distribution of land use types in Suzhou City
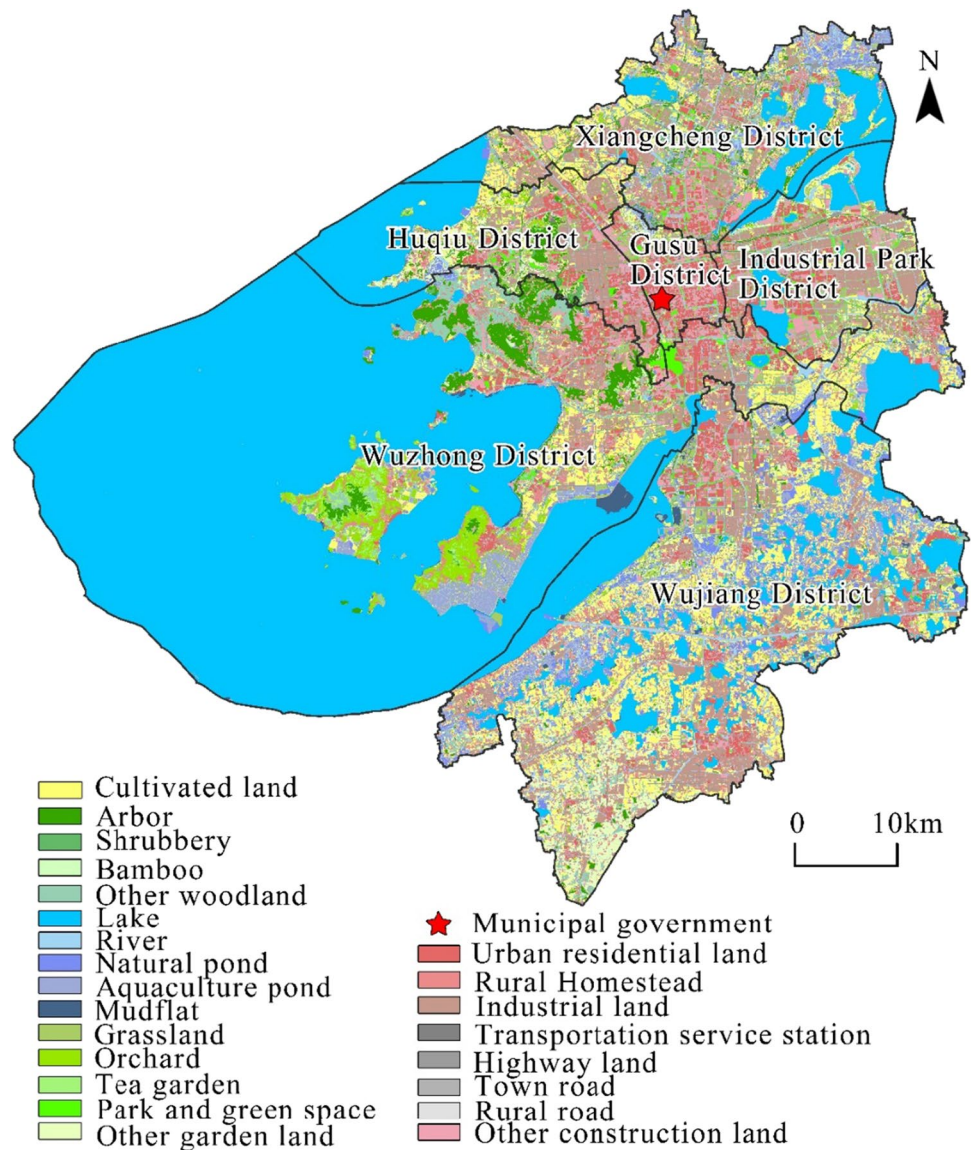
Index selection and research methods

Indicators for ecosystem service evaluation

Four criteria were used to select the indicators for ecosystem service assessment:

(1) The Millennium Ecosystem Assessment categorizes ecosystem services into supporting, provisioning, regulating, and cultural services. This paper only covers provisioning, regulating, and cultural services, as supporting services are the foundation for other services and do not directly benefit humans.

(2) Stakeholders in Suzhou prioritize preserving high-quality cultivated land through the "*Four Million Mu*"

project in 2012 and reducing CO_2 emissions by 2020 through the "*Low-carbon development plan of Suzhou City*" in 2014. The policy highlights the importance of food production and carbon sequestration services in Suzhou.

(3) The supply–demand relationship of indicators can be measured at the same time and can be evaluated in the form of currency.

(4) Accessibility and spatial expressiveness of the data.

Three categories and five sub-categories of ecosystem service were chosen, including water production, food production, air purification, carbon sequestration, and tourism and leisure (Table 1). Appendix A provides a detailed description of measurement methods for all indicators.

Table 1 Indicators for urban ecosystem service evaluation

Service type	Specific services	Indicator interpretation
Provisioning service	Water production	Supply: surface and sub-surface water resources
		Demand: agricultural, industrial, and residential consumption of water resources
	Food production	Supply: food including grain, oil, vegetable, and meat that are produced by the ecosystem
		Demand: foods such as grain, oil, vegetables, and meat consumed by humans
Regulating service	Air purification	Supply: the digestion of SO_2, NO_2, dust, and other pollutants by the ecosystem
		Demand: SO_2, NO_2, dust, and other pollutants emitted by industry and motor vehicles
	Carbon sequestration	Supply: the amount of CO_2 that is sequestered by plants through photosynthesis
		Demand: the amount of CO_2 emission from maintaining social and economic development
Cultural service	Tourism and leisure	Supply: tourism, outdoor recreation, entertainment, and leisure services provided by the ecosystem
		Demand: residents' need for tourism, outdoor recreation, entertainment, and leisure activities

Supply–demand ratio of ecosystem service

We use the ratio to measure the supply–demand matching of ecosystem service. The formula was as below (Li et al. 2016).

$$R = \frac{V_S - V_D}{(V_{SMAX} + V_{DMAX})/2} \tag{1}$$

where V_S and V_D are the supply value and demand value of ecosystem service in streets or towns; V_{SMAX} and V_{DMAX} are the maximum value of supply value and demand value in Suzhou City; R is the supply–demand ratio. Positive values indicate an excess of supply over demand, zero values indicate a balance between supply and demand, while negative values indicate an excess of demand over supply.

Coupling coordination model

This study uses the coupling coordination model to explain the correlation and interaction between supply–demand matching of ecosystem services and urban spatial governance. The formula was as below (Ma et al. 2013).

$$\begin{cases} D = \sqrt{C \times T} \\ C = \left[u_1 \times u_2 / \left(\frac{u_1 + u_2}{2} \right)^2 \right]^{1/2} \\ T = au_1 + bu_2 \end{cases} \tag{2}$$

where u_1 is the normalized data of supply–demand ratio of ecosystem service; u_2 is the normalized data of intensity of ecological control based on urban functional zoning; T is the comprehensive evaluation index of ecosystem services and urban functional zoning, and a and b represent the contribution degree. We think they are equally important, and both of which are taken as 0.5; C represents the degree of coupling,

while D represents the degree of coupling coordination. The D value range is 0 to 1. The greater the D value, the more coordinated the development.

Results and analysis

Supply and demand value of selected ecosystem services

The supply and demand values of five ecosystem services in Suzhou City were calculated as shown in Fig. 4.

The supply value of the water production service is less than the demand value. The distribution of supply value presents an "inner low and outer high" circled structure, while the distribution of demand value is highly consistent with the distribution of industrial water. The supply value of water production service is 4.86×10^9 CNY, and its distribution presents a circular structure centered on Suzhou ancient city as the water production value of peripheral areas is significantly higher than that of the central area (Fig. 4(a-1)). The demand value of water production service is 6.73×10^9 CNY. The Pearson correlation analysis result shows that the correlation coefficient between the demand value of water production service and industrial water consumption is 0.9, which is highly positive. This may explain that the development of township enterprises has a significant impact on regional water consumption (Fig. 4(a-2)).

The supply value of food production service is less than the demand value. The distribution of supply value is similar to the distribution of cultivated land and aquaculture pond, while the distribution of demand value and population is similar. The supply value of food production service is 1.62×10^{10} CNY and has a Pearson correlation coefficient with the area of cultivated land and the area of aquaculture pond at 0.76 and 0.95, respectively. This indicates that supply value is mainly influenced by the capacity of crop cultivation and aquaculture (Fig. 4(b-1)). The demand value of
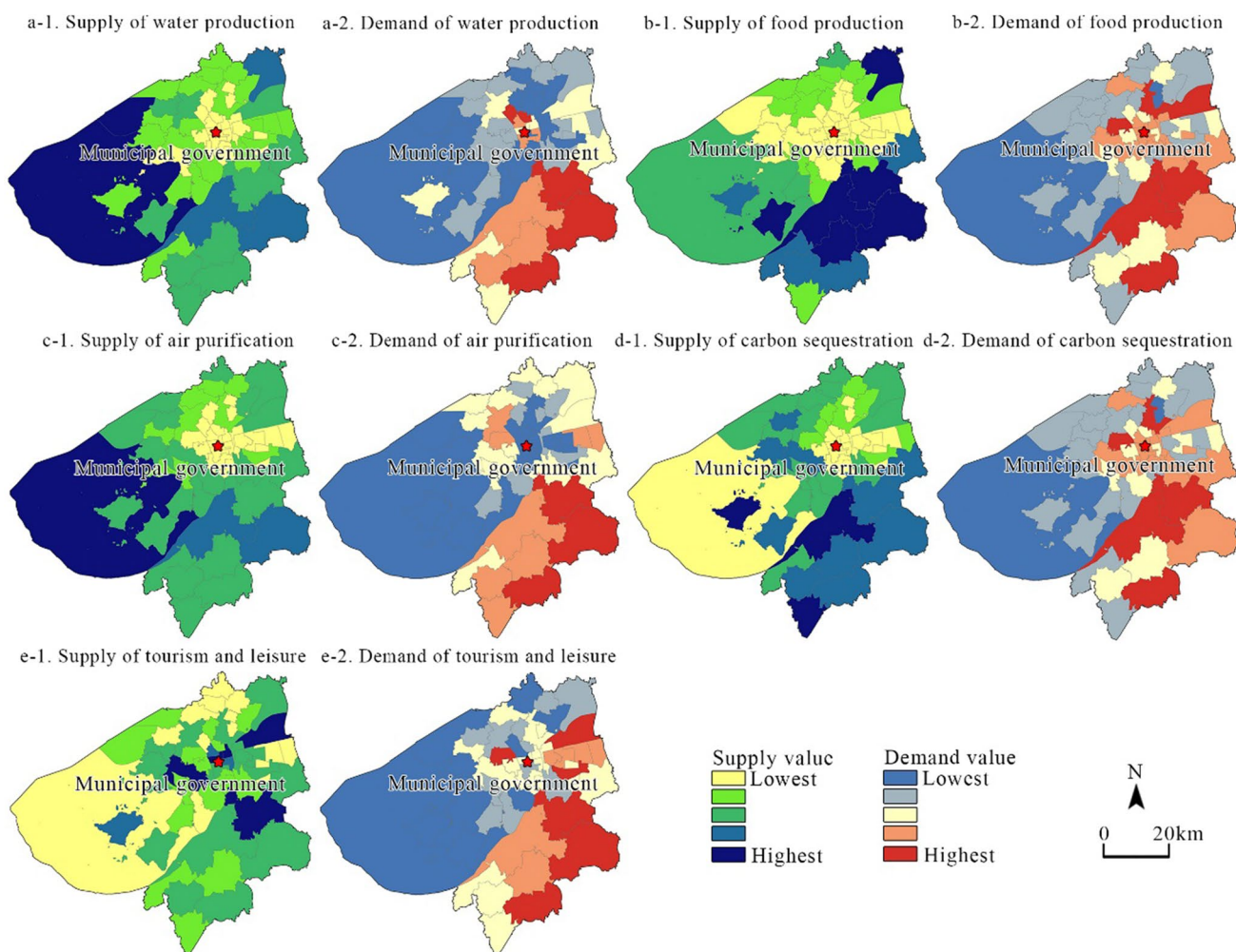
Fig. 4 Supply and demand value of selected ecosystem services in Suzhou City

food production service was 2.69×10^{10} CNY. The larger the population is, the greater the demand could be (Fig. 4(b-2)).

The supply value of air purification service exceeds the demand value, and the distribution of supply value presents the characteristic of a circulated structure. The distribution of demand value is similar to the distribution of industrial waste gas emission. The supply value of air purification service is 1.32×10^{8} CNY, with high values mainly distributed in the surrounding forests and water resource-rich areas. The low values are mainly concentrated in the old urban areas where construction land is the main land use type. The supply value of air purification service exhibits a typical circle structure (Fig. 4(c-1)). The demand for air purification service is valued at 3.51×10^{7} CNY. The southern Wujiang District has a high concentration of township enterprises and large industrial emissions, making it the main area of air purification demand (Fig. 4(c-2)).

The supply value of carbon sequestration service is 8.62×10^{7} CNY and is less than the demand value. The

distribution law of supply value is consistent with that of cultivated land, woodland, and garden land (Fig. 4(d-1)). The Pearson correlation coefficients between the supply value and the area of cultivated land, woodland, and garden land are, respectively, 0.68, 0.61, and 0.75. The value of demand for carbon sequestration service is 2.64×10^{9} CNY. The more the population, the greater the demand for carbon sequestration service (Fig. 4(d-2)).

The supply value of tourism and leisure service is less than the demand value, and the distribution law of supply value and the tourism development level are similar. The supply value of tourism and leisure service is 9.36×10^{9} CNY, with the high values concentrated in the areas of high tourism resource endowment and long tourism development history (Fig. 4(e-1)). The demand value of tourism leisure service is 1.03×10^{10} CNY, and the distribution is affected by population and the time cost from the residential area to parks (Fig. 4(e-2)).

Supply–demand matching of selected ecosystem services

By measuring the supply–demand value ratio of selected ecosystem services in Suzhou City, we analyzed the supply and demand matching status (Fig. 5).

Result shows that the demand of water production service exceeds the supply, and there is distinctively spatially heterogeneity in the matching results. The main area where demand exceeds supply is the central old city and the southeast area (Fig. 5a). The ratio of supply to demand value of water production service is − 0.07, and there are 30 regions that have negative values. The old urban area is a regional center as well as an important tourism destination, with a large number of tourists and numerous shops. It is the main demand area for industrial water and domestic water, which has a thermal power consumption of 500 million m^3 and domestic water consumption of 101 million m^3, exceeding other regions disproportionately. The southeast region is a major area of township enterprises and agricultural lands and is the main demand area for industrial water and agricultural water. Its general industrial water consumption and agricultural water consumption amounts to 118 million m^3

and 265 million m^3, ranking first in the region. There are 26 areas that have positive values, and mostly are adjacent to large areas of waters such as Tai Lake and Yangcheng Lake.

The quantity matching of food production service shows that demand exceeds supply, and the spatial matching exhibits a circular structure. The area of demand exceeding supply is mainly located in the old city center and its periphery (Fig. 5b). There are 44 districts that have negative values, with an average value of − 0.1 in terms of the supply–demand value ratio of water production service. Except for Shengze town, where there is a cluster of township enterprises, most of the demand exceeding supply areas are clustered in and around the old central district. The cause of such formation is the urbanization of rural regions as a result of the expansion of the old city. There are 12 areas that have positive values, mainly in the sparsely populated outer regions, which also play as the main production areas of regional aquatic, fruit, and food crops.

The supply–demand matching of air purification service shows that supply exceeds demand, with significant spatial variance. The areas where demand exceeds supply are mainly located in industrial landscapes (Fig. 5c). The supply–demand ratio of air purification service is 0.06, and
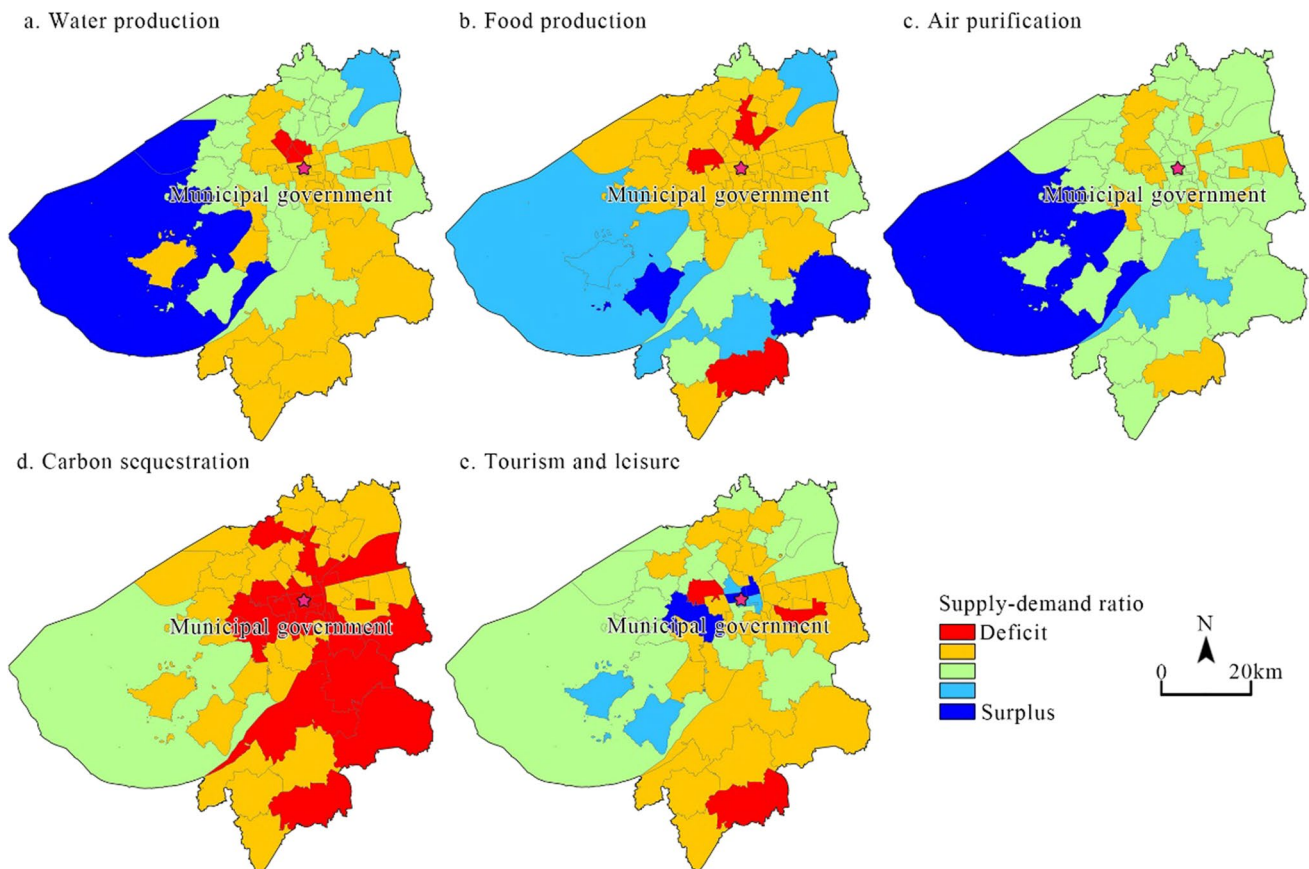

Fig. 5 Supply and demand matching of selected ecosystem services in Suzhou City

there are 12 areas that have negative values. The industrial agglomeration in the areas has led to a great deal of air pollution, which results in a serious mismatch between the supply and demand of air purification service. There are 44 areas with positive values, in which there is little industrial land and a large proportion of ecological land and sufficient supply capacity of air purification service.

In summary, the demand of carbon sequestration service exceeds the supply. There are obvious differences in spatial matching. All regions except for Tai Lake are in short supply (Fig. 5d). The ratio of supply to demand of carbon sequestration service is −0.54, and there are 55 regions that have negative values, which indicates that the carbon sequestration capacity of plants in Suzhou City is far from enough to meet the carbon emission demand of residents. Thus, it is easy to get "greenhouse effect." The three regions with the largest negative values are Shengze town (−1.88), Tongli town (−1.5), and Yuanhe street (−1.33), indicating that population distribution has significantly increased the imbalance between supply and demand of carbon sequestration service.

The quantity matching of tourism and leisure service shows that demand exceeds supply, and the spatial matching has a significant difference. The regions with insufficient supply are mainly located in the regions with insufficient tourism resources (Fig. 5e). The average ratio of supply and demand is −0.02. There are 32 areas that have negative

values, most of which have a large permanent population and a small number or low level of parks in residential areas. There are 24 positive areas, scattering around the ancient city, Tai Lake, and Yangcheng Lake, including the classical gardens of Suzhou, old water town, ancient villages, and famous lakes.

Relationship between supply–demand matching and urban functional zoning

The main functional zoning system is the basis to optimize the development and protection of a country's territory. Meanwhile, the functional zone planning, as the top-level spatial planning to coordinate different development and layouts, has become a sustainable and stable mean of spatial governance which has been adopted by the Chinese governments at all levels (Jie 2017). In 2014, the Suzhou Government issued "Implementation Opinions on Major Functional Zones in Suzhou," which proposed to divide Suzhou City into three categories and five sub-categories. The division adopted streets and towns as a unit, including optimization and upgraded area, key expanded area, moderately developed area, restricted developing area, and forbidden developing area, with the intensity of development, weaken in order (Fig. 6a). Main functional areas are presented in more detail in Appendix B. Since then, the main functional zoning has
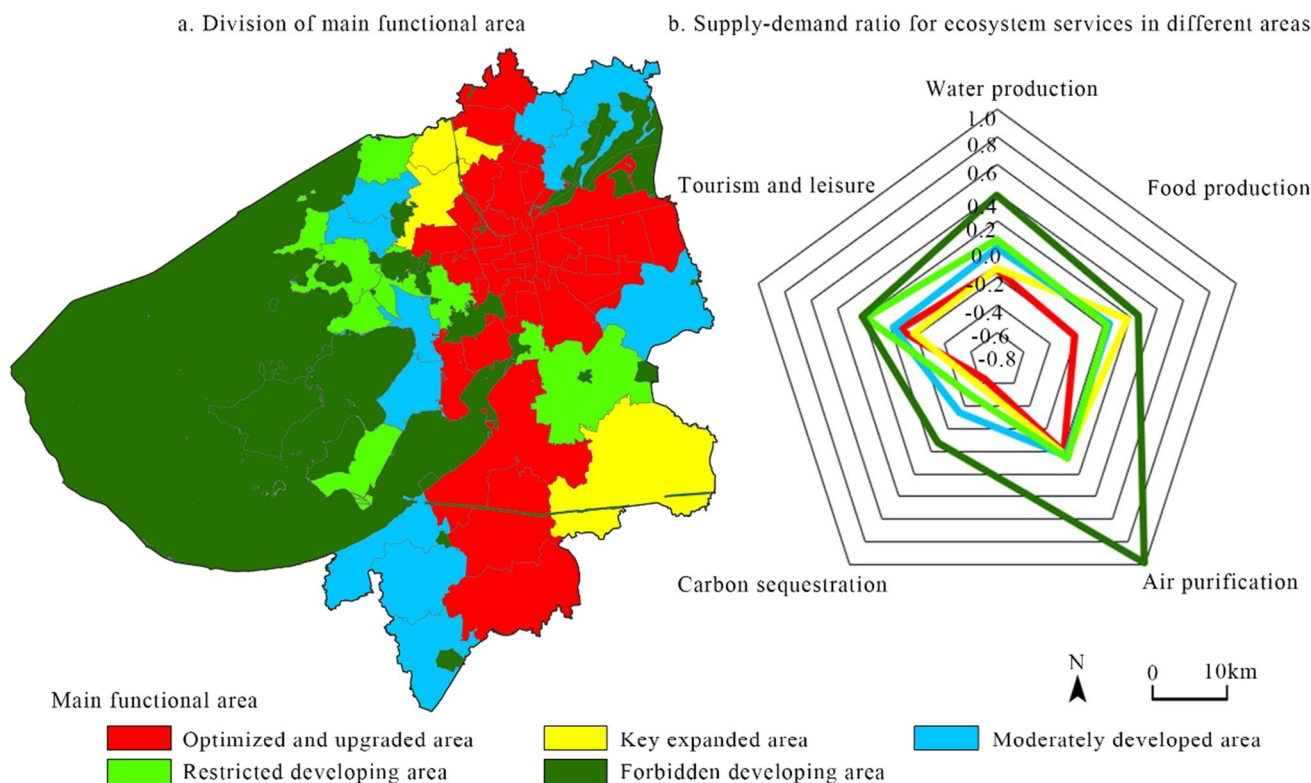

Fig. 6 Selected ecosystem services and urban functional zoning

become the basic standard for the division of urban functional areas in Suzhou City.

The division of the main functional areas is based on the carrying capacity of resources and environment, the existing development density, and the development potential (Jie 2015). It can be seen from the concept that the classification basis took both the ecological system and the social system into consideration. Therefore, the relationship between urban functional zoning and the supply–demand matching of ecosystem services can be further analyzed to provide a theoretical basis for the participation of ecosystem services in spatial governance.

Figure 6 shows that the supply–demand relationship of selected ecosystem services is affected by urban functional zoning, and the supply–demand matching degree of different urban functional zones varies significantly. First, based on the intensity of ecological management and control, the five urban functional areas were assigned 1–5 points, respectively. The Pearson correlation analysis shows that the correlation coefficients between the intensity of ecological control and the supply–demand matching ratio of water production, food production, air purification, carbon sequestration, and tourism and leisure are 0.6, 0.68, 0.59, 0.52, and 0.48 separately, showing a significant positive correlation. This means that the greater the intensity of ecological control, the better the matching degree of supply and demand. In other words, as the development intensity increases, the deficit of selected ecosystem services becomes more and more serious. In the analysis of the supply–demand matching of water production, food production, air purification, carbon sequestration, and tourism and leisure, 66.67%, 68.18%, 81.25%, 60%, and 68.75% of the areas in short supply locate in the optimized and upgraded areas with high development intensity, respectively. Second, from Fig. 6b, we see that the supply–demand ratio of selected ecosystem services shows that the optimized and upgraded areas have the largest negative value, followed by key expanded areas, moderately developed areas, restricted developing areas, and prohibited developing areas.

Third, in order to further explore the relationship between the supply–demand matching of selected ecosystem services and urban functional zoning, the coupling coordination model was used to measure the coupling coordination degree between supply–demand ratio of selected ecosystem services and the intensity of ecological control intensity in different functional areas (Fig. 7). Among them, the values
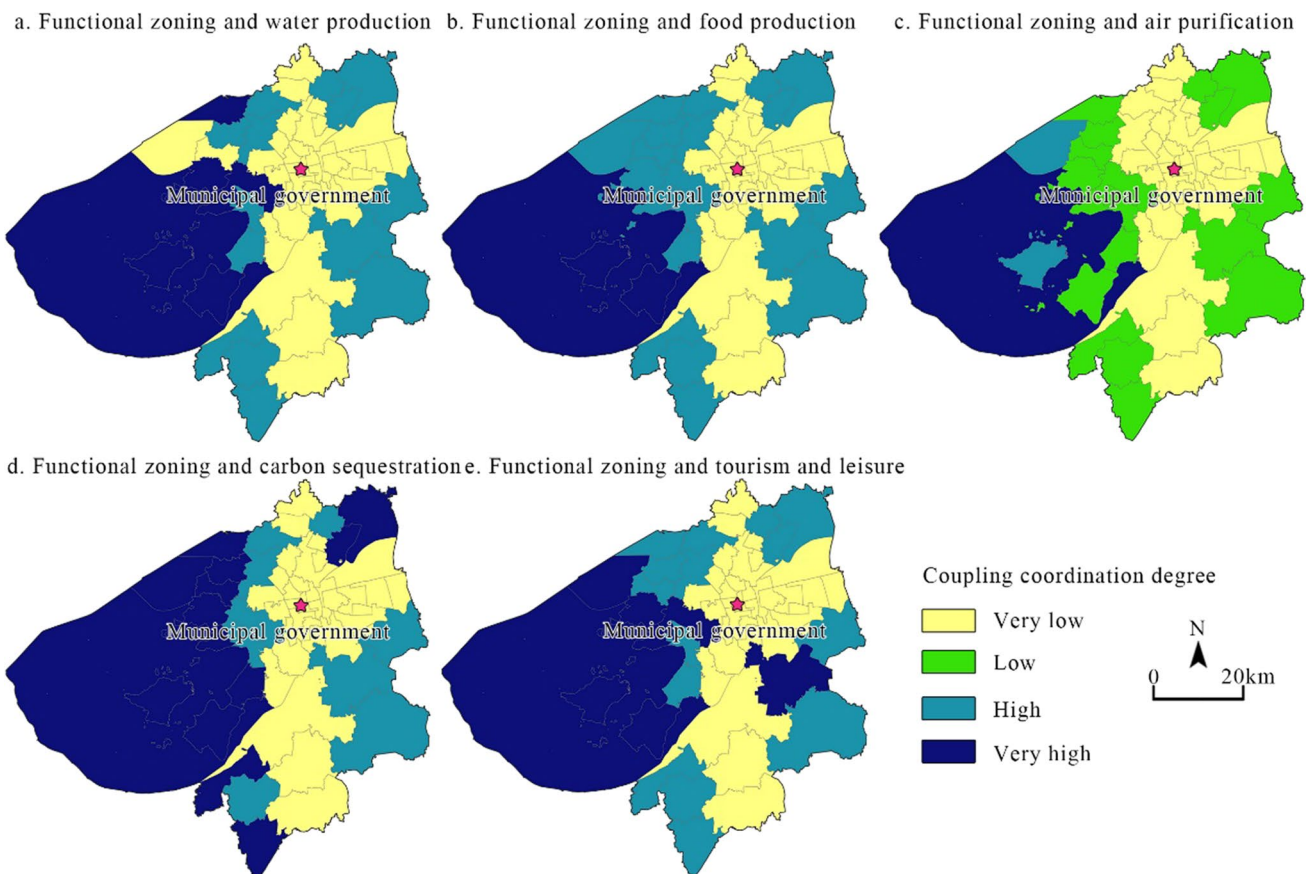

Fig. 7 Coupling coordination of selected ecosystem services and functional zoning

of 0–0.3, 0.3–0.5, 0.5–0.8, and 0.8–1 represent the very low, low, high, and very high degree of coupling coordination, respectively.

Figure 7 shows that, on the whole, the degree of coupling coordination between the supply–demand ratio of selected ecosystem services and the intensity of ecological control in Suzhou City is low. No matter what kind of ecosystem services, the number of streets or towns with very low degree is more than half. In addition, the distribution of coupling coordination degree shows a typical circular structure. The degree of coordination is very low in the central old city and the vicinity, and the uncoordinated situation gradually improves outward.

Discussions

Integrating ecosystem services into urban spatial governance

Urban spatial governance involves the exercise of power to manage the use and development of urban space. Urban spatial governance can influence the provision, distribution, access to ecosystem services, value, and trade-offs with other urban functions (Liu and Wu 2022; Liu and Russo 2021). For example, the construction of buildings and infrastructure can alter natural habitats and reduce the availability of ecosystem services (Peng et al. 2017). Alternatively, urban green spaces, such as parks and gardens, can provide important ecosystem services, including air purification, carbon sequestration, and recreation opportunities (Lyu et al. 2018; Pukowiec-Kurda 2022). Numerous studies have explored the relationship between ecosystem services and urban spatial governance, emphasizing the significance of integrating ecosystem services into urban planning in order to promote sustainable development (Alberti et al. 2003; Zhang et al. 2022a). The incorporation of ecosystem services into urban planning can effectively tackle environmental and social issues, including climate change, loss of biodiversity, and social inequality (Frantzeskaki et al. 2019; Lam and Conway 2018). Nevertheless, obstacles persist in integrating ecosystem services into urban spatial governance, such as insufficient data availability, stakeholder conflicts of interest, and inadequate appreciation of the value of ecosystem services (Cortinovis and Geneletti 2018; McDonald et al. 2008).

Matching the supply and demand of ecosystem services is crucial for encouraging sustainable usage and management of natural resources and for ensuring that ecosystem services are delivered in a manner that caters to the requirements of both humans and nature (Baró et al. 2015; Zhang et al. 2022b). The supply of ecosystem services relies on the inherent structure, process, and function of ecosystems, which exist independently of human intervention. This reflects the ecosystems' potential ability of ecosystems to provide products and services (Jones et al. 2016; Schröter et al. 2014). The demand of ecosystem services is influenced by various factors, including the economy, education, culture, policy, and regulations, reflecting human preferences for different types of ecosystem services (Zhang et al. 2021). Many scholars have explored the spatiotemporal characteristics of supply–demand matching of different ecosystem services, which promotes ecosystem services from a theoretical concept to policy making (Schirpke et al. 2019; Shi et al. 2020). The current research on the relationship between the supply and demand of ecosystem services can be mainly summarized as concept interpretation, evaluation method, and practical application (Hegetschweiler et al. 2017; Wei et al. 2017). The methodology of measuring ecosystem services value includes market-based valuation and non-market valuation. Market-based valuation refers to the process of determining the value of an ecosystem service by examining the prices of comparable goods or services in the market (Costanza et al. 1997; Schulp et al. 2014). On the other hand, non-market valuation methods involve estimating the value of an ecosystem service through various techniques, such as surveys, choice experiments, and revealed preference methods like travel cost or willingness to pay methods (Paracchini et al. 2014; Semmens et al. 2018).

In this context, the paper combines market-based and non-market-based valuation techniques to introduce several key innovations. Firstly, it provides a micro-level visualization of the supply and demand value of selected ecosystem services in high-density population areas. Secondly, the matching degree between the supply and demand of selected ecosystem services is evaluated. Lastly, it explores the relationship between the supply–demand matching of selected ecosystem services and urban functional zoning. This analysis not only deepens the understanding of the supply and demand of ecosystem services but also contributes to the integration of ecosystem services in urban spatial governance.

Policy relevance and implications

Observations from the Suzhou case indicate that development intensity and the ratio of supply–demand matching have a negative correlation. The supply and demand of selected ecosystem services are influenced by urban functional zoning, and greater development intensity leads to a tighter relationship between supply and demand. Research on the matching of supply and demand for ecosystem services can aid in the assessment and regulation of urban spatial governance. When development intensity is lower and ecological control is stricter, the balance between supply and demand for ecosystem services is better. In this situation, urban spatial governance and ecosystem services promote

each other and develop in tandem. However, when there is a deficit of ecosystem services, it indicates that the intensity of ecological control lags far behind the supply of ecosystem services. Therefore, strengthening ecological protection and environmental governance is necessary when accelerating development in such areas. The above analysis highlights that the government carries out spatial planning and actions from top to bottom based on a comprehensive consideration of ecosystem capacity and social system demand in order to protect and utilize land resources more efficiently and regulate human activities appropriately. This leads to the establishment of urban function zoning. Each urban functional area formulates unique urban management policies based on its positioning, resulting in unbalanced distributions of land, industry, population, and other factors that may impact the degree of supply–demand matching for ecosystem services. However, the degree of supply–demand matching for urban ecosystem services can also serve as an indicator for evaluating the rationality of urban function zoning and regulating urban spatial planning through policy and management (Fig. 8).

The main factors affecting the evaluation of ecosystem service value are land use, industrial activities, and population growth due to their direct and indirect impacts on the supply and demand of ecosystem services (MA 2005). Land use changes, such as deforestation, urbanization, and agriculture, can alter the ecosystem's structure and function, leading to a decline in the provision of ecosystem services (Foley et al. 2005; Song et al. 2018). Industrial activities can also have adverse impacts on the environment, including water and air pollution, which can harm the quality and quantity of ecosystem services (De Groot et al. 2010). Population growth and associated consumption patterns can increase the demand for ecosystem services, leading to overexploitation and depletion (Costanza 2020). Therefore, a comprehensive assessment of ecosystem services must consider the impacts of land use, industry, and population on ecosystems to accurately evaluate their value. A couple of regulation strategies are proposed from the following three aspects.

Firstly, the optimized developing area is the key to enhancing the core competitiveness of the city, and it is also the main generating area of environmental pollutants and the clustering area that is in short supply of ecosystem services. It can be seen that protecting cultivated land and ecological land as well as strengthening the construction of green infrastructure in high-intensity developing zones can help release the tension between supply and demand of ecosystem services, improve the quality of urban life, and enhance a region's core competitiveness. Secondly, the industry is the sector that accounts for the largest proportion of urban water consumption, air pollutant emissions, and greenhouse gas emissions. Industrial clusters can easily cause that demand exceeds the supply of ecosystem services. Therefore, eliminating dirty industries, encouraging the parsimonious use of industrial land, and promoting the transformation of the industrial structure to modern service industries and high-tech industries could be useful to alleviate the problem of ecosystem services in short supply. Thirdly, one of the reasons for the mismatch between the supply and demand of urban ecosystem services is the over-concentration of the population. It is important to lead the population towards the surrounding new districts with high carrying capacity through employment opportunities properly. These strategies are integral parts of improving urban spatial governance and achieving sustainable urban development.

Directions for further study

Inevitably, there are some limitations in this paper. This paper only focused on the quantification of five selected

Fig. 8 Supply–demand matching of ecosystem service and urban spatial governance
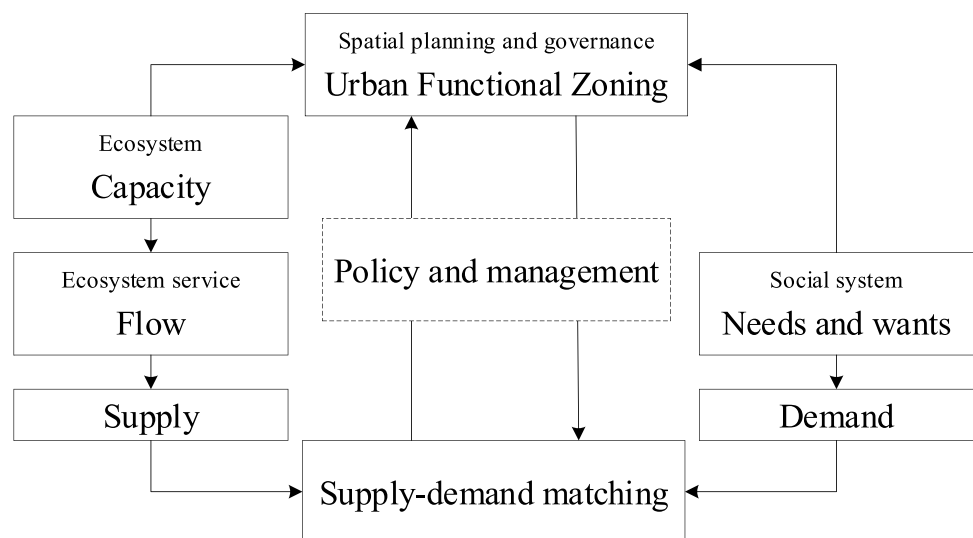
ecosystem services due to data accessibility limitations. Therefore, a comprehensive assessment of the supply–demand relationship of urban ecosystem services was not conducted. Some ecosystem services such as high-temperature regulation, flood regulation, water purification, and noise control were not included in the calculations. On the other hand, this paper did not fully investigate the factors, evolution process, and driving mechanism of the supply–demand relationship of ecosystem services.

Future research can be strengthened from the following aspects. Firstly, more types of ecosystem services should be taken into account in the assessment. Secondly, the diachronic comparison, cross-scale comparison, and driving mechanism of the supply–demand matching of ecosystem services can be strengthened. Thirdly, it is necessary to consider the evolution of urban space and the needs of multi-stakeholders in an analysis of the relationship between ecosystem services and urban spatial governance.

Conclusions

The study aimed to answer three questions related to the relationship between supply–demand matching of ecosystem services and urban spatial governance in high-density population areas. The results are as follows.

In Suzhou City, the supply value of water production, food production, carbon sequestration, and tourism and leisure is lower than the demand value, while the supply value of air purification exceeds the demand value. The spatial matching of supply and demand exhibits a typical circular structure, with areas where demand exceeds supply mostly located in and around the old city. Secondly, the degree of coupling coordination between the supply–demand ratio of selected ecosystem services and the intensity of ecological control is low. The relationship between the supply and demand of selected ecosystem services is influenced by urban functional zoning. As the development intensity increases, the relationship between the supply and demand of ecosystem services becomes more strained. Finally, research on the supply–demand matching of ecosystem services can aid in the assessment and regulation of urban functional zoning. Urban spatial governance can be regulated based on land, industry, and population, taking into account the supply and demand of ecosystem services.

In conclusion, the article documents significant differences between the supply and demand values of ecosystem services yet also points to significant opportunities to weave ecosystem services into urban management.

Author contribution All authors contributed to the study conception and design. Conceptualization, methodology, and original draft were written by Feng Sun. Review, editing, and funding acquisition were performed by Jinhe Zhang. Visualization was completed by Yuhua Xu. Project administration was performed by Wenjie Hu. Data curation was performed by Yu Cao. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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