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Temporal–spatial dynamics of typical ecosystem services in the Chaobai River basin in the Beijing-Tianjin-Hebei urban megaregion

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Human demand for ecosystem services dominates ecosystem changes and impacts the temporal–spatial patterns of ecosystem services and their trade-offs. In the process of urbanization, the supply service, regulation service, and cultural service of the ecosystem are difficult to improve in synergy in the city and its surrounding areas, which is tough for urban construction and development. This study took the Chaobai River basin located in the Beijing-Tianjin-Hebei urban megaregion in northern China as the research area. The temporal and spatial changes from 2000 to 2015 of three typical ecosystem services in the study area, including food production, water conservation, and recreation, were evaluated and analyzed through modeling. The ecosystem service hotspots, service-gain areas, and service-loss areas were identified based on spatial analysis. The dynamic change mechanism of ecosystem services was explored from the perspective of land use change and hotspot analysis. The results showed that (1) recreation and food production services showed an increasing trend, while water conservation showed a fluctuating increasing trend. (2) The service-gain area was significantly larger than the service-loss area. (3) The main land use change form in the study area during the study period was the regional conversion of cultivated land to forest land and construction land, which led to the increase in water conservation services and the reduction of food production services in the corresponding patches. However, this conversion did not affect the overall improvement of the three ecosystem services in the study area. (4) Ecosystem service hotspots have gradually changed from being single-service dominant to two co-leading services. The area of food production-recreation hotspots continued to increase, indicating synergy between them. The area of water conservation-recreation hotspots continued to decrease, indicating trade-offs between them. Different types of ecosystem services improve in synergy in the Beijing-Tianjin-Hebei urban megaregion in the process of urbanization through the improvement of agricultural technology and productivity and the promotion of leisure and sightseeing agriculture. This provides an example for other cities.

KEYWORDS

ecosystem services, hotspots analysis, trade-offs, Chaobai River basin, Beijing-Tianjin-Hebei urban megaregion

Introduction

Ecosystem services are the benefits that human beings obtain from the ecosystem (Costanza et al., 1997). They are an important link between ecosystem processes and social well-being (Abera et al., 2021). They can better reveal the man-land relationship and have broad application prospects for ecosystem management. Therefore, ecosystem services have rapidly become the research focus and frontier of ecology and geography ever since the 1990s when they were proposed (Daily et al., 2009; Bennett et al., 2010). The "Millennium Ecosystem Assessment" carried out by the United Nations in 2000–2005 divided ecosystem services into four categories: supply services, regulation services, support services, and cultural services. It further clarified the index system and methods and evaluated global ecosystem services (Millennium Ecosystem Assessment, 2005). Current research on ecosystem services mainly focuses on the evaluation and pricing of ecosystem services (Vemuri and Costanza, 2006; Fleskens et al., 2009; Costanza et al., 2014), trade-offs (Dymond et al., 2012; Lu et al., 2014; Jia et al., 2022), relationship with human well-being (Engelbrecht, 2009; Xu et al., 2020), and ecological management policy design (Ouyang et al., 2016; You et al., 2017). These studies have improved the research depth and theoretical basis of ecosystem services and promoted the enhancement of ecological management based on ecosystem services.

Land use change analysis is the basic means to assess the impact of human activities on ecosystem services (Wang et al., 2023). The assessment and trade-offs of ecosystem service and regional ecosystem management based on land use have become the focus of ecosystem services research (Shi et al., 2018; Shu et al., 2022). At present, scholars have studied the impact of land use change on ecosystem services and their trade-offs at different scales (Estoque and Murayama, 2016; Yu et al., 2017; Jia et al., 2022). However, the impact of urbanization on ecosystem services in rapidly urbanized areas is relatively lacking (Liu et al., 2018a,b). It is difficult to coordinate the improvement of supply services, regulation services, and cultural services in cities and surrounding areas, which is a Gordian knot for urbanization. The Beijing-Tianjin-Hebei urban megaregion is not only the political, cultural, and international exchange center of China but also one of the fastest-growing growth poles in terms of regional economic and social development. At the same time, it is located on the Huang-Huai-Hai Plain which is an important grain production area in China (Lei et al., 2018). The rapid urbanization and intensive urban expansion in this region have greatly changed the land use. The socioeconomic and ecological conditions have undergone drastic changes in this area (Liu et al., 2018a,b). Scientific assessment of the impact of land use change on ecosystem services will play an important role in the sustainable development in this region.

There are multiple nonlinear relationships among different ecosystem services, mainly manifested as trade-offs and synergies. Related studies either analyzed the spatial distribution of ecosystem services supply through spatial analysis and mapping (Kandziora et al., 2013) or analyzed the relationship among different ecosystem services by means of correlation analysis or local statistical analysis (Li et al., 2020). Some researchers have focused on the identification and analysis of the distribution of ecosystem service hotspots (Gao et al., 2020). The identification of tradeoff hotspots could help us to make a preliminary analysis of the tradeoff between two ecosystem services (Zheng et al., 2016). Based on hotspot analysis, the spatial combination patterns of high-value samples of ecosystem services were identified, thereby integrating differentiated management methods at the grid scale (Li et al., 2016). However, an analysis of the temporal changes of ecosystem service hotspots is missing. Thus, the association between hotspots and the relationships among ecosystem services could not be established. Therefore, taking the Chaobai River basin in the Beijing-Tianjin-Hebei urban megaregion as the study area, this article analyzed the dynamic change mechanism of ecosystem services from the perspective of land use change and hotspot analysis to deeply understand the impact of land use changes and policy measures on ecosystem services and their spatial patterns in a rapid urbanization region.

Materials and methods

Study area

The Chaobai River basin was taken as the representative area of the Beijing-Tianjin-Hebei urban megaregion in this study. As a special area stretching across Beijing, Tianjin, and Hebei Province, it is not only an important development zone for the coordinated development of Beijing, Tianjin, and Hebei but also an ecological barrier for the capital, Beijing. With the promotion of the coordinated development of Beijing-Tianjin-Hebei, the industrial layout between urban agglomerations has been gradually optimized, and the spatial compactness is constantly increasing. Many non-capital functions are gradually being dispersed to Tianjin and Hebei. The Chaobai River basin relieves a portion of Beijing's non-capital functions. In addition, as the intersection of the Beijing-Tianjin-Hebei urban megaregion, it is gradually becoming an important connection point for the coordinated development of the urban megaregion. The improvement of transportation inevitably occupies land resources in the surrounding areas of cities and also forces the restructuring and integration of land use structures within the region. Therefore, the coordinated development of Beijing-Tianjin-Hebei poses certain challenges to the rational layout and optimization of land use in this region, which in turn affects regional ecosystem services (Song et al., 2019). A study of the temporal–spatial dynamic of typical ecosystem services and their response to land use changes in this area can reflect the impact of coordinated development and the relieving of non-capital functions on the land use and ecosystem services at the watershed scale.

The Chaobai River flows through Hebei, Beijing, and Tianjin, with a total length of 458 km and a drainage area of 19,500 km^2 (Figure 1). The average elevation of the basin is approximately 1,500 m. The west and north are dominated by middle-sized mountains, and the southeast is dominated by low mountains, hills, and plains. It is situated in the transition area between a middle temperate zone and a warm temperate zone, as well as a semi-arid zone and a semi-humid zone with the climate of continental monsoon. The average annual precipitation is approximately 500 mm. Brown soil and cinnamon soil are widely distributed in the basin. High vegetation coverage and rich vegetation types (mainly coniferous and broad-leaved mixed forest) appear in this area.

Data sources

The datasets employed were land use, NDVI, meteorological, elevation, scenic spots, and tourist numbers. The land use data were

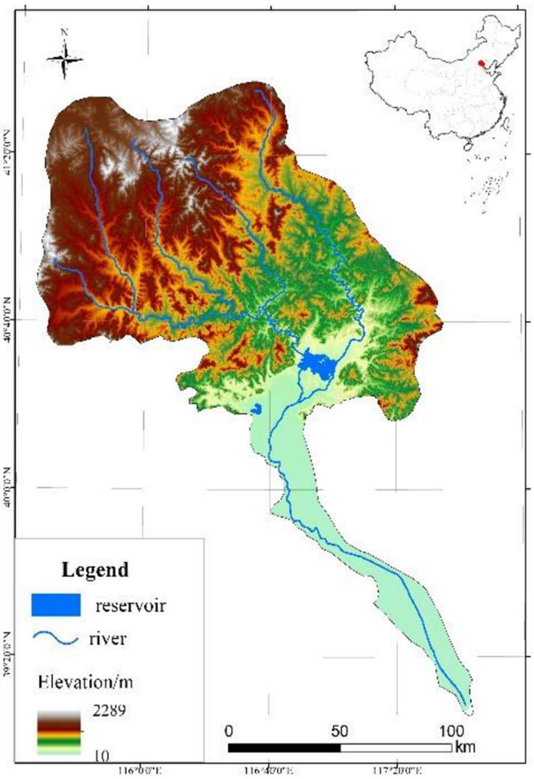

FIGURE 1
Location of the study area.

obtained from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, with a resolution of 30 m. The NDVI data were derived from MOD13Q1 NDVI dataset[1] with a resolution of 250 m. The meteorological data was obtained from the Chinese National Meteorological Information Center.[2] The elevation data were obtained from the NASA/USGS published SRTM Global DEM.[3] The scenic spots and tourist numbers were selected mainly from the National Bureau of Statistics.

Quantification of forest ecosystem services

The Chaobai River basin is located in the Huang-Huai-Hai Plain, one of China's important grain production areas. The cultivated land in the region has important food production functions (Su et al., 2020). Upstream of the Chaobai River is the catchment area of the Miyun Reservoir, which is the source of domestic water for Beijing and Tianjin. Therefore, the water conservation function of the Chaobai River basin is of great significance to ensure the ecological security and coordinated development of the Beijing-Tianjin-Hebei urban megaregion. Moreover, it is located in the core area of the Beijing-Tianjin-Hebei urban megaregion with a large population density, rich tourism resources, and strong tourism demand, which leads to outstanding entertainment and leisure services. This study evaluated the three ecosystem services including water conservation, food production, and recreation in the study area, representing regulation services, supply services, and cultural services, respectively.

Water conservation

In this article, assuming that the interaction between surface water and groundwater was negligible, the water conservation capacity can be defined as the amount of water retained by the ecosystem, which can be calculated by the water balance equation (Lan et al., 2019; Yang et al., 2019) as follows:

$$WC = P - ET - R_a \tag{1}$$

$$R_a = P \times \alpha \tag{2}$$

where WC is water conservation capacity (mm), P is precipitation (mm), ET is evapotranspiration (mm), R_a is surface runoff (mm), and a is runoff coefficient. The water yield (P-ET) was calculated in the modified InVEST model. The InVEST model's water conservation module, grounded in the Budyko hydrothermal coupling water balance and the average annual rainfall (Budyko, 1974; Donohue et al., 2012), while taking into account the actual amount of evapotranspiration, has the following equation for the annual production flow of water yield (Zhang et al., 2001):

$$Y(x) = \left(1 - \mathrm{AET}(x) / P(x)\right) \times P(x) \tag{3}$$

$$AET(x)/P(x) = 1 + PET(x)/P(x) - \left[1 + \left(PET(x)/P(x)\right)^{\omega}\right]^{1/\omega} \mathrm{SE_P} = \mathrm{R} \times \mathrm{K} \times \mathrm{LS} \tag{4}$$

$$PET(x) = K_c(l_x) \cdot ET_0(x) \tag{5}$$

$$\omega(x) = Z \cdot Y(x) = \left(1 - \mathrm{AET}(x)/P(x)\right) \times P(x)\left(AWC(x)/P(x)\right) + 1.25 \tag{6}$$

$$AWC(x) = \min\left(Soil\ Depth, Root\ Dpeth\right) \times PAWC \tag{7}$$

where Y(x) is the average annual yield at pixel x (mm), P(x) is the average annual precipitation at pixel x (mm), AET(x) is the actual annual evapotranspiration at pixel x (mm), and PET is the potential evapotranspiration. ET0(x) shows the evapotranspiration of the reference crops and represents the influencing factor of the specific land use/cover type transpiration. Kc(lx) is the evapotranspiration coefficient (Allen, 1998). AWC(x) indicates the effective soil water content, and Z is an empirical constant, also known as a seasonal constant, reflecting hydrogeological characteristics such as regional precipitation distribution. PAWC indicates the plant available water capacity fraction. More details can be found in the InVEST User Guide. The runoff coefficient is determined according to a related study (Du et al., 2022).

1 https://search.earthdata.nasa.gov/
2 http://www.cma.gov.cn/
3 https://lpdaac.usgs.gov/

Food production

The CASA model is used to calculate the net primary productivity (NPP) of cultivated land (Potter et al., 1993), which stands for food production (Li et al., 2015; Lyu et al., 2018). The CASA model involves three basic formulas:

$$PP(x,t) = APAR(x,t) \times \varepsilon(x,t) \quad (8)$$

$$APAR(x,t) = SOL(x,t) \times FPAR(x,t) \times 0.5 \quad (9)$$

$$\varepsilon = f_1(x,t) \times f_2(x,t) \times w(x,t) \times \varepsilon_{max} \quad (10)$$

where NPP(x,t) denotes the net primary productivity of pixel x at time t, APAR(x,t) denotes the incident solar radiation absorbed by the canopy at a given period (MJ·m^{-2}), and $\varepsilon(x,t)$ denotes the light energy utilization rate (gC·MJ^{-1}). FPAR(x,t) denotes the proportion of photosynthetically active radiation absorbed by the vegetation canopy (Ruimy et al., 1994); SOL(x,t) denotes total solar radiation (MJ·m^{-2}) (Li et al., 2019); $f_1(x,t)$ and $f_2(x,t)$ are temperature stress coefficients (Potter et al., 1993); $w(x,t)$ is the water stress coefficient (Piao et al., 2001); and ε_{max} is the maximum light energy use efficiency (gC·MJ^{-1}) of the vegetation under ideal conditions. More details about the CASA model can be found in previous studies (Zhu et al., 2007).

Recreation

In this study, the annual tourist arrivals, scenic spot density, distance from scenic spots, distance from roads, distance from rivers, and distance from residential areas in the study area were considered as the main influencing factors for recreation service in the study area. The distribution of each factor was obtained through ArcGIS spatial analysis based on statistical yearbook data and GIS vector data. The maximum normalization method was adopted to normalize the spatial distribution data of each factor. The recreation service was calculated according to the normalized data and weight determined. The weight of each factor and the calculation formula for recreation service are as follows.

$$Sre = 0.3 \times Np + 0.2 \times Ds + 0.2 \times Sd + 0.1 \times Dro + 0.1 \times Dri + 0.1 \times Dse(x,t) \quad (11)$$

where Sre is the value of recreation service and Np, Ds, Sd, Dro, Dri, and Dse are the normalized data of annual tourist arrivals, scenic spots density, distance from scenic spots, distance from roads, distance from rivers, and distance from residential areas, respectively.

This method can identify the spatial distribution characteristics of tourism activity intensity, which represents the recreation service, based on the geographical location and tourist arrivals of scenic spots supplemented by geographical information elements such as roads and residential areas using the ArcGIS spatial analysis module. This method can not only avoid the uncertainty of traditional questionnaire survey methods but also reflect the tourism activity intensity in the non-scenic areas to some extent.

Impact of land use change on ecological services

Based on the evaluation results of three ecosystem services, the value differences in the three services from 2000 to 2015 were calculated using a raster calculator in ArcGIS. The distribution areas with positive values were regarded as service-gain areas. The distribution areas with negative values were regarded as service-loss areas. The land use change process from 2000 to 2015 was analyzed according to land use data. The main land use transformation types were identified. The spatial overlay analysis of the main land use transformation types and the gain and loss areas of the three ecosystem services were carried out to analyze the response of ecosystem services to land use change.

Hotspots analysis of ecosystem service

Firstly, the average value of each ecosystem service was calculated, and the regions with values greater than the average value were considered the hotspot areas for each ecosystem service. Then, the hotspot areas of three ecosystem services were spatially overlaid to create the overall ecosystem service hotspots in the study area. Hotspot areas with a single ecosystem service type were defined as Class I service hotspots. Hotspot areas with two ecosystem service types were defined as Class II service hotspots. Hotspot areas with three ecosystem service types were defined as Class III service hotspots. The spatial distribution characteristics of ecosystem service hotspots were analyzed. Furthermore, the temporal changes of the areas of different types of hotspots were analyzed to illustrate the trade-offs and synergy between different ecosystem service types.

Results

Temporal dynamic of typical ecosystem services

The recreation and food production services showed an increasing trend from 2000 to 2015. The water conservation service showed a fluctuating trend (Table 1). High-value areas of water conservation service were mainly distributed around the Miyun Reservoir. The water conservation capacity upstream of the Chaobai River basin was much higher than that in the middle and lower reaches. The cultivated land was mainly distributed in the plain areas in the middle and lower reaches of the basin, as well as the river valley areas in the upper reaches of the basin. The NPP of cultivated land in the middle and lower reaches of the basin was higher than that in the upper reaches. High-value areas of recreation service were mainly distributed around the urban area (Supplementary material).

TABLE 1 Changes in ecosystem services from 2000 to 2015.

Year	2000	2005	2010	2015
Water conservation (mm)	29.15	42.2	64.2	48.06
Food production (gC/m^2/a)	193.07	213.02	220.84	243.54
Recreation	0.18	0.19	0.2	0.21

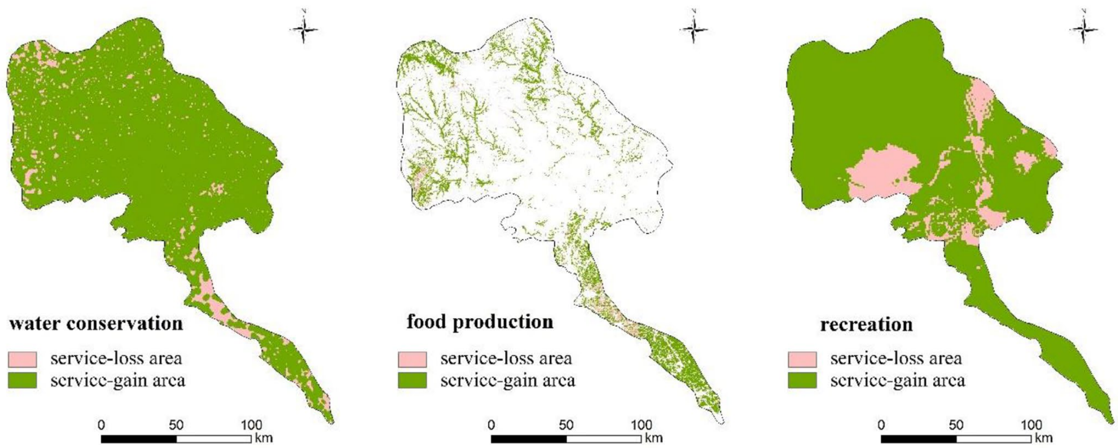

FIGURE 2
Spatial distribution of ecosystem service changes.

Spatial dynamic of typical ecosystem services

The service-gain area was significantly larger than the service-loss area. The service-gain area occupied 91.05, 89.67, and 85.14%, for food production, water conservation, and recreation ecosystem services, respectively. The service-loss area for food production services was mainly distributed in the central area of the lower reaches of the basin. The service-loss area for water conservation services was mainly distributed in the lower reaches of the basin and northwest of the upper reaches of the basin. The service-loss area for recreation services was mainly distributed in the central and eastern parts of the study area (Figure 2).

Land use change analysis

The land use change process was analyzed based on the land use data of 2000, 2005, 2010, and 2015. It was found that the area of forest land was the largest, accounting for about 65% of the total area, followed by the cultivated land and grassland, accounting for about 20% and about 10%, respectively. The areas of other land use types were relatively small. The area of cultivated land in the study area has been continuously decreasing, while the area of construction land increased continuously on the contrary. The areas of other land use types have no significant changes (Table 2).

The upper reaches of the Chaobai River basin are mainly occupied by forest land, with a certain area of cultivated land and grassland distributed in the river valley area. The middle and lower reaches of the basin are mainly occupied by cultivated land, with a certain area of construction land and a water area (Figure 3). According to the land use transfer matrix analysis, the main land use conversion direction was cultivated land to forest land and construction land from 2000 to 2015, with conversion areas of 343.54 km^2 and 240.89 km^2, respectively (Table 3).

Response of ecosystem services to land use change

Based on the results of the land use transfer matrix analysis, we analyzed the impact of land use change on ecosystem services, focusing on cultivated land change. First, the conversion areas of cultivated land to forest land and construction land from 2000 to 2015 were identified. Then, these identified areas were overlaid with the gain and loss areas of the three ecosystem services to illustrate the response of ecosystem services to land use change.

It was found that the spatial distribution of patches converted from cultivated land to construction land widely overlapped with the service-loss areas for food production and water conservation, with the overlapping areas accounting for 93.18 and 82.79%, respectively. The spatial distribution of patches converted from cultivated land to forest land widely overlapped with the service-loss areas for food production and the service-gain areas for water conservation, with the overlapping areas accounting for 91.36 and 72.67%, respectively (Figure 4). Therefore, the conversion of cultivated land to construction land can lead to the loss of food production services and the decrease of water conservation services. Although the conversion of cultivated land to forest land led to the loss of food production services, the regional water conservation services can be improved. Under the comprehensive consideration of the temporal variation of the three ecosystem services, it can be seen that the land use change only affected the ecosystem services on a regional patch scale, and did not affect the overall improvement of the three ecosystem services in the study area during the research period.

Hotspot analysis of ecosystem service

Area statistics and spatial distribution of ecosystem service hotspots

The Class I service hotspots had the largest distribution area, occupying more than 60% of the total area. The Class II service hotspots occupied approximately 1/3 of the total area and the Class III service hotspots accounted for only approximately 1% of the total area. Among the Class I service hotspots, the area of water conservation service hotspots was the largest, accounting for approximately 60%; the recreation service hotspots accounted for approximately 1/3; the food production service accounted for only approximately 5%. Among the Class II service hotspots, the area of the water conservation-recreation hotspots was the largest, accounting for approximately 80%, followed by food production- recreation hotspots, accounting for approximately 20%. The area of water conservation-food production hotspots was the smallest, accounting for only approximately 3% (Table 4).

The Class I service hotspots were widely spread in the study area. The Class III service hotspots were concentrated in a certain part of the lower reaches of the basin. As for the Class II service hotspots, the water conservation-recreation hotspots were mainly distributed in the eastern part and middle reaches of the basin, especially in the areas around the Miyun Reservoir. The service hotspots for food production-recreation, as well as for food production-water conservation, were scattered in the downstream plain areas and the upstream valley areas (Figure 5).

Temporal dynamic of the area of ecosystem service hotspots

From 2000 to 2015, the area of Class I service hotspots decreased continuously. On the contrary, the area of Class II service hotspots continued to increase. The area of Class III service hotspots showed a fluctuating trend (Table 4). The hotspots of ecosystem services in the study area have gradually changed from being single-service dominant to two co-leading services. Each type of Class I service hotspot showed a fluctuating trend. As for the Class II service hotspots, the area of food production-recreation hotspots continued to increase, indicating synergy between them. The area of water conservation-recreation hotspots continued to decrease, indicating the trade-offs between them.

TABLE 2 Land use composition from 2000 to 2015 (%).

Land use type	2000	2005	2010	2015
Forest land	64.30	64.72	65.13	65.20
Grassland	9.67	9.87	9.76	9.75
Cropland	20.88	20.07	19.33	18.90
Water area	2.07	1.81	1.75	1.85
Construction land	2.99	3.45	3.96	4.22
Unused land	0.08	0.08	0.07	0.08

Discussion

Variations of cultivated land and food production service

The results of this study indicate that although the cultivated land area shows a continuous downward trend, food production services improved in the study area during the study period. Lu et al. (2020) calculated the food production service in the Beijing- Tianjin-Hebei urban megaregion from 1980 to 2015 based on statistical yearbook data. They also analyzed the changes in land use and food production services. Their research found that in the past 35 years, the cultivated land in the Beijing-Tianjin-Hebei urban megaregion had continued to decrease, but more than 80% of the regional food production services had improved, which is consistent with our study. Yu et al. (2019) present a country-level comparison to understand how cropland area change contributes to cereal production variation across the world's major cereal producers. It was found that although the cropland area had decreased from 2000 to 2010, China and USA achieved a marked increase in actual production. In contrast, Brazil, Argentina, and Nigeria have a relatively lower increase in actual production. This indicated that China better exploited cropland productivity, which is also consistent with our study. The improvement in agricultural productivity is the main reason for the increase in food production services in this area. On the one hand, during the rapid development of urbanization, great importance has been attached to the degree of cultivated land protection. Instead of sacrificing high-quality cultivated land due to the need for urbanization, basic farmland protection zones have been designated and the encroachment of construction land on basic farmland is strictly prohibited. On the other hand, the quality of cultivated land has continued to improve due to a high level of land consolidation. The promotion of farmland public infrastructure, the construction of high-standard farmland, and the development of agricultural

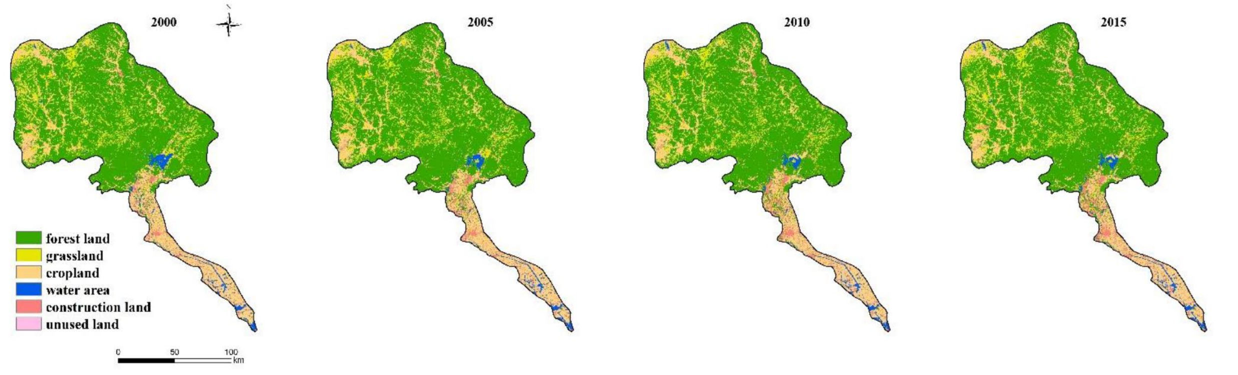

FIGURE 3
Land use map of the study area in 2000, 2005, 2010, and 2015.

TABLE 3 Land use transfer matrix from 2000 to 2015 (km²).

2015 2000	Forest land	Grassland	Cropland	Water area	Construction land	Unused land
Forest land	12,670.74	192.28	175.14	7.09	39.26	3.07
Grassland	209.96	1,659.60	65.95	11.15	21.56	0.76
Cropland	343.54	103.38	3,503.77	55.83	240.89	3.43
Water area	26.26	21.97	59.05	298.45	14.37	0.42
Construction land	18.36	6.91	41.65	3.56	538.84	0.29
Unused land	2.44	1.10	0.83	0.67	3.19	8.90

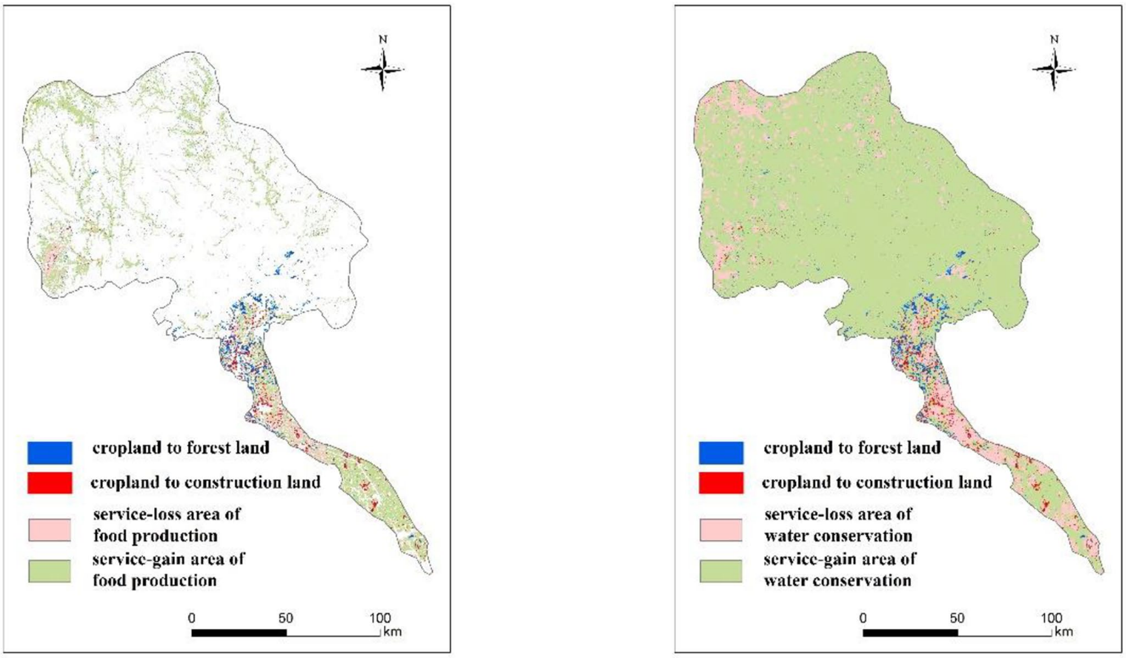

FIGURE 4
Spatial overlay of main land use change types and ecosystem service changes.

mechanization have not only increased food production services but also farmers' income. It can be seen that we can extricate food production service from cultivated land areas to a certain degree through agricultural productivity improvements caused by scientific management and agricultural policy-making.

Synergy between food production services and recreation services

According to the study results, there was a synergistic relationship between food production services and recreation services. This was mainly determined by the multifunction and specific location of cultivated land in the study area. Cultivated land is a comprehensive system composed of natural geographical factors and socio-economic factors. It not only has traditional food production functions, but also has the functions of regulating climate, inheriting agricultural culture, and providing recreation space (Zhou et al., 2021). The importance of the multiple functions of cultivated land has gradually become prominent with the development of society. The land use mode of cultivated land has extended from traditional and single production functions to cultural landscape functions, ecological functions, and social security functions (Xiong et al., 2021). In the Beijing-Tianjin-Hebei urban megaregion, residents in the central urban area have an urgent functional demand for tourism and leisure on cultivated land (Chen et al., 2018). The cultivated land adjacent to urban areas has unique location advantages, resulting in a gradual increase in the popularity of agricultural tourism attractions such as leisure farms, picking gardens, and agritainment. Cultivated land can not only keep its food production function but can also meet the cultural service needs of a large number of central urban residents. In the middle and lower reaches of the Chaobai River basin, based on its location advantages, leisure and sightseeing agriculture has been developed and the cultural service of cultivated land has been strengthened (Li and He, 2022). New forms of high-quality development of leisure agriculture, such as agricultural theme parks and agricultural carnivals, have been formed and developed which contributes to the synergy between food production service and recreation service.

Maria et al. (2014) measured 12 ecosystem services and analyzed their interactions in the floodplain of the Piedra River in central Spain. According to their research result, there was no interaction between food production services and recreation services. It can be seen that the relationship between the two services varies in different regions.

Trade-offs between recreation service and water conservation service

The hotspots for water conservation-recreation services were mainly concentrated in the eastern part and middle reaches of the basin, especially in the areas around the Miyun Reservoir. This area is adjacent to Miyun Reservoir and has important water conservation functions. At the same time, relying on high-quality natural scenery resources, tourism activities in this region are relatively intensive. Moreover, the degree of transportation convenience plays a critical role in the release of tourism potential. After the opening of the Beijing-Chengde Expressway in 2009, tourism has developed rapidly in this area. Many tourism facilities have been built and the number of tourists has increased significantly. The study results show that the hotspot areas of water conservation-recreation services show a decreasing trend, indicating that there was a trade-off between the two which is consistent with Chen et al. (2021) as they pointed out that the trade-off between the two also appears in Beijing Bay. This reflects that the explosive development of tourism has brought certain pressure to the regional ecological environment, which ultimately affects regional ecosystem services to a certain extent. It is suggested that tourism activities should be restricted appropriately in such areas where the hotspot areas of water conservation-recreation services are significantly reduced.

TABLE 4 Area statistics of ecosystem service hotspots.

Hotspots type	2000	2005	2010	2015
Class I service hotspots	11,619.96	11,375.99	10,428.52	9,142.29
Food production	507.23	582.65	628.87	536.55
Water conservation	7,132.76	7,160.21	6,609.90	4,795.21
Recreation	3,979.97	3,633.13	3,189.75	3,810.53
Class II service hotspots	5,289.73	5,372.63	5,411.99	5,505.75
Water conservation- food production hotspots	202.10	320.08	308.4	395.17
Food production-recreation hotspots	800.39	834.78	921.84	1,109.95
Water conservation-recreation hotspots	4,287.24	4,217.79	4,181.75	4,000.63
Class III service hotspots	164.51	129.67	186.69	190.13

Integration of ecosystem services and land use management

The Chaobai River basin is not only an important development zone in Beijing-Tianjin-Hebei urban megaregion but also an ecological barrier for the capital of Beijing. Regional development should give priority to eco-environment protection. Although different types of ecosystem services improve in synergy in this area generally, it is still necessary to pay attention to areas where trade-offs between ecosystem services appear, especially areas where both food production services and water conservation services continue to decrease. In future studies, it is recommended to incorporate ecosystem services into land use planning. Land use planning can effect changes in ecosystem services through the conduction of land use. Ecosystem services can be improved through the construction of a reasonable land use pattern. Paula and Oscar (2012) developed a methodological protocol of strategic environmental assessment to incorporate the valuation of ecosystem services in land use plans. The protocol was applied in rural land planning at Balcarce, a department representative of the Southeast Pampas Region (Argentina). How to rationally allocate land resources and balance the relationship between different ecosystem services to realize optimal ecosystem service value are the focus of future research.

Limitations and data uncertainty

Although this study chose water conservation, food production, and recreation as the key ecosystem services due to their

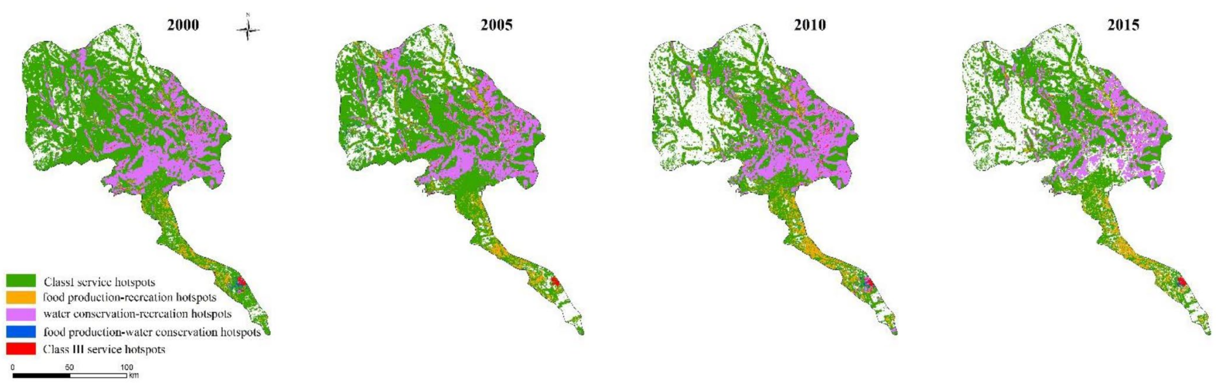

FIGURE 5
Spatial overlay of main land use change types and ecosystem service changes.

representativeness and importance in this area, other ecosystem services such as carbon storage, heat wave mitigation, sediment retention, water purification, and flood and landslide hazard mitigation are not involved because the corresponding data was missing. Moreover, the accuracy of ecosystem services estimation needs further improvement due to the constraints in data collection. For example, the accuracy of the spatial distribution of scenic spots and annual tourist arrivals is greatly influenced by data sources. Finally, this study analyzed the response of typical ecosystem services to land use change using spatial overlaying analysis and failed to reveal the impact mechanism between them, and the relationships exhibited some degree of uncertainty.

Policy implications and suggestions

The middle and lower reaches of the Chaobai River basin are the main supply areas of food production services. Against the backdrop of the continuous reduction of agricultural land area and the increasing scarcity of high-quality farmland resources in the Beijing- Tianjin-Hebei urban megaregion, the situation of cultivated land quality and supply of food production services is becoming increasingly severe. In the future, farmland should be carefully protected to ensure that the area of farmland stops decreasing. Moreover, the level of agricultural technology needs to be further enhanced; crop variety optimization and refined management levels should be improved in order to achieve a dual harvest of high crop yield and quality. At the same time, both mandatory and incentive measures should be adopted to manage the protection of cultivated land. Cultivated land occupation must be constrained by overall land use planning from the very beginning. The occupation and compensation of cultivated land should be balanced. Furthermore, on the premise of protecting the quality of existing cultivated land, diversified planting and culture cultivation should be strengthened to promote the healthy development of the ecotourism industry to realize the coordinated development of regional ecological environment protection and economic development.

The upstream area of the Chaobai River basin is the main supply area for water conservation services. The eco-environment quality in this area has a huge impact on the safety of the water supply and regional ecology of the Miyun Reservoir. The trade-off between water conservation and recreation services indicates that tourism activities have a certain negative impact on the ecosystem. Therefore, the eco-environment should be strictly protected through comprehensive watershed management and ecological protection and restoration projects. Large-scale tourism development and construction projects should be strictly prohibited. Human interference activities should be controlled severely. The employment and income of residents in this region should be ensured through the implementation of major ecological engineering construction and ecological compensation.

Conclusion

In this study, the temporal–spatial dynamics of typical ecosystem services in the Chaobai River basin in the Beijing-Tianjin-Hebei urban megaregion were analyzed. The response of ecosystem services to land use change was analyzed by identifying the corresponding spatial position and overlap area of main land use conversion patches and ecosystem service variations. The temporal changes of the areas of different hotspot types were analyzed to characterize the relationship between different ecosystem services. The main research conclusions are as follows:

(1) The recreation and food production services showed an increasing trend, while water conservation showed a fluctuating increasing trend in the Chaobai River basin in the Beijing-Tianjin- Hebei urban megaregion. The service-gain area was significantly larger than the service-loss area.
(2) The main land use change form in the study area during the study period was the regional conversion of cultivated land to forest land and construction land, which led to the increase in water conservation services and the reduction of food production services in the corresponding patches. However, this conversion did not affect the overall improvement of the three ecosystem services in the study area.
(3) Ecosystem service hotspots were gradually changing from being single-service dominant to two co-leading services. The area of food production-recreation hotspots continued to increase, indicating synergy between them. The area of water conservation-recreation hotspots continued to decrease, indicating trade-offs between them. The reduction of the cultivated land area did not necessarily lead to the reduction of food production services.
(4) We can extricate food production services from cultivated land areas to a certain degree through agricultural productivity improvement caused by scientific management and agricultural policy-making. The high-quality development of leisure agriculture promoted synergy between food production services and recreation services. The explosive development of tourism in certain regions affected regional ecosystem services to some extent.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JZ: conceptualization, methodology, and writing–original draft preparation. CL: methodology. HW: data analysis. XL: software and formal analysis. QQ: supervision and writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2023.1201120/full#supplementary-material

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