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Spatiotemporal Changes and Driving Mechanisms of Ecosystem Service Supply–Demand Contradictions Under Urbanization

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Abstract: Clarifying the driving mechanisms of ecosystem service (ES) supply and demand under urbanization is of significant importance for urban ecological planning and management. However, how the balance of ES supply and demand and its driving mechanisms vary with the degree of urbanization has been little studied. In this study, we analyzed the spatiotemporal changes and the correlations between ES supply and demand and the degree of urbanization in the Zhengzhou Metropolitan Area (ZZMA) from 2000 to 2020 and further explored the driving mechanisms behind these changes. The results showed that, (1) between 2000 and 2020, the ZZMA experienced a deficit in comprehensive ES supply and demand, and regions with rapid urbanization development were more likely to trigger imbalances in ES supply and demand; (2) the spatial mismatch between low–high ES supply and demand was primarily distributed in the built-up areas of various cities, while the high–low spatial mismatch was mostly found in forest and grassland areas; (3) the comprehensive urbanization level of the ZZMA was spatially negatively correlated with the ratio of ES supply and demand. Regions with lower ES balance were more susceptible to disturbances caused by urbanization; (4) population density was the key factor influencing the supply and demand of carbon sequestration, oxygen release, water conservation, and food provision services, while the proportions of forest land and construction areas had the greatest influence on the supply and demand of air purification and leisure services. It is important to ensure the ecological status of the northwestern, southwestern, and central mountainous and forested areas; maintain the agricultural status of the main grain-producing areas in the eastern plains; strengthen ecological restoration and green infrastructure in built-up areas; and formulate differentiated management policies to promote the sustainable supply of ES and safeguard the ecological security of the region.

Keywords: urbanization; ecosystem services supply and demand; spatial correlation; driving factors; Zhengzhou Metropolitan Area

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1. Introduction

ES is a bridge connecting the natural ecosystem and social systems, in which humans can obtain benefits, either directly or indirectly, through transformations [1]. Rapid urbanization has profoundly affected ES functions and constitutes a serious threat to the sustainable development of urban areas worldwide [2]. In 2019, the Intergovernmental

Science-Policy Platform on Biodiversity and ES (IPBES) reported that human activities had caused severe alterations in 75% of the global terrestrial environment and led to rapid declines in most ES functions [3]. As a result, the supply and demand of ES have become increasingly imbalanced. Rapid urbanization has led to regional ecological degradation, landscape fragmentation, and other issues [3], triggering ecological security challenges such as ES degradation and mismatches between ecosystem supply and demand [4–6]. Against the backdrop of weakening natural ecological functions, the imbalance between ecological supply and human demand has intensified the mismatch between ES supply and demand. ES contradictions can be understood as the conflict between the weakening of ES functions caused by urbanization or other human activities and the increasing demand for ES. This contradiction becomes more pronounced during the process of urbanization. These challenges have affected the stability and sustainability of ecosystems and have exacerbated the ecological risks faced by urbanized areas. ES supply–demand mismatch refers to the imbalance between the services provided by ecosystems and the demands of human society, indicating that ecosystems are unable to meet the growing demand for ES from humans, which may lead to ecological security issues and risks to sustainable development. Given the increasing impact of human activities on urban ecosystems, there is an urgent need to clarify the processes of ES creation and utilization and assess the spatiotemporal changes in ES under rapid urbanization. This would provide a scientific basis for achieving regional ES balance promoting sustainable development.

In recent years, the burgeoning interaction between human societies and natural ecosystems has increasingly highlighted the criticality of ES supply (ESs) and ES demand (ESd) issues [7]. ESs refers to the goods and services produced by ecosystems for humans, and ESd is understood as the sum of all ecosystem goods and services currently consumed or used within a specific area and period [8]. Initial research sought to clarify ESs and ESd from the perspective of fundamental resources, such as water, food, and energy [9], predominantly adopting macroscopic scales encompassing municipal, provincial, and national domains. Subsequently, the scope of inquiry expanded, embracing a diverse array of scales, including urban areas, forests, and mountainous regions [10]. However, investigations pertaining to ESs and ESd at the metropolitan circle level remain notably underexplored. As time has progressed, the realms of ecological footprint, soil conservation, cultural services of ecosystems, and human well-being have increasingly become focal points of research. The primary focus of these studies has been on the quantification of ESs and ESd, the alignment between supply and demand, and the dynamics of their relationship. For instance, Wei et al. [11] conducted research on ESs in the Manas River Basin, finding that mismatches between supply and demand significantly affect human well-being. Similarly, Xu et al. [12] explored the spatial heterogeneity in changes of ESs and ESd, indicating a negative correlation between demand and supply of ES in certain regions. These studies predominantly employ methodologies such as land use estimation, ecological process simulation, and expert judgment to assess the supply and demand of ES or the quantitative relationships between them. For example, the research by Mashizi et al. [13] revealed the synergistic interaction between the supply and demand of ES in the Iranian Plateau, noting that the lack of ES was primarily in lowland areas. Additionally, Jiang et al. [14] discovered that landscape fragmentation and population growth lead to an imbalance in ESs and ESd, with a significant correlation between population density, individual landscape indicators, and ES balance.

However, previous research often relies on singular, static analyses, which fail to explore the temporal and spatial dynamics of both ESs [15] and ESd. This is particularly evident in studies that integrate factors like urbanization and human well-being. Additionally, while the existing research has predominantly investigated the driving factors of ESs, there have been few quantitative studies to examine the drivers of ES change from a supply–demand perspective, leaving the mechanisms behind ESs and ESd changes unclear. Therefore, research on the spatial and temporal dynamics of ES supply and demand at the metropolitan area level, along with their drivers, is of great significance for regional development. Such research will unravel the complexities and underlying mechanisms of ESs and ESd at this scale, providing a scientific foundation for the future ecological sustainability of metropolitan areas.

As an important transportation hub and major grain-producing area in Central China, ZZMA holds a strategic position for China's food security and sustainable development. As the urbanization process within ZZMA continues to accelerate, urban environmental pressures have intensified, leading to prominent conflicts between human activities and the natural environment [16]. In light of this context and the imperative of achieving sustainable development in human society, there is an urgent need to delve into the relationship between urbanization, ESs, and ESd, along with a comprehensive understanding of the driving mechanisms behind this relationship. Accordingly, the objectives of this study were to (1) conduct an analysis of the levels of urbanization within ZZMA and the spatiotemporal dynamics of ESs and ESd during 2000–2020; (2) elucidate the spatial correlations and clustering patterns between urbanization and the balance of ESs and ESd; (3) investigate the driving factors behind the spatiotemporal variations in the ES supply–demand ratio, along with their spatiotemporal driving mechanisms; and (4) propose recommendations for future urban development, ecological planning, and management. Based on the research objectives, we propose the following hypotheses to guide our study:

H1. *There is a significant correlation between the urbanization process in ZZMA and the balance of ES supply and demand.*

H2. *There are significant spatial differences in the patterns of ES supply–demand mismatches across different geographical areas.*

H3. *Socioeconomic factors and natural factors have a significant impact on the supply–demand relationship of ES.*

2. Materials and Methods

2.1. Research Area

ZZMA is part of Henan Province and is an important driver of high-quality development in Central China, covering an area of approximately 58,800 km^2. It comprises nine cities, including Kaifeng City, Luoyang City, Pingdingshan City, Xinxiang City, Jiaozuo City, Xuchang City, Luohe City, and Jiyuan City, with Zhengzhou City as its core. The topography is characterized by the plains, the low mountains, and hills, with the terrain gradually descending from west to east. The temperate climate features four distinct seasons and an average annual precipitation of approximately 848 mm, making this precipitation suitable for agricultural development. Currently, ZZMA has a total population of 46.7 million, with a GDP of 0.48 trillion USD, accounting for 47.25% of the province's population and 55.70% of its economy while occupying only 35.21% of the province's land [17]. The land use is dominated by cultivated land, followed by woodland and construction land (Figure 1). In December 2021, the Publicity Department of the Henan Provincial Party Committee announced the expansion of ZZMA from "1 + 4" cities to "1 + 8" cities [18]. This expansion aims to build a high-capacity modern metropolitan area that faces international competition and supports the rise of Central China.

2.2. Conceptual Framework and Data Sources

First, we analyzed the spatiotemporal dynamics of urbanization, ESs and ESd, in the Zhengzhou Metropolitan Area, as well as the spatial matching characteristics of ESs and ESd. Second, we analyzed the spatial correlation and aggregation patterns of urbanization and ES supply–demand ratios. Third, we explored nine driving factors behind the spatiotemporal changes in the supply–demand ratio of ES. Finally, based on the above results, we made recommendations for future urban development and ecological planning and management. The research framework is shown in Figure 2.

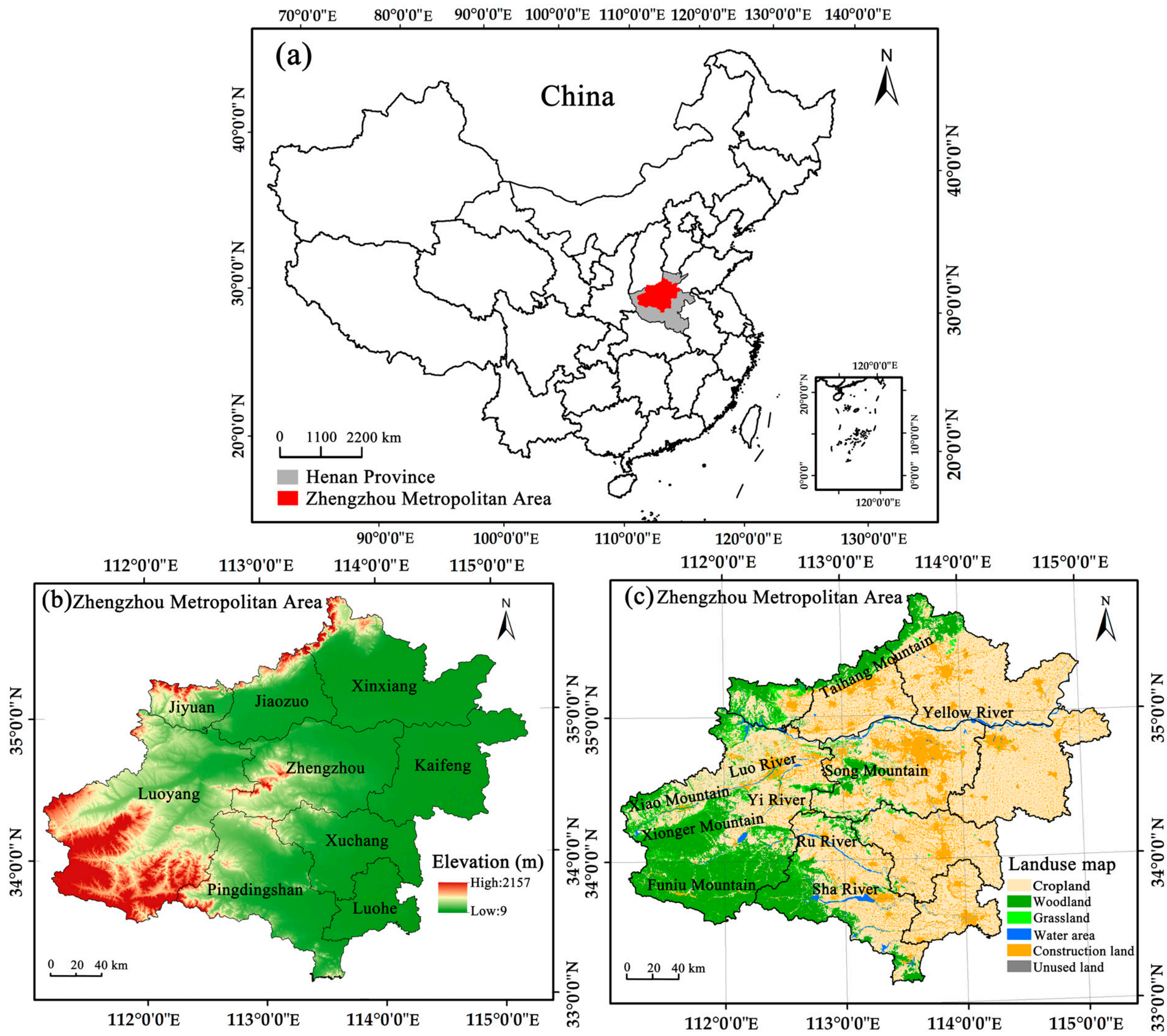

Figure 1. Study area overview: (**a**) location of Zhengzhou Metropolitan Area, (**b**) elevation distribution, (**c**) land use classification of the study area.

This study utilizes both natural and socioeconomic data, as shown in Table 1. Natural data include land use, elevation, precipitation, temperature, and the normalized difference vegetation index (NDVI); socioeconomic data include population, GDP density, food, and various price data. Additionally, land use data were derived from the GlobeLand 30 dataset with a resolution of 30 m, with over 88% decoding accuracy after confusion matrix verification. Six types of land cover were obtained using ArcGIS 10.2 reclassification: namely, cultivated land, woodland, grassland, water area, construction land, and unused land. GDP density data were obtained from Scientific Data [19] (due to missing data for 2020, 2019 data were used instead), with a resolution of 1 km. Food price and various economic data were obtained from the China Statistical Yearbook, Henan Statistical Yearbook, and the National Food and Strategic Reserves Administration. ArcGIS 10.2 was applied to divide the study area into a 1 km $\times$ 1 km grid to calculate the level of urbanization and the value of the supply and demand of ES within the grid, allowing for an in-depth exploration of urbanization and ES on a smaller unit scale. We selected spatial data for the Zhengzhou Metropolitan Area for the years 2000, 2010, and 2020, spanning a time period of 20 years. All spatial data were resampled to a 1 km resolution using ArcGIS 10.2 software.

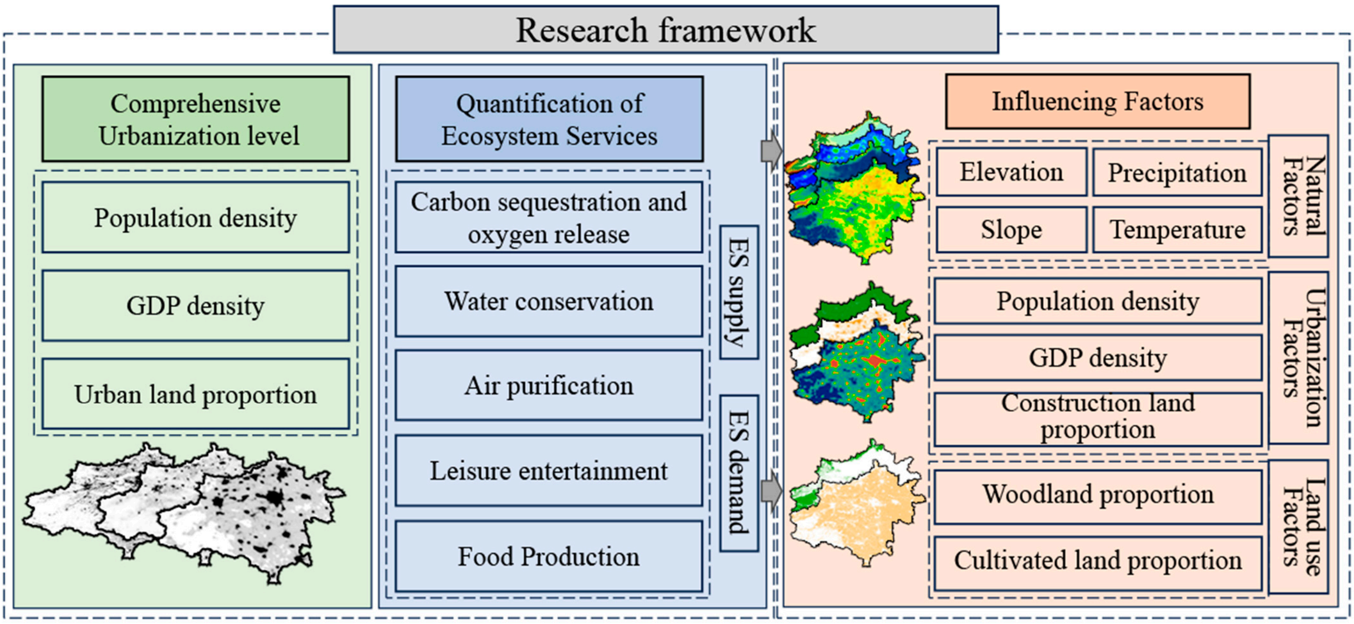

Figure 2. Research framework.

Table 1. Basic data and sources.

Data Description	Spatial Resolution	Data Sources
land use	30 × 30 m	GlobeLand 30 dataset (http://www.webmap.cn/mapDataAction.do?method=globalLandCover) accessed on 1 October 2023
elevation	30 m	ASTER GDEM V30 dataset
precipitation	30 m	National Ecosystem Science Data Center (https://www.nesdc.org.cn/) accessed on 5 October 2023
temperature	30 m	National Ecosystem Science Data Center (https://www.nesdc.org.cn/) accessed on 5 October 2023
normalized difference vegetation index (NDVI)	30 m	National Ecosystem Science Data Center (https://www.nesdc.org.cn/) accessed on 5 October 2023
population	100 m	WorldPop (AfriPop and AsiaPop projects) (https://hub.worldpop.org/) accessed on 15 October 2023
GDP density	1 km	Scientific Data [19]
food and various price data	-	China Statistical Yearbook (https://www.stats.gov.cn/sj/ndsj/) Henan Statistical Yearbook (https://tjj.henan.gov.cn/) accessed on 15 October 2023 National Food and Strategic Reserves Administration (http://www.lswz.gov.cn/) accessed on 15 October 2023

2.3. Comprehensive Urbanization Level

Urbanization makes an important contribution to social progress and rapid economic development [20]. The comprehensive urbanization level of ZZMA was constructed from three dimensions: population urbanization, urbanization of economic development, and urbanization of land expansion. The three indicators—population density, GDP density, and the proportion of urban land—were standardized, equally weighted, and integrated into the final comprehensive urbanization level [21].

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

$$U = \frac{U'_{1,j} + U'_{2,j} + U'_{3,j}}{3} \quad (2)$$

where $U_{i,j}$ is the original value of the $i-th$ urbanization index in grid j, and $U'_{i,j}$ is the standardized value. $U_{i,max}$ and $U_{i,min}$ denote the minimum and maximum values of the $i-th$ urbanization index for all grids, respectively; U denotes the final comprehensive urbanization index, and $U'_{1,\ j}$, $U'_{2,\ j}$, and $U'_{3,\ j}$ denote the three urbanization indices.

2.4. Quantification of ES Supply and Demand

Agricultural development, regional climate, population density, and socioeconomic development are closely related to ES [8,22]. In this study, based on the characteristics of the study area—such as its diverse ecosystem types, the terrain consisting primarily of plains and low mountain hills, and its role as a key food provision area due to fertile soil in the eastern plains—five ES were selected: namely, carbon sequestration and oxygen release, water conservation, air purification, leisure entertainment, and food provision services. These services were chosen to align with the concerns of local stakeholders, including the government and residents, and with the practical availability of relevant data. Furthermore, this research establishes a widely applicable model for estimating the supply value of ES and considers the material value of ES that humans actually consume or expect to obtain as the ES demand.

Therefore, this study integrated socioeconomic data to quantitatively assess the supply and demand of these five ES according to the characteristics of the study area.

2.4.1. Carbon Sequestration and Oxygen Release

(1) Supply

The amount of CO_2 fixation and oxygen release by plants can be estimated through the net primary productivity and the photosynthesis equation. Specifically, plants absorb 1.63 kg of CO_2 and release 1.19 kg of O_2 for every 1.00 kg of dry matter produced. This process contributes to carbon sequestration and oxygen release services [23]. The amount of CO_2 absorbed and O_2 released by different landscape categories, serving as the supply for carbon sequestration and oxygen release services, was evaluated in combination with the carbon tax method using the following equation:

$$W_s = (V_c \cdot U_c + V_o \cdot U_o) \times S \quad (3)$$

where W_s indicates the supply value of carbon sequestration and oxygen release service; V_c indicates the amount of CO_2 fixation corresponding to each landscape type; V_o indicates the amount of O_2 release corresponding to each landscape type; U_c indicates the value of fixing unit mass of CO_2; U_o indicates the value per unit mass of O_2; S indicates the area of each landscape type (km^2). The amount of CO_2 absorbed and O_2 released by different landscape types is shown in Table 2 [24].

Table 2. CO_2 uptake and O_2 release in different landscape types (10^4 kg/hm^2·a^{-1}).

Landscape Types	Woodland	Cultivated Land	Grassland	Water Area
CO_2 fixation amount	1.11	0.50	0.40	0.31
O_2 release amount	0.81	0.37	0.29	0.22

(2) Demand

Energy is the driving force of human production and life. Human energy consumption produces large amounts of CO_2, which exacerbates global warming. Plant carbon sequestration helps mitigate climate change by absorbing CO_2. The amount of carbon sequestration and oxygen release by plants is uniformly calculated, which constitutes the demand for carbon sequestration and oxygen release services. In this study, we used the annual per capita CO_2 emissions in China and the corresponding amount of O_2 consumption as the demand for carbon sequestration and oxygen release services [23]. The demand was then evaluated using the carbon tax method, as described by the following equation:

$$W_d = P_{pop} \times \left(U_c + \frac{32}{44} U_o \right) \times R \quad (4)$$

where W_d denotes the demand value of carbon sequestration and oxygen release service; P_{pop} indicates the population density (same as below); R indicates the annual CO_2 emission per capita.

2.4.2. Water Conservation

(1) Supply

The soil water storage capacity method and the integrated water storage capacity method are used to calculate soil water storage. These calculations are based on factors such as soil layer thickness [24], soil capacity, and soil porosity. The integrated water storage capacity is also evaluated based on vegetation types. These methods are then used to estimate the supply value of water conservation services in the Zhengzhou Metropolitan Area. The formula is as follows:

$$D_{si} = D_{1i} + D_{2i} \quad (5)$$

$$D_{1i} = Y \times C_b \quad (6)$$

$$Y = \rho \times h \times p \times s_1 \quad (7)$$

$$D_{2i} = (Q_1 + Q_2 + Q_3) \times C_b \quad (8)$$

$$Q_1 = r \times l \times s_2 \quad (9)$$

$$Q_2 = f \times q \times s_2 \quad (10)$$

$$Q_3 = h \times k \times s_2 \quad (11)$$

where D_{si} indicates the supply value of water conservation; D_{1i} is the supply value of cultivated land for water conservation services; Y is the quality of water conservation; C_b is the cost of constructing 1 m^3 of storage capacity in China; ρ is the soil capacitance; h is the thickness of the soil; p indicates the soil moisture content; s is the area of cultivated land; D_{2i} is the supply value of woodland and grassland for water conservation; C is the cost of reservoir storage; Q_1 is the water retained by the forest canopy; Q_2 is the water-holding capacity of the dead leaf layer; Q_3 is the soil's water storage capacity from precipitation; r is the amount of precipitation; l is the rate of forest canopy retention; f is the dry mass of dead branches and leaves layer; q is the rate of saturated water absorption; h is the depth of the soil; k indicates the noncapillary porosity of the soil; s_2 is the area of woodland and grassland landscape. The relevant parameters are quoted from Zou et al. [24].

(2) Demand

In this study, we mainly consider residential production ad domestic and ecological water consumption and evaluate the value of water conservation service demand by combining the per capita water demand and reservoir construction cost per unit of water [25] with the following formula:

$$D_d = A \times P_{pop} \times C_b \quad (12)$$

where D_d indicates the demand value of water conservation; A indicates the water requirement per capita; C_b indicates the cost of constructing 1 m^3 of storage capacity in China.

2.4.3. Air Purification

(1) Supply

Vegetation can absorb and degrade harmful substances in the air, thereby improving the air quality. In this study, we mainly primarily focus on the purification effect of plants on SO_2, NO_x, and dust and evaluate the value of air purification services in the study area. This evaluation is based on the amount of air purification per unit area of the landscape and the cost of air pollutant purification using the following equation [26]:

$$K_s = \sum_{n=1}^{4} Q_n \times U_n \times S \tag{13}$$

where K_s indicates the supply value of air purification service (USD); Q_n indicates the amount purified by vegetation for the nth air pollutant; U_n indicates the cost of purifying the n-th air pollutant.

(2) Demand

Industrial and vehicular emissions have led to significant air pollution. This has created a demand for air purification services to protect residents' health and maintain a healthy ecological environment. In this study, we primarily focused on the purification cost of four air pollutants: SO_2, NO_2, $PM_{2.5}$, and PM_{10} and evaluated the demand value of air purification services by considering the population density [25], as expressed by the following equation:

$$K_d = \sum_{n=1}^{3} P_n \times H \times P_{pop} \times C_n \times S \tag{14}$$

where K_d denotes the demand value of air purification services; P_n denotes the concentration of the n-th pollutant gas; H denotes the height to purify the polluted gas, taking 20 m; C_n denotes the purification cost of the nth pollutant gas.

2.4.4. Leisure Entertainment

(1) Supply

The natural ecological environment provides beautiful scenery and a comfortable leisure environment for people. It helps them relax physically, feel happier, and enriches their spiritual and cultural lives. These benefits can be considered the supply of leisure and recreation services. The equivalence factor method [27] was used to calculate the value of leisure and recreation services provided by each unit area of green space in the ZZMA (Table 3). The overall value of leisure and recreation service supply was evaluated by combining various types of landscape areas using the following formula:

$$I_s = C_a \times S \tag{15}$$

where I_s indicates the supply value of leisure entertainment services; C_a indicates the value of leisure entertainment services provided per unit area of green space.

Table 3. The value of leisure entertainment services per unit area of green space (10^4 USD km^{-2}).

Landscape Types	Cultivated Land	Woodland	Grassland	Water Area	Average
Value	1.82	1.98	1.26	4.04	2.28

(2) Demand

Residents go to parks, green areas, and other natural ecological environments for recreation, sports, and other leisure activities to release pressure and soothe the mood; this spiritual demand is the demand for leisure entertainment services. Green space per capita was used as a demand indicator for leisure entertainment services [28]. The demand value of leisure entertainment services was assessed by combining the population density with the average value of leisure entertainment services provided per unit area of green space. The formula is as follows:

$$I_d = P_{pop} \times J \times C_a \quad (16)$$

where I_d denotes the demand value of leisure entertainment services; J is the park green area per capita, assumed to be 14.4 m^2.

2.4.5. Food Provision

(1) Supply

The supply value of food provision service was assessed using a linear relationship between land use and the NDVI [8], combined with the total annual food provision in the ZZMA. The formula is as follows:

$$F_s = \frac{NDVI}{NDVI_{sum}} \times G_{sum} \times C_C \quad (17)$$

where F_s indicates the supply value of food provision services; $NDVI$ indicates the NDVI of cultivated land; $NDVI_{sum}$ denotes the sum of the NDVI in the study area; G_{sum} is the annual grain yield; C_C is the price of major grain, same as defined below.

(2) Demand

The act of obtaining and using food crops from ecosystems to meet physiological and social needs creates the demand for food provision services. The demand for food provision is affected by various factors, including population size. This study assesses the demand for food provision services by considering the per capita food consumption and average food prices [25]. The calculation is as follows:

$$F_d = P_{pop} \times W \times C_C \quad (18)$$

where F_d denotes the demand value of food provision services; W denotes food consumption per capita.

2.4.6. The Ecological Supply–Demand Balance

The ecological supply–demand ratio (ESDR) is an efficient indicator to depict the status of ES [8,29], which can reflect the relationship between the supply and the demand for ES in ZZMA: negative (deficit), positive (surplus), or zero (balance) [30]. The formula can be expressed as follows:

$$ESDR = \frac{S - D}{\frac{S_{max} + D_{\max}}{2}} \begin{cases} > 0, surplus \\ = 0, balance \\ < 0, deficit \end{cases} \quad (19)$$

where $ESDR$ represents the supply–demand ratio per ES; S and D stand for the supply and the demand for ES, respectively; S_{max} denotes the maximum value of the supply; $D_{\max}$ denotes the maximum value of the demand. When ESDR is less than 0, it indicates a deficit (undersupply); when greater than 0, it indicates a surplus (oversupply); and when equal to 0, it indicates a balance between supply and demand.

To explore the integrated supply and demand matching of ES, the mean ESDR of the five ES was calculated to obtain the comprehensive ecological supply–demand ratio (CESDR) for the study area. The formula is as follows:

$$CESDR = \frac{1}{n} \sum_{i=1}^{n} ESDR_i \quad (20)$$

where n is the number of ES, n = 5 in this study; $ESDR_i$ indicates the ESDR of the i − th ES.

2.5. Spatial Correlation Analysis

Spatial autocorrelation analysis assesses whether the distribution of elements is correlated with neighboring elements [27]. Local spatial autocorrelation is typically analyzed using Moran's I scatter plot and local indicators of spatial association (LISA). Moran's I scatter plot reflects the correlation between spatial unit elements and neighboring elements. LISA decomposes the global Moran's I into individual spatial units to form a LISA clustering map, which displays the ES supply and demand values, as well as the specific locations of spatial aggregation or differentiation between urbanization and ES in ZZMA. The LISA clustering plot and correlation pattern of Moran's I are shown in Table 1. The formulas are as follows:

$$I = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x}) / S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} \tag{21}$$

$$I_i = \frac{(x_i - \overline{x})}{S^2}\sum_{j} w_{ij}(x_j - \overline{x}) \tag{22}$$

$$S^2 = \frac{1}{n}\sum_{j}(x_i - \overline{x})^2 \tag{23}$$

where I is the global Moran's I; n is the total number of spatial units; x is the element value; w_{ij} is the spatial weight. This study builds w_{ij} based on the queen adjacency criterion using GeoDa software 1.16; w_{ij} takes the value of 1 when the spatial units are adjacent and 0 otherwise. I takes a value between -1 and 1. The closer I is to 1, the stronger the positive spatial correlation, indicating a more concentrated distribution of elements. The closer I is to -1, the stronger the negative spatial correlation, reflecting a greater disparity in distribution. An I value of 0 indicates no spatial autocorrelation, suggesting a random distribution.

2.6. Identify the Driving Factors

Geodetector reveals the spatial distribution patterns of geographic phenomena and their drivers [31]. Factor detection and interaction detection in the Geodetector model were used to identify the main factors and their interactions affecting the ESDR of the ZZMA. Considering data availability, nine factors were selected across three categories: natural factors (elevation, slope, precipitation, and temperature), urbanization factors (population density, GDP density, and construction land proportion), and land use factors (woodland proportion and cultivated land proportion). The formula is as follows:

$$q = 1 - \frac{1}{N\sigma^2}\sum_{i=1}^{L} N_i \sigma_i^2 \tag{24}$$

where q indicates the explanatory power of the detection factor on the dependent variable, with a range of $[0, 1]$. The larger the q value, the stronger the explanatory power of the independent variable x on the dependent variable y and vice versa; N and σ^2 represent the total sample size and variance, respectively; L indicates the number of probe partitions; N_i and σ_i^2 stand for the sample size and variance of different partitions.

3. Results

3.1. Dynamic Analysis of the Comprehensive Urbanization Level

From 2000 to 2020, Zhengzhou City experienced a continuous and substantial increase in its comprehensive urbanization level, with a growth rate of 138.71%. This upward trend was observed across various regions, with Zhengzhou showing the highest increase at 189.95%. By 2020, Zhengzhou had taken the top position in terms of the comprehensive urbanization level.

The comprehensive urbanization level exhibited distinct spatial heterogeneity (Figure 3). During the study period, regions with higher comprehensive urbanization levels expanded outward from the central urban areas of each city, with Zhengzhou City experiencing the most significant expansion. The northern and southwestern regions lagged in urbanization due to mountainous terrain and environmental constraints, which hindered development. In addition, it continued to rise in rural areas, and the extent of high-value urbanization expanded. Areas with high growth values were mainly located on the outskirts of central cities. In contrast, areas with low growth values were primarily found in central cities and the northern, southwestern, and central mountainous regions. This was because the urbanization level in central areas had already reached saturation, and further development could only expand outward. Meanwhile, the complex terrain and significant topographical variations in the northwest, southwest, and central mountainous areas posed additional challenges to urbanization.

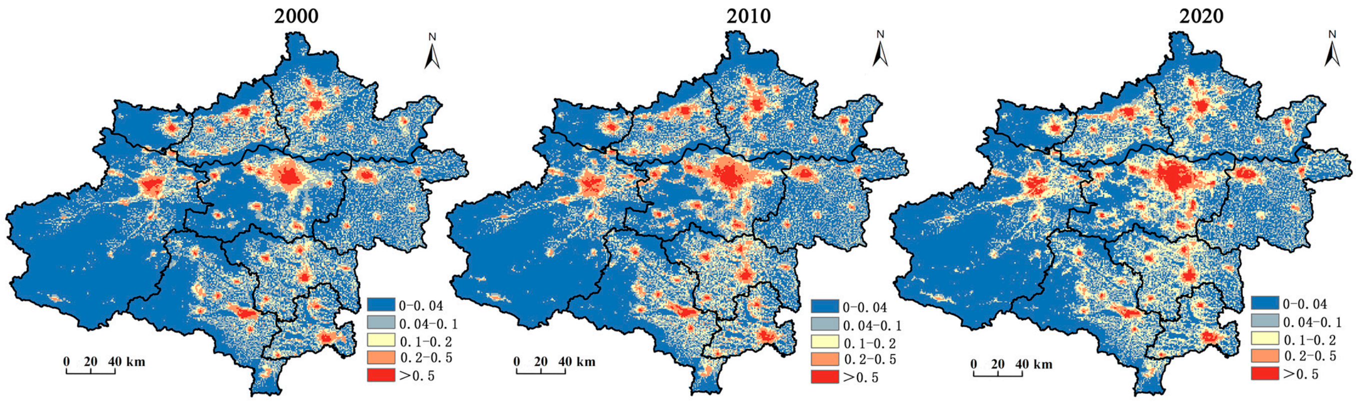

Figure 3. Comprehensive urbanization levels in 2000–2020.

3.2. Characterization of the Spatial and Temporal Variability in ES Supply and Demand

3.2.1. Spatiotemporal Analysis of the Supply and Demand of ES

Overall, both the total supply and demand for ES increased from 2000 to 2020 (Table 4), with supply rising by 1.59 billion USD and demand rising by 12.60 billion USD. For individual ES, the supply of carbon sequestration, oxygen release, water conservation, and leisure entertainment continued to decrease. The supply of air purification first increased, then decreased, but showed an overall upward trend. The supply of food provision increased steadily year by year. The demand for all five ES showed an increasing trend.

Table 4. ES supply and demand values from 2000 to 2020 (10^8 USD).

ES Type	2000		2010		2020	
	Supply	**Demand**	**Supply**	**Demand**	**Supply**	**Demand**
Carbon sequestration and oxygen release	92.67	751.36	91.36	815.16	87.86	871.75
Water conservation	4.80	15.76	4.77	17.09	4.61	18.28
Air purification	5.82	0.05	6.04	0.06	5.95	0.06
Leisure entertainment	9.88	0.13	9.64	0.14	8.87	0.15
Food provision	54.50	19.61	67.05	21.27	76.30	22.75
Total	167.68	786.91	178.85	853.72	183.59	912.99

In terms of spatial distribution, the total ES supply was primarily concentrated in the woodland and grassland between the northern, southwestern, and central mountain ranges (Taihang Mountain in the north; Xiao Mountain, Xiong'er Mountain, and Funiu Mountain in the southwest; and Song Mountains and Ji Mountain in the central area). Low-value areas were mainly located in the urban construction land of each city (Figure 4). The spatial distribution of the supply values for carbon sequestration, oxygen release, water conservation, and air purification services was similar to the total ES supply. However, the low-value areas for air purification covered most of the study area, except for the high-value regions. The high-value areas for leisure entertainment were concentrated in the water bodies (Yellow River in the north, Shaying River and Ru River in the south, and Yi River and Luo River in the west) and woodland between the northern, southwestern, and central mountain ranges. Low-value areas were located mainly in the urban construction land of each municipality. High food provision supply was concentrated in the plains in the east and north. In contrast, low supply was found in urban construction land and woodland and grassland between the mountains in the southwest and north. The spatial distribution of the ES demand did not vary significantly during the study period. The spatial distribution of the five ES and total ES demand was similar, with high values concentrated in the urban centers of each municipality and expanding outward, while low values were mainly found in the southwestern and northern woodland and grassland.

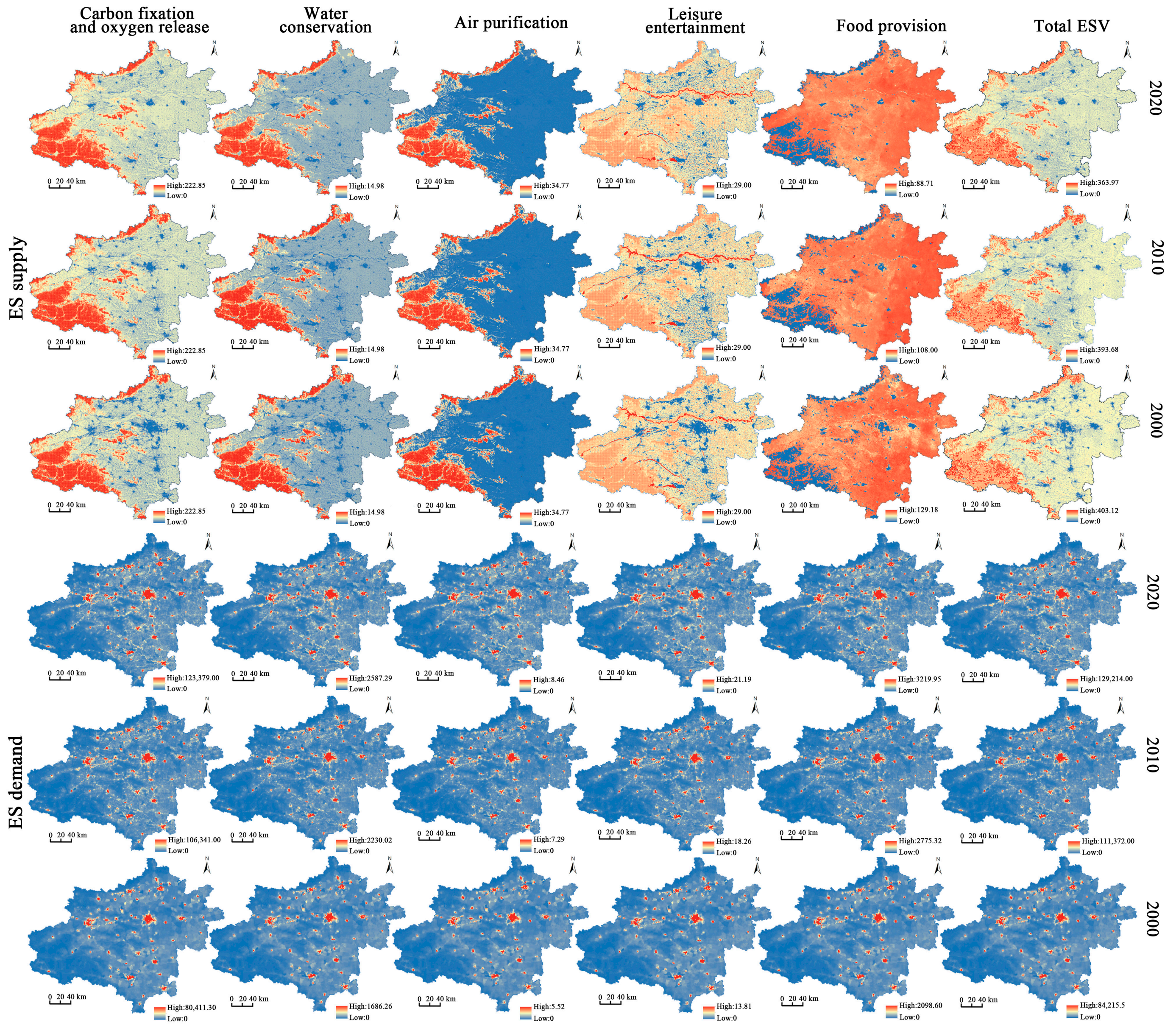

Figure 4. Spatial distribution of the supply and demand values of ES from 2000 to 2020. The top three rows display the spatial distribution of the ES supply values, while the bottom three rows show the spatial distribution of the ES demand values. In the maps, red indicates high values and blue indicates low values.

3.2.2. The Spatiotemporal Variation of the Ecological Supply–Demand Ratio of ESV

In general, the CESDR in ZZMA remained in deficit from 2000 to 2020 and continuously deteriorated. For individual ES, the ESDR for carbon sequestration, oxygen release, and water conservation services was in deficit and continued to deteriorate. However, the ESDR for air purification, leisure entertainment, and food provision services was in surplus. The ESDR for air purification and leisure entertainment continued to decline, while the ESDR for food provision continued to increase.

As shown in Figure 5, the surplus areas of CESDR were scattered across the study area, while the deficit areas were primarily located in the central urban regions. The supply–demand imbalance in these areas shifted from surplus to deficit over time. The surplus areas for carbon sequestration, oxygen release, and water conservation services were primarily located in the woodland and grassland of the northern and southwestern mountains. These regions are rich in forest resources, have a sparse population, and possess significant ecological advantages. The surplus areas for air purification, leisure entertainment, and food provision services were scattered across the study area. These areas had a dense population and relatively well-developed urban systems. However, the occupation and destruction of ecological resources were more severe, causing the supply of ES to exceed demand.

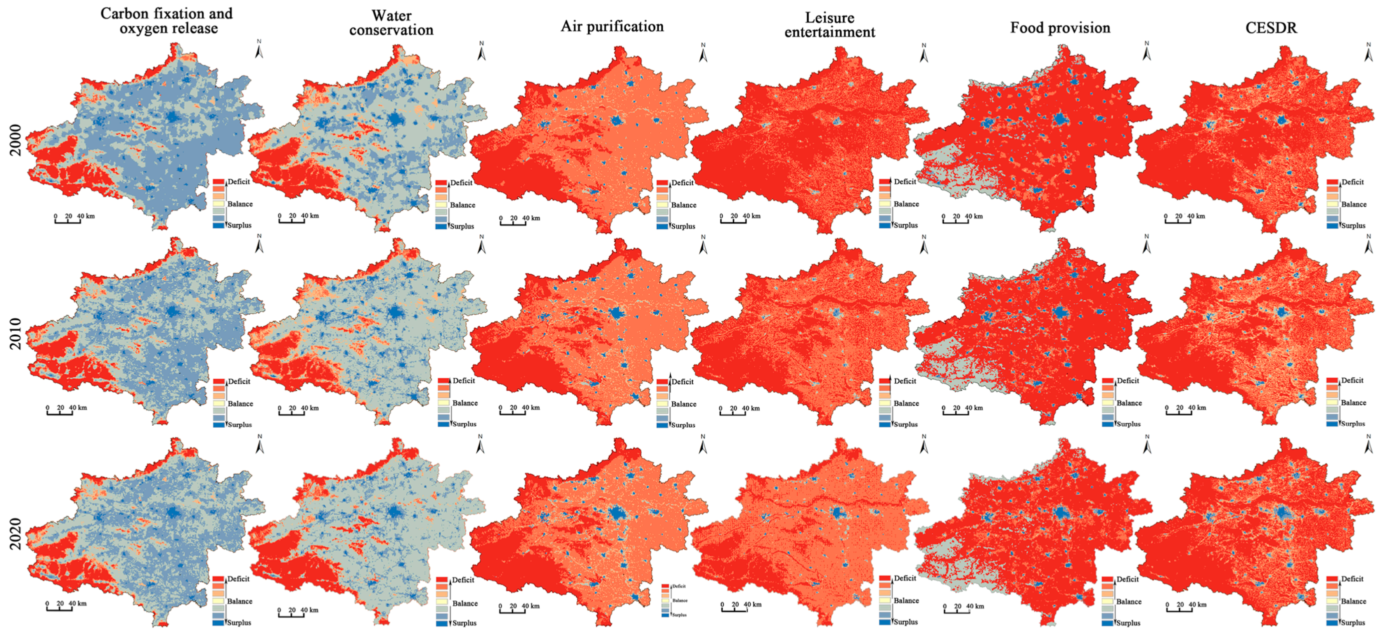

Figure 5. Spatial distribution of ESDR from 2000 to 2020. The maps display the distribution of supply–demand statuses, including deficit areas (red), balanced areas (yellow), and surplus areas (blue).

3.3. Matching Supply and Demand of ES

Bivariate local spatial autocorrelation analysis of the ES supply and demand from 2000 to 2020 showed that Moran's I for both supply and demand was less than 0, indicating negative spatial correlation (Table 5). For carbon sequestration, oxygen release, water conservation, and leisure entertainment services, Moran's I for supply and demand first decreased and then increased. However, the overall trend was a decrease, with increasing negative spatial correlation. Moran's I for air purification supply and demand continued to increase, and the negative spatial correlation weakened. Moran's I for food provision and total ES supply and demand continued to decrease, with an increasing negative spatial correlation.

Table 5. Global Moran's I for the ESDR in the ZZMA.

ES Types	2000	2010	2020
Carbon sequestration and oxygen release	−0.291	−0.297	−0.294
Water conservation	−0.246	−0.248	−0.247
Air purification	−0.191	−0.187	−0.177
Leisure entertainment	−0.318	−0.335	−0.331
Food provision	−0.005	−0.025	−0.072
CESDR	−0.343	−0.360	−0.365

There were four types of spatial matching of ES supply and demand values in the ZZMA: high–high spatial matching (high supply–high demand), low–low spatial matching (low supply–low demand), low–high spatial mismatch (low supply–high demand), and high–low spatial mismatch (high supply–low demand). Since Moran's I was less than 0, the dominant spatial matching types were "low–high spatial mismatch" and "high–low spatial mismatch". Figure 6 shows that the low–high aggregation areas of the ES supply and demand values were mainly distributed in the construction lands of each municipality. The high–low aggregation areas of the total ES supply and demand values were also identified. The high–low aggregations of the total ES supply and demand values, including carbon sequestration and oxygen release, water conservation, air purification, and leisure entertainment services, were mainly located in the southwestern, central, and northern intermountain woodland and grassland. In contrast, the high–low aggregation areas of food provision services supply and demand values were primarily located in the eastern plains. Figure 6 provides a visual representation.

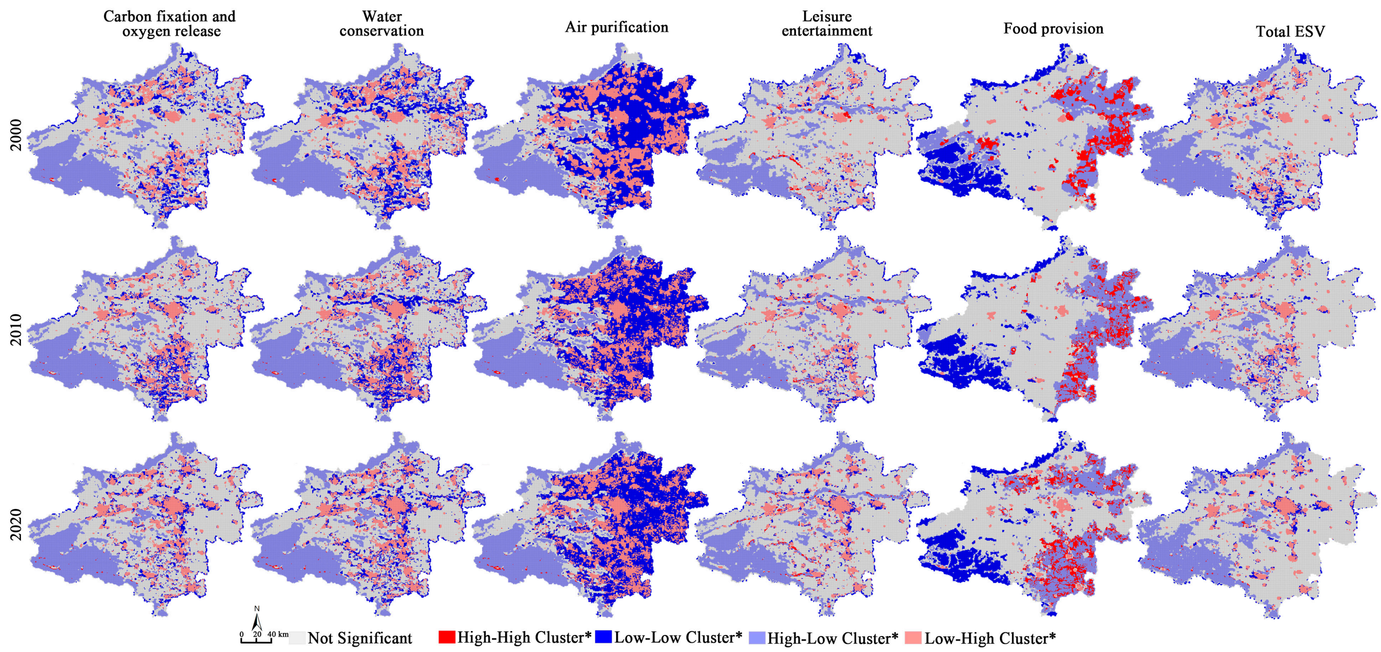

Figure 6. Spatial correlation distribution of the supply and demand values of ES ("*": $p < 0.05$). The map shows high–high clusters (red), low–low clusters (blue), low–high clusters (light blue), and high–low clusters (pink), with gray areas indicating regions that are not statistically significant.

3.4. Correlation Analysis of the Comprehensive Urbanization Level and ESDR

Moran's I for the comprehensive urbanization level and CESDR in the ZZMA from 2000 to 2020 was −0.633, −0.627, and −0.655, respectively. These values were significant at the 95% confidence level (Table 6). All Moran's I values were less than 0, with minimal fluctuation and an overall decreasing trend. This indicates that urbanization in the ZZMA had a significant negative spatial correlation with CESDR, which continued to strengthen, leading to a more pronounced spatial aggregation effect. Moran's I for the comprehensive urbanization level and the five ESDRs were all negative, indicating a significant negative spatial correlation between the comprehensive urbanization level and these ESDRs in the study area. Among these, the negative spatial correlations between integrated urbanization and the supply–demand ratios of carbon sequestration and oxygen release, water conservation, and food provision services continued to weaken. The negative spatial correlation between integrated urbanization and the ESDR for air purification and recreation continued to increase.

Table 6. Moran's I value for the comprehensive urbanization level and ESDR from 2000 to 2020.

Years	Carbon Sequestration and Oxygen Release	Water Conservation	Air Purification	Leisure Entertainment	Food Provision	CESDR
2000	−0.612	−0.623	−0.305	−0.473	−0.523	−0.633
2010	−0.558	−0.571	−0.324	−0.527	−0.465	−0.627
2020	−0.504	−0.518	−0.338	−0.612	−0.437	−0.655

To further explore the spatial aggregation effects of the comprehensive urbanization level and ESDR, LISA aggregation maps were created using Geoda software. As shown in Figure 7, the main patterns of aggregation between the comprehensive urbanization level and ESDR were high–low and low–high aggregations. Among these, the high–low agglomerations of both the comprehensive urbanization level and ESDR were mainly located in the urban centers of each municipality. The low–high agglomerations of the comprehensive urbanization level and CESDR were mainly found in the northern, southwestern, and central mountainous regions, as well as in the northern Yellow River Basin. The low–high agglomerations of the comprehensive urbanization level and ESDR for carbon sequestration and oxygen release, water conservation, and air purification services were all found mainly in the northern, southwestern, and central mountainous regions. The LISA aggregation maps for the comprehensive urbanization level and ESDR for leisure entertainment were generally consistent with the maps for CESDR. The low–high agglomerations of ESDR for the food provision service and the comprehensive urbanization level were mainly concentrated in the eastern plains.

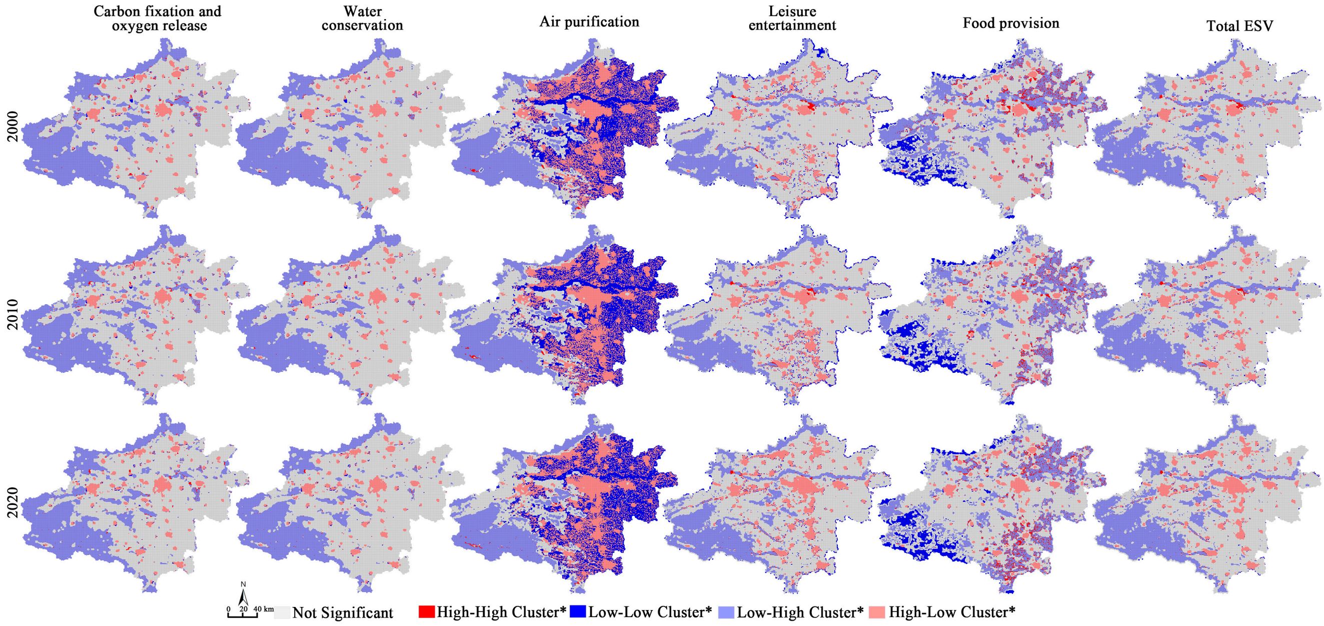

Figure 7. LISA aggregation diagram of the comprehensive urbanization level and ESDR ("*": $p < 0.05$). The map shows high–high clusters (red), low–low clusters (blue), low–high clusters (light blue), and high–low clusters (pink), with gray areas indicating regions that are not statistically significant.

3.5. Analysis of the Driving Factors of ESDR

3.5.1. Single-Factor Detection

The analysis results of the driving factors on the spatial differentiation of ESDR showed that all factors were significant at the 95% confidence level. Table 7 shows that the effect of population density on CESDR was the largest but gradually decreased over time. The second most influential factors were the proportion of construction land and GDP density, both of which had increasing driving forces. The driving force of precipitation on CESDR was the weakest and continuously decreased. From the perspective of ES, population density exerted the greatest driving force on the supply–demand ratios for carbon sequestration and oxygen release, water conservation, and food provision services. This was followed by GDP density and the proportion of construction land.

Table 7. Single-factor detection of ESDR.

Years	ES Types	Nature Factors				Urbanization Factors			Land Use Factors	
		1	2	3	4	5	6	7	8	9
2000	A	0.0501	0.0501	0.004	0.0434	0.9208	0.3867	0.3091	0.0454	0.0026
	B	0.0732	0.0758	0.0037	0.0632	0.9131	0.3868	0.3178	0.0741	0.0072
	C	0.6499	0.7567	0.0048	0.5786	0.2332	0.0501	0.1604	0.988	0.6885
	D	0.0754	0.0709	0.1138	0.1605	0.2213	0.1481	0.5397	0.1066	0.075
	E	0.0203	0.0239	0.0031	0.0136	0.7997	0.3418	0.2801	0.0327	0.0947
	F	0.0637	0.059	0.0346	0.0758	0.6827	0.3528	0.5359	0.0716	0.0363
2010	A	0.0463	0.0473	0.0054	0.0382	0.9065	0.2901	0.2835	0.0438	0.0041
	B	0.0664	0.07	0.0062	0.0555	0.8996	0.2939	0.2946	0.0689	0.0041
	C	0.655	0.7804	0.0679	0.6048	0.1694	0.0619	0.1837	0.9883	0.6482
	D	0.0906	0.0933	0.0807	0.1553	0.2841	0.1873	0.5977	0.1229	0.0874
	E	0.0225	0.0266	0.0069	0.0151	0.7686	0.2523	0.2487	0.0362	0.1296
	F	0.0665	0.0692	0.0273	0.0789	0.6739	0.3142	0.5622	0.08	0.0469
2020	A	0.0404	0.0409	0.0028	0.0346	0.9155	0.2513	0.2168	0.0386	0.0074
	B	0.0571	0.0598	0.0026	0.0492	0.9095	0.2572	0.2299	0.0595	0.0035
	C	0.658	0.786	0.0114	0.601	0.1633	0.0664	0.2232	0.9882	0.5542
	D	0.1065	0.1138	0.0477	0.1411	0.3002	0.2966	0.6838	0.1415	0.0874
	E	0.0195	0.025	0.001	0.0137	0.7705	0.2506	0.2177	0.0357	0.1625
	F	0.074	0.077	0.0158	0.0778	0.6606	0.3761	0.5813	0.0886	0.0594

A. Carbon sequestration and oxygen release; B. Water conservation; C. Air purification; D. Leisure entertainment; E. Food provision; F. CESDR. 1. Elevation; 2. Slope; 3. Precipitation; 4. Temperature; 5. Population density; 6. GDP density; 7. Construction land proportion; 8. Woodland proportion; 9. Cultivated land proportion.

The proportion of cultivated land exerted the weakest driving force on the supply–demand ratio for carbon sequestration and oxygen release services. Precipitation had the weakest driving force on the supply–demand ratio for water conservation and food provision services. Woodland proportion had the strongest driving force on the supply–demand ratio for air purification services, followed by slope and elevation, while precipitation had the weakest driving force. The proportion of construction land had the strongest driving force on the supply–demand ratio for leisure entertainment, followed by population density and GDP density, while the proportion of cultivated land had the least influence.

3.5.2. Interactive Factor Detection

The results of geographical interaction detection showed that ESDR was influenced by multiple external factors, with interactions existing between the driving factors. The explanatory power of the interaction between any two factors was greater than that of a single factor, and the impact of the interaction was significantly amplified. The results indicated varying degrees of pairwise or nonlinear enhancement. As shown in Figure 8, during the study period, CESDR in the ZZMA had the strongest interaction between population density and construction land proportion, with q values exceeding 0.81 and increasing year by year. Additionally, the interaction between population density and cultivated land proportion had q values above 0.73, initially showing a decreasing trend followed by an increase but with an overall weakening. From the perspective of ES, carbon sequestration and oxygen release, water conservation, and the food provision service supply and demand ratio were most strongly influenced by population density and other factors, with q values above 0.76. The air purification service had the strongest interaction between the woodland proportion and other factors, with q values above 0.98. The leisure entertainment service had the strongest interaction between the proportion of construction land and other factors, with q values above 0.53. In conclusion, the interaction between urbanization factors and other factors had a significant impact on the ratio of ESDR in the ZZMA.

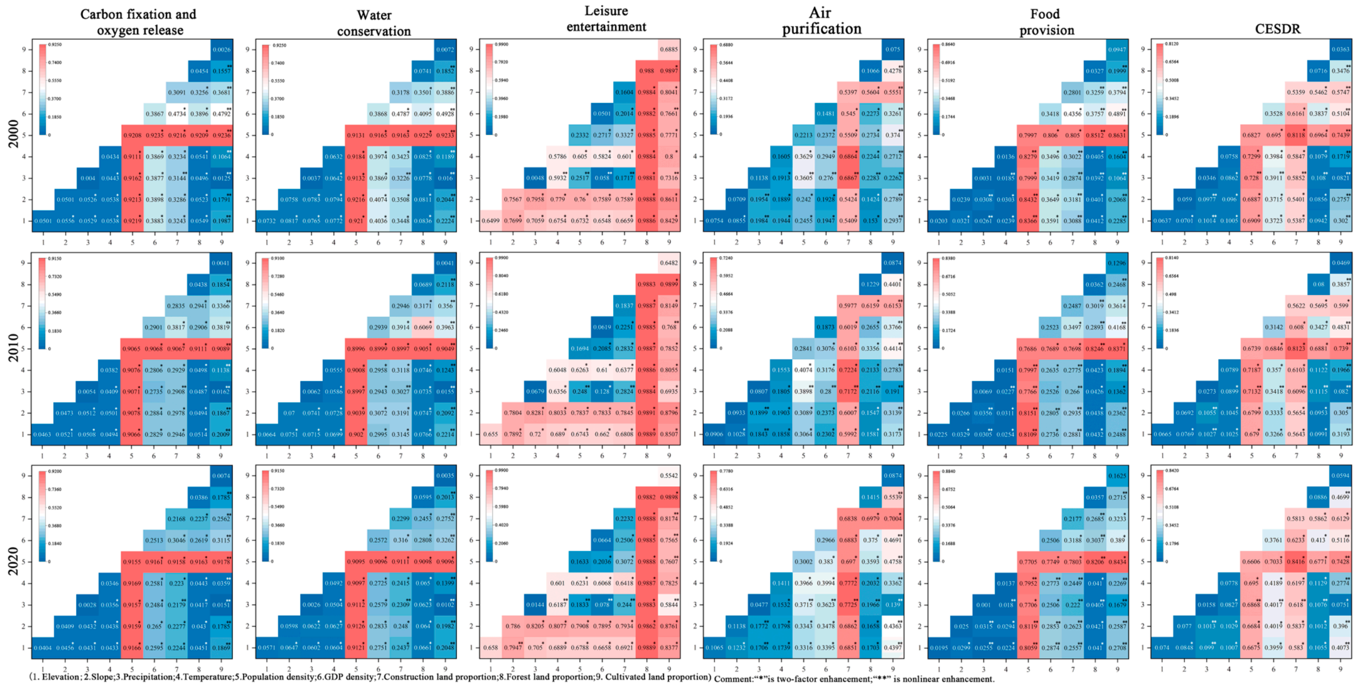

Figure 8. Two-factor detection of ESDR. Correlation coefficients of the ES supply–demand ratios with various driving factors in the Zhengzhou Metropolitan Area for 2000, 2010, and 2020. Asterisks (*) indicate two-factor enhancements, and double asterisks (**) indicate nonlinear enhancements.

4. Discussion

4.1. Contradiction Between the Supply and Demand for ES

As urbanization accelerates, the demand for ES in the built-up areas of ZZMA continues to increase. However, the limited supply capacity of ES in these areas has led to a shift from surplus to deficit, exacerbating the imbalance of ES supply and demand across the entire study area. This results in spatial mismatches such as low–high and high–low spatial mismatches. This finding aligns with the research of Yang [32], Xiao [33], and Ai [34], who also observed that urbanization contributes to an imbalance between ES supply and demand. Zhang et al. [35] found that the process of urbanization has intensified the spatial imbalance between the supply and demand of ESs in the Pearl River Delta. This result is consistent with our findings in the ZZMA, suggesting that the impact of urbanization on the supply and demand of ESs is a common issue in rapidly urbanizing regions. Additionally, Zhang et al. [36] observed that, in the Yellow River Delta, ecological supply resources are facing significant reductions, while ecological demand resources are showing an upward trend. This pattern mirrors the findings in our study, particularly in areas where the demand for ES is increasing but supply is insufficient to keep pace. Chen et al. [37] explored the contribution of ES supply to societal demand in the context of urbanization-related land use changes in Shanghai. They found that changes in land use significantly affect the spatial distribution of ESs and exacerbate the mismatch between supply and demand.

Similarly, our study indicates that, as the level of urbanization in the ZZMA increases, the supply of carbon sequestration, oxygen release, water conservation, and other essential ES gradually decreases. This further confirms the close relationship between urbanization and the imbalance of ES supply and demand.

By comparing our results with prior studies, it becomes clear that urbanization processes generally intensify spatial mismatches in ES supply and demand. These mismatches are not unique to the ZZMA but are also observed in other urbanizing areas. However, differences between regions may arise from factors such as local geographical conditions, policy contexts, and uneven regional development. This comparative analysis helps contextualize our findings within the broader field and enhances the credibility of the study. Our study highlights that, as urbanization progresses, areas with low-value ESs expand, and high-demand ES areas follow the direction of urban expansion, further confirming the negative impact of urbanization on ES. Moving forward, the ZZMA should focus on balancing urban development with ecological protection to ensure the long-term sustainability of ES.

4.2. Driving Force Analysis of ESDR

The driving force of various factors on the spatial and temporal changes of different ESDR varies. Population density has the strongest driving force on the supply–demand ratios of carbon sequestration, oxygen release, water conservation, and food provision services. The proportion of forest land exerts the strongest influence on the supply–demand ratio of air purification services, while the proportion of built-up areas has the greatest impact on the supply–demand ratio of open space recreation services. This indicates that the influence of anthropogenic factors is stronger than that of natural factors to some extent. These findings provide a reliable basis for the orderly guidance and scientific management of land expansion for construction, population distribution, and the balance between urban development and ecological safety.

Some studies have shown that ES supply and demand are not only related to nature and urbanization but also closely related to regional policies [38]. For example, Llopis et al. [39] found that the implementation of protected area policies can prevent the continuous loss of global climate regulation and intrinsic value. Zhao et al. [40] found that the key landscape types in the region can be protected through economic regulation and policy constraints, thus improving the value of ES. In this study, the implementation of policies at different levels from 2000 to 2020 was also an important driving force for changes in ES supply and demand in the ZZMA. In 2001, the Henan Provincial Government Work Report [41] emphasized the adjustment of urban–rural structures, urbanization improvement, and promotion of urban expansion, leading to the increase of ES demand in built-up areas. Additionally, national key ecological projects such as implementing natural forest protection and converting farmland to forest in the upper and middle reaches of the Yellow River have expanded forest areas with strong ecological functions, thereby enhancing ES. In 2011, the Guidance of the State Council on Supporting Henan Province to Accelerate the Construction of the Central Plains Economic Zone [42] proposed supporting the optimization of the layout of central cities. A spatial pattern with the central city as the core and the surrounding counties and functional areas as clusters will be formed. This was the same direction as the spatially dislocated expansion of the ESd and ES supply–demand. This showed that regional policies have an important influence on ES supply and demand. Therefore, regional policies can be used to regulate urban development, protect natural ecology, and promote the coordinated development of urbanization and ecology.

With rapid economic development, urban construction land has continuously expanded, while agricultural land has been largely converted into urban land, leading to an insufficient supply of ES. Our analysis found that areas with a higher GDP density showed a significant increase in the demand for ES, especially for basic services such as water resources, air purification, and food provision. However, the supply of these services has not kept pace, exacerbating the imbalance between supply and demand. The population in the ZZMA significantly increased between 2000, 2010, and 2020. The influx of the population has driven the expansion of urban space, with agricultural land being converted into construction land, directly intensifying the competition for land and water resources. Meanwhile, population growth has led to an increasing demand for ES such as food provision and water regulation. However, due to limited land availability, the supply of ES has not grown in tandem, leading to a clear mismatch between supply and demand. This migration trend is closely related to the urban–rural structure adjustment policy introduced by the Zhengzhou municipal government in 2001, which emphasized promoting economic development through urbanization and infrastructure construction. At the national level, urbanization-promoting policies, such as those supporting the construction of the Central Plains Economic Zone, further facilitated the migration of the population into urban and surrounding areas.

4.3. Balancing the Development Path of Urban Future Construction and ES Supply and Demand

The study of urbanization and the changing supply and demand of ES in the ZZMA has highlighted the critical ecological status of the mountainous regions in the north, southwest, and center. It has also underscored the agricultural importance of the eastern plains as a major grain-producing area. A differentiated ES management strategy is proposed, harmonizing agricultural, ecological, and urban spaces to protect vital ecological function areas and grain provision regions. For the mountainous areas in the northwest, southwest, and central regions, which have a high supply and low demand for ES, an ecology-first approach is emphasized. This approach includes protecting natural forests, optimizing vegetation structures, and intensifying efforts to restore ecological barriers in the Taihang Mountains in the northwest, the Funiu Mountains in the southwest, and the ecological green heart of the Songshan area in the center. These actions aim to form a "one heart and two screens" ecological security pattern. Additionally, the development of scenic areas and the improvement of transportation networks are proposed to fully utilize ecological resources. In high ES water bodies, a "one belt and multiple corridors" [18] ecological model is being developed to maintain the national ecological belt of the Yellow River's main stream and the ecological corridors of rivers like the Shaying and Yiluo. In the eastern plains, as the main grain-producing area, the emphasis is on protecting farmland and promoting the construction of high standard farmland [43] to increase grain yields. Furthermore, facing the conflict between ES supply and demand brought on by urbanization, green and coordinated development based on ecological protection is advocated. This includes improving the connectivity of ecological networks, establishing a complete ecological compensation mechanism, and strengthening suburban development to alleviate environmental pressure.

4.4. Limitations and Future Perspectives

In this paper, we explored the balance of ES supply and demand, and its driving mechanisms vary with the degree of urbanization. The methodology employed in this study can be applied to other rapidly urbanizing regions globally. However, the analysis presents certain limitations that could be addressed in subsequent research. Firstly, the analysis primarily examined five types of ES (carbon sequestration, oxygen release, water conservation, food production, air purification, and recreation). Expanding the categories of ESs considered could provide a more comprehensive understanding of the complexities and interdependencies among various ES and their responses to urbanization. Secondly, this study relies on data with specific spatial and temporal resolutions, which may not capture the subtle dynamics and scale variations of ES supply and demand. Future research should consider incorporating higher-resolution data to explore the changes in ES supply and demand and their driving mechanisms more comprehensively across multiple scales.

5. Conclusions

This research evaluated the driving mechanisms behind the dynamic changes in ES supply, demand, and the ES supply–demand ratio in relation to urbanization levels. It also proposed segmented optimization strategies for future urban and ecological environment construction. The conclusions of the paper are as follows: From 2000 to 2020, Zhengzhou's urbanization significantly increased, leading to continuous growth in ESs and ESd values. However, an imbalance in ESDR was observed, particularly in rapidly urbanizing areas. Spatial mismatches in the ES supply and demand were mainly characterized by low supply–high demand and high supply–low demand patterns. There is a negative correlation between the overall urbanization levels and ESDR, with higher urbanized areas having a lower ES balance. The study recommends enhancing ecological protection, leveraging eco-tourism, advancing modern agriculture, improving urban ecological network connectivity, and promoting urban–rural integration to achieve sustainable development in Zhengzhou and other rapidly urbanizing regions.

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Data Availability Statement: The natural and socioeconomic data used in this study are openly accessible. Land use data were obtained from the GlobeLand30 dataset with a resolution of 30 m (http://www.webmap.cn/mapDataAction.do?method=globalLandCover, accessed on 10 July 2022), and the land cover classification accuracy was over 88% after confusion matrix verification. The six land cover types (cultivated land, woodland, grassland, water area, construction land, and unused land) were reclassified using ArcGIS 10.2. Elevation data were sourced from the ASTER GDEM V30 dataset with a resolution of 30 m (https://earthdata.nasa.gov, accessed on 14 July 2022). Precipitation, temperature, and NDVI data were accessed from the National Ecosystem Science Data Center (http://www.nesdc.org.cn/, accessed on 20 July 2022), all with a resolution of 30 m. Population data came from the WorldPop project (https://www.worldpop.org, accessed on 15 July 2022), with a resolution of 100 m. GDP density data were obtained from Scientific Data [16], with a resolution of 1 km (due to missing data for 2020, 2019 data were used; accessed on 18 July 2022). Socioeconomic data were retrieved from the China Statistical Yearbook (https://www.stats.gov.cn/sj/ndsj/, accessed on 20 July 2022), the Henan Statistical Yearbook (https://tjj.henan.gov.cn/, accessed on 20 July 2022) and the National Food and Strategic Reserves Administration (http://www.lswz.gov.cn/, accessed on 21 July 2022). The study area was divided into 1 km × 1 km grids using ArcGIS 10.2 to calculate the urbanization level and ES supply–demand values, enabling an in-depth analysis on a finer spatial scale.

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Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Sun, R.; Jin, X.; Han, B.; Liang, X.; Zhang, X.; Zhou, Y. Does Scale Matter? Analysis and Measurement of Ecosystem Service Supply and Demand Status Based on Ecological Unit. *Environ. Impact Assess. Rev.* **2022**, *95*, 106785. [CrossRef]
2. Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J. The Value of the World's Ecosystem Services and Natural Capital. *Ecol. Econ.* **1998**, *25*, 3–15. [CrossRef]
3. IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). *Global Assessment Report on Biodiversity and Ecosystem Services*; IPBES Secretariat: Bonn, Germany, 2019.
4. Zhang, Z.; Wang, Q.; Yan, F.; Sun, Y.; Yan, S. Revealing spatio-temporal differentiations of ecological supply-demand mismatch among cities using ecological Network: A case study of typical cities in the "Upstream-Midstream-Downstream" of the Yellow River Basin. *Ecol. Indic.* **2024**, *166*, 112468. [CrossRef]

5. Ke, X.; Wang, X.; Guo, H.; Yang, C.; Zhou, Q. Urban ecological security evaluation and spatial correlation research-----based on data analysis of 16 cities in Hubei Province of China. *J. Clean. Prod.* **2021**, *311*, 127613. [CrossRef]
6. Wen, J.; Hou, K. Research on the progress of regional ecological security evaluation and optimization of its common limitations. *Ecol. Indic.* **2021**, *127*, 107797. [CrossRef]
7. Tao, Y.; Tao, Q.; Sun, X.; Qiu, J.; Pueppke, S.G.; Ou, W.; Guo, J.; Qi, J. Mapping Ecosystem Service Supply and Demand Dynamics under Rapid Urban Expansion: A Case Study in the Yangtze River Delta of China. *Ecosyst. Serv.* **2022**, *56*, 101448. [CrossRef]
8. Xiang, H.; Zhang, J.; Mao, D.; Wang, Z.; Qiu, Z.; Yan, H. Identifying Spatial Similarities and Mismatches between Supply and Demand of Ecosystem Services for Sustainable Northeast China. *Ecol. Indic.* **2022**, *134*, 108501. [CrossRef]
9. Serna-Chavez, H.; Swenson, N.; Weiser, M.; van Loon, E.E.; Bouten, W.; Davidson, M.D.; van Bodegom, P.M. Strong Biotic Influences on Regional Patterns of Climate Regulation Services. Glob. Biogeochem. *Cycle* **2017**, *31*, 787–803. [CrossRef]
10. Zhuang, Z.; Li, C.; Gu, H.; Han, Q.; Hou, S. Research progress and hot-spot analysis of the supply-demand relationship of ecosystem services based on CiteSpace. *Ecol. Sci.* **2022**, *41*, 212–222.
11. Wei, H.; Liu, H.; Xu, Z.; Ren, J.; Lu, N.; Fan, W.; Zhang, P.; Dong, X. Linking Ecosystem Services Supply, Social Demand and Human Well-Being in a Typical Mountain–Oasis–Desert Area, Xinjiang, China. *Ecosyst. Serv.* **2018**, *31*, 44–57. [CrossRef]
12. Xu, Z.; Peng, J.; Dong, J.; Liu, Y.; Liu, Q.; Lyu, D.; Qiao, R.; Zhang, Z. Spatial Correlation between the Changes of Ecosystem Service Supply and Demand: An Ecological Zoning Approach. *Landsc. Urban Plan.* **2022**, *217*, 104258. [CrossRef]
13. Khosravi Mashizi, A.; Sharafatmandrad, M. Investigating Tradeoffs between Supply, Use and Demand of Ecosystem Services and Their Effective Drivers for Sustainable Environmental Management. *J. Environ. Manag.* **2021**, *289*, 112534. [CrossRef] [PubMed]
14. Jiang, M.; Jiang, C.; Huang, W.; Chen, W.; Gong, Q.; Yang, J.; Zhao, Y.; Zhuang, C.; Wang, J.; Yang, Z. Quantifying the Supply-Demand Balance of Ecosystem Services and Identifying Its Spatial Determinants: A Case Study of Ecosystem Restoration Hotspot in Southwest China. *Ecol. Eng.* **2022**, *174*, 106472. [CrossRef]
15. Cao, J.; Wang, L.; Cao, W. Research on Ecological Zoning Based on the Differential Pattern of Ecosystem Service Supply and Demand—Taking Nanjing Metropolitan Area as an Example. *Resour. Dev. Mark.* **2022**, *38*, 520–528.
16. Xin, R.; Skov-Petersen, H.; Zeng, J.; Zhou, J.; Li, K.; Hu, J.; Liu, X.; Kong, J.; Wang, Q. Identifying Key Areas of Imbalanced Supply and Demand of Ecosystem Services at the Urban Agglomeration Scale: A Case Study of the Fujian Delta in China. *Sci. Total Environ.* **2021**, *791*, 148173. [CrossRef]
17. The Public Notice of Zhengzhou Metropolitan Ecological Protection and Construction Plan (2020–2035). Available online: http://www.henan.gov.cn/2020/10-18/1829391.html (accessed on 9 September 2023).
18. New Urbanization Plan of Henan Province (2021–2035). Available online: https://www.henan.gov.cn/2022/02-16/2399795.html (accessed on 10 September 2023).
19. Chen, J.; Gao, M.; Cheng, S.; Hou, W.; Song, M.; Liu, X.; Liu, Y. Global 1 km × 1 km gridded revised real gross domestic product and electricity consumption during 1992–2019 based on calibrated nighttime light data. *Sci. Data* **2022**, *9*, 202. [CrossRef]
20. Wang, J.; Zhou, W.; Pickett, S.T.; Yu, W.; Li, W. A multiscale analysis of urbanization effects on ecosystem services supply in an urban megaregion. *Sci. Total Environ.* **2019**, *662*, 824–833. [CrossRef] [PubMed]
21. Yang, Y.; Li, J.; Wang, L.; Wang, Y.; Wang, Z.; Yao, C. Impact of urbanization on supply and demand of typical ecosystem services in Yangtze River Delta. *J. Nat. Resour.* **2022**, *37*, 1555–1571. [CrossRef]
22. Jiang, C.; Yang, Z.; Wen, M.; Huang, L.; Liu, H.; Wang, J.; Chen, W.; Zhuang, C. Identifying the Spatial Disparities and Determinants of Ecosystem Service Balance and Their Implications on Land Use Optimization. *Sci. Total Environ.* **2021**, *793*, 148472. [CrossRef]
23. Xiao, W. Research on Supply and Demand of Green Infrastructure Ecosystem Services and Optimization of Landscape Pattern. Master's Thesis, Shaanxi Normal University, Xi'an, China, 2019.
24. Zou, Y. Study on the Response and Optimization of Ecosystem Service Value of Land Use Landscape Pattern Change in Xi'an City. Master's Thesis, Shaanxi Normal University, Xi'an, China, 2018.
25. Du, W.; Ren, C.; Zhang, Z.; Luo, Y. Construction of Ecological Security Pattern in the Metropolitan Area of Chongqing Based on the Supply and Demand of Ecosystem Services. *Landsc. Archit. Acad. J.* **2022**, *39*, 30–38.
26. Wei, H.; Yang, Y.; Wu, Q. Relationship between air purification service and landscape pattern of urban green space in city with more haze. *Bull. Soil Water Conserv.* **2021**, *41*, 292–299.
27. Zhang, X.; Li, H.; Xia, H.; Tian, G.; Yin, Y.; Lei, Y.; Kim, G. The Ecosystem Services Value Change and Its Driving Forces Responding to Spatio-Temporal Process of Landscape Pattern in the Co-Urbanized Area. *Land* **2021**, *10*, 1043. [CrossRef]
28. Larondelle, N.; Lauf, S. Balancing Demand and Supply of Multiple Urban Ecosystem Services on Different Spatial Scales. *Ecosyst. Serv.* **2016**, *22*, 18–31. [CrossRef]
29. Li, J.; Jiang, H.; Bai, Y.; Alatalo, J.M.; Li, X.; Jiang, H.; Liu, G.; Xu, J. Indicators for Spatial–Temporal Comparisons of Ecosystem Service Status between Regions: A Case Study of the Taihu River Basin, China. *Ecol. Indic.* **2016**, *60*, 1008–1016. [CrossRef]
30. Cui, F.; Tang, H.; Zhang, Q.; Wang, B.; Dai, L. Integrating Ecosystem Services Supply and Demand into Optimized Management at Different Scales: A Case Study in Hulunbuir, China. *Ecosyst. Serv.* **2019**, *39*, 100984. [CrossRef]
31. Li, H.; Wang, Y.; Wang, J.; Song, S.; Xu, D. Landscape stability dynamics and its driving forces in core area of ejina oasis from 2013 to 2020. *Bull. Soil Water Conserv.* **2022**, *42*, 125893.
32. Yang, Y.; Jun, Z.; Sui, X.; He, X. Study of the Spatial Connection between Urbanization and the Ecosystem-A Case Study of Central Yunnan (China). *PLoS ONE* **2020**, *15*, e0238192. [CrossRef]

33. Xiao, R.; Lin, M.; Fei, X.; Li, Y.; Zhang, Z.; Meng, Q. Exploring the Interactive Coercing Relationship between Urbanization and Ecosystem Service Value in the Shanghai–Hangzhou Bay Metropolitan Region. *J. Clean. Prod.* **2020**, *253*, 119803. [CrossRef]
34. Ai, J.; Sun, X.; Feng, L.; Li, Y.; Zhu, X. Analyzing the spatial patterns and drivers of ecosystem services in rapidly urbanizing Taihu Lake Basin of China. *Front. Earth Sci.* **2015**, *9*, 531–545. [CrossRef]
35. Zhang, Z.; Peng, J.; Xu, Z.; Wang, X.; Meersmans, J. Ecosystem services supply and demand response to urbanization: A case study of the Pearl River Delta, China. *Ecosyst. Serv.* **2021**, *49*, 101274. [CrossRef]
36. Zhang, Z.; Wang, Q.; Feng, Y.; Sun, Y.; Liu, N.; Yan, S. The spatio-temporal evolution of spatial structure and supply-demand relationships of the ecological network in the Yellow River Delta region of China. *J. Clean. Prod.* **2024**, *471*, 143388. [CrossRef]
37. Chen, J.; Jiang, B.; Bai, Y.; Xu, X.; Alatalo, J.M. Quantifying ecosystem services supply and demand shortfalls and mismatches for management optimisation. *Sci. Total Environ.* **2019**, *650*, 1426–1439. [CrossRef] [PubMed]
38. Zhu, Z.; Kasimu, A. Analysis and Simulation of the Spatial Autocorrelation Pattern in the Ecosystem Service Value of the Oasis Cities in Dry Areas. *J. Ecol. Rural. Environ.* **2019**, *35*, 1531–1540.
39. Llopis, J.C.; Chastonay, J.F.; Birrer, F.C.; Bär, R.; Andriatsitohaina, R.N.N.; Messerli, P.; Heinimann, A.; Zaehringer, J.G. Year-to-Year Ecosystem Services Supply in Conservation Contexts in North-Eastern Madagascar: Trade-Offs between Global Demands and Local Needs. *Ecosyst. Serv.* **2021**, *48*, 101249. [CrossRef]
40. Zhao, Z.; Wang, K.; Xiang, K.; Xie, X. Assessment on Agricultural Landscape Pattern and Ecosystem Service Values of Jidong Plain—A Case Study of Luan County. *Res. Soil Water Conserv.* **2012**, *19*, 221–226+230.
41. Henan Provincial Government Work Report. Public Announcement. Available online: https://www.henan.gov.cn/2006/08-11/226996.html (accessed on 8 October 2023).
42. Guidance of The State Council on Supporting Henan Province to accelerate the Construction of Central Plains Economic Zone. Available online: http://www.gov.cn/zhengce/content/2011-10/07/content_8208.htm (accessed on 8 October 2023).
43. Notice of the Ministry of Agriculture and Rural Affairs on Printing and distributing the National High-Standard Farmland Construction Plan (2021–2030). Available online: http://www.ntjss.moa.gov.cn/zcfb/202109/t20210915_6376511.htm (accessed on 10 October 2023).