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Dynamic Analysis of Supply and Demand Coupling of Ecosystem Services in Loess Hilly Region: A Case Study of Lanzhou, China

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Abstract: The relationship between the supply and demand for ecosystem services (ESs) is a key issue for the rational allocation of natural resources and optimisation of sustainable development capacity. This paper investigateed the dynamic evolution features of supply and demand of four ESs in Lanzhou of China, namely, water supply, food supply, carbon fixation and soil retention services. The cross-sectional data of 2005 and 2017 were used for calculating ESs value and its supply and demand through ArcGIS software, InVEST model, elastic coefficient model and coupling coordination model. Results showed that: 1) from 2005 to 2017, the supply of water supply services increased, the demand of soil retention services decreased, and the supply and demand of food supply and carbon fixation services increased. The high-value areas of service supply were mainly distributed in the rocky mountain areas in the southeast and northwest with high vegetation coverage, while the high-value areas of demand were mainly distributed in the urban areas and surrounding areas with high population density. 2) There were five different types of coupling relations. Water supply service was dominated by a negative coupling type D, which means that the decrease in demand for ESs has had a positive response on the supply of ESs. Negative coupling type C was the main type of food supply and carbon fixation services, which means that the increase in demand for ESs has had a negative response on the supply of ESs. All three services were supplemented by a positive coupling type A, which means that the increase in demand for ESs has had a positive response on the supply of ESs. Soil retention service generally exhibits a positive coupling type B, which means that the decrease in demand for ESs has had a negative response on the supply of ESs. 3) Over the past 12 yr, the coordination degree of supply and demand of water supply, food supply and soil retention services decreased, and the coordination degree of carbon fixation service increased. Various types of ES had a low degree of coupling and coordination, showing different characteristics of temporal and spatial evolution. The areas with imbalanced ESs supply and demand were mainly distributed in urban areas dominated by construction land. The research results are valuable to the optimisation of urban and rural ecological environments and the sustainable development of territory space under the framework of ecological civilisation, including similar ecologically vulnerable areas in other developing countries.

Keywords: loess hilly region; supply and demand of ecosystem services (ESs); coupling coordination degree; elastic coefficient; coupling relation

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1 Introduction

Ecosystem services (ESs) are manifestations of the structure and function of the ecosystem and the ecological processes that benefit humanity (Costanza et al., 1997). They are used as an ecological basis for the survival and development of human society, but this process has also caused an impact on the balance of supply and demand for ESs. The supply of ESs refers to the capacity of ecosystems to provide services and products at target time series nodes and research units (Burkhard et al., 2012), and the demand for ESs refers to products or services that people need, including products or services that they wish to obtain (Burkhard et al., 2012; Peng et al., 2017a). The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) divided ESs into four categories, namely, provisioning, regulating, supporting, and cultural services, and proposed a conceptual framework for the relationship between ESs and human well-being worldwide. In recent years, the integration of ESs and human well-being has become the core content and new direction of ecological research (Luederitz et al., 2015). The rapid development of urbanisation and industrialisation has led to the continuous transformation and reconstruction of urban and rural land use space (Liu et al., 2018), which has resulted in the imbalance of supply and demand of regional ESs and destruction of the ecological environment. Therefore, it is necessary to explore the coupling relationship between the supply and demand of ES and clarify the law of its temporal and spatial evolution. This is an important foundation to solve the conflict between the ecological environment protection and economic social development, and to realize the coordinated and sustainable development of the human land system. Meanwhile, clarifying the relationship between supply and demand of ecosystem services also provides an important theoretical basis for rational allocation and sustainable development of regional natural resources.

Since the 1990s, ES has gradually attracted the attention of western countries in the fields of ecology and geography. Early scholars investigated the structure, process and function of the ecosystem (Kremen et al., 2007; Naeem, 2008; Alama et al., 2016), the generation mechanism of ESs (Boyd and Banzhaf, 2007), the definition of supply and demand of ESs and the improvement of research frameworks from an ecological point of view (Troy and Wilson, 2006; Petrosillo et al., 2009). Since 2000, many studies have quantitatively evaluated the relationship between supply and demand and its impacts on the consumption of natural resources. Examples of such studies include those on supply and demand quantification (Schulp et al., 2014; Wolff et al., 2017), supply and demand mismatch (Syrbe et al., 2017; Wu et al., 2019), supply and demand balance at different spatial scales (Larondelle and Lauf, 2016; Roces-Díaz et al., 2018) and dynamic relationship between supply and demand (Kroll et al., 2012; Tao et al., 2018). The supply and demand of ESs were quantitatively assessed based on the impact of spatial relationships of ESs (Seppelt et al., 2012; Syrbe et al., 2017). Several methods were used to analyse service providers, service beneficiaries and the spatial relationship between them (Ruhl et al., 2007; Syrbe and Walz, 2012). Scholars used land use estimation, ecological process simulation, expert experience discrimination, spatialisation methods (e.g., Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) and ARtificial Intelligence for Ecosystem Services (ARIES) models) and the ESs supply and demand matrix method based on land use/land cover change (Burkhard et al., 2012; Peña, 2015).

In the past decade, Chinese scholars studied the supply and demand of ESs and actively introduced western research literature (Nedkov and Burkhard, 2012; García-Nieto et al., 2013). Most researches mainly focused on the value of ecological services, the evolution of supply and demand patterns (Li et al., 2008; Hu et al., 2015), the coupling relationship between urbanisation and ESs value (Peng et al., 2017a), and supply and demand balance and space matching (Wang et al., 2019). Recent research has started to focus on the coupling of supply and demand for ESs, including supply-demand coupling approaches for ESs, coupling mechanisms and driving factors (Wu et al., 2019), the spatial association of ESs with land use and land cover change (Chen et al., 2019), and spatial patterns of ecological security coupled with the supply and demand of ESs (Zhang et al., 2017). Several scholars emphasised the importance of identifying the transport path of ESs flows to clarify the coupling relationship between the supply and demand of ESs because ESs flows can establish spatiotemporal connections between the supply and demand of ESs (Liu et al. 2017).

Scholars conducted multi-scale research on watersheds, national level, regions (urban agglomeration) and cities for the supply and demand of ESs (Wei et al., 2017; Bukvareva et al., 2019). Many achievements have been obtained through quantitative analyses and measurement of the supply and demand of ESs. Few studies focused on the coupling relationship amongst urbanisation, other factors and the supply and demand coupling mechanism of river basin ESs. Few studies evaluated the coupling of supply and demand of ESs because of limited research data and research methods, and a gap exists in dynamic coupling analysis in different periods. Furthermore, especially for China, many studies focused on the ecological services of countries, regions and watersheds. Most of the research areas were those with good ecological environment and developed economy, such as the middle and lower reaches of the Yangtze River in East China (Tao et al., 2018).

As a typical ecologically fragile area in China, Loess Hilly area has concentrated a large number of poor people in urgent need of development. The incoordination between social economic development and ecological protection is prominent (Liu and Wang, 2018). As a fast-growing city in the loess hilly region, Lanzhou in China is facing tremendous pressure to strike a balance between ecological environmental protection and social and economic development and it is a typical representative region. Therefore, in the western regions with fragile ecology and underdeveloped economy, quantitative research and analysis on the supply and demand of ES and its coupled dynamic characteristics will help clarify the supply and demand relationship of ES and provide new ideas for the study of human land system coupling in Loess hilly region, which is crucial to the optimisation of land space and harmonious development between human and nature. Taking Lanzhou city as an example, this paper tried to provide an analytical framework for the coupling and coordination of ESs through constructing the supply and demand elasticity coefficient and the coupling coordination degree models, so as to reveal the characteristics of the coupling relationship between the supply and demand of urban ESs and the spatial and temporal differentiations of the coupling and coordination. This paper will theoretically help deepen the exploration of the supply and demand coupling relationship and the characteristics of ESs in urban areas. It also provide new research ideas and policy suggestions for optimising natural, socioeconomic, and ecological spatial patterns in the Loess Hilly region and promote the coordinated development of supply and demand coupling of ESs in urban areas.

2 Method and Data

2.1 Study area

Lanzhou is located in the upper reaches of the Yellow River and west of the Loess Plateau. It is a transitional zone between the Qinghai-Tibet Plateau and the Loess Plateau (Fig. 1). Lanzhou has a typical temperate semi-arid continental monsoon climate. Its special geographical location and natural conditions have formed four kinds of geomorphic units and distinctive ecological patterns, namely, rocky mountains, valley plains, intermountain basins and hilly ridges. Rocky mountainous areas are mainly distributed in the western and southern borders of the city. The steep mountainous terrain leads to a strong water flow. Many 'V-shaped' gullies with a largecuttingdepthexist.Theareahasrelativelyabundantrainfall and dense vegetation, and it is an important forest and ecological barrier area in the city. The valley plains are mainly distributed along Yellow River, Huangshui River, Datong River, Zhuanglang River and Wanchuan Valley. This area is mainly affected by the long-term alluvial and flood of rivers, resulting in the continuous development of two banks with abundant water sources and fertile soil. It is the main grain production area in the city. The main intermountain basins include Lanzhou, Qinwangchuan and Yuzhong, which are flat and densely populated with high industrial agglomeration and frequent social and economic activities. They are the concentrated areas of urban industrial and agricultural development. Loess hilly ridges are mainly distributed in the northern part of the city. There are isolated loess ridges or narrow short beams with sparse vegetation due to the strong cutting of the terrain and active and severe soil erosion. They are typical fragile and ecological protection areas. Three counties and five districts are under the jurisdiction of the city, and these include 111 towns and streets with a total area of 13 083 km^2. The permanent population was 3.12 million and 3.73 million at the end of 2005 and 2017, respectively.

2.2 Data sources

Land use data were obtained from the autumn cloud-free Landsat thematic mapper TM remote sensing data provided by the United States Geological Survey

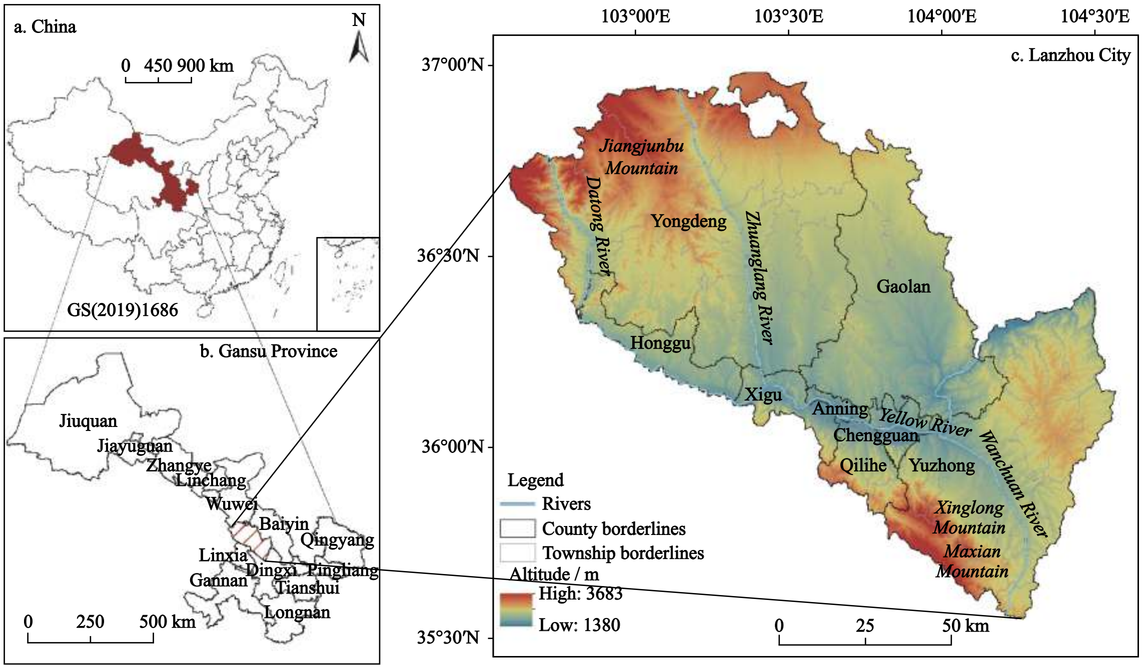

Fig. 1 Location of the study area in China

(USGS) for Earth Observation Resources and Science (rank number (130-131/34-35)) (http://glvis.usgs.gov/). Land use data in 2005 and 2017 were interpreted based on Google Earth images and land use change survey data of Lanzhou in 2005 and 2015, and the classification data interpretation accuracy exceeded 93%. Digital elevation model (DEM) data were obtained from a geospatial data cloud with 30 m spatial resolution (http://www.gscloud.cn/). The Landsat 7 ETM SLC-off and Landsat 8 OLI_TIRS remote sensing data of the Normalized Difference Vegetation Index (NDVI) were provided by Geospatial Data Cloud (http://www.gscloud.cn). The annual precipitation, temperature, solar radiation and other meteorological data of Lanzhou in 2005 and 2017 were from the National Meteorological Data Network (http://data.cma.gov.cn/). Soil data of Lanzhou were derived from the Soil Science Database (http://vdb3.soil.csdb.cn/) . The population data of each township and energy consumption data were obtained from Lanzhou Statistical Yearbook (http://tjj.lanzhou.gov.cn/), and water consumption data were from Gansu Water Resource Bulletin (http://slt.gansu.gov.cn). Population density raster data were calculated based on the population density data of each county and the population density spatialisation method proposed by Yan et al. (2011). The total food demand was derived from food security objectives at different social stages developed by the State Food and Nutrition Consultant Committee (http://sfncc.caas.cn/). Carbon emission parameters were obtained based on the research results of Tu and Liu (2014). All of these raster data were unified in GIS and sampled as 100 m × 100 m grids, which were calculated with a Xian_1980_3_Degree_GK_Zone_33 coordinate system.

2.3 Supply and demand assessment of ESs

In recent years, various ecological problems have become increasingly prominent with the construction of Lanzhou's National New District and the growth of the county's economy. The specific issues are the tight supply of water resources, serious soil erosion, unbalanced food supply and high carbon emissions. These problems have exerted a serious negative impact on human production space, living space and ecological space. Therefore, the supply and demand of ESs in the city were evaluated from four aspects, namely, water supply, food supply, carbon fixation and soil retention services, on the basis of the natural ecological environment characteristics of Lanzhou and the needs of the people. The specific evaluation methods and calculation procedures are shown as follows.

2.3.1 Evaluation method and calculation of ESs supply

Current supply evaluation methods, such as value equivalent (Li et al., 2008), material quality (Li et al., 2016) and energy values, have gradually increased and matured with the deepening of research on the supply and demand of ESs. Nevertheless, there are still inconsistencies in the definition and evaluation of demand, including the use of construction land ratio, economic density and population density to characterize the demand for ES (Peng et al., 2017b). The key point is that human beings triggered supply-demand changes, in-situ service coupling and flow of ESs to supply and demand areas according to their needs. Therefore, this paper assessed the demand for ESs on the basis of regional population density according to human needs. From the perspective of social or individual preferences, the demand for ESs was defined as the quantity and quality of ecosystem services that humans expect to obtain (Syrbe et al., 2017).

(1) Water supply service

Using the water yield module of InVEST model and taking 1 km grid as the unit, the water supply service value was estimated.

$$Y_{xj} = \left(1 - \frac{AET_{xj}}{P_x}\right) \times P_x \quad (1)$$

where Y_{xj} is water yield of grid x, land type j (mm); AET_{xj} is average annual evapotranspiration (mm); P_x is the average annual precipitation (mm).

(2) Food supply service

There was a significant linear relationship between grain output, livestock product output and *NDVI*. Based on land use/cover type, the total grain output was distributed according to the ratio of the grid *NDVI* value to the total cultivated land *NDVI* value, and the output of meat, eggs, and milk was distributed according to the ratio of the grid *NDVI* value to the total *NDVI* value of grassland and woodland.

$$G_i = \frac{NDVI_i}{NDVI_{\text{sum}}} \times G_{\text{sum}} \quad (2)$$

where G_i is the yield of food, meat and milk distributed to grid i; G_{sum} is the total amount of food, meat and milk; $NDVI_i$ is the normalised vegetation index of grid i; and $NDVI_{\text{sum}}$ is the sum of *NDVI* in cultivated land, grassland or woodland in the study area.

(3) Carbon fixation service

Using the carbon fixation module of InVEST model, the carbon fixation service value was estimated.

$$C_{\text{tot}} = C_{\text{above}} + C_{\text{below}} + C_{\text{soil}} + C_{\text{dead}} \quad (3)$$

where C_{tot} is the total carbon fixation supply (t/ha), C_{above} is the aboveground biochar, C_{below} is the underground biochar, C_{soil} is the organic carbon in the soil; C_{dead} is the dead organic carbon.

(4) Soil retention service

Using the sediment retention module of *InVEST* model, the soil retention service value was estimated.

$$A = R_{\text{pe}} \times K_{\text{se}} \times LS \times (1 - P \times C) \quad (4)$$

where A is the soil retention capacity (t/(ha·yr)), R_{pe} is the average annual precipitation erosion calculated by the precipitation erosivity formula proposed by Wischmeier and Smith. (1958), K_{se} is the soil erosion calculated by the formula based on soil organic matter content and soil particle composition proposed by Williams and Arnold. (1997), LS is the terrain factor calculated based on the slope length factor calculation method of DEM based on the filling process, P is the soil and water conservation factor calculated by slope index α and C is the vegetation cover management factor.

2.3.2 Evaluation and calculation of ESs demand

The demand for water supply services is the actual annual water supply demand per capita. The demand and spatial distribution of regional water supply service can be obtained by multiplying the per capita water supply demand with the raster data of population density. The demand for food supply service is the number of ESs safety goals achieved by the society at all stages. The demand and spatial distribution of food supply services are obtained by multiplying the per capita food security target of different social stages developed by the State Food and Nutrition Consultant Committee with the raster data of population density. The demand for carbon sequestration services is related to the following conditions: In the process of energy consumption, a large amount of carbon emissions will affect human production, life and ecology. The total energy consumption in 2005 and 2017 was multiplied by the carbon emission coefficient to obtain the total energy carbon emission, divided by the permanent population in Lanzhou and multiplied by the raster data of population density to obtain the spatial distribution map of carbon fixation service demand. The demand for soil retention service represents the quantity and quality of ESs that the society or individuals expect to acquire and achieve. The demand for soil retention service was difficult to quantify with population density because of the influence of topography, precipitation, vegetation and other factors.

(1) Water supply service, food supply service and carbon fixation

The demand for the three ESs mainly changed because of the change in population. Thus, this study used quantitative changes in population density to quantitatively measure the demand. The higher the population density was, the higher the demand was.

$$D_y = D_{py} \times \rho_{\text{pop}} \tag{5}$$

where D_y is the demand for y (water supply, food supply and carbon fixation) service, D_{py} is the per capita demand for service y; ρ_{pop} is the raster data of population density.

(2) Soil retention service

Using the sediment retention module of InVEST model, the soil retention service demand was estimated.

$$U = R_{\text{pe}} \times K_{\text{se}} \times LS \times P \times C \tag{6}$$

where U is the soil retention demand (t/(ha·yr)).

2.4 Coupling method for the supply and demand of ESs

2.4.1 Elastic coefficient model

Liu et al. (2007) explained that the coupled system of human and nature implies a nonlinear dynamic mechanism, and they pointed out that the evolution of the system is accompanied with various phenomena, such as threshold changes, mutual feedback loops between systems, time lag, heterogeneity and abruptness. The elastic coefficient refers to the ratio of change rate of two variables that are related to each other in a certain period. It can measure the interaction between a variable and the magnitude of another related variable (Liu and Li, 2010). Therefore, an elasticity coefficient model of supply and demand of ESs was established in this study to characterise the dependence of ESs supply and demand changes in a region at a certain period. The rate of change of ESs was used to reflect the interannual variation of regional ESs and comprehensively analyse the dynamic coupling characteristics between supply and demand. The calculation formula is as follows:

$$ESEC = SCR/DCR \tag{7}$$

$$SCR(DCR) = \left(n\sum_{i=1}^{n} ia_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} a_i\right) \Bigg/ \left(n\sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2\right) \tag{8}$$

where $ESEC$ is the supply and demand elasticity coefficient for ESs; SCR and DCR are the supply change rate and demand change rate, respectively; a_i indicates the supply (demand) of ESs in ith year. SCR (DCR) > 0 indicates that a certain ESs supply (demand) shows a growing trend. SCR (DCR) < 0 indicates that a certain ESs supply (demand) shows a decreasing trend. SCR (DCR) = 0 indicates that supply (demand) is in a stable state, and the interaction between supply and demand changes is small.

Therefore, on the basis of the supply and demand elasticity coefficient, demand change rate and supply change rate, the coupling relationship between supply and demand was divided in this paper into five categories (A: double increase; B: double decrease; C: demand increases and supply decreases; D: demand decreases and supply increases; E: demand changes and supply unchanged), and the specific division is shown in Table 1.

2.4.2 Coupling coordination degree model

A coupling coordination degree model was used to determine whether the coordination degree is good or bad. The coupling coordination degree measurement model in physics can well characterize two (or more) systems through various interactions and coordination degree, which determines the order and structure of the system when it reaches the critical region, and determines the

Table 1 Supply and demand coupling relationship model based on the change in elasticity coefficient

Relationship	ESEC	DCR	SCR	Characteristics	Type
Positive coupling	ESEC > 0	DCR > 0	SCR > 0	The increase in demand for ESs has a positive response on the supply of ESs	A
		DCR < 0	SCR < 0	The decrease in demand for ESs has a negative response on the supply of ESs	B
Negative coupling	ESEC < 0	DCR > 0	SCR < 0	The increase in demand for ESs has a negative response on the supply of ESs	C
		DCR < 0	SCR > 0	The decrease in demand for ESs has a positive response on the supply of ESs	D
No coupling relationship	ESEC = 0		SCR = 0	The increase or decrease in demand for ESs has no response on the supply of ESs	E

Notes: ESEC: supply and demand elasticity coefficient; DCR: demand change rate; SCR: supply change rate; ESs are ecosystem services trend of the system from disorder to order (Liu et al., 2011). We used the concept and model of capacity coupling in physics to calculate the coupling degree and coupling coordination degree between the supply and demand of ESs and to characterise the coordination type of the supply and demand of ESs. The function calculation formula is as follows (Sun et al., 2019):

$$K = \sqrt{C \times T} \tag{9}$$

$$T = \alpha X_1 + \beta X_2 \tag{10}$$

$$C = \left(\frac{\sqrt{U_1 U_2}}{\frac{U_1 + U_2}{2}} \right)^n \tag{11}$$

where K is the coupling coordination degree that combines the coupling degree and the comprehensive supply and demand index, and it can determine the coordinated development of a region. C is the degree of coupling, and the value is 0–1. U_1 is the measurement of ESs supply, U_2 is the measurement of ESs demand and T is the comprehensive supply and demand index that requires max-min standardisation on the measured values of supply and demand and non-dimensionalisation. X_1 and X_2 are the normalised values of U_1 and U_2, respectively. Considering that the supply and demand of ESs are equally important for ecological environmental protection and promotion of human well-being, the same weight was taken as $\alpha = \beta = 0.5$, and T is 0–1; n was the adjustment factor that can increase the degree of discrimination. Coupling coordination degrees $0 \le D \le 0.1$, $0.1 < D \le 0.2$, $0.2 < D \le 0.5$, $0.5 < D \le 0.8$ and $0.8 < D \le 1$ indicated lowest-coupling, low-coupling, moderate-coupling, high-coupling and extreme high-coupling coordination, respectively.

3 Results

3.1 Spatial and temporal pattern of supply and demand of Ecosystem services (ESs)

3.1.1 Spatial and temporal pattern of ESs supply

In the spatial distribution, the supply of water supply services, carbon fixation services and soil retention services all showed an increasing distribution pattern from central to northwest and southeast. The high-value areas were mainly distributed in the rocky mountain areas such as Xinglong Mountain, Maxian Mountain and Jiangjunbu Mountain in the northwest and southeast, while the low-value areas were mainly distributed in the areas with low vegetation coverage, relatively less precipitation and intense human activities in the north-central part. The supply pattern of food supply services decreased from northwest to southeast. The high-value areas were mainly distributed in the valley areas such as Zhuanglang River, Datong River, Huangshui River and Wanchuan River, as well as the irrigation areas in Yuzhong and Qinwangchuan great basin, while the low-value areas were mainly distributed in the urban development areas with intensive human activities, the mountainous areas with steep terrain and the northwest with high distribution of unused land.

From 2005 to 2017, the supply of water supply services decreased, while the supply of food supply services, carbon fixation services and soil retention services increased. Among them, the areas with significant increase in water supply services were mainly distributed in Jiangjunbu Mountain Forest Farm and Liancheng National Nature Reserve in the northwest, and the average water production increased from 270.12 m^3/ha to 351.91 m^3/ha, mainly due to the increase of annual precipitation from 327 mm to 374 mm and vegetation coverage from 0.73 to 0.86. The areas with significantly reduced were mainly distributed in Maxian Mountain and Xinglongshan National Nature Reserve south of Wanchuan River, and the average water production reduced from 350.69 m^3/ha to 276.49 m^3/ha, which was mainly affected by the decrease of average precipitation for many years (Fig. 2a). The areas where food supply services increased significantly were mainly in the northwest, and the average supply increased from 1391.07 t/km^2 to 2708.03 t/km^2. The cultivated land resources in this area were relatively concentrated, and with the continuous improvement of agricultural modernization level, the grain output per unit cultivated land area also increased continuously, and the food supply was sufficient (Fig. 2b). The areas where the supply of food supply services decreased significantly were basically the same as those where the supply of carbon fixation services decreased significantly, mainly in Lanzhou New District, and the average supply decreased from 957.66 t/km^2 and 5019 t/km^2 to 0 and 4029 t/km^2, respectively. This area is an important economic growth pole in Northwest China, an important strategic platform for opening to the west and a demonstration area for undertaking industrial transfer. Therefore, in order to realize the construction and devel-

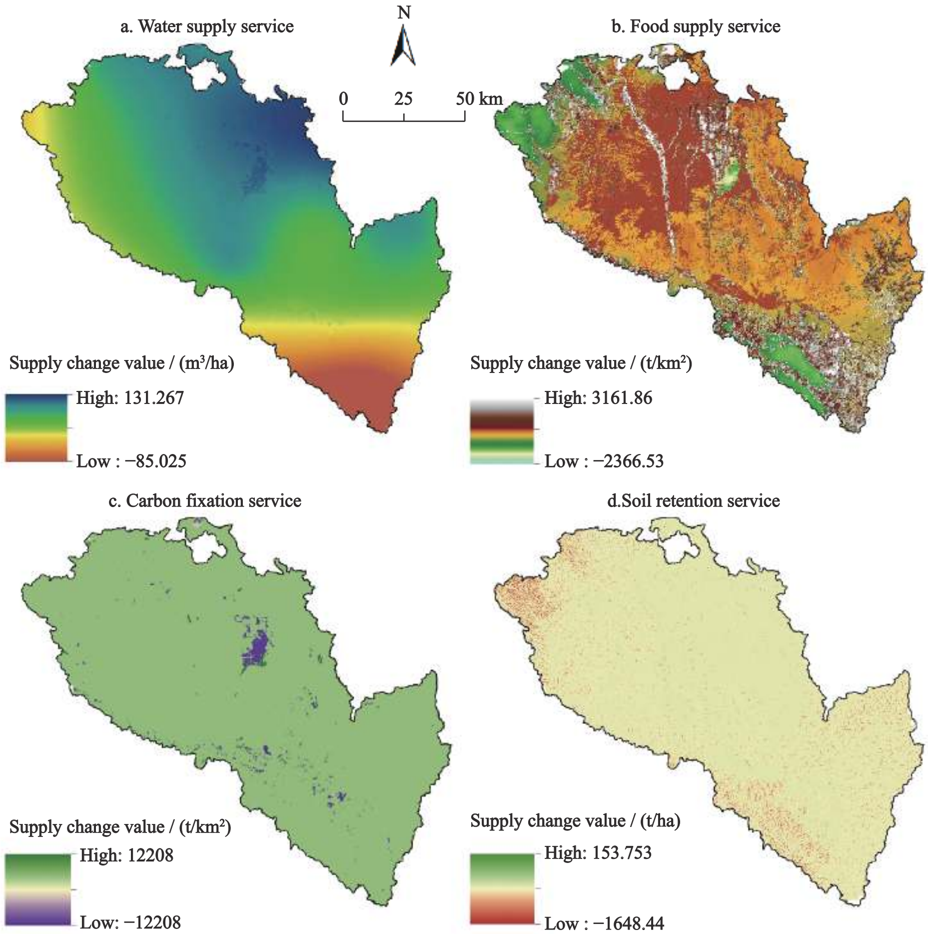

Fig. 2 Spatial-temporal distribution of the supply of various Ecosystem services (ESs) in Lanzhou City in 2005 and 2017

opment of Lanzhou New District, the urban construction index increases, the cultivated land decreases relatively, and the vegetation coverage rate decreases, resulting in a decrease in the regional supply of two services (Fig. 2c). The supply of soil retention services was greatly affected by precipitation erosion, soil erosion and land use types. Although the regional precipitation was in a dynamic change process for many years, the changes of soil texture, soil type, ecosystem type and terrain fluctuation degree were small, and the supply of soil retention services did not change significantly on the whole (Fig. 2d).

3.1.2 Spatial and temporal pattern of ESs demand

In the spatial distribution, the demand for water supply service, food supply service and carbon fixation service generally presented a decreasing distribution pattern from the middle to the northwest and southeast. The high-value areas were mainly distributed in the valley areas with high population density, good social and economic development and high degree of urbanization, such as Zhuanglang River, Datong River, Huangshui River, Wanchuan River and Yellow River, while the low-value areas were mainly distributed in the areas with scattered population and mainly agricultural production in northwest and southeast. The demand for soil retention services showed an increasing distribution pattern from the middle to the northwest and southeast. The high-value areas were mainly distributed in the areas with large topographic relief and more precipitation in the northwest and southeast, while the demand for soil retention services in other areas was small.

From 2005 to 2017, the demand for water supply services, food supply services and carbon fixation services increased, while the demand for soil retention services decreased. Among them, the demand for water supply service (Fig. 3a), food supply service (Fig. 3b) and carbon fixation service (Fig. 3c) increased significantly in the main urban area of Lanzhou, especially in Chengguan District, Qilihe District and Anning District, and the average demand increased from 2583.16 m^3/ha,

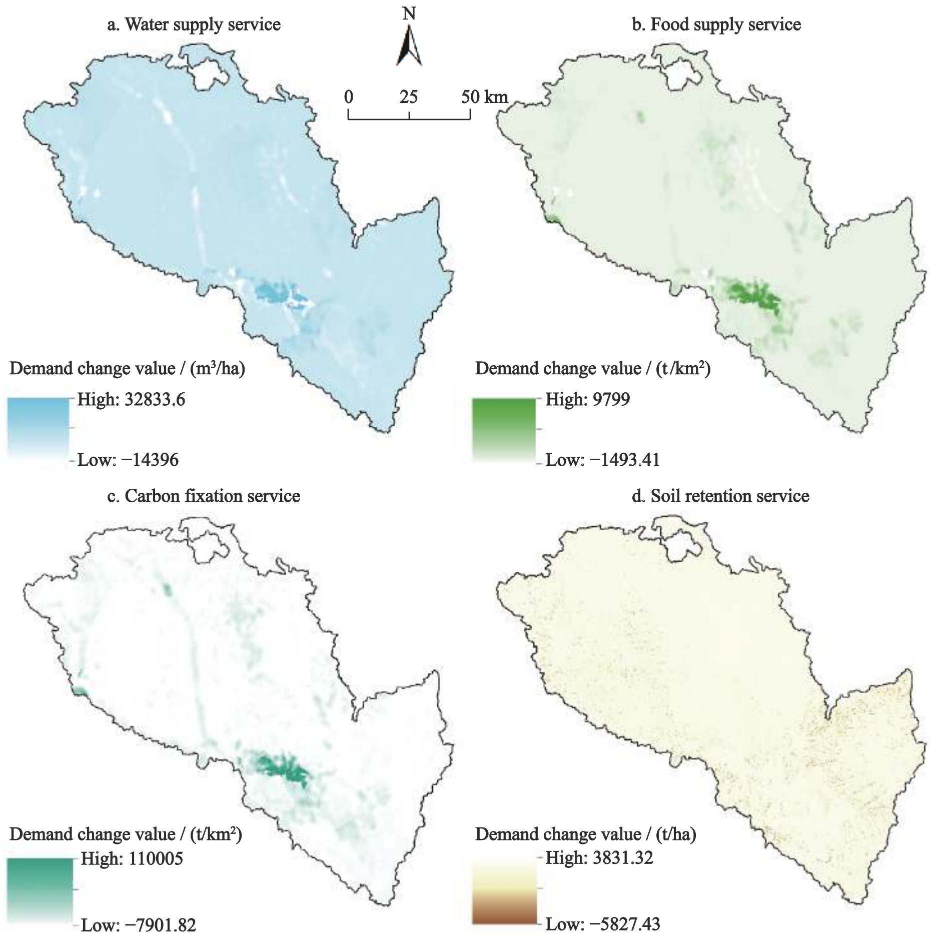

Fig. 3 Spatial-temporal distribution of the demand of various ESs in Lanzhou City in 2005 and 2017

353.46 t/km^2, 2528.88 t/km^2 to 5646.54 m^3/ha, 1128.71 t/km^2, 12021.21 t/km^2, mainly because these areas are the areas with the highest degree of urbanization and the highest population density in Lanzhou. With the rapid development of social economy, the primary industry, secondary industry, tertiary industry and per capita GDP of Lanzhou increased from 2.213 billion yuan (RMB), 24.999 billion yuan, 29.492 billion yuan and 18 296.000 yuan to 6.147 billion yuan, 88.174 billion yuan, 158.034 billion yuan and 67 881.000 yuan respectively, which increased more than four times. Moreover, the population density of these three regions increased from 4041 persons/km^2, 1085 persons/km^2, 2489 persons/km^2 to 6332 persons/km^2, 1458 persons/km^2 and 3443 persons/km^2, respectively, so the demand for water supply services, food supply services and carbon fixation services increased significantly. The areas with significant changes in demand for soil retention services were mainly distributed in the northwest and southeast (Fig. 3d). Due to the implementation of the project of returning farmland to forest and grassland, land comprehensive improvement project and ecological modification project, the vegetation coverage in this area increased, the soil erosion phenomenon decreased, and the water and soil loss per unit area decreased by 13.19 t/ha from 20.66 t/ha, so the demand for soil retention services decreased.

3.2 Coupling relationship between supply and demand analysis of ESs

Positive and negative coupling are divided into elastic coefficients ESEC > 0 and ESEC < 0 based on the elasticity coefficient and the change rates of supply and demand of ESs. The average data of supply and demand changes are counted to townships (streets) to analyse the coupling characteristics of the dynamic changes in the supply and demand of four ESs in Lanzhou during 2005–2017 and to reveal the coupling relationship of ESs in each region.

The coupling relationship between supply and demand of water supply service was dominated by a negative coupling type D (ESEC < 0) and assisted by a positive coupling type A (ESEC > 0) (Fig. 4a). Among them, type D was mainly distributed in the northwest, northeast and north of the Yellow River Valley in central China, accounting for 55.86% of the regional area. The demand for water supply services in this area decreased, while the supply increased. To a certain extent, the decrease of demand had a positive dynamic response to the increase of supply. type A was mainly distributed in Jiangjunbu Mountain, Qinwangchuan basin and the Yellow River Valley, accounting for 34.23% of

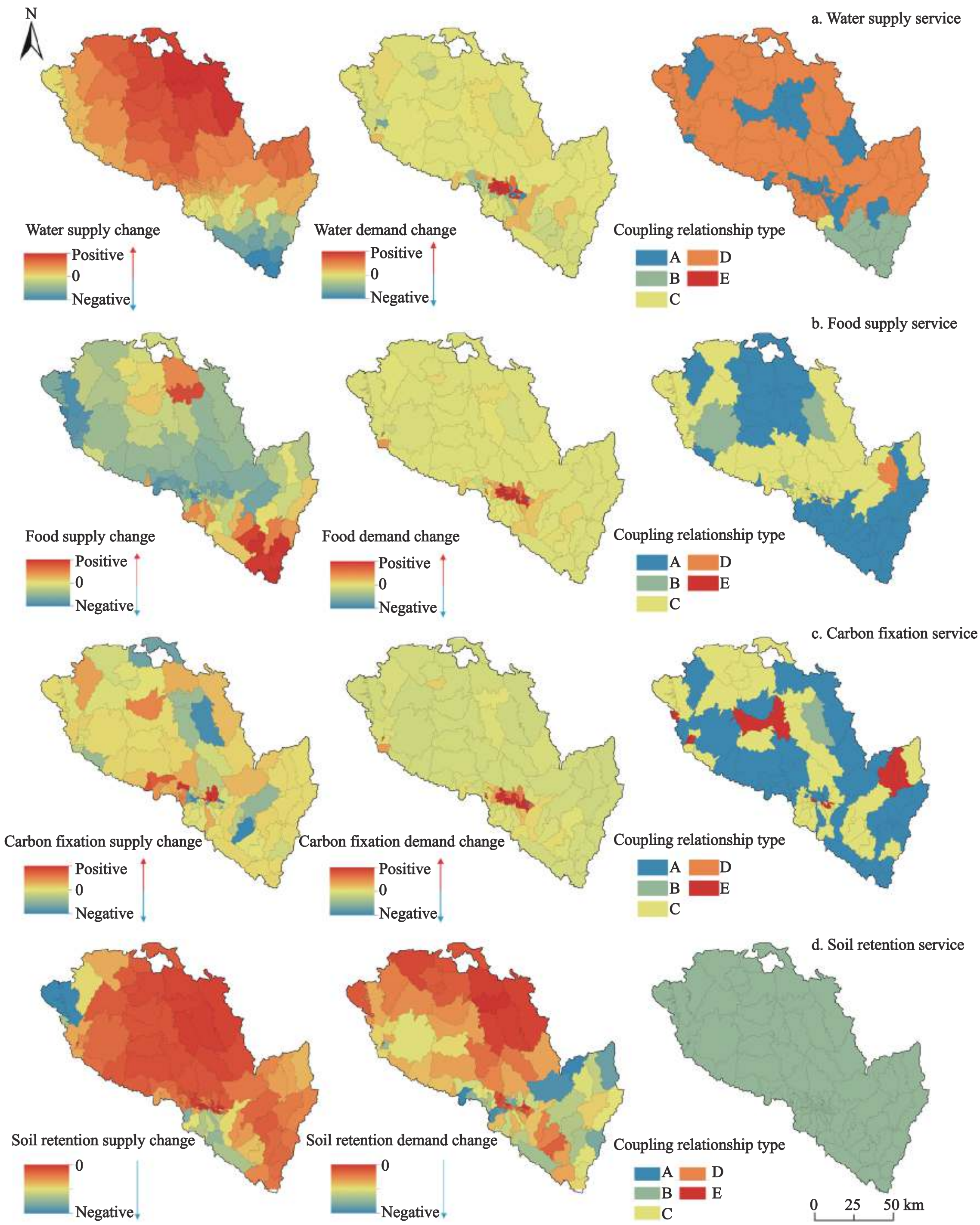

Fig. 4 Dynamic changes and coupling characteristics of ESs supply and demand in Lanzhou City from 2005 to 2017

the regional area. The supply of Jiangjunbu Mountain and Qinwangchuan basin in this region increased significantly. The dynamic increase of demand in the Yellow River Valley of Lanzhou City was remarkable, and the increase of demand had a positive dynamic response to the increase of supply to a certain extent.

The coupling relationship between supply and demand of food supply service was dominated by a negative coupling type C (ESEC < 0) and assisted by a positive coupling type A (ESEC > 0) (Fig. 4b). Among them, type C was mainly distributed along the Datong River and Yellow River Valley, accounting for 48.65% of the regional area. The demand for food supply services in this area increased dynamically, while the supply decreased dynamically. The increase of demand had a negative dynamic response to the decrease of supply to a certain extent. Type A was mainly distributed along Zhuanglang River in the north and Xinglong Mountain, Maxian Mountain and Yuzhong Basin in the southeast, accounting for 43.24% of the regional area. The dynamic increase of food supply service in this area was remarkable, and the dynamic increase of demand had a positive dynamic response to the dynamic increase of supply to a certain extent.

The coupling relationship between supply and demand of carbon fixation service was dominated by a negative coupling type C (ESEC < 0) and assisted by a positive coupling type A (ESEC > 0) (Fig. 4c). Among them, type C was mainly distributed in Liancheng National Nature Reserve in the north and the piedmont area of Jiangjunbu Mountain, Qinwangchuan and Yuzhong Basin, Yuzhong Beishan and Lanzhou City, accounting for 42.34% of the regional area. The demand for carbon fixation services in this area increased dynamically, while the supply decreased dynamically. To a certain extent, the increase of demand had a negative dynamic response to the decrease of supply. Type A was mainly distributed in the loess hilly area between Huangshui River and Zhuanglang River, the loess hilly area north of the Yellow River, and the piedmont of Maxian Mountain, accounting for 37.84% of the regional area. The supply of carbon fixation services in this area increased significantly, and the dynamic increase of demand had a significant positive dynamic response to the dynamic increase of supply to a certain extent.

The coupling relationship between supply and demand of soil retention service was dominated by a positive coupling type B (ESEC > 0) (Fig. 4d). Among them, the dynamic reduction of soil retention service supply was mainly in the mountainous areas such as Liancheng National Nature Reserve and Xinglong Mountain National Nature Reserve in the northwest and Qilihe District in Lanzhou City. Due to the influence of precipitation and land use degree, the dynamic change of precipitation erosion in this area was remarkable. The areas with significantly reduced demand for soil retention services were mainly distributed in the Yellow River Valley and Yuzhong County in the southeast. Due to the strengthening of urban blue-green space construction such as urban green space and parks, and the implementation of ecological projects such as vegetation restoration in the loess hilly region in the southeast, the actual soil erosion in these areas reduced, and the demand for soil retention services reduced significantly.

The comprehensive analysis of the coupling characteristics of the dynamic changes of supply and demand of four ESs in Lanzhou from 2005 to 2017 shows that the dynamic coupling of the supply and demand of ESs is mainly negative coupling and supplemented by the double-increase positive coupling type. With the rapid expansion of Lanzhou and the improvement of social and economic levels in the past 12 yr, the material demands of urban and rural residents for production, living and ecological space have continuously increased. At the same time, the increase in ecological and environmental problems has led to a reduction in the supply of ESs. With the implementation of strategic guidelines, such as 'lucid waters and lush mountains are invaluable assets' and 'building the life community of mountains, rivers, forests, fields and lakes', the awareness of ecological environment protection should be improved, and the sustainable and coordinated development of ESs supply and demand should be promoted while satisfying self-material needs.

3.3 Coordination pattern and evolution features of the supply and demand coupling of ESs

On the whole, the coordination of supply and demand of water supply service spreads from the high-value region of the central city to the surrounding regions. The regions with low and moderate coupling coordination are distributed in the cities with concentrated industries, high economic levels and high water consumption. Other regions are basically dominated by low coupling and coordination. This condition shows that the development of supply and demand coupling for water supply service is characterised by low coordination (Fig. 5a). Coordination of food supply service coupling increases from west to east, but the change is insignificant. The low-coordinated regions are mainly scattered in the west, north of Yellow River basin valley, and north of Yuzhong Mountain. The low supply and demand capacity of these regions is difficult to maintaining long-term coordinated development. The low and moderate coupling coordination areas are distributed in places with high food demand and strong food supply capacity, such as eastern Xinglong Mountain and Yuzhong Basin. Therefore, the supply and demand of the food supply service area are relatively different, and the development of coupling is low in coordination (Fig. 5b). The coordination of carbon fixation service gradually increases from the centre to the east and west. The low coupling coordination is mainly distributed in the Loess hilly area with low vegetation coverage between Huang-

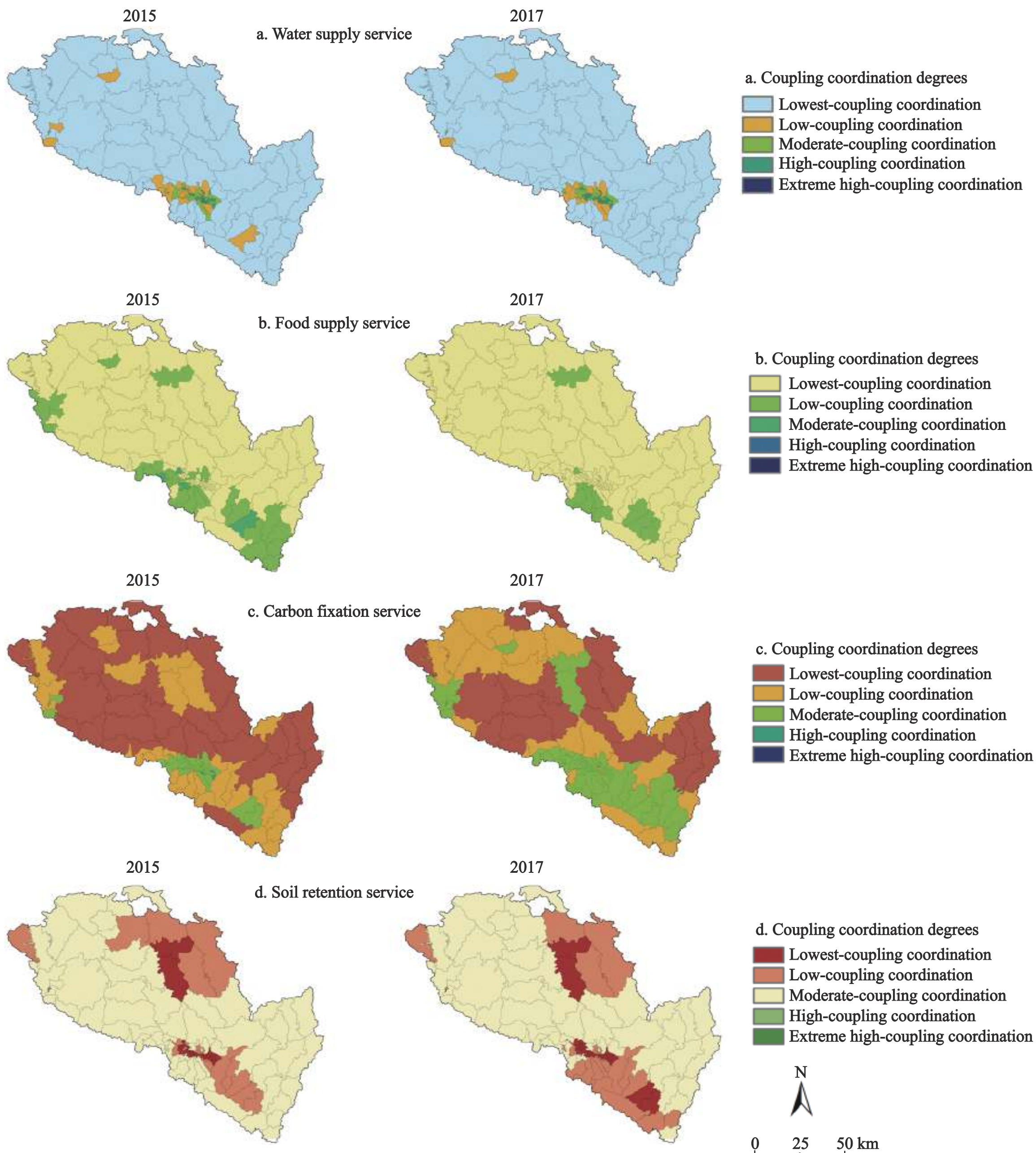

Fig. 5 Spatial distribution of supply and demand coupling coordination types of various ESs in Lanzhou City from 2005 to 2017

shui River and Zhuanglang River, north of the Yellow River valley and north of Yuzhong. The low coupling coordination area is distributed along Datong River and Zhuanglang River, Qinwangchuan Basin and around Xinglong Mountain where the vegetation coverage rate is high and the terrain is flat, with a strong carbon fixation supply capacity. The moderate coupling coordination is mainly concentrated in urban areas with dense population, high industrial agglomeration, immense energy consumption and high demand for carbon fixation service. Thus, the supply and demand of carbon fixation service are obviously different, and the development of supply and demand coupling is low in coordination (Fig. 5c). The low coupling coordination of soil retention service is scattered in urban areas with minimal soil erosion, such as Qinwangchuan Basin. The low coupling coordination is distributed in eastern and western mountainous areas with high precipitationl erosion and high vegetation coverage, in the northern area with low precipitation erosion and in the Loess Hilly area with low vegetation coverage. The moderately coordinated coupling areas are continuously distributed from east to west, with severe soil erosion but strong soil retention capability. The central region has low soil erosion and low soil retention capacity; thus, the development of supply and demand coupling is moderately coordinated (Fig. 5d).

From 2005 to 2017, the supply and demand coordination of water supply, food supply and soil retention services decreased to different degrees, and the coordination of carbon fixation service increased (Table 2). The area where the water supply service coordination decreased is mainly distributed in the urban region where demand increases coupled with the type A relation. The area with decreased food supply service coordination is distributed in stony mountains, intermountain basins and valley basins in the east with a significant positive supply increase. The increase in the coordination of carbon fixation service is mainly concentrated in the eastern and western regions with higher vegetation coverage and along the Datong River coupled with type C, where the demand increases and supply decreases. The reduction of soil retention service coordination is distributed in eastern and western stony mountains with severe rainfall erosion and a negative increase in soil retention capacity coupled with type B. Therefore, the coordination of various services in Lanzhou is as follows: water supply service (value: 0.0372) < food supply service (value: 0.0533) < carbon fixation service (value: 0.1183) < soil retention service (value: 0.2540), which is dominated by low coordinated coupling. The coordination of low- and moderate-coordinated regions decreases in varying degrees, and no double-optimal region exists with high and extreme coupling coordination of ESs. The imbalanced coupling relationship of ESs are mainly distributed in urban regions dominated by construction land. The further outspread of construction land reduces the supply capacity of ecosystems in the Loess hilly area where the original ecological environment is fragile. With the enhancement of people's living levels and the agglomeration of large populations into cities, the demand of cities increases, and the coordination of ESs in urban areas decreases.

The proportion in the same period is grouped according to each coupling coordination type by using the frequency analysis method (Yang et al., 2015), and the statistical results are fitted to the evolution curves of supply-demand coupling of ESs in 2005 and 2017. At the same time, the overall ESs supply and demand coupling evolution curve (Fig. 6) is fitted for nearly 10 yr based on the data of the two stages.

Water supply service shows a wave variation characterised by low coupling coordination to moderate and high coupling coordination, and the evolutionary situation is close to an 'S-shaped' growth curve (Fig. 6a). The coupling types are mostly concentrated in the low-

Table 2 Coordination degree of supply and demand coupling of four Ecosystem services (ESs) in Lanzhou City from 2005 to 2017

ESs	Coupling coordination degree		Changes in coupling coordination degree
	2005	2017	
Water supply service	0.0408	0.0335	−0.0073
Food supply service	0.0658	0.0408	−0.0250
Carbon fixation service	0.1002	0.1363	0.0361
Soil retention service	0.2628	0.2451	−0.0177

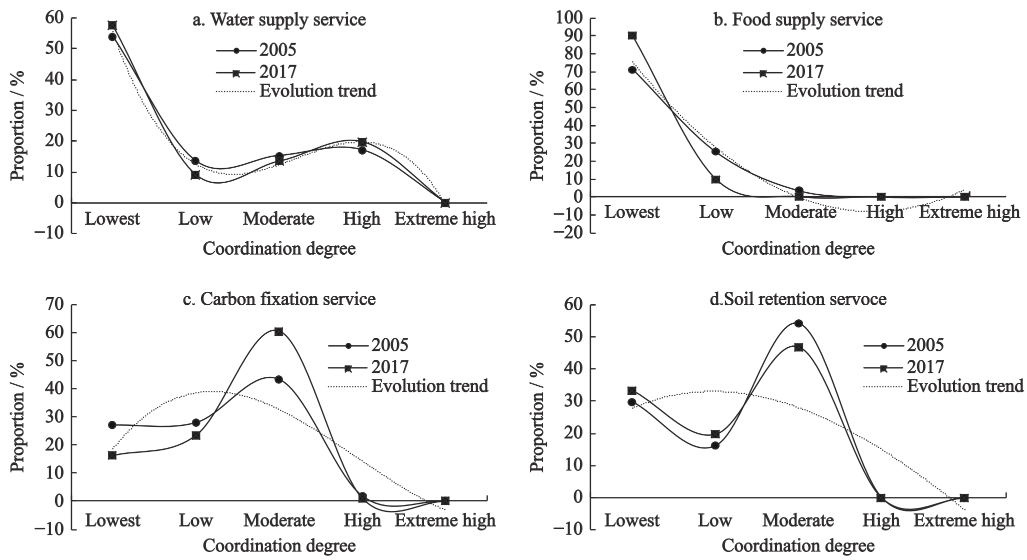

Fig. 6 Coordination evolution curve of the supply and demand of ESs in Lanzhou City in 2005 and 2017

coordinated phases, and moderately coordinated coupling tends to develop into highly coordinated coupling. The coordination of the supply and demand of water supply service is coordinated from low to moderate coupling. In addition, several moderately coordinated coupling areas gradually change to the highly coordinated stage, and the coupling coordination of the supply and demand of water supply service in this region develops into a reasonable and orderly state.

Food supply service shows a decreasing evolution characteristic from low coupling coordination to high coupling coordination, and the evolution is close to a 'U-shaped' curve (Fig. 6b). The type of coupling coordination is basically at a low level. The evolutionary condition implies that the food supply service coupling coordination will continue to develop into an unreasonable disorderly state from low coupling coordination and cannot move to an orderly state until a minimum peak occurs. Thus, the coordinated development and optimisation of food supply and demand are imminent.

Carbon fixation and soil retention services exhibit a normal distributed variation from low coordinated coupling to moderately and highly coordinated coupling with accelerating attenuation. The evolution is close to an 'inverted U-shaped' curve (Figs. 6c, 6d), and moderately coordinated coupling is the main type of significant change. Over time, the coupling coordination will become concentrated towards the moderate coupling coordination level. Therefore, further optimisation measures are required to promote the orderly state of the two services to a high level of coupling and coordination.

4 Discussion

As a typical ecologically fragile area in China, the Loess Hilly area is characterised by broken terrain, sparse vegetation, serious soil erosion and relatively backward social and economic development. Due to the existence of the dual urban-rural structure in the underdeveloped areas of the west, the level of coupling coordination between supply and demand of ESs in the Loess Hilly region is significantly lower, which is different with the economically developed east China (Ou et al., 2018; Shi and Shi, 2018). And with the promotion of 'Western Development' and 'Silk Road Economic Belt' strategies, the social economy of this region has rapidly developed and has encountered increasing contradiction between social economic development and ecological protection. Empirical research on Lanzhou City deepens the geographic theory research of this type of regional ESs, provides a theoretical basis for the balance of supply and demand of urban and rural ESs in the Loess Hilly region, and serves as a guide for the rational allocation of ecological resources and ecological restoration in the region and the same type of region.

4.1 Dynamic analysis of supply and demand coupling of water supply service

As we all know, the rational allocation of water resources is very important for regional socio-economic development, and rapid urbanization is still the main reason for the shortage of regional water resources (De Lima et al., 2018). However, according to the current management policies, the relationship between supply and demand and spatial distribution characteristics of water resources are still unclear, which leads to the lag of decision-making and the blindness of decision-makers (Chen et al., 2020). The loess hilly region suffers from drought and lack of water resources. Therefore, by dynamically evaluating the water supply of natural ecosystem and the water demand of human production and living system, this study reveals the coupling relationship between supply and demand, the coordinated development of supply and demand and its development trend, which will be of great practical significance to the rational utilization and protection of water resources in the loess hilly region.

The research results showed that the coupling relationship between supply and demand of water supply service was dominated by a negative coupling type D and assisted by a positive coupling type A. Precipitation did not change significantly in type D areas, and the dynamic increase of water supply service was mainly affected by factors such as available water content of vegetation, root depth of vegetation and land use/cover type (Ellison et al., 2012). The dynamic decrease of the demand for water supply services was mainly due to the decrease of population density. With the advancement of urbanization, the population in the Loess hilly region concentrated in cities and towns, and the rural population reduced sharply, resulting in a decrease in the demand for regional water supply services. Type A region was mainly affected by climate change, although the change was not significant, but the dynamic change value of water supply service supply was greater than zero. The dynamic increase in demand for water supply services was mainly due to the population gathering in cities and the per capita water demand increased sharply due to the development of urbanization (Jim, 2013; Zhao et al., 2018). Consistent with the existing research results, the rapid development of urbanization drives the change of land use/cover types (mainly for the transformation of forest land, grassland and cultivated land to construction land) and population density (Wang et al., 2014; Palacios-Agundez et al., 2015), which led to the imbalance between supply and demand of regional water supply service and the decrease of coupling coordination. Therefore, natural ecosystems should be protected and restored in urbanized areas, so as to reduce the imbalance between supply and demand of ecosystem services brought about by urban expansion, and promote the coupling of supply and demand of ecosystem services and the sustainable development of social economy (Gómez-Baggethun and Barton, 2013; Jim, 2013; Sirakaya et al., 2018). However, the non-urbanized area in the Loess hilly region accounts for a relatively large area, so the coupling relationship between supply and demand of water supply services in the study area presents type D overall, and the coupling degree between supply and demand presents an evolution from disordered low-level coupling coordination to orderly moderate and high-level coupling coordination, and the evolution trend is close to an 'S-shaped' growth curve. Therefore, these areas should continue to increase the construction of ecological protection and restoration projects, maintain the integrity of existing natural ecosystems, restore natural vegetation in mountainous areas, strictly limit the scale of land development, and enhance the supply capacity of regional water supply services.

4.2 Dynamic analysis of supply and demand coupling of food supply service

Food security is the foundation of national and regional economic and social stability, and grain yield is the most important index to measure food security. Therefore, the core content of maintaining regional food security is to stabilize and improve regional grain yield (Yao et al., 2016). Since 2004, China's grain output has achieved sustained growth for 12 yr, and its current production capacity has stabilized at over 600 million tons (Yao et al., 2016; He and Zeng, 2018). However, due to the emphasis on production and neglect of ecology, excessive use of chemical fertilizers and pesticides, agricultural non-point source pollution, degradation of agricultural ecological environment and other issues, the sustainability of food production has been greatly reduced. For example, in 2015, the amount of chemical fertilizer applied per unit area in China was 361.4 kg/ha, far higher than the internationally recognized upper limit of 225 kg/ha, which was 2.86 times that of the United States and 2.75 times that of the European Union (Li et al., 2018; Yao et al., 2019), therefore, it is particularly important to ensure the sustained and steady growth of grain production capacity to maintain China's food security. At the same time, some scholars also pointed out that population growth, economic development and urbanization will lead to rapid changes in the food consumption structure of urban and rural residents, and the total amount of food consumption will continue to increase, which will lead to the mismatch between food supply and demand and bring more serious threats to China's food security (Kearney, 2010). On the whole, China's grain problem has changed from total shortage to structural contradiction, and the regional contradiction between supply and demand will be a major practical problem faced by China's grain production (He and Zeng, 2018). Therefore, it is of great significance to study the coupling relationship between regional grain supply and demand and the coordinated development and evolution trend, so as to guide the region to formulate relevant policies and measures such as optimizing grain production layout, leading food consumption, and ensuring food security.

The research results showed that the coupling relationship between supply and demand of food supply service was dominated by a negative coupling type C and assisted by a positive coupling type A. In type C areas, the dynamic reduction of food supply service was mainly due to the expansion of urban land, the decrease of cultivated land in cities and surrounding areas, the decline of cultivated land quality and food supply capacity. The significant increase in the demand for food supply services was mainly due to the increase of population density, and the improvement of economic development level leads to rapid changes in the food consumption structure of urban and rural residents, and the total amount of food consumption increased constantly (Kearney, 2010), especially the population density in Anning District and Chengguan District increased from 2489 persons/km^2 and 4041 persons/km^2 to 3443 persons/km^2 and 6332 persons/km^2, per capita GDP rose from 11 608 yuan and 22 565 yuan to 59 814 yuan and 72 398 yuan. The rapid development of social economy and urbanization led to a significant increase in the demand for regional food supply services. The significant increase of food supply service in type A region was mainly due to the concentration of cultivated land resources, the construction of high-standard farmland and the development of agricultural modernization, which makes the regional food supply capacity improve. Especially in Qinwangchuan, Yuzhong Basin and Zhuanglang Valley, not only the cultivated land resources are concentrated, but also the agricultural irrigation water consumption is sufficient, and the agricultural production infrastructure is complete, so the supply of food supply services increased significantly. The demand for food supply services in type A region increased dynamically, but due to the restriction of population density and economic development level, the dynamic increase of demand was not significant. The type C region should control the expansion of urban land, implement regional stock development, minimize incremental development, ensure cultivated land area, and improve cultivated land quality and productivity. The type A area is the two major grain producing areas in the north and south of Lanzhou City. Although the supply and demand of food supply services are in a positive dynamic response, there are also significant hidden dangers. With the continuous advancement of industrialization and urbanization, the characteristics of the main body of agricultural labour force are increasingly obvious, and the agricultural production cost is constantly increasing (Yao et al., 2019). Therefore, it is of great importance to speed up the transformation from traditional agriculture to modern agriculture, improve agricultural infrastructure, model production and management, and continue to improve regional grain output. On the whole, the food supply service is still mainly reverse coupling, which belongs to the type of low coupling coordination. However, because the evolution trend is close to 'U-shaped', it shows an evolution trend from low-level coupling coordination to high-level coupling coordination. Therefore, it is necessary to continue to increase scientific and rational modern agricultural production and management mode, improve regional grain output and ensure the sustainable development of food supply and demand.

4.3 Dynamic analysis of supply and demand coupling of carbon fixation service

Carbon fixation service is a process in which natural vegetation captures and seals CO_2 in the atmosphere, which is an important regulation service in the ecosystem and can effectively slow down the global warming trend (Houghton et al., 2012; Huang et al., 2016). With the rapid urbanization process, the surge of impermeable water surface occupies a large amount of vegetation that can be used for carbon fixation (Sun et al., 2017), and the increase of urban population also brings more carbon emissions to urban areas (Fang et al., 2015), so the relationship between supply and demand of carbon fixation services in urban areas becomes increasingly tense. Lanzhou is a city with relatively fast economic development in the Loess hilly region. In recent years, with the construction of Lanzhou National New District and the growth of county economy, the change of land use/cover and the rapid increase of energy consumption have led to the imbalance between supply and demand of carbon fixation within the region. Although it is very difficult to pursue the absolute balance between supply and demand of carbon fixation services within cities, it is very important to clarify the dynamic response of supply and demand of carbon fixation services in time and space, clarify the coordinated development degree and evolution trend of supply and demand, and evaluate the sustainable change of urban areas. At the same time, the implementation of emission reduction policies needs to be implemented from individuals, streets to counties and districts from bottom to top. Analyzing the relationship between supply and demand of carbon fixation services within cities is conducive to strengthening the environmental perception of residents in different regions and promoting the smooth implementation of relevant policies (Meng et al., 2018).

The research results showed that the coupling relationship between supply and demand of carbon fixation services was dominated by a negative coupling type C and assisted by a positive coupling type A. In type C areas, the supply of carbon fixation services decreased significantly, especially in Lanzhou New District, urban area and Yuzhong county. The expansion of construction land in this area resulted in the decrease of natural vegetation, vegetation coverage and supply capacity of carbon fixation services. The dynamic change of carbon fixation service supply in type A region is not significant, but the change value is greater than zero, mainly because the supply capacity of carbon fixation service is directly related to natural vegetation (Muñoz-Rojas et al., 2011). In recent years, the green area has been increased through the implementation of projects such as returning farmland to forest and grassland and urban green space construction, but the effect is not significant and needs to be further improved. The significant increase in demand for carbon fixation services is mainly due to the increase of population density, and the rapid improvement of social and economic level leads to the continuous increase of carbon emissions and per capita energy consumption of urban residents in the process of living and transportation. Compared with the existing research results, the rapid urbanization process and the increase of urban population density are still the main reasons for high energy consumption and high carbon emissions (Deng et al., 2015; Li et al., 2016; Zhan et al., 2017), but there is a serious imbalance between supply and demand of carbon fixation services in urban areas, which leads to low coordination of supply and demand coupling in the whole region. Therefore, the urban areas with high degree of urbanization should speed up industrial transfer, promote energy conservation and emission reduction, improve land use efficiency, transform land use from extensive use to intensive economical use (Hersperger et al., 2018), develop urban green infrastructure, improve urban parks and green spaces, and improve the supply capacity of carbon fixation services within cities. Other non-urban areas should further reduce the pressure of human activities on the ecosystem, strengthen the protection of ecological environment, adjust the regional land use structure, maintain the advantages of economic development and ecological conditions (Wang et al., 2019), and ensure the sustainable development of the region.

4.4 Dynamic analysis of supply and demand coupling of soil retention service

Soil erosion is a major global environmental problem, which leads to land degradation and reduction of ecosystem services (Keesstra et al., 2018), and at the same time restricts human survival and development and regional economic and social sustainable development (Ganasri and Ramesh, 2016; Cook et al., 2017). China is one of the countries with the most serious soil erosion in the world, and 51% of its land area has suffered from soil erosion (Zhong et al., 2020). As a typical ecological fragile area in China, the loess hilly region has loose soil, broken terrain, criss-crossing hills and gullies, and arid climate. Soil erosion has become an important factor restricting the socio-economic development and the improvement of people's living standards in this region. Soil retention service is an important regulation service of ecosystem, which is the guarantee to control soil erosion, prevent soil degradation and reduce the risk of geological disasters (Fu et al., 2011; Frank et al., 2014; Liu et al., 2019). Improving the soil retention service can effectively alleviate the ecological and environmental problems such as soil fertility decline and agricultural non-point source pollution caused by soil erosion (Costanza et al., 1997). Therefore, revealing the spatial distribution characteristics of soil retention service supply and demand, and making clear the coupling relationship between supply and demand and the degree of coupling and coordinated development are very important to ensure the sustainable development of regional life, production and ecological space. The research results showed that the coupling relationship between supply and demand of soil retention service was dominated by a positive coupling type B. Both supply and demand decrease dynamically, mainly in the loess hilly and gully region in the northwest and southeast, which is prone to precipitation erosion due to its large terrain slope and low vegetation coverage. Therefore, continuing to strengthen the protection and restoration of natural ecosystems and implementing afforestation projects, especially in riparian areas and steep slopes, can effectively reduce soil erosion (Kim and Arnhold, 2018). The coupling coordination between supply and demand of soil retention services is low, but the changing area presents an 'inverted U-shape', which will evolve from disordered low coupling coordination to orderly moderate and high coupling coordination with time. Therefore, in the future construction, the implementation of soil and water conservation engineering measures, together with vegetation construction and farming measures, which can effectively control soil erosion, ensure food production, enhance the ability to cope with natural disasters, and effectively promote the improvement of ecological environment, people's living standards and social and economic development in the Loess hilly region.

5 Conclusions

The prominent contradiction between economic development and ecological environment has become the biggest obstacle to the future development of the region. In order to achieve sustainable economic and social development, managers should infiltrate the concept of sustainable ecosystem management into the specific decision-making process. As a bridge between natural ecosystem and human society, the supply and demand of ecosystem services reflect the complex dynamic relationship between ecosystem and human society. The research results showed that the coupling relationship between supply and demand of ecosystem services was dominated by a negative coupling relationship and assisted by a positive coupling type A in Lanzhou City. Rapid urbanization leads to population agglomeration, change of land use type and improvement of social consumption level, which are the main driving factors affecting the coupling of supply and demand and regional sustainable development. During the study period, the coupling coordination degree of supply and demand of various ecosystem services in Lanzhou is still in a low or lower coupling coordination development stage, but the evolution trend of the coupling coordination degree changed from disordered low of lower coupling coordination to orderly moderate and higher coupling coordination. Therefore, in the future, it is important to continue to increase the protection and restoration of natural vegetation and pay attention to the construction of blue-green space in urban areas, so as to ensure the sustainable development of regional economic development and ecological environment. Generally speaking, the implementation of more localized and effective land use decision-making and ecosystem management strategies can provide guiding direction for rational allocation and remediation of regional ecological resources, realize the coordinated development of ecology and economy, and enhance the sustainability of regional development.

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