Environmental Research Communications

PAPER

Modelling the dynamic of ecosystem service supply and demand in Chengdu-Chongqing twin-city economic circle, China

Zhonglin Tang*, Yuting Wang and Min Fu

1 Research Center for Economy of Upper Reaches of the Yangtze River & School of Economics, Chongqing Technology and Business University, Chongqing, People’s Republic of China
2 College of electronics and Internet of things Engineering, Chongqing Industry Polytechnic College, Chongqing, People’s Republic of China
* Author to whom any correspondence should be addressed.
E-mail: tangzl@ctbu.edu.cn

Keywords: Chengdu-Chongqing twin-city economic circle, ecosystem services, supply and demand pattern

Abstract
Research on ecosystem service supply and demand relations is necessary for effective ecosystem management and rational allocation of resources. Based on the Ecosystem Services Value Evaluation, calculation of Land Use Development Index (LDI) and Ecosystem Services Supply-Demand Ratio (ESSDR), the coupling pattern of ecosystem services supply and demand in the Chengdu-Chongqing Twin-city Economic Circle were described. The results showed that the ESSDR in the researched area basically maintained a pattern of gradual improvement from the dual core to the peripheral circle in terms of spatial structure. An obvious inter-annual difference in the supply and demand patterns was also observed, which showed that the change trend of ESSDR before and after 2000 was opposite. The accelerated urbanization and population migration brought about by the Western Development Strategy exacerbated the imbalance between supply and demand of ecosystem services, the relationship between supply and demand of ecosystem services show an overall negative correlation, but there were obvious regional difference. The coupling status was significantly greater in the southern Sichuan urban agglomeration than others in terms of the quantitative characteristics.

As a pivotal bridge binding human society and natural ecosystem, ecosystem services research has gradually become a hotspot in research on geography, ecology and other disciplines since SCEP (Study of critical environment problems, SCEP) was first proposed in 1970 [1–3]. From paying attention to the environmental conditions and processes of the ecosystem for human survival, to emphasizing the relationship between ecosystem services and human well-being since the Millennium Ecosystem Assessment was carried out, the focus of ecosystem services research has shifted from pure cognition of natural attributes to multidimensional deconstruction of coupling natural attributes and socio-economic attributes [1, 3, 4]. For a long period of time, research on ecosystem services mainly focused on the ‘supply side’ of ecosystem services, and emphasized the research on the natural attribute characteristics of ecosystem services, such as the classification, evaluation and study of the balance of ecosystem services [5–7]. In contrast, the ‘demand side’ of ecosystem services failed to receive sufficient attention. Research on the impact of ecosystem services on human well-being mainly laid stress on the description of human social demand via the change of value and material quality of a certain function, while ignoring the exploration of the supply, demand and supply-demand status of ecosystem services. With the constant improvement of research on ecosystem services, people gradually attach more importance to human well-being and demands in ecosystem services research. Boyd J [4], Burckhard [8]maintained that it is necessary to enhance the cognition of human needs in the research of ecosystem services. Without human well-being, ecosystem structure and processes cannot give rise to services.

In recent years, centering on the supply and demand of ecosystem services, the academia has conducted exploration and research from the multiple facets of concept definition, model algorithm, practical application and the like [9–13]. For instance, in terms of research methods, public participation, supply-demand
relationship matrix, ecological footprint and modeling have been subsequently introduced into the research on ecosystem service supply and demand. In the current research on the supply and demand of ecosystem services, depicting the spatial heterogeneity and dislocation of supply and demand is a core issue. Many scholars have studied this issue from various spatial and temporal scales [9, 10]. On the spatial scale, the current research covers administrative divisions, natural river basins and other geographical units, but still focuses on the small and medium-sized spatial scales, on the temporal dimension, most are static cross-section studies, whereas research on the spatial distribution and laws of ecosystem service supply and demand within long time series is relatively little. Therefore, it is imperative that the relevant research expand and extend its depth and breadth to deepen the understanding of spatial heterogeneity of supply and demand of ecosystem services and its spatial dislocation to solve the practical problems in natural resource management.

The Chengdu-Chongqing Twin-city Economic Circle is located in the upper reaches of the Yangtze River boasts rich geomorphic units, complex and diverse habitats, and prominent biodiversity. Simultaneously, natural disasters such as earthquakes, floods and mud-rock flows occur frequently. For that reason, the Circle is characterized with both the importance and vulnerability of ecosystem services. Hence, it is of top priority to conduct the ecological barrier construction in the upper reaches of the Yangtze River and ecological security protection over the Three Gorges Reservoir area. At the same time, this region also features the highest level of industrialization and urbanization in the upper reaches of the Yangtze River, with its population and economic density ranking first in the West. The conflicts between economic development and ecological environment protection are therefore prominent. Air pollution, non-point source pollution, river and lake shrinkage, soil and water loss have become several problems in regional environmental governance [13]. Supported by multiple national strategies such as the construction of the Yangtze River Economic Belt and that of the Chengdu-Chongqing Twin-city Economic Circle, the region is bound to usher in new economic and social development opportunities. Against such backdrop, it is imperative that measures are taken to deepen the depiction of the ecosystem service supply and demand in the region and coordinate regional development from the perspective of ecosystem service supply and demand, thus addressing the issues of reconciling the confrontation between regional population, economy, resources and environment, protecting the ecosystem services and biodiversity from being threatened and consequently spreading to other facets of human society, economy and life.

However, current studies have mostly focused on single city scales, such as Chengdu city and Chongqing city, etc, and there are fewer portrayals and discussions of the Chengdu-Chongqing twin-city economic circle and its ecosystem service supply and demand. Hence, with the national strategic region of the Chengdu-Chongqing Twin-city Economic Circle in view, this study starts from the supply and demand of ecosystem services to demonstrate the supply and demand of ecosystem services with the revised value of ecosystem services and the ecosystem service demand with the land use development index, construct the supply-demand ratio of ecosystem services, and characterize the coupling degree of supply and demand of ecosystem services. On that basis, it seeks to measure the relationship between the ecosystem service supply and demand in order to provide data support and decision guidance for regional natural resource management, effective resource allocation and corresponding ecological compensation policy making.

1. Methods

1.1. Research region

The Chengdu-Chongqing Twin-city Economic Circle is located in the Sichuan Basin and the upper reaches of the Yangtze River. It covers 27 districts (counties) including Yuzhong, Wanzhou and Qianjiang in Chongqing, and parts of Kaizhou and Yunyang, and 15 prefectural-level cities such as Chengdu, Zigong and Luzhou in Sichuan Province, with a total area of approximately 185,000 square kilometers (figure 1). In terms of spatial economic connections, it can be divided into the Chengdu urban agglomeration, the Chongqing urban agglomeration, the North Sichuan urban agglomeration and the South Sichuan urban agglomeration. The Chengdu-Chongqing Twin-city Economic Circle is situated at the forefront of the country’s Western Development strategy and is where the Yangtze River Economic Belt and the Belt and Road Initiative converge. Boasting the two National Cities of Chongqing and Chengdu, whose GDP both aggregate at over one trillion yuan, the region has the densest population, the most concentrated industries and the highest density of cities and towns in West China. In 2019, GDP of the region accounted for up to 33.25% of the total in western China and about 6.67% of the whole country.

1.2. Data source

The data involved in this study mainly includes land use status data, socio-economic statistics data, and NDVI data, etc. Among them, land use status data mainly come from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/). The spatial resolution is 30 meters; the
socio-economic data is primarily from the statistical yearbooks of Sichuan, Chongqing and the relevant counties and cities from 1990 to 2018, and the China Statistical Yearbooks (County-level) over the years; the NDVI data is mostly from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences, of which the NDVI data in 1990 as obtained from the Landsat TM images by band operation.

1.3. Research methods

1.3.1. Ecosystem service supply calculation

Ecosystem services supply represents the capacity of ecosystem products and services that can be provided by a particular region in a particular period of time [8]. According to the research methods adopted by Peng [9], this paper uses the value of ecosystem services to characterize the supply of ecosystem services. The calculation of ecosystem service value is based on the equivalent factor method proposed by Xie [9], which divides the ecosystem service functions into four categories and nine sub-categories. Meantime, considering the error of national parameters in the process of characterizing regional characteristics, the average grain yield price of the Chengdu-Chongqing Twin-city Economic Circle in 2018 was used to revise it. The average grain yield price was derived from the 2018 Sichuan and Chongqing statistical yearbooks, and this study uses the ratio of the output value of agriculture, forestry, animal husbandry and fishery to land use area in 2018 (1416.70 Yuan hm$^{-2}$) as the correction coefficient. As a result, the unit price list of the ecosystem service value of Chengdu-Chongqing Twin-city Economic Circle was created (table 1).

The ecosystem service value of county-level units is calculated per the unit pricelist of the ecosystem service value of the Chengdu-Chongqing Twin-city Economic Circle and the data of various land use type area over the years. At the same time, in light of the difference of land use area of each district and county, to facilitate the horizontal comparison of ecosystem service supply capacity among districts and counties, the average unit area ecosystem service value ($a_{ESV}$) of each district and county is calculated to reflect the ecosystem service supply capacity.

$$a_{ESV} = \sum_{i=1}^{n} V_{Ci} \cdot \frac{U_i}{U}$$

Where, $a_{ESV}$ is the value of ecosystem services per unit area; $U_i$ and $U$ are respectively the area and total land area of Type $i$ land; $V_{Ci}$ is the total value of ecosystem services of Type $i$ land.

1.3.2. Ecosystem service demand calculation

Currently, there are distinct differences in the understanding of ecosystem service demand between domestic and foreign scholars, which results in differing calculation methods. In this paper, while referring to the relevant research, the ecosystem service demand is defined as the demand and preference of human beings for the production and consumption of ecosystem products and services in a particular time and region by combining...
Villamagna’s [13] definition of ecosystem service demand. Coupled with the actual situation of the research area, this paper uses land use development index (LDI) to represent the demand of ecosystem services. LDI comprises three parts: the proportion of construction land, population density and economic density. The higher the proportion of construction land, the higher the degree of human society’s land development in the region; the higher the population density, the higher the demand for ecosystem services; the higher the economic density, it reflects the supply and sharing of ecosystem services The higher the degree of preference. The calculation formula of LDI is as follows [9]:

\[ LDI = D_i \cdot \log(P_i) \cdot \log(E_i) \]

Where, LDI represents land use development index; \( D_i \), \( P_i \) and \( E_i \) stand for the proportion of construction land, population density and per capita GDP respectively. The purpose of deploying logarithm is to eliminate the index fluctuation caused by substantial differences in the population density and per capita GDP in a few extremely developed areas.

1.3.3. Ecosystem service supply and demand ratio

On the basis of the above mentioned research, this study adopted the ratio of ecosystem service value per unit area and land use development index (LDI), namely the ecosystem service supply and demand ratio (ESSDR) to characterize the coupling of ecosystem services supply and demand.

\[ ESSDR = \frac{\log(aESV)}{LDI} \]

In the aforesaid formula, the higher the ESSDR index, the better the coupling between supply and demand. In a bid to further present the spatio-temporal coupling of supply and demand of ecosystem services, the results are classified into 5 levels according to the quantile classification method in ArcGIS10.2 by using the quantile classification method in the Technical Guide for Ecological Protection Red Line Delineation of the Ministry of Environmental Protection, China. The results are classified as Worst, Worse, Medium, Better, and Best from low to high.

1.3.4. Ecosystem service supply and demand quadrant division

To further demonstrate the temporal and spatial dynamics of ecosystem service supply and demand, this study standardized the supply and demand of ecosystem services via Z-score, and divided the supply and demand of ecosystem services into four quadrants according to the x-axis and y-axis respectively. Among them, Quadrants I ~ IV represent high demand supply, low supply high demand, low supply low demand and high supply demand respectively.

\[ s = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x - \bar{x})^2} \]

Where, \( x \) is the supply or demand of ecosystem services after the standardization of evaluation units, \( \bar{x} \) is the regional average value, \( S \) is the regional standard deviation, and \( n \) is the total number of evaluation units.
2. Results

2.1. Ecosystem service supply and demand spatial distribution

In view of the quadrant distribution of ecosystem service supply and demand in various prefectural–cities (table 2 and figure 2), the distribution of ecosystem services supply and demand quadrants of each prefectural-level city in the Chengdu-Chongqing Twin-city Economic Circle changed substantially between 1990 and 2000, which was primarily shown in the decrease of cities in the fourth quadrant and the sharp increase of cities in the second quadrant. The quadrant division of cities trended towards the stable level after 2010. Among them, the quadrant distributions of Chongqing and Guang’an are relatively stable, which are in Quadrant 1. That is closely intertwined with the fact that the two cities are typical mountainous cities, with good ecological background conditions and a strong demand for urban development; plain cities such as Chengdu, Deyang and Suining can basically stay within Quadrant 2, that is, ‘low supply high demand’ quadrant. Cities in this quadrant are densely populated and do not have many natural habitats. With the increase of population concentration, the demand for ecosystem services is also on the rise year by year. Meishan and Leshan are basically in the third quadrant, namely low supply low demand quadrant; while Ya’an, Yibin and Neijiang in Southern Sichuan urban agglomeration are all in the fourth quadrant, i.e. high supply and low demand quadrant, which is in line with the higher ecological background conditions of the Southern Sichuan urban agglomeration and the low urban development intensity there. Additionally, Nanchong and Zigong displayed a trend of quadrant movement before and after 2000, and transferred from the second quadrant to the fourth quadrant, reflecting the acceleration of urban development during this period, the increase of urban population and economic growth, and the augmenting demand for ecosystem services.

The distribution of ecosystem services supply in the research area from 1990 to 2018 is shown in figure 3. In general, the distribution pattern of ecosystem service supply in each county is relatively stable. Among them, Ya’an and Leshan in the Southern Sichuan urban agglomeration have the highest supply of ecosystem services per unit area, with the value per unit area exceeding 23,800 yuan ha\(^{-1}\). In 2018, Shimian County of Ya’an reached 25,800 yuan ha\(^{-1}\), which is the highest unit area of each county in the past years. The low value areas of ecosystem service supply per unit area are mainly located in the Chengdu urban agglomeration, for example, Pidu District of Chengdu (6600 yuan ha\(^{-1}\); 2018), Xindu District of Chengdu (8700 yuan ha\(^{-1}\); 2018). From the average level of the four major urban agglomerations, it can be told that from 1990 to 2018, the supply per unit area of the Southern Sichuan urban agglomeration was the highest, ranging between 17,300–17,600 yuan ha\(^{-1}\), followed by the Chongqing urban agglomeration with a range of 15,800–16,200 yuan ha\(^{-1}\), and the Northern Sichuan urban agglomeration of 14,500–14,600 yuan ha\(^{-1}\). The Chengdu urban agglomeration was the lowest, ranging between 13,800–14,000 yuan ha\(^{-1}\).

Figures 4(a)–(d) show the LDI data calculated based on the grid processing of population and GDP [14]. It can be found that there are noticeable spatial differences in the distribution trend of the national economic factors in the Chengdu-Chongqing Twin-city Economic Circle. In general, it is high in the two cores, low in the periphery and moderate in the center. The spatial correlation between population and economic distribution is strong. To further demonstrate the spatial distribution difference of ecosystem service demand, this research...
carried out county unit statistics and spatial mapping of ecosystem service demand as shown in figures 4(e)∼(f). The demand for ecosystem services in the Chengdu-Chongqing Twin-city Economic Circle is high in the two cores, low in the periphery and moderate in the central part (figure 4). From 1990 to 2018, the high value areas of ecosystem service demand were mainly located in the city proper of Chongqing in the Chongqing urban agglomeration and Chengdu in the Chengdu urban agglomeration, with the LDI values both exceeding 0.60. Among them, the LDI value of the Yuzhong District of Chongqing reached 1.66 in 2018, which was the highest among various county units in the past years; the low value areas of ecosystem service demand were mainly distributed in Ya’an and Leshan of the Southern Sichuan urban agglomeration, whose LDI values both lower than 0.3. Compared with the dual core cities, namely, the city proper of Chongqing and the city of Chengdu, socio-economic development and population density are lower in those regions, hence less demand for ecosystem services. In general, between 1998 and 2018, demand for ecosystem services in the Chongqing urban agglomeration was the highest among the four urban agglomerations, with the LDI values basically maintained between 0.44 ∼ 0.78; second to that was the Chengdu urban agglomeration, with the LDI values ranging from 0.44 to 0.74; the Northern Sichuan urban agglomeration, with the LDI values ranging from 0.41 to 0.73; and the Southern Sichuan urban agglomeration, with the LDI values ranging between 0.32 ∼ 0.60.

2.2. Analysis on the ecosystem service supply and demand pattern and changes
By building on the analysis of the supply and demand of ecosystem services, this research deploys the ratio of ecosystem service supply and demand to represent the coupling of the latter, and quantifies the coupling status of supply and demand with the mean standard deviation method. From 1990 to 2018, the spatial-temporal coupling pattern of ecosystem services supply and demand in the Chengdu-Chongqing Twin-city Economic Circle basically remained stable, displaying a sound coupling situation at the outer circle layer, a poor coupling between supply and demand in the Chengdu-Chongqing dual-core region, and a moderate supply-demand pattern in the central region of Chengdu and Chongqing. At the same time, the interannual and regional differences in the coupling of ecosystem services supply and demand are obvious, as shown in figures 5 and 6.
While comparing the supply-demand coupling of ecosystem services, the Southern Sichuan urban agglomeration has the best coupling of ecosystem services supply and demand, averaging at 32.41, followed by the Chongqing urban agglomeration, the Chengdu urban agglomeration and the Northern Sichuan urban agglomeration, with the average ESSDRs standing at 19.11, 19.08 and 18.38, respectively.

2.3. Characteristics of the ecosystem service supply and demand quantity relationship
To further specify the correlation between the supply and demand of ecosystem services and the characteristics of quantitative relationship between variables, this research adopted the Pearson correlation coefficient and the linear regression method commonly used in statistical analysis to quantitatively analyze the correlation and quantitative relationship characteristics between the supply and demand of ecosystem services in the research area between 1990 and 2018. The results of correlation analysis of ecosystem services supply and demand of the Chengdu-Chongqing Twin-city Economic Circle from 1990 to 2018 are shown in table 3. Except some of the...
years, they could all pass the correlation significance test. The results showed that the supply of ecosystem services decreased with the increase of demand for ecosystem services, and vice versa. The correlation between supply and demand of ecosystem services is also increasing year by year. The correlation between supply and demand of ecosystem services in the four urban agglomerations reached the highest value in 2018, which is closely related to the rapid growth of regional economic volume in this period. According to the results, the supply and demand of ecosystem services in the Chengdu urban agglomeration and the Southern Sichuan urban agglomeration passed the correlation significance test between 2000 and 2018, and the correlation of the Chengdu urban agglomeration is greater than that of the Southern Sichuan urban agglomeration. This is primarily attributed to higher population density, stronger economic development vitality and higher demand...
for ecosystem services in the Chengdu urban agglomeration. Meanwhile, the former did greater damage to the natural ecological environment, the supply of urban ecosystem services was less and yet the consumption was more dramatic [15]. The supply and demand of ecosystem services in the Chongqing urban agglomeration from 2010 to 2018, and from 1990 to 2018 in the Northern Sichuan urban agglomeration passed the correlation significance test, showing an rising trend. However, the supply and demand of ecosystem services in the Chongqing urban agglomeration between 1990 and 2000 and between 2000 and 2010 in the Northern Sichuan urban agglomeration failed to pass the correlation significance test, which indicated that although there were strongly correlations between the demand and supply of ecosystem services from the perspective of urban agglomerations, the spatial variation also existed. This variation stemmed to a greater extent from data variation within the sample, i.e., there were large internal differences between the ecosystem service supply and demand for each administrative unit within the urban agglomeration, resulting in a non-significant correlation for the urban agglomeration as a whole.

This research conducted further analysis on the quantitative relationship between the supply and demand of ecosystem services in different years with the method of univariate linear regression analysis. The regression results all passed the significance test, and the estimated values of parameters were negative. It can be told from figure 7 that there is a negative correlation between the supply and demand of ecosystem services in different regions and years in the Chengdu-Chongqing Twin-city Economic Circle, which further indicates that the areas with high demand for ecosystem services have higher utilization and development degree of natural ecosystem due to frequent human activities and rapid economic development, and the underlying surface of the city changes substantially, thus significantly debilitating the ecosystem service supply function of the natural ecosystem [15–17].

Simultaneously, seen from the quantitative characteristics of the supply-demand relationship of ecosystem services, there are noticeable regional differences. For instance, in the same year, the slope of the regression equation of the Southern Sichuan urban agglomeration is distinctly greater than that in the other three urban agglomerations. The major reason lies in the difference of ecological background among regions. Among them, Muchuan County, Mabian County, Ebian County and others in the Southern Sichuan urban agglomeration are state-level and provincial-level key ecological function areas located within the Qionglai

| Table 3. Correlation analysis of ecosystem services supply-demand in the Chengdu-Chongqing Twin-city economic circle over the research years. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Supply 1990     | Supply 2000     | Supply 2010     | Supply 2018     |
|                 | Pearson         | Sig.            | Pearson         | Sig.            | Pearson         | Sig.            | Pearson         | Sig.            |
| Chengdu-Chongqing Twin-city Economic Circle | Demand1990 | -0.601a 0.000 | Demand2000 | -0.624 0.000 | Demand2010 | -0.750 0.000 | Demand2018 | -0.794 0.000 |
| Chengdu urban agglomeration | Demand1990 | -0.882 0.000 | Demand2000 | -0.827 0.000 | Demand2010 | -0.888 0.000 | Demand2018 | -0.891 0.000 |
| Chongqing urban agglomeration | Demand1990 | -0.234 0.190 | Demand2000 | -0.304 0.086 | Demand2010 | -0.450 0.009 | Demand2018 | -0.722 0.000 |
| Southern Sichuan urban agglomeration | Demand1990 | -0.660 0.000 | Demand2000 | -0.679 0.000 | Demand2010 | -0.884 0.000 | Demand2018 | -0.888 0.000 |
| Northern Sichuan urban agglomeration | Demand1990 | -0.494 0.020 | Demand2000 | -0.282 0.203 | Demand2010 | -0.316 0.151 | Demand2018 | -0.493 0.020 |

* indicates that the correlation is significant at the level of 0.01 (double tail).

b indicates that the correlation is significant at the level of 0.05 (double tail).
Mountain biodiversity preservation ecological protection red line and the Minshan Mountain biodiversity maintenance water conservation ecological protection red line. The ecological background is healthy, and at the same time, the restrictions of natural ecosystem development and utilization are greater, meaning there are more districts and counties with 'high supply-low demand' than in the other urban agglomerations.

3. Discussion

The Chengdu-Chongqing twin-city economic circle is not only an important ecological barrier in the upper reaches of the Yangtze River in China, but also an important pivot point of China’s western development strategy. How to effectively protect the environment in the process of economic development is the primary issue facing the Chengdu-Chongqing twin-city economic circle. Although there are many studies on ecosystem services in the Chengdu-Chongqing twin-city economic circle, they are mostly focused on the level of single cities such as Chengdu and Chongqing [18–21], lacking an overall knowledge of the economic circle. Meanwhile, most of the current studies focus on the research of ecosystem service supply, such as water conservation, soil conservation, and production supply, there is a lack of discussion on the demand for ecosystem services in urban agglomerations and the coupling relationship between ecosystem service supply and demand. Thus bringing much inconvenience to alleviate the man-land contradiction and solve the problems of natural resource management. Therefore, this study constructs an evaluation system of ecosystem service supply and demand from the perspective of the economic circle as a whole, so that it has a unified and comparable metric basis, and thus portrays the actual situation of ecosystem service supply and demand in the economic circle in a more detailed manner.

Judging from the ecosystem service supply, South Sichuan urban agglomerations have the highest ecosystem service supply capacity, followed by the Chongqing urban agglomerations, northern Sichuan urban agglomerations and Chengdu urban agglomerations. The reasons for the differences in ecosystem service supply capacity of urban agglomerations can be attributed to the differences in natural ecological background conditions, population, and economic development levels of each region, resulting in an unbalanced spatial distribution of ecosystem service supply [15, 22, 23]. Generally speaking, regions with high ecosystem service supply have smaller populations and relatively lower economic development levels. Meanwhile, the climate is optimum, the precipitation is sufficient, the vegetation coverage is high, and the ecological environment is seldom damaged, which can provide more ecosystem services [24] such as the South Sichuan urban agglomeration; while areas with high demand for ecosystem services are mostly located in developed areas with...
high population density, rapid urbanization process and high degree of land development and utilization, where the areas of woodland, grassland, wetland and other ecological land types are smaller, the supply of ecosystem services is less, and the ecological pressure is high, hence higher demand for ecosystem services such as the Chengdu urban agglomeration and the Chongqing urban agglomeration [9, 13].

In terms of the coupling of ecosystem service supply and demand, the Chengdu-Chongqing Twin-city Economic Circle also shows large spatial and temporal differences, factors such as urbanization, economic development intensity, and population migration have greatly influenced the pattern of supply and demand for ecosystem services. For example, during 1990 and 2000, due to relatively fewer economic activities and urban construction activities as well as relatively low population density, the ecological environment was less affected by human activities, and the demand for ecosystem services was not strong, so it was in a period of surplus supply and small demand for ecosystem services, of which the South Sichuan urban agglomeration featured the highest degree of coupling thanks to its enabling ecological background. After 2000, the coupling of the supply and demand of ecosystem services started to display substantial regional differences. First, from the comparison of supply-demand ratio, the ESSDR index of each county unit in the region was basically lower than that in 2000 and showed a continuous downward trend. The major reason was that with the gradual implementation of the western development strategy, the Chengdu-Chongqing Twin-city Economic Circle has seen large-scale economic activities since 2000. During this period, the growth rate of urban residential land, traffic land and industrial land was higher than 150%, and the urbanization rate was further elevated, which led to the loss of the original natural habitat and the further change of urban underlying surface morphology and structure [11, 15, 17, 22]. Forest land, grassland and water area that can provide important ecosystem services decreased drastically, and fell into the ‘double dilemma’ situation of less supply of ecosystem services and high demands for ecosystem services, resulting in a significant downward trend of coupling between supply and demand of ecosystem services. In addition, it could be told from the quantitative relationship between supply and demand of ecosystem services that there is a negative correlation between the supply and demand of ecosystem services in the research area, namely, with the increase of demand for ecosystem services, the supply of ecosystem services decreases, which is consistent with the research conclusion of Peng [9], in Guangdong Province. Simultaneously, seen from the fitting regression model, the slope of the South Sichuan urban agglomeration is smaller than that of other urban agglomerations owing to its solid ecological background conditions. Shown in the change of quantitative characteristics, it signifies that the impact of changes in ecosystem service supply is relatively small.

At present, the Chengdu-Chongqing twin-city economic circle is in a new round of western development process, it is critical to effectively avoid the negative environmental impacts brought about by economic development, such as shrinking wetlands, watershed pollution, etc. Reflected in the supply and demand of ecosystem services, it means the coupling degree of supply and demand was significantly reduced, and the coordination between the supply and demand of ecosystem services among regions was unbalanced. In the limited space of land development, it is necessary to clarify the supply and demand characteristics of different urban agglomerations in the process of urbanization in order to meet the demand of ecosystem services brought about by population agglomeration and the sustainable development of natural ecosystem services and biodiversity so as to realize targeted zoning management and planning. Based on this research, we suggest that in areas with rapid urbanization such as the Chengdu urban agglomeration and Chongqing urban agglomeration, on the one hand, increase the control of unreasonable human activities, moderate the population size, orderly transfer polluting industries, build a green and economical industrial system, and reduce the pressure of urban development on the ecosystem. On the other hand, set reasonable ecological preservation areas in the existing natural or semi natural habitats with key functions of biodiversity conservation and ecosystem services to ensure the effective and sustainable supply of urban ecosystem services. In urban agglomerations with better ecological background and lower demand for ecosystem services, such as the southern Sichuan urban agglomeration, efforts should be made to maintain the integrity of the natural ecosystem, increase the protection of the natural ecosystem, improve the ecological compensation system, and adjust the government’s ecological and environmental performance assessment standards to better strengthen the effective supply of ecosystem services. At the same time, green infrastructure construction should be increased, some environment-friendly and resource-saving industries could be moderately undertaken, and the development of green industries such as recreation and tourism should be promoted.

4. Conclusion

The results show that: (1) between 1990 and 2018, the supply and demand patterns of ecosystem services in the Chengdu-Chongqing Twin-city Economic Circle were largely varied, and the overall situation was as follows: the coupling of the peripheral circle was good, of the supply and demand of the Chengdu-Chongqing dual cores was poor, and the spatial pattern of supply and demand of Central Chengdu-Chongqing area substantially
lagged behind. The regions with good coupling of ecosystem services supply and demand were mainly distributed in the South Sichuan urban agglomeration and the Northeast and Southeast Chongqing urban agglomeration with solid ecological background and less ecological demands; areas with moderate supply and demand of ecosystem services were mainly distributed in the North Sichuan urban agglomeration and the West Chongqing urban agglomeration; areas with poor coupling degree of ecosystem services supply and demand were mainly distributed in the Chengdu city proper in the Chengdu urban agglomeration and the city proper of Chongqing, namely the dual-core area, which have high urbanization rate and the most frequent human economic activities, whereas the forest and grass coverage rate and landscape greening rate are relatively low. (2) The coupling between supply and demand of ecosystem services displayed significant inter annual differences. From 1990 to 2000, the coupling of supply and demand of ecosystem services in the Chengdu-Chongqing Twin-city Economic Circle continued to improve, while after 2000, the coupling of ecosystem services supply and demand showed a continuous downward trend, which was highly consistent with the large-scale economic development activities in this period. (3) There is a negative correlation between the supply and demand of ecosystem services in the Chengdu-Chongqing Twin-city Economic Circle, but there are noticeable regional differences in the relationship between supply and demand of ecosystem services. With changing ecosystem service supply, changes to the ecosystem service demand in the South Sichuan urban agglomeration is smaller than that in other urban agglomerations.

Additionally, there are still many deficiencies in this research. (1) On account of limited data available, this research uses ecosystem service value and Land Use Development Index (LDI) to represent the supply and demand of ecosystem services, while index selection and measurement remains to be completed; (2) the main research content of this paper is quantitative evaluation of the supply and demand of ecosystem services as well as the coupling in Chengdu-Chongqing Twin-city Economic Circle. Restricted by the current research topic, discussion on the reason and process of the coupling change of supply and demand, the environmental effect and burden in the process of supply and demand change is not deep enough, which needs to be fine-tuned.

Acknowledgments

We gratefully acknowledge the Supported by National Social Science Fund of China (20CJL022).

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Author contributions

Zhonglin Tang conceived and designed the experiments; Zhonglin Tang performed the experiments; Zhonglin Tang and Min Fu analyzed the data; Zhonglin Tang contributed materials / analysis tools; Zhonglin Tang and Min Fu wrote the paper, Zhonglin Tang reviewed drafts of the paper.

ORCID iDs

Zhonglin Tang  https://orcid.org/0000-0001-5635-4746

References

[1] Bukhard B, Kroll F, Nedkov S and Müller F 2012 Mapping ecosystem service supply, demand and budgets Ecological Indicators 21 17–29
[2] Costanza R, Arge, Groot R D, Farberk S and Belt M V D 1997 The value of the world’s ecosystem services and natural capital Nature 387 253–60
[3] Schulp C J E, Lautenbach S and Verburg P H 2014 Quantifying and mapping ecosystem services: demand and supply of pollination in the European Union Ecol. Indic. 36 131–41
[4] Boyd J and Banzhaf S 2007 What are ecosystem services? The need for standardized environmental accounting units Ecol. Econ. 63 616–26
[5] Mehring M, Ott E and Hummel D 2018 Ecosystem services supply and demand assessment: Why social-ecological dynamics matter Ecosystem Services. 30 124–5
[6] Sadi N and Spray C J 2018 Ecosystem services bundles: challenges and opportunities for implementation and further research Environ. Res. Lett. 13 113001
[7] Yahdjian L, Sala O E and Havstad K M 2016 Rangeland ecosystem services: shifting focus from supply to reconciling supply and demand Frontiers in Ecology & the Environment. 13 44–51
[8] Burkhard B, Groot R D, Costanza R, Seppelt R, J, Rgensen S E and Potschin M 2012 Solutions for sustaining natural capital and ecosystem services Ecol. Indic. 21 1–6

[9] Peng J, Yang Y, Xie P and Liu Y 2017 Zoning for the construction of green space ecological networks in Guangdong Province based on the supply and demand of ecosystem services Acta Ecologica Sinica. 37 4562–72

[10] Troy A and Wilson M A 2007 Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer Ecol. Econ. 60 435–49

[11] Zhai T, Wang J, Jin Z and Yuan Q I 2019 Change and correlation analysis of the supply-demand pattern of ecosystem services in the Yangtze river economic belt Acta Ecologica Sinica. 15 5414–24

[12] Xiao Y, Xie G, Chunxia L U and Jie X U 2016 Involvement of ecosystem service flows in human wellbeing based on the relationship between supply and demand Acta Ecologica Sinica. (https://doi.org/10.5846/stxb201411172274)

[13] Yan Y, Jieyuan Z, Gang W and Yunjun Z 2017 Review and prospective applications of demand, supply, and consumption of ecosystem services Acta Ecologica Sinica. 37 2489–96

[14] Liu H, Jiang D, Yang X and Luo C 2005 Spatialization approach to 1km Grid GDP supported by remote sensing. Journal of Geo-information Science 7 120–3

[15] Lang W U, Zhou T G, Wen L, Liu X L and Zha X B 2018 Study on spatio-temporal relationship between PM2.5 and urbanization based on remote sensing data—a case study of Chengdu-Chongqing urban agglomeration Resources & Environment in the Yangtze Basin 9 2142–52

[16] Feng H, Zou B and Tang Y 2017 Scale- and region-dependence in landscape-PM2.5 correlation: implications for urban planning Remote Sensing. 9 918

[17] Wang J, Zhang J, Jiang H and Lu Y 2015 API-based assessment on urban air environment bearing capability in China Frontiers of Environmental Science & Engineering. (https://doi.org/10.1007/s11783-014-0662-0)

[18] Luo Y, Liu S, Zhang C, Ning R and Zhou J 2020 Evaluation of urban ecosystem service value under new urbanization—a case study of chengdu city ESS Web of Conferences. 165 02028

[19] Ma J, Peng M, Li C, Yue P and Hong W 2014 Temporal and spatial variation of ecosystem service value in the three gorges reservoir region( chongqing section) based on land use Scientia Silvae Sinicae 50 17–26

[20] Xue L L, Yuan X Z, Wang Y H, Bang-Liang H E and Liu F B 2015 Evaluation and analysis of the value of wetland ecosystem service in chongqing Journal of Sichuan Forestry Science and Technology. 36 7–15

[21] Yao Y 2021 Estimation of Urban Ecosystem Services Value: A Case Study of Chengdu, Southwestern China Remote Sensing. 13 13

[22] Liu X, Tian G, Feng J, Wang J and Kong L 2018 Assessing summertime urban warming and the cooling efficacy of adaptation strategy in the Chengdu-Chongqing metropolitan region of China Sci. Total Environ. 610–611 1092–102

[23] Shi K, Li Y, Chen Y, Li L and Huang C 2019 How does the urban form-PM_(2.5) concentration relationship change seasonally in Chinese cities? A comparative analysis between national and urban agglomeration scales J. Clean. Prod. 239 1–13

[24] Lin G, Jiang D, Fu J, Wang D and Li X 2019 A spatial shift-share decomposition of energy consumption changes in China Energy Policy 135 1–9