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Article

Matching Supply and Demand of Coal-based Urban Ecosystem Services

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Abstract: With the acceleration of urbanization, the ecological environment has gradually deteriorated, the supply and demand relationship of ecosystem services has gradually become unbalanced, and human well-being has been seriously threatened. In particular, coal-using cities are facing the dual pressure of the ecological environment and resource depletion due to the concentration of population and resources, and environmental contradictions. Thus, exploring the relationship between the supply and demand of ecosystem services and their evolution help promote scientific ecological management. By using multi-source data from Huainan City in 2010 and 2020 and the ecosystem service supply and demand matrix and ArcGIS quantitative measurement of the supply, the demand and supply of ecosystem services in Huainan City were investigated. The result implies the following. (1) During 2010–2020, the supply of ecosystem services in Huainan has decreased year by year. In terms of spatial distribution, the ecosystem service supply in Huainan City was high in the south and low in the north, and there is a significant regional differentiation, (2) Between 2010 and 2020, the demand for ecosystem services in Huainan City increased year by year, and its spatial distribution was similar to the distribution of ecosystem service supply. (3) Due to the decline in the supply of ecosystem services between 2010 and 2020, the demand for ecosystem services has increased, which leads to changes in the matching degree of supply and demand of ecosystem services in Huainan City.

Keywords: Coal-based cities, Ecosystem services, Supply, Demand, Supply and demand matrix

1. Introduction

In the process of industrialization, urbanization, and rapid economic and social development, ecological and environmental problems such as soil erosion, drought, deforestation, excessive resource consumption, and challenges to biodiversity have become increasingly prominent and restricted the sustainable development of human society [1–3]. Faced with the global ecological crisis, human beings began to reflect on the relationship between man and nature, and the concept of sustainable development gradually emerged, as ecological civilization has started. Ecological civilization is the product of the development of industrial civilization, a new requirement for the harmonious coexistence of man and nature as the only way for human development [4].

In coal resource-based cities, resources and the environment have undergone profound changes in their ecological background and socio-economic characteristics during their development [5]. The high-intensity exploitation of coal resources leads to the continuous expansion of the surface subsidence and the serious destruction of cultivated land and residential areas. Mining area and village relocation cause the expansion of construction land, while the regional land changes its structure and spatial layout dramatically, which makes the relationship between people and land tense. In addition, coal mining requires a large amount of ecological land, which leads to the reduction of crop yield and the destruction of the landscape. The fly ash and wastewater produced by coal power plants cause great pollution to the environment. On the other hand, rapid urbanization brings about energy and resource consumption, environmental damage, and expansion of construction, which pressure on the ecological environment significantly [6–8]. Therefore, under the effects of coal mining and urbanization, the ecological problems faced by coal resource-based cities are also different from those of other cities. The problems of people and land are prominent, and both the ecosystem and the social system are facing enormous pressure. Only by optimizing the land space and promoting the matching between supply and demand of ecosystem services, the ecological construction and sustainable development of coal resource-based cities can be realized.

This research is carried out on the supply and demand of ecosystem services in terms of the carrying capacity of ecosystem services [9] and the value of ecosystem services [10]. The early research on the supply and demand of ecosystem services focused

on the introduction of concepts and the construction of a theoretical framework [11]. Since 2000, scholars have explored the supply and demand of ecosystem services in theory and practice. From the evaluation method, Burkhard et al. used an expert experience discrimination method to evaluate the supply and demand of ecosystem services in eastern Germany [12]. Due to the subjectivity and limitation of the expert experience discrimination method, experts and scholars such as Boithias et al. used the model simulation method to evaluate the supply-demand ratio of water supply capacity in the Ebro River Basin by simulating the water production module in the InVEST model [13]. Maes et al. pointed out that model simulation needs a thorough understanding of ecosystem processes, so expert knowledge is often used to fill the gaps in data [14]. From the research content, the research on the supply and demand of ecosystem services mainly focuses on regulation, supply, and cultural services, among which supply services mainly involve the supply and demand of food, energy, and water. For example, Serna-Chavez studied the supply and demand of global climate regulation services and groundwater irrigation services [15]. Stürck et al. calculated the actual supply of flood regulation services in Europe by using a hydrological model STREAM. From the perspective of research areas, the research was mostly focused on large areas such as river basins and urban agglomerations [16].

At present, scholars have done a lot of research in the field of the supply and demand of ecosystem services, but they have paid less attention to the spatio-temporal evolution of ecosystem services, the evolution law of supply and demand pattern of ecosystem services, and its influencing mechanism. The research on coal resource-based cities is still insufficient, and the research on the supply and demand of ecosystem services needs to be further optimized. Therefore, we measured the supply and demand of ecosystem services in Huainan, a typical coal resource city, in 2010 and 2020, the relationship between the supply and demand, and the matching degree of supply and demand to provide reference and basis for ecosystem service management in Huainan.

2. Materials and Methods

2.1. Study Area

Huainan City in Anhui Province is selected as the research area. Huainan City is located in the middle part of the Huaihe River, in Anhui Province, with an area of 2584 km^2 and a population of 2.46 million. Huainan City is one of the 14 large coal bases in China, with abundant coal resources of the reserve of 15.3 billion tons, accounting for about 50% of East China's coal reserves. There are 14 large mines, with a coal production capacity of 77.1 million tons per year. As a result of coal mining, a large mined-out area has undergone ground collapse, resulting in house and farmland damages. As of 2018, the subsidence area formed by coal mining in Huainan City has reached 298.6 km^2. As Huainan is located in a high water level area, the water accumulation after subsidence is common. In coal mining, a large number of solid wastes are piled up, which damages the landscape and land resources. The discharge of wastewater and waste residue such as tailings causes environmental problems such as water pollution and soil pollution. Meanwhile, with the development of urbanization, the area of the urban built-up area increased from 42 to 130 km^2 from 2000 to 2018, and the urbanization rate increased from 44.76 to 64.11%. The resource and environment deprivation effect of urbanization is remarkable, which leads to the loss of cultivated land resources, water shortage, habitat fragmentation, and air pollution. Under the long-term extensive development, human activities in this area are intense, ecological and environmental problems are highly concentrated, and the contradiction between supply and demand is prominent. Coal mining and urbanization seriously affect the well-being of residents in this area. At the same time, there are significant spatial differences in the multi-structure of cities, mines, and townships in the study area. There are mining areas in different development stages and many control measures (relocation, land reclamation, and ecological restoration), which are typical and representative in coal resource-based cities.

2.2. Materials

The data used in this research include the following: (1) Land use data (2010 and 2020), which comes from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn) and has a spatial resolution of 30 m. Using ArcGis10.5 mask extraction tool, the land use data of Huainan is obtained. (2) The social and economic data of Huainan City come from China Urban Statistical Yearbook, China County Statistical Yearbook, and Huainan Statistical Yearbook in 2011 and 2021.

2.3. Methods

2.3.1. Measurement of Supply and Demand of Ecosystem Services

According to the characteristics of the natural ecological background and social development's demand for ecosystem services in Huainan City, the supply and demand of ecosystem services in Huainan City were calculated from three aspects combined with the availability of data: supply service, regulation service, and cultural service. We used the evaluation matrix method of supply and demand of ecosystem services proposed by Burkhard et al. On the basis of the original supply and demand measurement matrix, we invited five experts for the natural and social environment of the study area who had a background in landscape ecology and geography. They scored the supply and demand level of ecosystem services of six types of land use and adjusted the original supply and demand matrix. The score of supply and demand is between 0 and 5, with 0 indicating no supply or no demand, and 5 indicating the maximum supply or demand. The higher the score, the higher the supply capacity/demand level. On this basis, the supply matrix and demand matrix of ecosystem services for the study area are formed. The supply matrix of ecosystem services determines the ability of specific services provided by different land use types, while the demand matrix reflects the demand of specific land use types for ecosystem services. According to the supply and demand matrix, the supply and demand of ecosystem services in Huainan City are measured.

Table 1. Evaluation Matrix of Ecosystem Services Supply in Huainan City.

	Supply Service			**Adjustment Service**				**Cultural Service**
	Food service	**Aquatic products service**	**Water yield service**	**soil conservation service**	**Water purification service**	**water conservation service**	**Carbon fixation service**	**Leisure service**
farmland	5	0	2	1	2	2	2	1
forest land	1	0	2	5	5	5	5	5
Grass land	1	0	1	4	3	3	3	4
water area	0	5	5	1	1	5	0	5
construction land	0	0	0	0	0	0	1	0
bare land	0	0	0	0	0	0	1	2

Table 2. Evaluation Matrix of Ecosystem Service Demand in Huainan City.

	Supply service			**Adjustment Service**				**Cultural Service**
	Food service	**Aquatic products service**	**Water yield service**	**Soil conservation service**	**Water purification service**	**water conservation service**	**Carbon fixation service**	**Leisure service**
farmland	0	0	0	2	2	3	1	2
forest land	0	0	0	0	0	0	0	0
Grass land	0	0	0	1	0	0	0	0
water area	0	0	0	0	0	0	0	0
construction land	5	5	5	5	5	5	5	4
bare land	0	0	0	0	0	0	0	0

2.3.2. Analysis of the Relationship between Supply and Demand of Ecosystem Services

The supply-demand matching degree (SDI) is constructed to describe the supply-demand matching of ecosystem services. The specific calculation formula is as follows.

$$\mathrm{SDI} = \frac{ES_S - ES_D}{ES_D} \quad (1)$$

where SDI is the matching degree between supply and demand of ecosystem services, ES_S is the supply of ecosystem services, ES_D is the demand for ecosystem services. SDI>0 indicates that supply exceeds demand, that is, surplus state, SDI=0 indicates that supply is equal to demand, that is, the balance between supply and demand; SDI<0 indicates that supply is less than demand, that is, the deficit state.

3. Results

3.1. Characteristics of Ecosystem Service Supply

The total supply of ecosystem services in Huainan City showed a decreasing trend, from 0.889×10^8 in 2010 to 0.846×10^8 in 2020. In 2010, the towns with the highest supply of ecosystem services were Anfeng, Yanliu Town, Xiaodian Town, Sanjiao Town, and Yaokou Township, among which the supply of ecosystem services in Anfeng was as high as 307×10^4, and the ecological supply levels of Yanliu Town, Xiaodian Town, Sanjiao Town, and Yaokou Township were 297×10^4, 273×10^4, and 270×10^4, respectively. The towns with a low level of ecosystem service supply are Shuihu Town, Tangji Town, Gaodian Township, Wan Fu Zhen, and Zhuangmu Town.

Compared with 2010, the ecosystem services in Huainan City decreased in 2020, and Anfeng remained the township with the highest ecosystem services in Huainan City, with an ecosystem service supply of 297×10^4. In 2020, compared with 2010, Yanliu Town, Sanhe Township, Shouchun Town, Sanjue Town, Yankou Town, and Yankou Town, which experienced the worst decline in ecosystem service supply levels, had 35×10^4, 28×10^4, 15×10^4, and 14×10^4, respectively. The supply level of ecosystem services has improved in areas such as Taodian Hui Township, Jiaoganghu Town, Shangyao Town, Sunmiao Township, Anfengtang Town, Yaokou Township, and Wabu Town. The spatial distribution of ecosystem service supply in Huainan has obvious regional differences (Fig. 1), showing a trend of higher in the south and lower in the north as a whole. Among them, the high-value areas of supply are mainly distributed in Shouxian, where farmland is concentrated, and the low-value areas of supply are mainly distributed at the intersection of Bagongshan district, Xiejiaji, and Tianjiaan, where urbanization is high and construction land is intensive.

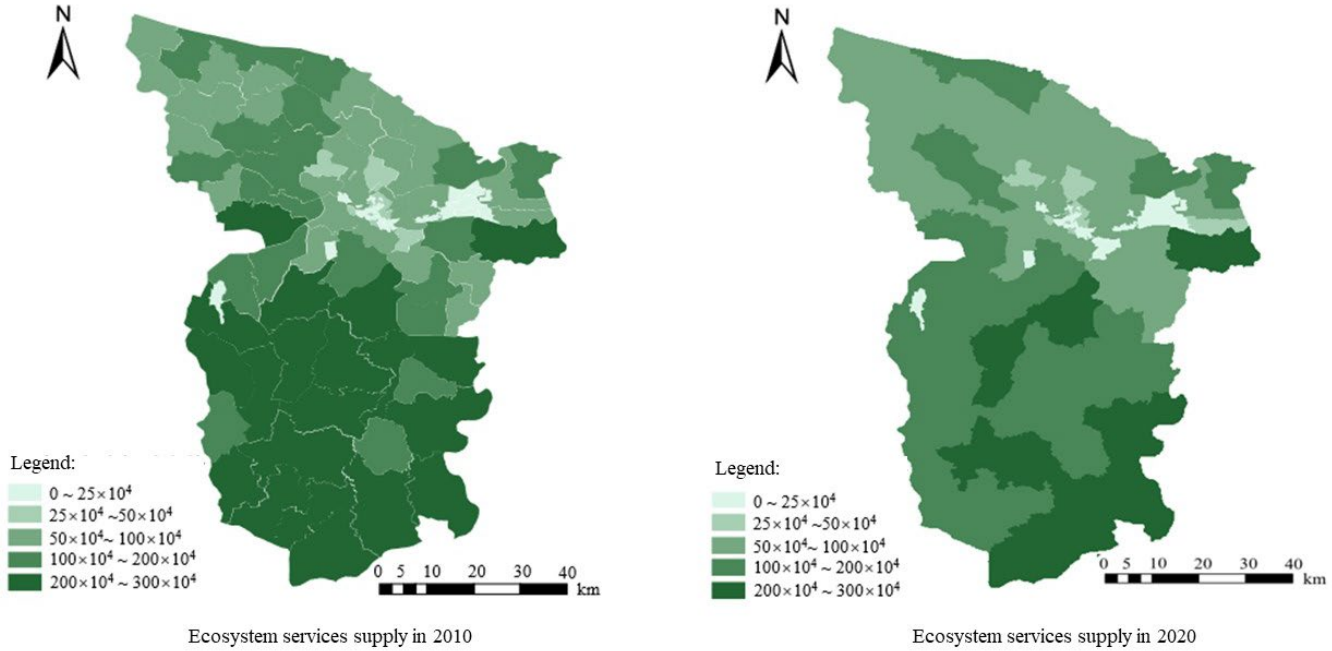

Fig. 1. Spatial-temporal distribution map of ecosystem service supply.

3.2. Characteristics of Ecosystem Service Demand

The demand for ecosystem services in Huainan showed an upward trend, from 0.7954×10^8 in 2010 to 0.8468×10^8 in 2020. Due to the development of urbanization, the population of Huainan is increasing and the construction land is expanding, which leads to the increasing demand for ecosystem services. Figure 2 shows that there is a significant difference in the demand for ecosystem services in Huainan, showing a trend of higher in the south and lower in the north as a whole. The towns with the highest demand for ecosystem services are concentrated in the southeast corner of Huainan, namely, Anfeng, Xiaodian, Yanliu, Sanjue, and Yankou, and the demand for ecosystem services is 278×10^4, 260×10^4, 256×10^4, 254×10^4, and 234×10^4, respectively. The reasons for the high demand for ecosystem services in these regions include the demand for construction land for ecosystem services and the demand for cultivated land for ecosystem services regulation. In 2020, compared with 2010, the demand for ecosystem services in Taodian Hui township, Jiaoganghu town, Shangyao town, Yaokou town, and Anfengtang town increased by 106×10^4, 95×10^4, 92×10^4, 79×10^4, and 79×10^4, respectively.

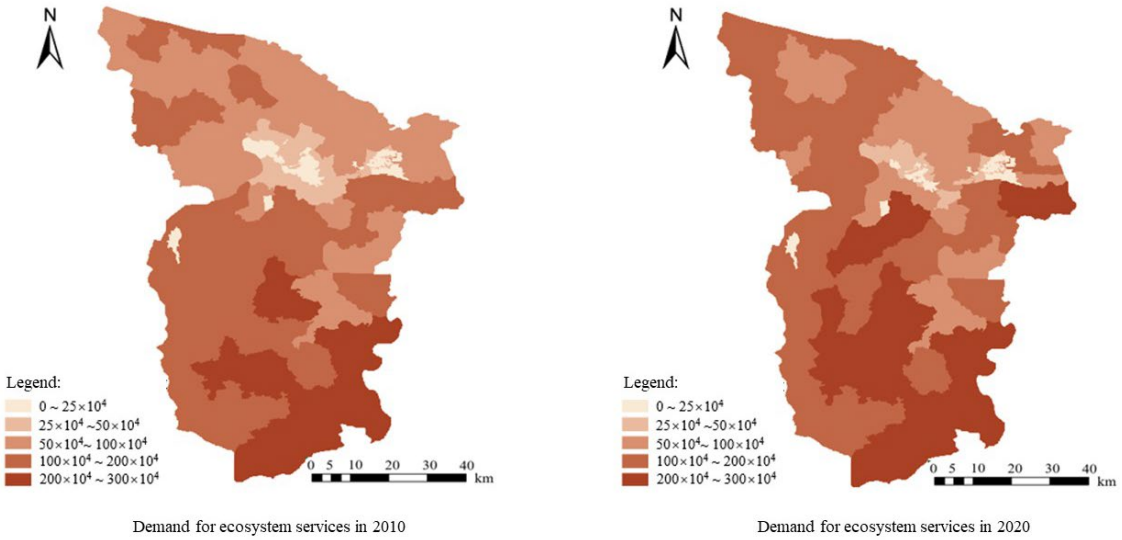

Fig. 2. Spatial-temporal distribution map of ecosystem service demand.

3.3. Matching Characteristics of Supply and Demand of Ecosystem Services

In addition, from the perspective of the spatial pattern (Fig. 3), the matching between supply and demand in Huainan showed a gradual imbalance trend from 2010 to 2020. In 2010, 62.91% of the towns and villages in which the supply of ecosystem services exceeded the demand, while only 28.23% of the towns and villages in which the supply of ecosystem services exceeded the demand by 2020. Among them, the villages and towns with the most severe drop in the matching degree between supply and demand are Miaoshan Forest Farm, Pengta Township, Hui Township in Li Chong, and Macheng Town in GaoKelvin Lau. These towns are mostly concentrated around the city, which is seriously affected by urban expansion, which is the main reason for the decline of their ecosystem services.

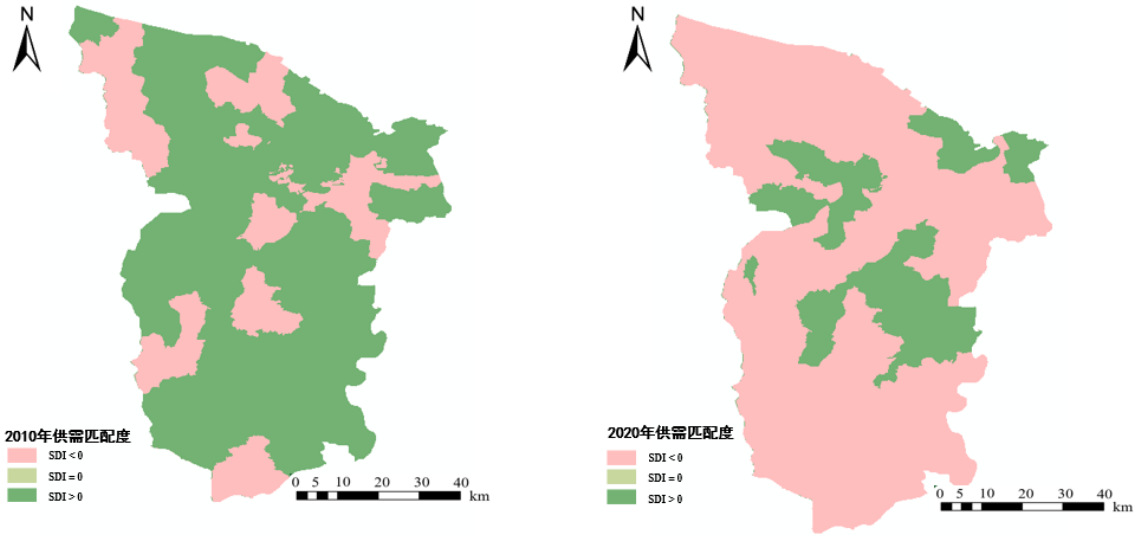

Fig. 3. Spatial-temporal distribution map of supply and demand matching degree.

In 2010, the areas where the demand for ecosystem services in Huainan exceeded the supply were mainly concentrated in the central and eastern parts of Huainan, the northwest and some southern areas, among which the low matching degree between supply and demand was mainly concentrated in Tianjiaan and Xiejiaji districts. By 2020, the areas where the demand for ecosystem services

is greater than the supply will expand in a large area, and the areas with good supply and demand will be distributed around the central city of Huainan.

4. Conclusions

Taking Huainan, a typical coal resource-based city, as an example, the multi-source data of Huainan in 2010 and 2020 was analyzed by combining the supply and demand matrix of ecosystem services and ArcGIS to quantitatively measure the supply, demand, and matching degree of supply and demand of food services, aquatic services, water production services, soil conservation services, water conservation services, carbon fixation services, and leisure and entertainment services in Huainan. The result is abstracted as follows:

(1) From 2010 to 2020, the supply of ecosystem services in Huainan decreased year by year. In terms of spatial distribution, the supply of ecosystem services in Huainan presented a distribution pattern of high in the south and low in the north, and there was a significant regional differentiation. With the rapid development of the economy and society, urban construction land increased and ecological land decreased, and the supply level of ecosystem services in Huainan City dropped significantly.
(2) From 2010 to 2020, the demand for ecosystem services in Huainan showed an increasing state year by year, and its spatial distribution was similar to that of the supply level of ecosystem services, showing that the demand for ecosystem services was higher in the south and lower in the north. The towns with a larger increase in demand for ecosystem services were Taodian Hui Township, Jiaoganghu Town, Shangyao Town, Yaokou Township and Anfengtang Town.
(3) As the supply level of ecosystem services declined from 2010 to 2020, the demand for ecosystem services continued to increase, which inevitably led to changes in the matching degree between supply and demand of ecosystem services in Huainan City. In Huainan City, the supply of ecosystem services exceeds demand in towns and villages from 62.91 to 28.23%, and the imbalance between supply and demand is serious. From the perspective of spatial distribution, towns with the high matching between supply and demand are distributed around the central city of Huainan.

Due to the intensification of human activities, the continuous improvement of socio-economic levels, and the acceleration of urbanization, the supply and demand of ecosystem services become important. To provide a reference and basis for exploring ecosystem service management in coal resource-based cities, we analyzed the multi-source data of Huainan in 2010 and 2020. Urban expansion and population increase also increased the demand for urban center construction land in Huainan City, increasing the demand for ecosystem services. The continuous erosion of urban ecological barriers and ecological land leads to the reduction of ecosystem service supply. Therefore, in future development, it is necessary to delimit the red line of protection, ensure the supply capacity of urban ecosystem services, and carry out the urban double repair. The construction of green infrastructure and the introduction of green industries are necessary to improve the supply level of ecosystem services. It is also required to change from the "incremental development" to the "stock development", establishing and improving the monitoring and early-warning mechanism of ecological security. It is demanded to demarcate the boundaries of urban development, strictly control urban expansion, and curb the growth of demand for ecosystem services. Through reasonable layout mode and management and control mechanism, we need to promote the stability of supply and demand of ecosystem services in Huainan City.

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