

Construction of ecological space management and control path from the perspective of ecosystem service function

——A case study of Dujiangyan City

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Abstract

Ecosystem services have a significant impact on human well-being, and differentiated ecosystem services function characteristics are an important basis for constructing ecological space management and control paths. With Dujiangyan City as the research target area, the spatial characteristics of three kinds of ecosystem service functions in the target area, namely water conservation, soil and water conservation and biodiversity, were quantified, and ecosystem service function models were established by using quantitative assessment method and model assessment method, so as to identify ecological Spaces of different importance and construct ecological space management and control paths. (1) The assessment results of the ecosystem service function in Dujiangyan City were classified into three levels: extremely important, important and generally important, with the area ratios of 21.40%, 32.02% and 46.58%, respectively; (2) The spatial distribution of ecosystem services is very important in the northern and western regions, followed by the southern regions, and generally important in the central and eastern regions; (3) Based on the obvious spatial differences of ecosystem service functions in Dujiangyan City, the ecological space management and control path of Dujiangyan City under the three levels of system management, hierarchical zoning management and directional management is constructed. The research results provide a scientific approach for the spatial reality analysis of urban ecosystem service functions and urban ecological environment management.

Keywords

Ecosystem service, Functional evaluation, Ecological space, Control path

1. Introduction

The ecological space at home and abroad is facing the threat of urbanization. From 1981 to 2020, the scale of urban construction land in China will expand from 6720km² to 58355.3km². The interactive impact of urban construction expansion and ecological environment constraints leads to the gradual blurring of the boundary between ecological space and construction space, and human beings can obtain various services from the ecosystem to maintain normal life. Therefore, it is also faced with the risk of gradually reducing the quality of the ecosystem and gradually weakening the transformation of service functions. In 2020, “the 14th Five-Year Plan” clearly requires improving the quality and stability of the ecosystem, guarding the security boundary of the ecological space, and ensuring the construction of ecological civilization, indicating that ecological space planning is an important work for human survival and quality of life. On the basis of ecosystem service function assessment, the construction of urban ecological space management and control path can maintain the integrity of the ecosystem, and provide

scientific guidance for the disorderly expansion of urban areas to aggravate the mutual development contradiction between ecological space and construction space.

Research on urban ecological space is mostly based on "three-life space" and used for ecological protection (Wang et al.,2017), delineation and control of ecological space (Xiong et al.,2018) and other purposes. Studies on ecological space control are mostly conducted from a qualitative point of view, and there are still problems such as blurred control boundaries and imperfect control systems. Gradually, some scholars have quantitatively studied urban ecological spatial zoning control measures from the perspective of ecosystem service assessment (Jing et al.,2023). In 1864, Marsh (Marsh,1864) proposed for the first time in his book *Man and Nature* that ecosystem has service functions, but it was not until the concept of ecosystem (Tansley,1864) was put forward in the 1940s that attention was paid to it, and in-depth research on ecosystem service functions began (Xie et al.,2001). From the structure of the ecosystem to the function of the main progressive development; In 1997, Daily et al. proposed that ecosystem service refers to the ecosystem products and ecosystem functions provided by natural ecosystems and their species to serve human life (Daily,1997), which is a universally recognized concept at present. Research on ecosystem service function has gradually shifted from single service function (Li et al.,2013) to research on ecosystem service model (Fan et al.,2022), mainly focusing on land use (Hasan et al.,2020) and ecological security (Peng et al.,2018), etc. There are also abundant studies on the combination of ecological space management and control, including urban agglomeration, province, county and other scales (Wang et al.,2020). Some scholars have discussed the ecological function zoning of Baiyangdian wetland under the integrated ecosystem service function indicators such as water supply and climate regulation, so as to protect the ecological environment (Zhu et al.,2020), or comprehensively evaluate the Marine ecosystem service function, and found that it is necessary to focus on the regulation of Marine support services and regulation services (Cheng et al.,2015). There are also quantitative assessments of supply services, regulation services and support services from the perspective of ecosystem service clusters, providing a new perspective for ecological functional zoning (Li et al.,2017). On the whole, there is no unified standard system for research methods of ecological space management and control (Xu et al.,2019), but comprehensive evaluation index is more scientific than single evaluation index to analyze ecological space management and control measures. In addition, studies on the combination of ecosystem services and ecological space mainly discuss the structure and function of ecosystems and the spatial distribution under human-land relationship from the perspectives of ecology and geography. However, studies on the combination of ecosystem services and urban control practice planning from the perspective of urban and rural planning are insufficient.

Dujiangyan City is a junction of mountainous and plain areas with complex ecological conditions and special spatial and geographical location. It is of practical significance to study the spatial characteristics of the importance of ecosystem service functions for urban ecological spatial zoning control. This paper took Dujiangyan City as an example, combined with the analysis methods of relevant scholars(Jiao et al.,2022; Wang et al.,2020), comprehensively evaluated the spatial characteristics of ecosystem service function through GIS spatial analysis and comprehensive evaluation of ecosystem service function, and defined the spatial characteristics of ecosystem service function in each region under the administrative boundary of Dujiangyan City, so as to carry out differentiated planning and control measures for the ecological space of Dujiangyan City.

2. Methodology

2.1. Study area

Dujiangyan City is located in the central part of Sichuan Province and the northwestern edge of Chengdu, China. The terrain in the region decreases from northwest to southeast, and is successively distributed

with mountains, hills and plains in the form of stairs. The geographical space presents zonal differentiation characteristics, and has the characteristics of disaster susceptibility and resource hierarchy. On the other hand, Dujiangyan is rich in ecological resources, but the built area of Dujiangyan is closely intertwined with the ecological space. The urbanization rate has increased from 42.19% in 2000 to 62.3% in 2021, indicating that it is in the stage of accelerating the development level of urbanization. Frequent construction activities and excessive consumption of ecological resources during the urbanization process lead to the weakening of ecosystem services. Ecological space is becoming more sensitive.

2.2. Index selection and model construction

According to the contents of < China Biological Diversity Protection Action Plan>, <Sichuan Biological Diversity Protection Action Plan>, < Announcement on Dynamic Monitoring Results of Water and Soil Loss in Dujiangyan City>, Dujiangyan Soil Erosion Dynamic Monitoring Results Announcement and other documents, as well as the analysis of the geological hazard distribution map of Dujiangyan City, combined with the above realistic scenarios of Dujiangyan City, Three key ecosystem service function indexes of soil and water conservation, water conservation and biodiversity were selected in the target area.

(1) Functional importance model for soil and water conservation

Due to the special mountain-plain terrain of Dujiangyan City, the evaluation of the importance of soil and water conservation functions plays a key role in the prevention and control of soil erosion and the self-regulation ability of the ecosystem to ensure the stability of the ecological space (Yang et al.,2005). In this paper, NPP quantitative index evaluation method is used to evaluate soil and water conservation function. The calculation formula is as follows (1) :

$$S_{pro} = NPP_{mean} * (1 - K) * (1 - F_{sio}) \quad (1)$$

NPP_{mean} : average annual net primary productivity of vegetation; F_{sio} : slope factor; K: soil erodibility factor.

(2) Functional importance model for biodiversity conservation

Through the analysis of the importance of biodiversity maintenance functions in Dujiangyan City, the integrity of ecosystem structure and the reasonable adjustment of urban climate can be realized (Ma et al.,2020), and the integrity of ecological space can be ensured through the balance of ecological environment. In this paper, the NPP quantitative index evaluation method was adopted to evaluate the biodiversity maintenance function. The calculation formula is as follows (2) :

$$S_{bio} = NPP_{mean} * F_{pre} * F_{tem} * (1 - F_{alt}) \quad (2)$$

F_{pre} : annual average precipitation; F_{tem} : annual average temperature; F_{alt} : elevation factor.

(3) Functional importance model for Water conservation

The evaluation of the importance of water conservation function is of great significance for monitoring the water resource environment, urban water use and social and economic development in key regions (Fu et al.,2013), and the protection and utilization of water ecological space can be ensured through the analysis of water conservation. In this paper, the water balance equation is used to evaluate the water source conservation function. The calculation formula is as follows (3) :

$$TQ = \sum_i^j (P_i - R_i - ET_i) * A_i * 10^3$$

$$(R_i = P_i * a) \quad (3)$$

P_i : annual average precipitation (mm); R_i : Surface runoff (mm); ET_i : Evapotranspiration (mm); A_i : Class i ecosystem area (km²); a : Runoff coefficient.

(4) Functional importance model of ecosystem services

The importance of soil and water conservation function, biodiversity maintenance function and water conservation function were disjunctive, and the integrated ecosystem service function importance model was obtained. The three ecosystem service functions are equally important to the ecological environment of Dujiangyan City. In order to maintain the neutrality of the research, the research on ecosystem service functions in the study area does not involve specific weights to one side and assumes that their weights are the same. The calculation formula is as follows (4) :

$$EI = \text{Max}[S_{bio}, S_{pro}, TQ] \quad (4)$$

S_{pro} : Importance of soil and water conservation function; S_{bio} : Importance of biodiversity conservation functions; TQ : Importance of water conservation function.

2.3. Technical route

The first step is to obtain and process the data, mainly through the Data Center of Resources and Environmental Sciences of the Chinese Academy of Sciences and geospatial data Cloud, using the vegetation normalization index processing, and the obtained data is unified in the coordinate system, and the accuracy is unified to 30m. The second step is to build the ecosystem service function model of Dujiangyan City by NPP quantitative index evaluation method, water balance equation and disconnection operation method. The third step is to analyze the calculation results, including the importance of soil and water conservation function, the importance of biodiversity maintenance function, the importance of water conservation function and the importance of ecosystem service function. The fourth step is to carry out the protection planning of Dujiangyan's ecological space, which mainly includes the control and optimization of ecological space and urban construction space(Figure 1).

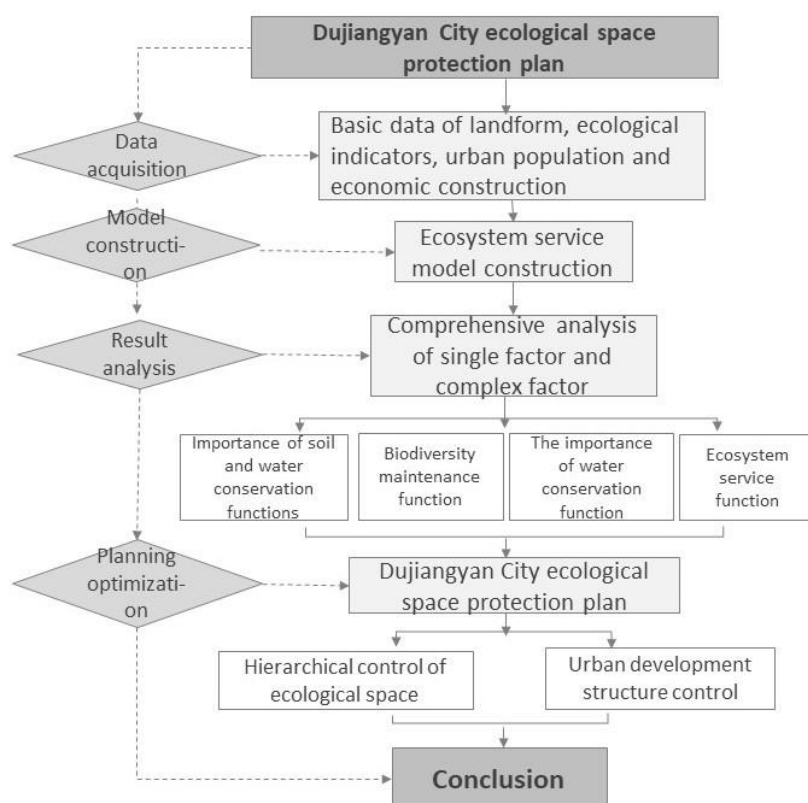


Figure 1 Technical route. Source: Author.

3. The discussion of calculation results

3.1. Single factor ecosystem service function analysis

(1) It can be seen from Table 1 that the spatial characteristics of functional importance of soil and water conservation in Dujiangyan City: In Dujiangyan, the area of the three levels of "extremely important", "important" and "generally important" increased step by step. In Dujiangyan, the area of "generally important" was 593.71km² (49.12%), followed by "important" and "extremely important" areas (244.51km², 372.18km² and 592.05km²). They account for 20.23% and 30.79% of the total land area of Dujiangyan City.

The most important areas of soil and water conservation function are mainly woodland and water area, which are mainly concentrated in Qingchengshan Town and Yutang Street in the west, some are distributed in clumps in Puyang Street in the east, and a few are scattered in Longchi Town in the north; The important areas of soil and water conservation function are mainly distributed in clusters in Longchi Town in the north and Ginkgo Street and Guankou Street in the middle, and a few bands are distributed in Qingchengshan Town and Yutang street, which are mainly forest systems and have high ecological service value; Areas with generally important soil and water conservation functions are mainly distributed in the southeast of Juyuan Town, Kuiguangta Street, Tianma Town, Happiness Street and Shiyang Town, mainly in urban and rural construction land and farmland (Figure 2).

Table 1 Evaluation results of soil and water conservation function importance. Source: Author.

Grade	Main street/town	Area	Ratio
The extremely importance of the soil and water	Yutang Street, Qingchengshan Town, Puyang Street	243.49km ²	20.14%

conservation capacity			
The importance of the soil and water conservation capacity	Longchi Town, Ginkgo Street, Guankou street	371.54km ²	30.74%
The general importance of the soil and water conservation capacity	Juyuan Town, Kuiguangta Street, Tianma Town, Happy street, Shiyang Town	593.71km ²	49.12%

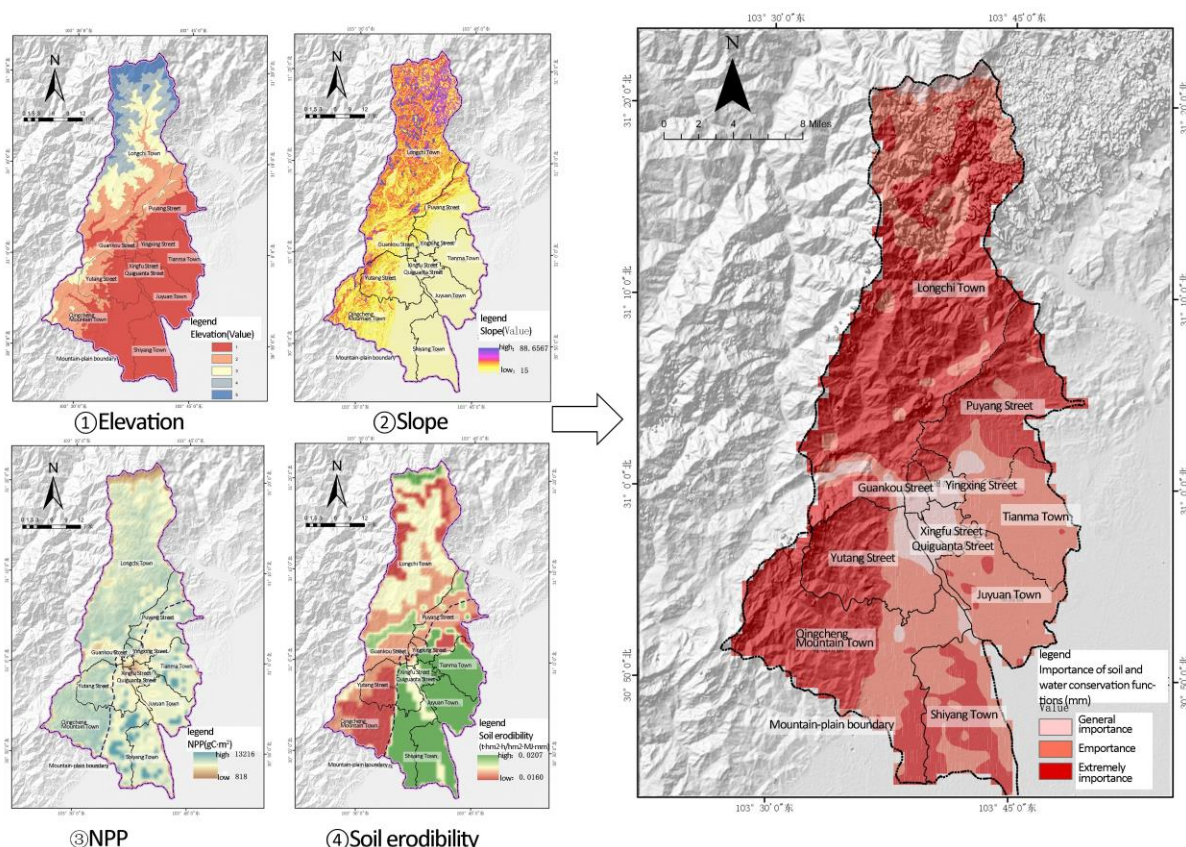


Figure 2 Spatial analysis of importance of soil and water conservation capacity in Dujiangyan City. Source: Author.

(2) As can be seen from Table 2, the spatial characteristics of the importance of biodiversity conservation functions in Dujiangyan City are as follows: the relative advantage of general importance is 598.21km², with an area ratio of 49.49%, followed by important and extremely important, with an area of 363.23km² and 247.30km², with an area ratio of 30.05% and 20.46%, respectively.

The areas with very important biodiversity maintenance function were mainly distributed in the form of blocky in Longchi Town and Qingchengshan Town. The areas with important biodiversity maintenance function were distributed in the form of sheet in Longchi Town in the north and concentrated in Qingchengshan Town and Shiyang Town in the south; The areas with generally important biodiversity conservation functions were concentrated in Juyuan Town, Kuiguangta Street, Xingfu Street, Tianma Town, Ginkgo Street, Guankou Street, Puyang Street and Yutang Street. The importance of biodiversity conservation functions in the central urban built-up area was lower than that in the northern and western mountain areas (Figure 3).

Table 2 Evaluation results of biodiversity conservation function importance. Source: Author.

Grade	Main street/town	Area	Ratio
The extremely importance of the biodiversity conservation service capacity	Longchi Town, Qingchengshan town	247.30km ²	20.46%
The importance of the biodiversity conservation service capacity	Longchi Town, Qingchengshan town, Shiyang town	363.23km ²	30.05%
The general importance of the biodiversity conservation service capacity	Juyuan Town, Kuiguangta Street, Happiness Street, Tianma Town, Ginkgo Street, Guankou Street, Puyang Street, Yutang Street	598.21km ²	49.49%

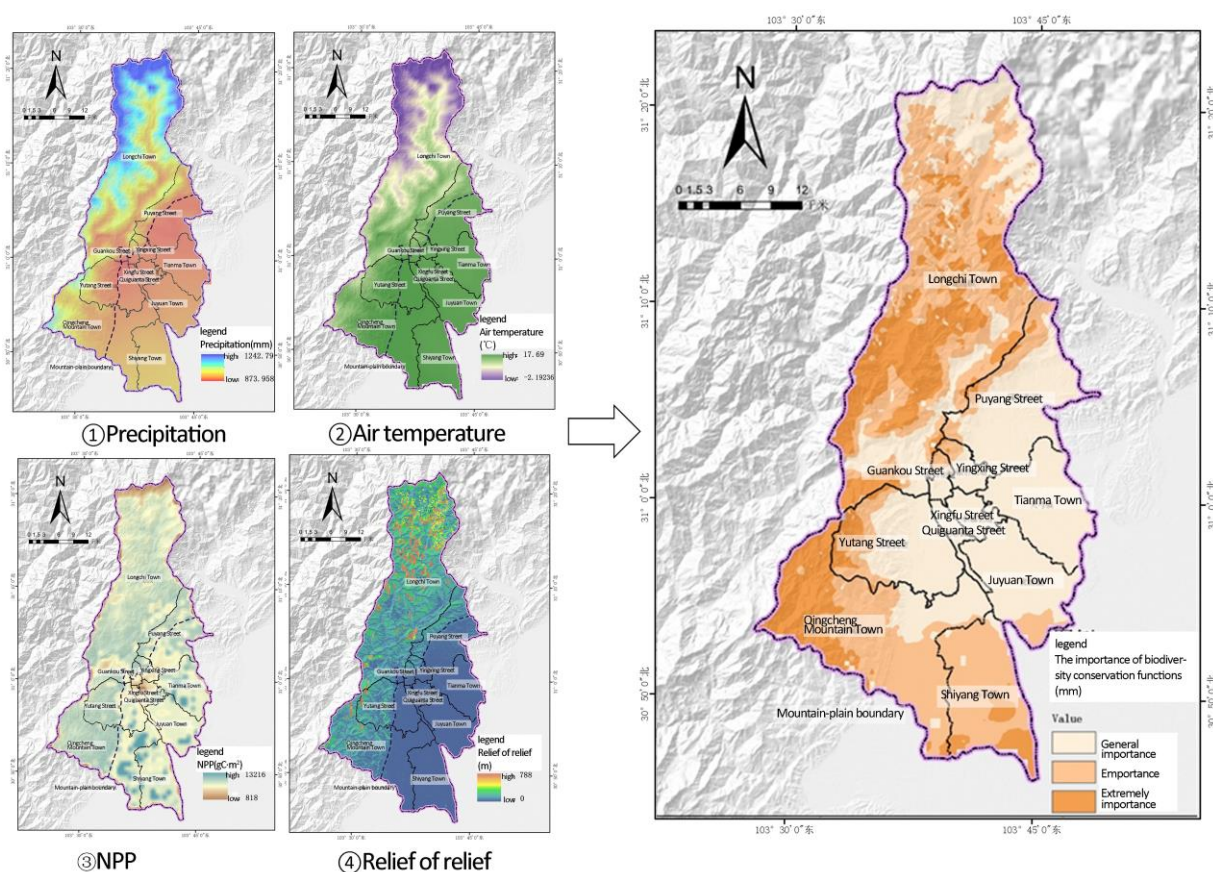


Figure 3 Spatial analysis of the importance of biodiversity conservation functions in Dujiangyan City. Source: Author.

(3) It can be seen from Table 3 that the spatial characteristics of the importance of water conservation function in Dujiangyan City are as follows: the areas of extremely important areas, important areas and generally important areas are 251.51km², 363.95km² and 593.28km², respectively, and the areas account for 20.81%, 30.11% and 49.08% respectively.

In Dujiangyan, seasonal natural rivers such as Puyang River and Baitiao River and perennial natural rivers such as Minjiang River are distributed in the area, and the overall water conservation function is significant. The most important areas of water conservation function are scattered in clusters and sheets

in Longchi Town in the north and Yutang Street and Qingchengshan Town in the west. The general important areas of water conservation function are concentrated in the eastern and southern Juyuan Town, Kuiguangta Street, Tianma Town, Happiness Street, Guankou Street, Shiyang Town, Ginkgo Street and Puyang Street (Figure 4).

Table 3 Evaluation results of the importance of water conservation function. Source: Author.

Grade	Main street/town	Area	Ratio
The extremely importance of the water conservation capacity	Longchi Town, Yutang Street, Qingchengshan Town	251.51km ²	20.81%
The importance of the water conservation capacity	Longchi Town, Yutang Street, Qingchengshan Town	363.95km ²	30.11%
The general importance of the water conservation capacity	Juyuan Town, Kuiguangta Street, Tianma Town, Happy Street, Guankou Street, Shiyang Town, Ginkgo Street, Puyang Street	593.28km ²	49.08%

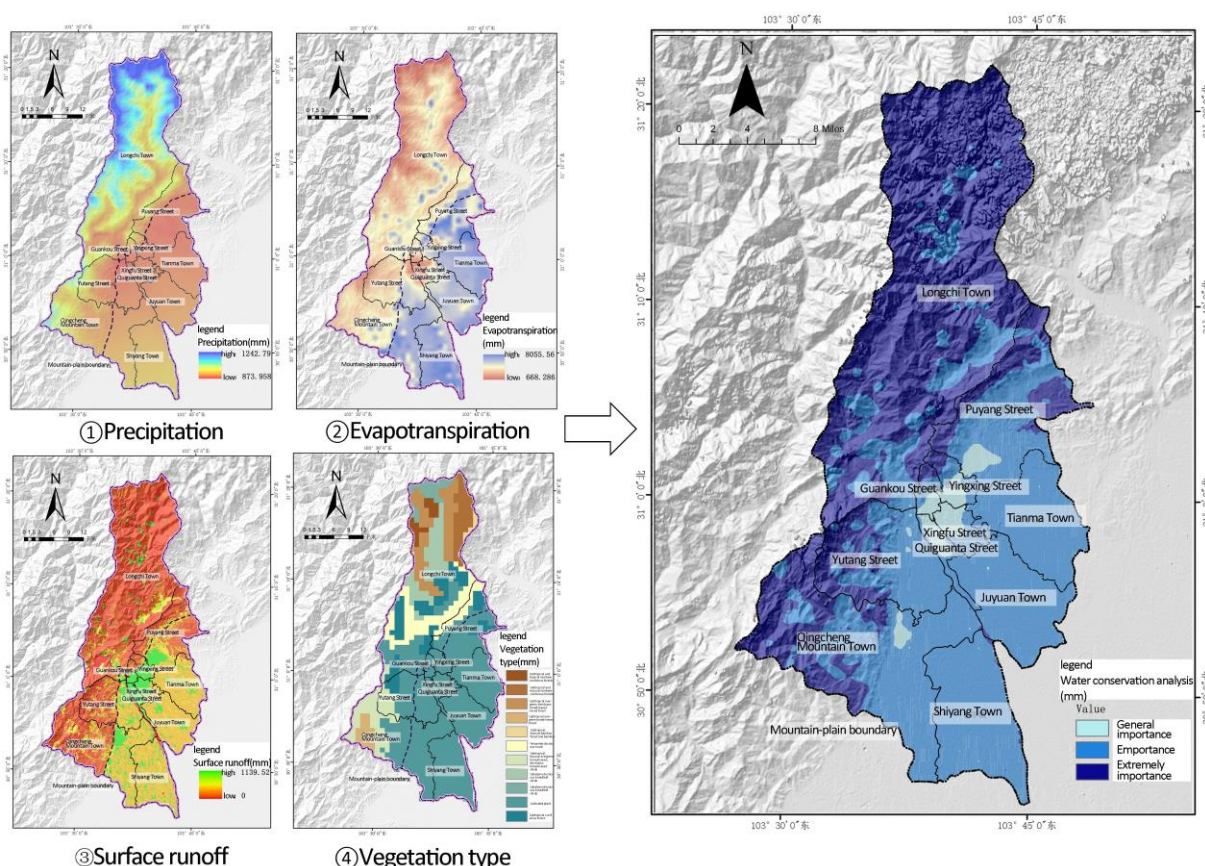


Figure 4 Spatial analysis of importance of water conservation function in Dujiangyan City. Source: Author.

3.2. Integrated analysis of ecosystem service functions

As can be seen from Table 4, the evaluation results of the importance of ecosystem service function in Dujiangyan City were divided into three grades from high to low: extremely important, important and generally important, with an area of 258.67 km², 387.04 km² and 563.03 km², accounting for 21.40%,

32.02% and 46.58%, respectively. On the whole, the importance of the ecological space in Dujiangyan City is mainly in the general importance level. Under the influence of urban construction expansion, the ecological space in Dujiangyan City is more and more fragile.

It can be seen from Figure 5 that the importance of ecosystem service functions in Dujiangyan City has significant spatial characteristics, showing that the importance level of ecosystem service functions in the north and west is extremely important, followed by the importance level in the south, and the importance level in the middle and east is low. Areas with very important ecosystem service function are mainly distributed in the northern and western mountainous areas in the form of concentrated contiguous areas, including Longchi Town, Yutang Street and Qingchengshan Town; The important areas of ecosystem service function are mainly distributed in the Shanyuan transitional zone of Dujiangyan City in the form of clusters and contiguous sections, including Puyang Street, Gingko Street, Guankou Street and Shiyang Town; Ecosystem service functions are generally important areas, mainly distributed in the central and eastern plains, including Happiness Street, Kuiguangta Street, Tianma Town, Juyuan Town.

Table 4 Results of comprehensive evaluation on the importance of ecosystem service functions. Source: Author.

	General importance		importance		General importance	
	Area/km2	Ratio/%	Area/km2	Ratio/%	Area/km2	Ratio/%
Water and soil conservation service capacity	243.49	20.14	371.54	30.74	593.71	49.12
Biodiversity maintenance function	247.30	20.46	363.23	30.05	598.21	49.49
Water conservation capacity	251.51	20.81	363.95	30.11	593.28	49.08
The importance of ecosystem service functions	258.67	21.40	387.04	32.02	563.03	46.58

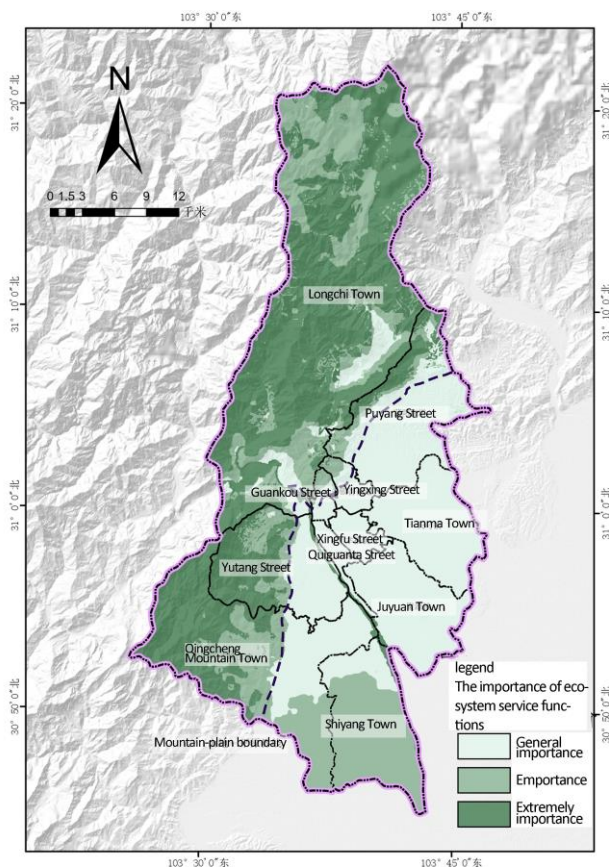


Figure 5 Spatial analysis of the importance of ecosystem service function in Dujiangyan City. Source: Author.

4. Strategy: Control path construction

According to the results of ecosystem service assessment, the overall ecosystem service function of Dujiangyan City is good, and the spatial distribution characteristics of extremely important areas, important areas and generally important areas are obvious. The evaluation results of the importance of ecosystem service function in Dujiangyan City directly show the importance of ecological space, and provide a scientific basis for the construction of urban ecological space management and control paths, including system management, hierarchical and regional management and control, and directional management and control, from macro urban development to micro and micro ecological situation analysis of small regions. The measures of ecological space control in Dujiangyan City have been gradually deepened (Figure 6).

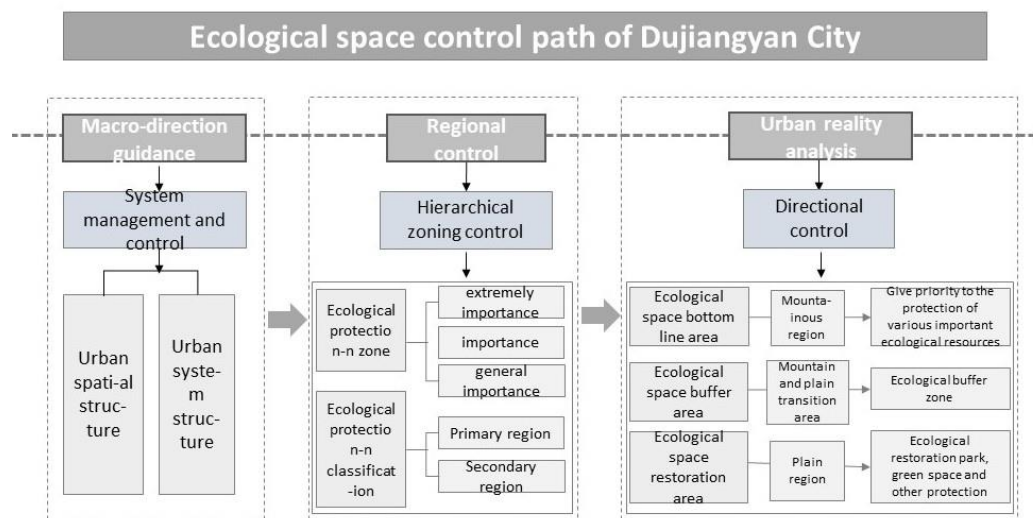


Figure 6 Schematic diagram of Dujiangyan City ecological space control path construction. Source: Author.

4.1. Systematic control of ecological space in Dujiangyan City

Through the spatial structure planning and urban system structure planning of Dujiangyan city under the background of ecological protection, the ecological space management and control of Dujiangyan City are guided from a macro perspective. The spatial structure planning of Dujiangyan City takes "four districts, four centers and three axes" as the development system to reduce the encroachment of ecological space in the process of urban construction of Dujiangyan City (Figure 7)

In the urban system structure planning of Dujiangyan city, each town develops in strict accordance with the orientation of ecological leading, agricultural leading and urban construction leading. The central urban area is the main area of urban economic development. Leading area of agricultural development: to improve the agricultural ecological environment through the protection of cultivated land and the guarantee of farmland quality; Leading areas of ecological protection: Villages within the core scope of ecological protection and those with a small population and poor infrastructure are mainly considered, and corresponding evacuation and relocation strategies are carried out according to the actual situation of each town and village (Figure 8).

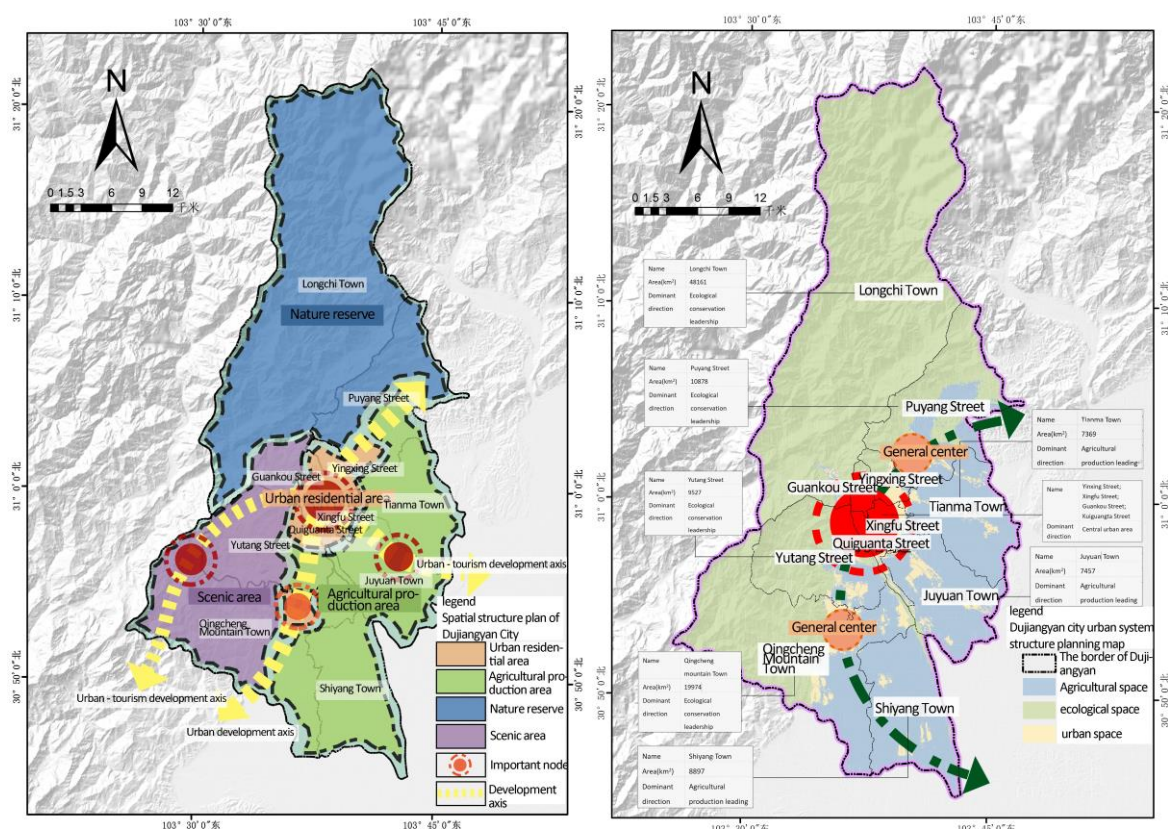


Figure 7 Spatial structure plan of Dujiangyan City. Source: Author.

Figure 8 Dujiangyan city urban system structure planning map. Source: Author.

4.2. Classification and zoning control of ecological space in Dujiangyan City

According to the assessment results of ecosystem service function, the ecological spatial importance zones of Dujiangyan City will be designated, including the extremely important areas for ecological protection, such as Longchi Town and Qingchengshan Town, etc., and the construction projects that damage the ecosystem service functions such as water conservation, biodiversity protection and soil and water conservation will be prohibited. In the important area of ecological protection mainly in Shiyang Town, large-scale and high-intensity human activities should be limited; Ecological protection is generally important areas, mainly in Ginkgo Street and Happiness Street, to prevent soil erosion and land desertification.

In addition, Dujiangyan City is divided into first and second level control areas (Table 5) : The first level control area includes all land within the ecological protection red line of Dujiangyan City, and all agricultural production and land construction and development are prohibited; The second-level control area is the ecological protection space outside the ecological protection red line of Dujiangyan City, involving forest land, water area, grassland and other ecological Spaces. It is the area that guarantees the overall ecological security pattern of Dujiangyan City and controls urban development and construction.

Table 5 Dujiangyan City level control area content. Source: Author.

Number	Type	Name	Main object of protection
1	Primary control area	National nature reserve	Rare animals such as giant pandas and forest ecosystems
		Cultural relic protection unit,	Water conservancy project: Dujiangyan

		World Heritage	
		National scenic spot	Mount Qingcheng
2	Secondary control area	Other ecological protection Spaces	Woodland, water, grassland, etc

4.3. Directional control of ecological space in Dujiangyan City

Based on the differentiated characteristics of the ecosystem service function space in Dujiangyan City, the ecological space management and control measures are put forward. The spatial differentiation of the importance of ecosystem service functions in Dujiangyan City is obviously related to the terrain. The importance of ecosystem service functions in the mountain area is the highest, followed by the transition area between mountain and plain, and the plain area, which are classified as the bottom line area of ecological space, the buffer area of ecological space, and the restoration area of ecological space, and the management and control measures are further classified.

In the mountain area of Dujiangyan City, the forest system and rivers are rich, and the ecosystem service function is significant. In the future development of Dujiangyan City, the protection measures for wild animals and plants, natural ecological base and resources are increased, and the construction of the project is clearly prohibited or the list of illegal construction projects has been made. In Puyang Street, Ginkgo Street, Guankou Street, Yutang Street and the central area of Qingchengshan Town, the transition area between mountain and plain is the place where the contradiction between urban construction and development and ecological resource protection is prominent. The ecological buffer zone is set up to reduce the damage of urban expansion to the ecosystem and ensure the integrity of ecological space. The plain area is the main construction area of the city, the population and industry are concentrated, and the transformation of ecosystem service functions is weak. On the basis of ecological restoration, ecological land such as parks and road green space in the city is strictly protected.

5. Conclusion

Starting from the three indexes of soil and water conservation function, biodiversity maintenance function and water conservation function, this study evaluated the ecosystem service function of Dujiangyan City through quantitative assessment method and model assessment method, and constructed the ecological space management and control path. The main conclusions are as follows:

- (1) The importance of ecosystem service functions in Dujiangyan City is divided into three categories: Extremely important, important and generally important, with an area of 258.67 km², 387.04 km² and 563.03 km², respectively. The area of extremely important and important ecosystem service function areas in Dujiangyan City accounted for 78.60% of the total area of the study area. The ecosystem service function needs to be strengthened.
- (2) The importance of ecosystem service functions in the northern and western regions of Dujiangyan is very important, followed by the southern region, and the central and eastern regions are generally important. Based on the special terrain analysis of Dujiangyan City, it is found that the importance of ecosystem service functions in the mountain area is the highest, followed by the mountain plain area and the plain area.
- (3) The evaluation results of the importance of ecosystem services reflect the importance of the ecological space in Dujiangyan City, and provide an important reference and basis for the construction of ecological space management and control paths. At the level of system control, through the spatial structure and urban system structure planning of "four districts, four centers and three axes" of Dujiangyan City, the direction of ecological space control of Dujiangyan City is guided. At the level of

classification and zoning control, the importance of leading ecological protection and different ecological Spaces such as level 1 and level 2 of each town are subject to zoning and grading control measures. At the level of directional control, based on the different characteristics of ecological space on different terrain such as mountain area, mountain and plain transition area and plain area, combined with the realistic scene of Dujiangyan City, targeted strategies are proposed.

Due to its special geographical location and ecological conditions, Dujiangyan City is a typical area for studying urban ecological space management and control measures from the perspective of ecosystem service functions. However, due to the resolution of data acquisition, there may be errors between the area results and the field situation. However, the geographical spatial pattern calculated by the model in this paper can reflect the geographical spatial characteristics of different ecosystem service functions in Dujiangyan City, build an ecological space control path on the basis of regional ecological spatial distribution characteristics, and provide an urban spatial layout plan under the background of ecological protection, which has certain significance for the implementation of regional ecological protection space.

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