

Evaluation of Multifunctionality of County-level Land in Chongqing

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Abstract: Evaluating the multifunctionality of land use at the county level is conducive to promoting the formation of a new pattern of territorial spatial development and protection, as well as facilitating the rational allocation of land resources in the context of urbanization. This paper constructs an index system for evaluating land multifunctionality from the economic, social, and ecological functions of land resources. Using relevant data from 38 districts and counties in Chongqing Municipality from 2011 to 2020 as samples, the multifunctionality of land use in each district and county of Chongqing Municipality is evaluated, and its spatiotemporal evolution characteristics are explored. The study shows that: (1) The overall functional enhancement of land use in each district and county of Chongqing Municipality is accompanied by a gradual reduction in spatial differences. The overall sustainability has increased from medium-low in 2011 to medium-high in 2020, exhibiting a spatial pattern of decreasing gradient from the main urban area to the new urban development areas in the northeast and southeast of Chongqing. (2) The economic function of each district and county in Chongqing Municipality has rapidly improved, with the main urban area exhibiting the strongest function and other districts and counties showing weaker spatial differentiation. The social function has increased rapidly, with higher levels observed in the main urban area and new urban development areas, and lower levels in the northeast and southeast of Chongqing. The improvement of ecological function in Chongqing Municipality is relatively limited, except for a few districts and counties showing relatively high enhancement, the overall ecological function remains poor.

Keywords: County-level, multifunctionality, evaluation, Chongqing

1. Introduction

The "Outline of the Fourteenth Five-Year Plan for National Economic and Social Development and the Long-Term Goals for 2035 of the People's Republic of China" proposes to "promote the formation of a new pattern of territorial spatial development and protection with distinct main functions, complementary advantages, and high-quality development." Due to the vast territory and large population of China, there are significant differences in natural resource endowments among regions. Therefore, not all land in the country is suitable for economic development. It is necessary to promote the balanced development of economic growth, social stability, and ecological protection within limited land resources. This imperative drives the need for land in different regions to serve multiple functions, exhibiting spatial and temporal variations[1-3]. Consequently, optimizing the pattern of territorial spatial development and protection essentially involves optimizing the multifunctionality of land use at the national level.

With the advancement of urbanization in China, the expansion of construction land has led to phenomena such as illegal occupation of arable land and serious ecological damage. The situation facing the rational utilization of land resources will become increasingly severe[4, 5]. This conflict in land resource utilization essentially reflects the negotiation between different land use goals and functions. Therefore, fully leveraging the multifunctionality of land to promote efficient land resource utilization is a key factor for regional sustainable development.

The concept of land use multifunctionality originally stemmed from agricultural multifunctionality, which refers to land not only serving the traditional function of food production but also providing various other products and services for humans, including social, economic, and environmental functions. International research on land use multifunctionality mainly focuses on sustainability impact assessment,

multifunctional land use indicators, and the relationship between land use and land functions[6]. In recent years, research on land use multifunctionality in China has seen rapid progress, primarily including the construction of indicator systems for land use multifunctionality, research on evaluation methods, and studies on influencing factors.

Current research on land use multifunctionality covers both qualitative and quantitative aspects. Qualitative research mainly focuses on defining concepts and connotations, while quantitative research mainly concentrates on the evaluation of land use multifunctionality and exploration of influencing factors.

In terms of defining concepts and connotations, the SENSOR project first proposed the concept of land use multifunctionality: it refers to the various products and services provided by land use processes within a certain region, including social, economic, and environmental functions[7]. Subsequently, different scholars have improved upon this concept from various perspectives, but it is generally agreed that land use multifunctionality encompasses multiple dimensions such as economic growth, social development, and ecological protection. In terms of evaluating land use multifunctionality, the evaluation units currently mainly include macro scales such as national, provincial, and municipal levels, as well as micro scales such as patches and grids. For example, scholars like Zhen Lin and Wei Yunjie used provincial-level statistical data as the basis to combine social and economic development data with land use data to construct evaluation indicator systems and conduct evaluations and research on national land multifunctionality[6]. Other scholars, such as Wang Feng and Zhang Yida, evaluated land use multifunctionality in Guangzhou and Lanzhou respectively using municipal-level statistical data[8, 9]. More scholars, such as Du Guoming, Wang Qingyang, and Wang Jiani, used prefecture-level or county-level administrative units as evaluation units, constructing indicator systems using county-level economic data and land data for evaluation[10-12]. To balance the dimensions of sustainable development—economic, social, and ecological—most scholars classify the types of land use multifunctionality into economic, social, and ecological functions. In terms of selecting evaluation methods, due to the significant differences in the indicator systems constructed by scholars during the evaluation process, there are also considerable differences in the evaluation methods chosen, with common methods including subjective weighting, analytic hierarchy process, entropy method, principal component analysis, and others. Research on the influencing factors of land use multifunctionality is relatively scarce. Scholars such as Wang Feng and Du Guoming mainly point out from a qualitative perspective that factors such as regional social and economic development, natural resource endowments, and land use policies drive changes in land use functions over time and space. Quantitative research in this area is still under exploration[8, 11].

In summary, existing research has provided clear definitions of land use multifunctionality and important references and examples for the selection of research scales, construction of indicator systems, and selection of research methods. However, against the background of intensified territorial spatial development and urbanization processes, how to scientifically and reasonably establish indicator systems to evaluate the multifunctionality of land use? How to accurately address the contradictions between development and land use? How to precisely explore the influencing factors of land use multifunctionality? These questions remain the focus of our research.

2. Overview of the Research Area and Data Sources

2.1 Overview of the Research Area

Chongqing Municipality, abbreviated as "Yu," is located in the southwestern part of China. It is a direct-administered municipality of the People's Republic of China, a national central city, and a megacity. It serves as the core city of the Chengdu-Chongqing economic circle in the Yangtze River Delta region. Chongqing Municipality governs 38 districts and counties with a total area of approximately 8,240 square kilometers. Situated in the eastern part of the Sichuan Basin, the terrain of Chongqing gradually descends from the Yangtze River valley from south to north, with the northwest and central parts predominantly characterized by hills and low mountains, while the southeastern part borders on the Da'aba Mountains and Wuling Mountains. In recent years, Chongqing Municipality has emerged as a national modern manufacturing base and a pilot area for comprehensive urban-rural reform. Coupled with the rapid development of its tourism industry, the city's economy, society, transportation, and population have experienced significant growth.

Chongqing is a typical city combining urban and rural areas, characterized by the unique situation of

being "a large city with a large rural area[13]." Since its establishment as a direct-administered municipality in 1997, Chongqing Municipality has witnessed notable development in its economy, society, and infrastructure construction. With the rapid growth of the economy and population, the construction land in Chongqing has expanded rapidly, leading to the conversion of a large amount of agricultural land into construction land. Moreover, phenomena such as illegal occupation of basic farmland for construction and severe damage to the ecological environment have occurred. The contradiction between urban development and ecological environment protection is becoming increasingly prominent, with the most significant contradiction being the multifunctional development of land use caused by changes in land use types.

Therefore, taking representative and typical Chongqing Municipality, which exhibits regional differences and evolution in land use multifunctionality, as an example, this paper constructs an evaluation index system for land use multifunctionality. Based on this system, it explores the spatial and temporal differentiation of single and comprehensive land use. The 38 districts and counties of Chongqing Municipality are taken as evaluation units in this study.

2.2 Data Sources

This study focuses on the spatial differences in land use multifunctionality in the counties of Chongqing Municipality in recent years. Data from the years 2011 to 2020 for the 38 counties of Chongqing Municipality were utilized for evaluation. The socioeconomic data were sourced from the "Chongqing Statistical Yearbook," statistical yearbooks of various districts and counties, as well as databases such as China Economy Network. Land data were calculated using 30-meter aerial remote sensing data instead

3. County-Level Evaluation of Land Use Multifunctionality

3.1 Indicator System for Land Use Multifunctionality Evaluation

Table 1: Multifunctional evaluation index system of land use in Chongqing

Primary Indicator	Secondary Indicator	Tertiary Indicator r	Calculation Method
Economic Function	Economic Development	Per Capita GDP	GDP / Total Resident Population (CNY/person)
		Economic Density	GDP / Total Area of the Region (100 million CNY/km ²)
	Construction Land Layout	Urbanization Level	Urbanization Rate of Registered Population (%)
		Development Intensity	Construction Land Area / Total Area of the Region
	Agricultural Production	Grain Production Area	Grain Sowing Area / Total Grain Sowing Area of the Municipality
		Grain Production Capacity	Grain Production / Total Grain Production of the Municipality
Land Reclamation Rate		Arable Land Area / Total Area of the Region	
Social Function	Population Carrying Capacity	Population Density	Total Resident Population / Total Area of the Region (people/km ²)
	Social Security	Per Capita Disposable Income	From Statistical Yearbook (CNY)
		Number of Beds in Health Institutions	From Statistical Yearbook (units)
		Urban-Rural Resident Income Balance Index	Per Capita Net Income of Farmers / Per Capita Disposable Income of Urban Residents
Cultural Landscape	Proportion of Water Area	Proportion of Water Area, including River Water Area, Lake Water Area, Pond Water Area, Aquaculture Water Area, and Reservoir Water Area, to Total Area of the Region	
Ecological Function	Ecological Protection	Forest Coverage Rate	Area of Forest Land / Total Area of the Region
		Proportion of Ecological Land	Sum of Area of Forest Land, Grassland, and Water Area (km ²)
	Ecological Value Realization	Economic Benefits of Ecological Land	GDP divided by Ecological Land Area (10,000 CNY/km ²)

Due to differences in research objectives or disciplinary perspectives, the methods of classifying land use multifunctionality types also vary. In order to balance the three dimensions of sustainable development: economic, social, and ecological, land use multifunctionality is generally classified into economic function, social function, and ecological function.

In light of this, this paper defines the land use functional objectives in Chongqing Municipality as the

total land use function, which is further divided into economic function, social function, and ecological function. Specifically, economic function refers to aspects such as ensuring sustained economic growth, stabilizing the pattern of construction land use, and maintaining food production. Social function includes aspects such as population carrying capacity, social security, and cultural landscapes. Lastly, ecological function mainly refers to a series of natural conditions provided by the land use system for human beings to produce and live in high quality, including ecological protection and the realization of ecological value.

In summary, this paper selects a total of 15 indicators including per capita GDP, economic density, urbanization level, development intensity, grain production area, grain production capacity, land reclamation rate, population density, per capita disposable income, number of beds in health institutions, urban-rural resident income balance index, water area proportion, forest coverage rate, ecological land area, and economic benefits of ecological land to construct the evaluation indicator system for land use multifunctionality in Chongqing Municipality, as shown in Table 1.

3.2 Steps for Land Multifunctionality Evaluation

(1) Determining Indicator Weights

The land multifunctionality evaluation index system constructed in this study involves multiple levels, dimensions, and various distinct indicators. The methods for determining weights comprise subjective weighting and objective weighting. Utilizing subjective weighting, particularly with an excessive number of involved indicators, poses considerable difficulty and may lead to potential inaccuracies. Therefore, this study employs the objective weighting method of entropy to assign weights to each indicator. Furthermore, it integrates the TOPSIS method to evaluate land use multifunctionality in the research area (specific weights are outlined in Table 2). The entropy method offers the advantage of standardizing data processing and objectively determining indicator weights based on the variation characteristics of multiple datasets. However, its limitation lies in its ability to only ascertain the optimal and worst values from observed data, thereby enabling quantitative ranking.

Table 2: Weight of multifunctional evaluation index of land use in Chongqing

Primary Indicator	Secondary Indicator	Tertiary Indicator	weights
Economic Function	Economic Development	Per Capita GDP	0.263
		Economic Density	0.246
	Construction Land Layout	Urbanization Level	0.132
		Development Intensity	0.155
		Grain Production Area	0.051
	Agricultural Production	Grain Production Capacity	0.051
		Land Reclamation Rate	0.102
Social Function	Population Carrying Capacity	Population Density	0.208
	Social Security	Per Capita Disposable Income	0.309
		Number of Beds in Health Institutions	0.246
		Urban-Rural Resident Income Balance Index	0.174
	Cultural Landscape	Proportion of Water Area	0.063
Ecological Function	Ecological Protection	Forest Coverage Rate	0.203
		Proportion of Ecological Land	0.303
	Ecological Value Realization	Economic Benefits of Ecological Land	0.495

(2) Determination of Indicator Thresholds and Data Normalization

Thresholds represent the ideal values that land can achieve under sustainable utilization conditions, and their determination is a crucial step in conducting land multifunctionality evaluation. In this study, we referenced relevant literature [14, 15] and determined the thresholds for each indicator based on the actual situation of land use in Chongqing Municipality. Subsequently, we standardized these thresholds.

(3) Calculation of Land Use Function Values

Land use function values are calculated based on the land use multifunctionality evaluation method to represent the level of land use function. A higher D value indicates a higher degree of land use function. The formula is as follows:

$$D = \sum W_1 U_v$$

In the formula, D represents the values of various land use functions; W1 denotes the weights at the indicator level, and U_v represents the standardized indicator values.

To illustrate the land policy situation reflected by the land use function values, this study adopts

functional realization values to represent the degree of realization of a certain land use function in Chongqing Municipality during a specific period. When the functional realization value is less than or equal to 1, the level of function is considered low sustainability; when the functional realization value is between 1 and 3, it indicates moderate sustainability; and when the functional realization value exceeds 3, it suggests high sustainability.

3.3 Evaluation Results of Land Use Multifunctionality

3.3.1 Overall Changes in Land Use Functionality

From the perspective of the overall functional realization values of each district and county, it can be observed that the overall land use functionality in Chongqing Municipality has significantly improved, and spatial disparities have narrowed. In 2011, the overall land use functionality was mostly at a moderate to low sustainability level. Only Yuzhong District demonstrated high sustainability, with a functional realization value of 15.4. Although Yuzhong District has a strong overall land use functionality, the dominance of land functions varies. Yuzhong District, as the central urban area of Chongqing, exhibits significant advantages in economic development, transportation, employment support, social security, and other aspects. Wanzhou District, Fuling District, Dadukou District, Jiangbei District, Shapingba District, Jiulongpo District, Nan'an District, Yubei District, Jiangjin District, and Rongchang District, among others, demonstrated moderate sustainability. Other districts and counties showed low sustainability. In 2011, the overall land use functionality of Chongqing Municipality was generally at a low sustainability level, with relatively low functional values and significant spatial disparities, indicating considerable development potential for land use multifunctionality.

By 2020, the overall land use functionality of Chongqing Municipality had significantly increased. Except for Yuzhong District, Dadukou District, Jiangbei District, Jiulongpo District, and Nan'an District all demonstrated high sustainability, while the vast majority of other districts and counties shifted to moderate sustainability. Only Qianjiang District, Chengkou County, Wushan County, and Wuxi County still exhibited low sustainability. Overall, the overall land use functionality values of each district and county in Chongqing Municipality have significantly improved, transitioning from low sustainability to moderate sustainability overall, with spatial disparities gradually narrowing.

In terms of changes in the overall functional values of each district and county, over the decade from 2011 to 2020, the overall functional realization values of the 38 districts and counties in Chongqing Municipality have shown an upward trend, with particularly notable increases in Nanan District and Beibei District, both of which have seen increases of over 100%, while Ba'nian District has exceeded 80%. Overall, the dynamic of the entire functionality has shown spatially significant improvements, with the central urban area of Chongqing Municipality demonstrating the most significant enhancement, followed by the development of new urban areas and the northeast of Chongqing, while the overall improvement in the southeast of Chongqing lags behind other regions in terms of differentiation characteristics.

3.3.2 Changes in Various Land Use Functions

Economic Functionality: Based on the economic functionality realization values, the spatial disparities in land use economic functionality in Chongqing Municipality were evident in 2011, exhibiting a pattern where the central urban area had the strongest functionality, while other districts and counties showed relatively weaker functionality. Yuzhong District had the highest functionality, with an economic functionality evaluation value of 5.4, more than double that of any other district or county, indicating high sustainability. Sixteen districts, including Wanzhou District, Fuling District, and Dadukou District, showed moderate sustainability, while the remaining areas exhibited low sustainability. By 2020, there was a significant overall improvement in economic functionality, with the spatial pattern of each district and county continuing to weaken from the central urban area outward, although the differences gradually narrowed. Jiangbei District and Nan'an District transitioned from moderate to high sustainability, with substantial increases in their overall functionality evaluation values, indicating an improvement in their land use multifunctionality. Except for Chengkou County, Fengjie County, Wushan County, Wuxi County, Shizhu County, and Youyang County, whose economic sustainability remained low, the remaining districts and counties were mostly at a moderate sustainability level. In terms of dynamic changes in economic functionality realization values, Nan'an District and Beibei District saw the largest increases, both exceeding 200%. Other districts and counties, such as Yuzhong District, Jiangbei District, Rongchang District, Bishan District, Liangping District, Fengdu County, and Xiushan County, also experienced increases of over 80%. This can be attributed to significant economic

development in the nine central urban districts of Chongqing, especially evident in their GDP growth and urbanization levels, leading to substantial increases in their economic functionality realization values. Additionally, urban development areas such as Bishan District and Rongchang District have experienced significant economic growth alongside the central urban districts, with per capita GDP and urbanization levels showing an upward trend year by year. The only difference is that due to differences in natural resource conditions and policy influences, the cultivated land area in the central urban districts has decreased over the past decade, leading to slight decreases in grain sowing and production. However, the agricultural production functionality in other development areas has improved year by year. In summary, the dynamic spatial gradient pattern of various economic functionality sub-functions is evident, while the overall functionality realization values of the economic system show an upward trend.

Social Functionality: Based on the realization values of social functionality, the overall level of land use social functionality in 2011 was generally moderate, exhibiting a spatial pattern where the central urban area and urban development areas had higher functionality compared to other districts and counties. Among them, Yuzhong District, Dadukou District, Jiangbei District, Shapingba District, Jiulongpo District, and Nan'an District were classified as highly sustainable, with Yuzhong District having the highest functionality realization value, reaching 37.8, while the evaluation values of the other five districts exceeded 4. Seventeen districts and counties, including Wanzhou District and Fuling District, had moderately sustainable social functionality, while the remaining districts and counties were classified as having low sustainable social functionality. Overall, apart from certain individual districts in the central urban area, the level of social functionality in Chongqing Municipality was moderate. By 2020, the social functionality of each district and county had improved rapidly. Yubei District transitioned from moderately sustainable to highly sustainable, while eight districts and counties such as Ba'nian District, Qianjiang District, Liangping District, and Fengdu County shifted from low sustainable to moderately sustainable. The increase in the realization values of social functionality in the remaining districts and counties was also significant. From the dynamic changes in social functionality realization values, it can be observed that all districts and counties, except for Yuzhong District which showed a slight decrease, demonstrated an upward trend. Among them, Ba'nian District, Wuxi County, and Shizhu County showed the most significant increases, all exceeding 80%. This is attributed to the significant enhancement of social security functions in various districts and counties of Chongqing Municipality in recent years, coupled with an increase in disposable income and the development of healthcare institutions, leading to the strengthening of social functionality. Yuzhong District may have experienced a slight decline in social functionality due to a decrease in population in recent years, coupled with its already highly sustainable social functionality. Overall, the development of social functionality in various districts and counties of Chongqing Municipality has been rapid, with further narrowing of spatial disparities among districts and counties.

Ecological Functionality: Based on the realization values of ecological functionality, there were significant spatial disparities in land use ecological functionality among districts and counties in Chongqing Municipality in 2011, but overall, the levels were relatively poor. Counties such as Chengkou County, Wulong District, Fengjie County, Wushan County, Wuxi County, Shizhu County, Youyang County, and Pengshui County showed relatively better ecological functionality, classified as moderately sustainable. Although Yuzhong District exhibited highly sustainable functionality, with the highest functionality realization value, it was not consistent with the current situation of Yuzhong District. This discrepancy may be due to the unreasonable and biased selection of indicators. Therefore, Yuzhong District is not considered here. The other districts and counties showed low sustainability, overall at a relatively poor level. The spatial pattern of ecological functionality realization rates increased sequentially from the central urban area to urban development areas, and then to the northeast and southeast of Chongqing. By 2015, there was some overall improvement in ecological functionality, but the spatial pattern still showed weaker functionality in the central urban area compared to the northeast and southeast of Chongqing, with insufficient improvement. Only two districts and counties, Kaizhou District and Yunyang County, transitioned from low sustainable to moderately sustainable, while Wushan County transitioned from moderately sustainable to low sustainable, possibly due to a decrease in the area of ecological land use. In terms of dynamic changes in ecological functionality realization values, most districts and counties showed an upward trend, but districts and counties such as Fuling District and Qianjiang District showed a slow decreasing trend, possibly due to a reduction in forest coverage and ecological land use in these areas. Overall, there is still significant room for improvement in ecological functionality, and the government should pay more attention to the ecological functionality of land use.

4. Conclusion

Through empirical analysis of the multifunctionality of land use in various districts and counties of Chongqing Municipality from 2011 to 2020, it is evident that the overall land use functionality has improved, with spatial disparities gradually diminishing. Overall sustainability has transitioned from medium-low in 2011 to medium-high in 2020, exhibiting a decreasing spatial gradient from the main urban area to the development zones and further to the northeast and southeast of Chongqing.

Among the sub-functions of land use in different districts and counties of Chongqing Municipality, there are varying spatial disparities in functionality realization rates and dynamic changes. Economic functionality has seen rapid enhancement, with the main urban area displaying the strongest functionality and other districts comparatively weaker spatial disparities. Social functionality has improved rapidly, with higher levels observed in the main urban area and urban development zones compared to the lower levels in the northeast and southeast of Chongqing. However, improvements in ecological functionality have been limited overall, with only certain districts showing notable enhancements.

In terms of land use sub-function indicators, agricultural production functionality has weakened in all districts and counties, especially in the main urban area, leading to an expansion of spatial disparities. Meanwhile, economic development, land use patterns, population carrying capacity, social security, and cultural landscape functionality have all strengthened across almost all districts and counties, with most of the spatial disparities in functionality dynamics narrowing.

The research results indicate a significant improvement in the multifunctionality of land use across various districts and counties of Chongqing Municipality from 2011 to 2020. However, alongside these improvements, significant spatial disparities in functionality realization values have emerged, necessitating region-specific policies. The government should focus on the following aspects: (1) In the main urban area, while strengthening infrastructure development such as transportation and economy, efforts should also be directed towards promoting circular economy and increasing investment in ecological environment construction and governance to significantly improve ecological functionality. (2) Strengthen financial support and industry development linkage in major agricultural production areas to promote agricultural modernization and stimulate agricultural production growth. (3) Explore innovative compensation mechanisms for key ecological functional areas, enhance fiscal transfer payments and ecological compensation, and improve ecological protection functionality.

This study provides a scientific basis for regional land use policy directions by evaluating the multifunctionality of land use in the study area. However, research on land use multifunctionality in the academic community is still limited, and the scientific validity of the selected indicators in this study is constrained by data limitations. Future research on the factors influencing land use multifunctionality and dynamic studies of regional disparities require further exploration.

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