Pol. J. Environ. Stud. Vol. 32, No. 3 (2023), 2689-2706
DOI: *10.15244/pjoes/161320* ONLINE PUBLICATION DATE: 2023-04-03

Original Research

Measuring the Greening Level of Construction Land in Rural Communities from the Perspective of Multi-Functions Using a Green Niche Method

Xiaokang Li[1, 2]*, Lin Lei[3]

[1]School of Civil Engineering, Architecture and Environment, Hubei University of Technology, Wuhan 430068, China
[2]Innovation Demonstration Base of Ecological Environment Geotechnical and Ecological Restoration of Rivers and Lakes, Hubei University of Technology, Wuhan 430068, China
[3]Changjiang Ecology (Hubei) Technology Development Co., Ltd, Wuhan 430011, China

Received: 16 December 2022
Accepted: 16 February 2023

Abstract

Green utilization of rural construction land (RCL) is key to implementing the UN 2030 Agenda for Sustainable Development and rural revitalization both in China and other countries. However, how to systematically analyze the green utilization level of RCL is still unclear. Thus, a novel method, the green niche of construction land functions in rural communities (GNCLFRC), was proposed based on ecological niche theory to measure the greening level of the RCL. From a systematic perspective, two aspects and five dimensions were proposed for consideration when analyzing GNCLFRC. One was the green niche of elements (GNE), including the greenness of social, economic, and environmental functions. The other was the green niche of state (GNS), including coupling coordination and the development location and potential of the functional system. The Yanhe Community, as a typical case at the microscale for rural revitalization and green utilization of RCL in China, was selected for an empirical application to verify the feasibility of the proposed method. Five Worldview satellite images with resolutions of 0.5 m in 2008, 2010, 2012, 2014, and 2016 and field investigation data obtained by using UAV, iRTK, and Qstar in 2018 and 2020 were used to analyze changes in the RCL and its functions in Yanhe. The two aspects and five dimensions were analyzed. The results showed that GNE in Yanhe continuously increased by 0.3057 to 0.9131 from 2008 to 2020, while GNS increased and then decreased from 2016 to 2020. However, the GNS remained between 0.8-0.9. The GNCLFRC increased yearly and remained above 0.9 for many years. The results indicate that the greening level of RCL in Yanhe is improving, which boosts its overall green development capacity and regional competitiveness. Moreover, the GNCLFRC analysis method and results can be used to guide the green utilization

*e-mail: lixiaokang@hbut.edu.cn

planning of RCL, green function-oriented regional zoning in rural areas, and green management of rural construction.

Keywords: rural community, construction land functions, greening level, green niche

Introduction

Compared with the rapid development of cities globally, rural decline due to urbanization has become a common problem faced by all countries worldwide [1, 2]. Rural recession, manifested in farmland loss, population decline, economic depression, and environmental degradation [3], leads to a decrease in rural development capacity and threatens rural sustainability and resilience [4]. However, it is still argued that rural areas will relocate to the development center due to emerging global issues, such as climate change, food and energy security, and biodiversity [5]. The green transformation and development of rural land are considered the fundamental strategy for reversing rural decline [6]. The European Union (EU) has launched the Rural Development Policy, including land use to respond to rural declines, such as land banking, land consolidation, and land redistribution [7]. Germany and France are typical member states in the EU that achieve land consolidation and village renewal. The Department of Rural Development and Land Reform of South Africa has also carried out a series of land reform policies to revitalize land use and achieve rural revitalization [8]. Various Asian countries, such as Japan [9], South Korea [10], Thailand [11], and Vietnam [12], have also adopted different policies and measures for rural land revitalization. In China, rural revitalization and green transformation, especially land consolidation, are important strategies for coping with global urbanization [13], enhancing rural development capacity and realizing rural sustainability. Modern rural social life relies on the sustainable construction and development of its communities to provide a basis for rural green revitalization [14, 15]. From a geographic perspective, the rural community refers to the space where rural residents carry out their daily living and productive activities. It can be geographically composed of one or more administrative villages.

As the material foundation and spatial support for rural community construction and the production and lives of rural residents [16], construction land plays a central role in the development of the rural population, resources, environment, and economy [17]. With the advancement of new urbanization in China, the demand for rural construction is increasing, which will lead to a substantial expansion of rural construction land (RCL) [18]. Therefore, the greening of the RCL is meaningful for both the green development of rural communities and China's new urbanization [3, 19]. The greening of RCL refers to a land use mode in which the fewest resources on limited land are consumed to obtain the maximum social, economic, and environmental benefits; the concept of green development guides the construction of green land use paths, aiming for harmony between humans and nature and utilizing green methods, technologies and policies as its tools. In 2021, the State Council of China issued the "Guiding Opinions on Accelerating the Establishment and Improvement of a Green, Low-Carbon and Circular Development Economic System", which advocates for green community creation actions and a rural construction evaluation system that can improve rural construction shortcomings. Methods for measuring and evaluating the greening level of construction land in rural communities are scientifically important and worth studying since they can monitor the green and high-quality development of rural communities and support the implementation of the requirements of the State Council of China.

There have been several studies on RCL in recent years. The research topics mainly focus on the consolidation [20], gradient difference and spatial pattern evolution of the structure [3, 19] and the human-land relationship [21] of the RCL. Changes and impacts on RCL due to urban expansion have also been researched [3]. Moreover, RCL is considered an integral part of research on rural land systems [22] and urban–rural construction land systems [23]. There are also some related studies similar to RCL, such as rural settlements, rural residential land, and courtyards. These studies more often concentrated on structural change and transition [16, 24], multifunction assessment [17], expansion and evolution mechanisms [18, 25], coupling characteristics with population and rural development [26, 27], and utilization efficiency [28].

In conclusion, existing studies have analyzed the utilization mechanism of RCL from different perspectives to support the green utilization of RCL and rural revitalization. However, there are still some shortcomings. First, there is still a lack of direct research on the greening of RCL, which seriously lags behind the study of urban construction land, as cities are valued over rural areas. Moreover, compared with arable land, research on RCL has also received less attention. For example, several studies have focused on the green utilization efficiency of urban land [29], urban construction land [30], arable land [31], and the green development level of arable land [32]. Limited research on the greening of RCL makes it challenging to guarantee high-quality management for RCL [19]. Second, research on evaluation methods for the greening level of RCL has received little attention, which inhibits testing the green utilization effect of RCL. However, assessment methods for greening level can be found in other research fields, such as the green development level of countries [33], regions [34], cities [35], and companies [36]. These studies provide ideas for establishing an analysis framework and evaluation index system and methods for measuring the greening level of the RCL. Third, most of the previous studies focused on meso or macro scales, such as district [18, 25], prefecture [3, 19], province [37], and nation [38]. Research on construction land use at the microscale, especially in rural communities and villages, is relatively neglected. In rural China, as the basic socioeconomic unit, rural communities are significant to rural revitalization. Research on construction land green use at the community and village levels can provide theoretical and practical guidance for optimally alleviating the rural issues that emerge during socioeconomic transitions [1].

One important step toward sustainable land use is to identify the multiple environmental, social, and economic functions of land use [39]. Assessment of the vulnerability and sustainability of land systems based on land functions is an important approach to understanding the coupled human-environment system [40]. The function of RCL refers to its ability to provide products and services [41], which comprehensively reflects its use mode and process. Multifunctional value can quantitatively describe the social, economic, and environmental benefits of land and is the core index for the greening level of construction land [42]. In addition, the essence of the greening level of construction land reflects its position in the rural green development system. Thus, it is appropriate to use the green niche method, a novel method proposed in this paper referencing the concept of ecological niches, to calculate the greening level of construction land.

The green niche for construction land functions in rural communities (GNCLFRC) refers to the location and function of construction land functions in the green development system of rural communities. The GNCLFRC includes two basic attributes: "state" and "potential". "State" is the result of competition and coordination among the subfunctions of the construction land function system and reflects the current development state of the system. "Potential" is the potential capacity of construction land functions for green development and reflects the trend in system development. The "state" is the basis for the development and change in "potential", and "potential" is the driving force for the change in "state". The concept of a green niche evolved from the concept of an ecological niche, which refers to the location and function of organisms in the community [43]. Each organism occupies its own niche space. Niche theory is an important concept in ecology for studying species competitiveness, species adaptability to the environment, and ecosystem diversity and stability [44]. The application of niche theory has gradually expanded from the biological field to land science research [45]. The niche of land use comprehensively reflects the space occupied and the location and function of various types of land in the land use system [46], including environmental, economic, and social niches [47]. The green niche is useful for understanding the relationship between competition, exclusion, and collaborative development among different rural communities. GNCLFRC can reflect not only the greening level of construction land in rural communities and its contribution to the green development of communities but also the competitiveness of different rural communities. The higher the green niche of the rural community is, the greater its attractiveness to the external population and resources and the greater its potential for internal sustainable development.

Coupling coordination in conjunction with development location and potential analysis offers an important approach to researching GNCLFRC. Coupling refers to the phenomenon in which two or more systems interact and influence one another. In a broad sense, it emphasizes the high degree of correlation between things [26]. Coordination is the benign coupling of systems or elements. The coupling coordination of a system determines its development state and is the basis for the system to develop from disorder to order. The complex relationship of mutual promotion and stress among multiple functions of construction land in rural communities has an important influence on the development and evolution of rural spatial patterns [48]. Excessive development of a certain function will affect the realization of other functions [49], thereby affecting the overall greening level of construction land. Exploring the coupling interaction between the multiple functions of construction land in rural communities is an important technical method for coordinating the social, economic, and environmental benefits of multiple relevant stakeholders in rural areas and optimizing the allocation of construction land resources [50]; it is also an important means for analyzing the "state" attribute of the GNCLFRC. Analyzing development location and potential can help clarify the constraining elements of the system of construction land functions and structure and is important for understanding the "potential" attribute of the GNCLFRC. Through coupling coordination and development location and potential analysis, the key factors that affect GNCLFRC can be extracted and optimized.

The paper aims to propose a method for measuring the greening level of construction land in rural communities from the perspective of multiple functions based on a green niche method and verify the applicability of the proposed method by applying it to empirical research on Yanhe Community, a typical ecological village in China. Therefore, the composition and quantification methods of RCL functions were analyzed first. Then, dimensions and factors, a function model, and a calculation method for GNCLFRC were proposed. Subsequently, an empirical study was conducted to validate the proposed method. Finally, the conclusions, implications, and limitations of the research were presented.

Material and Methods

Study Area

The Yanhe Community is a national ecological demonstration village in China, and the authors' team has participated in its planning and construction for many years. It is located in Wushan town, Xiangyang city, Hubei Province, and has a total community area of 1163.24 hm^2, 303 households, and 1050 residents. The planning and utilization of construction land in this community is a demonstration project based on multifunction integration, making it a typical and feasible object for researching the application of the GNCLFRC [51]. Moreover, as a national ecological community, Yanhe Community has experienced great changes in both the ecology and economy due to construction land use changes, and it has been transformed from a poor, messy community into a national ecological and economic demonstration community. The experience of the Yanhe Community can offer lessons for other similar rural communities since an increasing number of rural communities will go through a similar development path as the Yanhe Community under the background of rural revitalization both in China and other countries around the world. It is meaningful to select Yanhe Community, a typical case at the microscale for rural revitalization and green utilization of RCL, to verify the feasibility of the proposed method for measuring the greening level of construction land in rural communities. The research period of the GNCLFRC for Yanhe Community is from 2008 to 2020, a complete community planning cycle. The current situation of the built-up area in Yanhe Community is shown in Fig. 2.

Data Sources and Processing

To monitor land use changes in Yanhe Community, five Worldview satellite images were used, with resolutions of 0.5 m in 2008, 2010, 2012, 2014, and 2016. Since the research scope is at a micro level and satellite data cannot meet the accuracy requirements, uninhabited aerial vehicles (UAVs) and global positioning system (GPS) tracking devices, called iRTK and Qstar, were used to obtain high-resolution images and accurate data on construction land. In addition, construction land use data of Yanhe Community in 2018

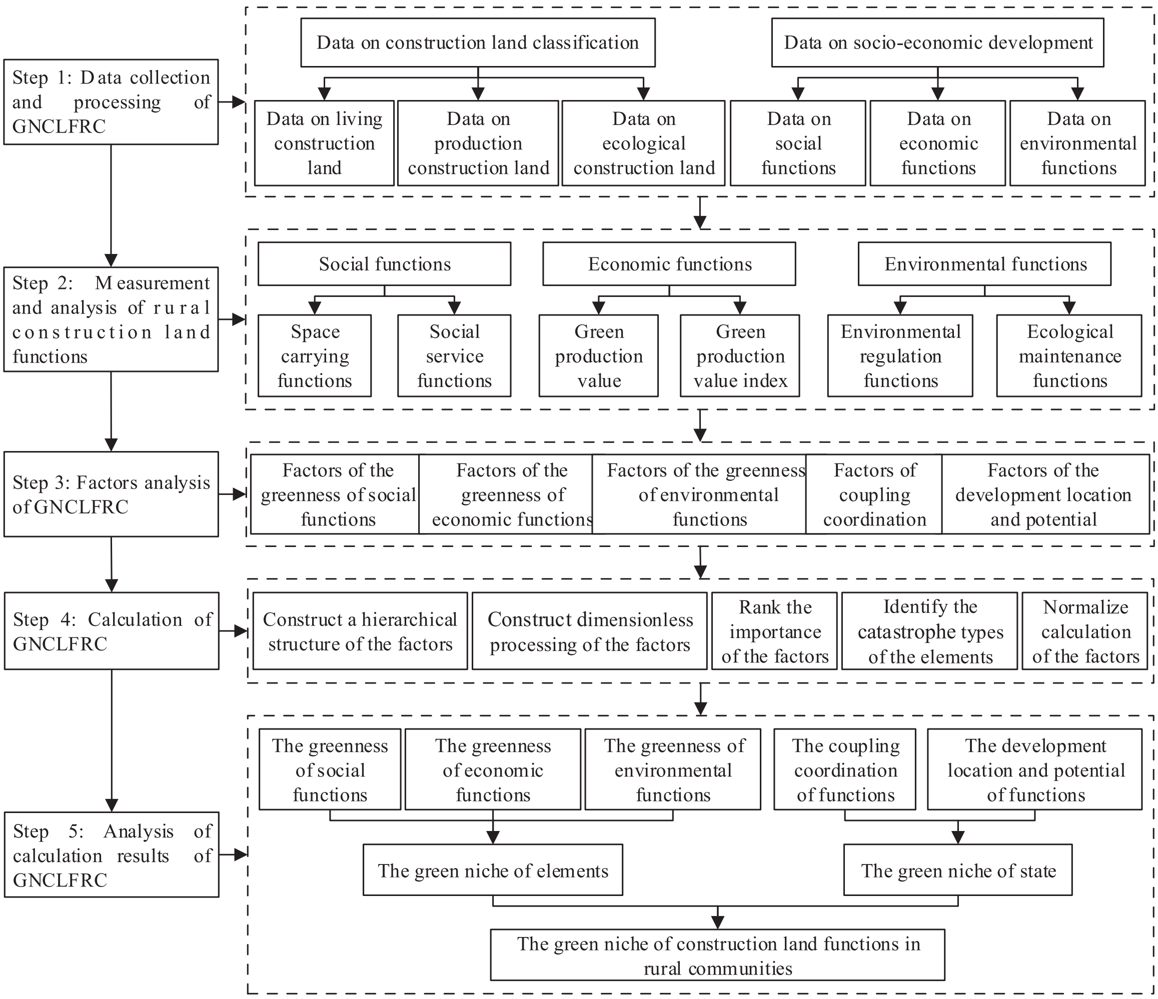


Fig. 1. The process of analyzing GNCLFRC.

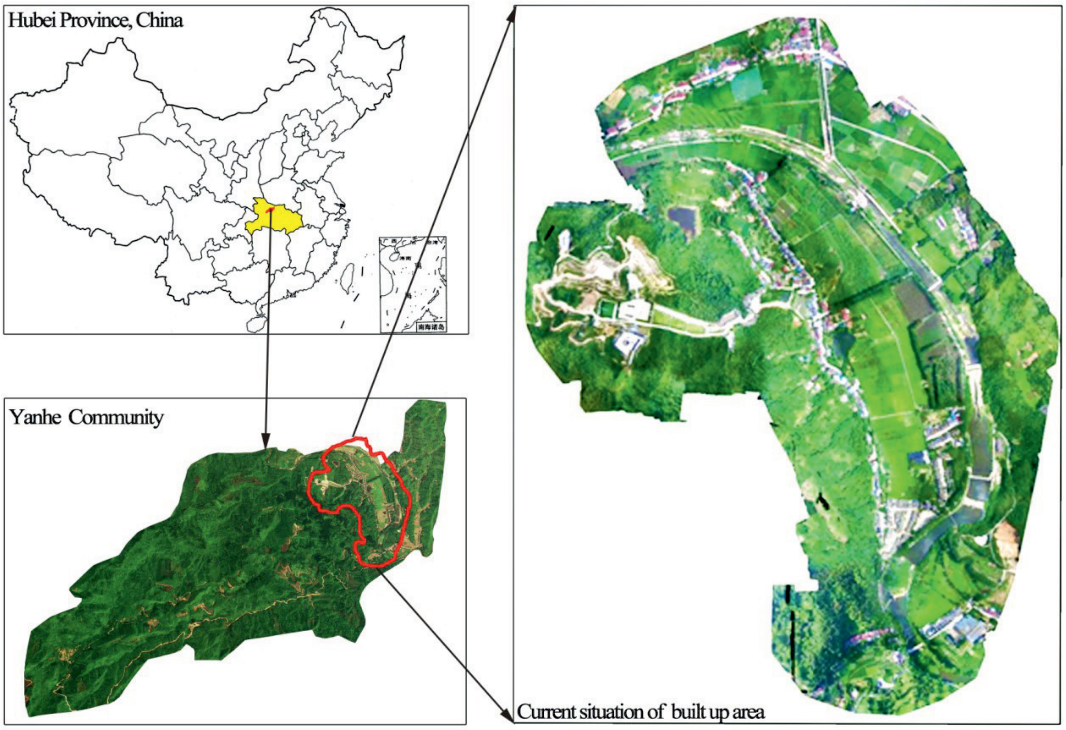


Fig. 2. Current situation of built-up areas in Yanhe Community.

and 2020 were obtained through field investigation by using UAV, iRTK, and Qstar. The socioeconomic data needed in this research were derived from questionnaire surveys and interviews with the village committee.

The preprocessing of the five remote sensing images, e.g., image cutting, geometric correction, and image enhancement, was achieved in ERDAS 9.2. Then, the five images after preprocessing were input into eCognition 8.9 for interpretation and classification. The land in the Yanhe community was classified into construction land and nonconstruction land (including woodland, water body, arable land, garden land, and unused land). The Kappa coefficients were all higher than 0.8. Subsequently, construction land was subdivided into residential land, public management and service facility land, industrial and mining storage land, commercial land, scenic spot facility land, and parks and green land according to the data from UAV, iRTK, and Qstar, which were processed in the Agisoft PhotoScan and Hi-Net Server software.

The Process of Analyzing GNCLFRC

The process of analyzing GNCLFRC can be divided into 5 steps, as shown in Fig. 1.

Calculation of Rural Construction Land Functions

According to the Chinese national standard Current Land Use Classification (GB/T 21010-2017), construction land in rural communities can be classified into residential land, public management and service facility land, industrial and mining storage land, commercial land, transportation land, scenic spot facility land, and parks and green land [52]. Construction land in rural communities has multifunctional properties [22], and different types of construction land provide different products and services [48]. According to the different attributes of these products and services provided by construction land, its functions can be divided into social, economic, and environmental functions [53]. Social functions are mainly provided by residential land, public management and service facility land, transportation land, and scenic spot facility land, which are collectively referred to as living construction land. Economic functions are mainly provided by industrial and mining storage land, commercial land, transportation land, and scenic spot facility land, which are collectively referred to as production construction land. Environmental functions are mainly provided by parks and green land, which is called ecological construction land.

Social Functions

The social functions of construction land in rural communities refer to the capacity of construction land to provide rural residents with carrying space, employment support, and social security, including carrying and social service functions. According to the characteristics of the social functions' composition, the cost replacement method is used to measure the value of various social functions.

The method of calculating the social function value of construction land in rural communities is shown in Equation (1).

$$FSO = FSO_1 + FSO_2 \tag{1}$$

where FSO is the value of the social functions, FSO_1 is the value of the space carrying functions, and FSO_2 is the value of the social service functions.

The space carrying functions of construction land in rural communities are mainly manifested in the ability of residential land and transportation land to provide locations for living and transportation for rural residents. The calculation method is shown in Equation (2).

$$\begin{cases} FSO_1 = FSO_{11} + FSO_{12} \\ FSO_{11} = (P_{lr} + P_{cr}) / T_1 \\ FSO_{12} = (P_{lt} + P_{ct}) / T_2 \end{cases} \tag{2}$$

where FSO_1 is the value of the space carrying functions; FSO_{11} and FSO_{12} are the values of the space carrying functions of residential land and transportation land, respectively; P_{lr} is the market land price of residential land; P_{cr} is the total construction cost of the housing projects carried by residential land; T_1 is the maximum service life of residential land, 70 years according to the "Interim Regulations of the People's Republic of China on the Assignment and Transfer of the Right to Use Urban State-owned Land"; P_{lt} is the market price of transportation land, referring to the calculation method of P_{lr}; P_{ct} is the total construction cost of the transportation projects carried by transportation land; and T_2 is the service life of roads, which is 10 years according to the operation period of the grade III highway.

The social service functions of construction land in rural communities are manifested in the employment support, public management, public service, and leisure and entertainment functions provided by various service facilities attached to construction land. The calculation method is shown in Equation (3).

$$\begin{cases} FSO_2 = FSO_{21} + FSO_{22} + FSO_{23} \\ FSO_{21} = Q_j \times P_j \\ FSO_{22} = \sum_{i=1}^{n} (P_{li} + P_{ci}) / T \\ FSO_{23} = I_t \end{cases} \tag{3}$$

where FSO_2 is the value of the social service functions; FSO_{21}, $FSO_{22,}$ and FSO_{23} are the values of the employment support, public management and services, and leisure and entertainment functions of construction land, respectively; Q_j is the employed population; P_j is the per capita wage of employees; P_{li} is the market land price of the ith type of construction land, referring to the calculation method of P_{lr}; P_{ci} is the construction cost of the ith type of public service facility; T is the service life of a public facility, taken as 50 years; and I_t is the total income from tourism in rural communities.

Economic Functions

The economic functions of construction land in rural communities refer to the ability to use construction land as a carrier to provide services for rural production activities and economic development. The economic functions of construction land in rural communities can be measured by the green production value.

The green production value puts the resource and environmental consumption generated in the process of rural economic development as production costs into economic accounting [54]. The calculation method is shown in Equation (4):

$$FEC = T_{PV} - L_R - L_E \tag{4}$$

where FEC is the value of the economic functions; T_{PV} is the total value of secondary and tertiary industries; L_R is the consumption value of natural resources; and L_E is the loss value of environmental pollution.

According to the main resources consumed in the development and utilization of construction land in rural communities, the consumption of water, energy, and land is selected to calculate the consumption value of natural resources. The calculation method is shown in Equation (5).

$$\begin{cases} L_R = L_W + L_{Ener} + L_C \\ L_W = Q_W \times P_W \\ L_{Ener} = Q_{Ener} \times P_{Ener} \\ L_C = S_C \times P_C \end{cases} \tag{5}$$

where L_R is the consumption value of natural resources; L_W is the consumption value of water resources; L_{Ener} is the consumption value of energy resources; L_C is the consumption value of cultivated land resources; Q_W is the consumption of water resources; P_W is the unit price of water resources; Q_{Ener} is the consumption of energy resources; P_{Ener} is the unit price of energy resources; S_C is the changed area of cultivated land; and P_C is the unit price of cultivated land resources.

The loss value of environmental pollution mainly refers to the cost of pollution treatment and protection, that is, the cost of avoiding environmental pollution, including treatment and maintenance costs. The calculation method is shown in Equation (6).

$$V = \sum_{i=1}^{m} R_i \times P_i + \sum_{j=1}^{n} M_j \tag{6}$$

where V is the loss value of environmental pollution; R_i is the treatment amount of the ith pollutant; P_i is the unit treatment cost of the ith pollutant; and M_j is the protection cost of the jth pollutant.

The degree of greening of the economic functions of construction land in rural communities can be measured by the green production value index. The green production value index of rural communities should increase yearly over time. It can be expressed with a mathematical formula:

$$\begin{cases} R_G(t+1) - R_G(t) \geq 0 \\ R_G = FEC / T_{PV} \end{cases} \tag{7}$$

where R_G is the value of the green production value index; FEC is the value of green production; T_{PV} is the total value of secondary and tertiary industries; and T is the time variable.

Environmental Functions

The environmental functions of construction land in rural communities refer to the ecological service functions provided by the system, which is composed of construction land and attached organisms. It is the ecological resources and environmental supply capacity provided by the land system to maintain the survival of organisms, including the functions of environmental regulation and ecological maintenance. Ecosystem service value (ESV) is used to measure the environmental functions of construction land in rural communities.

The method for calculating the ESV of ecological construction land was derived from the calculation model proposed by Costanza [55] and the equivalent factor proposed by Xie [56]. The calculation method is shown in Equation (8).

$$\begin{cases} ESV_{ECL} = \sum_{j=1}^{n} A_j E_{rj} \\ E_{rj} = e_{rj} E_n \\ E_n = \frac{1}{7} \sum_{i=1}^{n} \frac{m_i p_i q_i}{M} \end{cases} \tag{8}$$

where ESV_{ECL} is the ESV of ecological construction land; A_j is the area of land use type j; E_{rj} is the value of the kind of ecosystem service r per unit area of ecological construction land type j; r is the kind of ecosystem service; e_{rj} is the equivalent factor of the kind of ecosystem service r of ecological construction land type j relative to the unit price of ecosystem services provided by the farmland ecosystem; E_n is the economic value of the natural grain production of farmland per hectare; i is the type of grain crop; m_i is the land use area of grain crops of category i; p_i is the market unit price of grain crops of category i; q_i is the annual yield per hectare of grain crops of category i; and M is the total area of grain crops.

Living and production construction land mainly affect the ecosystem service functions of hydrological regulation [57], gas regulation, and waste purification [58], and the resulting ESV loss can be compensated only by human economic activities. According to Rao [58], the value of hydrological regulation and waste purification services is measured by the cost of rural residents' freshwater consumption and the cost of waste treatment.

The calculation method for the service value of hydrological regulation is shown in Equation (9).

$$ESV_{HR} = -\sum_{i=1}^{2} W_i \times P_i \tag{9}$$

where ESV_{HR} is the service value of hydrological regulation; W_i is the water consumption from residents' living and industrial production; and P_i is the unit price for residential and industrial water.

The calculation method for the service value of waste treatment is shown in Equation (10).

$$\begin{cases} ESV_{WT} = ESV_{WT-L} + ESV_{WT-P} + ESV_{WT-T} \\ ESV_{WT-L} = -(W_{ds} \times P_{ds} + Q_{dw} \times P_{dw}) \\ ESV_{WT-P} = -(W_{iw} \times P_{iw} + M_{is} \times P_{is} + G_{ig} \times P_{ig}) \\ ESV_{WT-T} = -\alpha \times Q_t \times P_t \end{cases} \tag{10}$$

where ESV_{WT} is the service value of waste treatment; $ESV_{WT\text{-}L}$, $ESV_{WT\text{-}p}$, and $ESV_{WT\text{-}T}$ are the costs of waste treatment from rural residents' living, production, and transportation, respectively; W_{ds} is the domestic sewage discharge; P_{ds} is the unit price of domestic sewage treatment; Q_{dw} is the number of households; P_{dw} is the price of domestic waste treatment per household; W_{iw} is the industrial sewage discharge; P_{iw} is the unit price of industrial sewage treatment; M_{is} is the amount of produced industrial solid waste; P_{is} is the unit price of industrial solid waste treatment; G_{ig} is the volume of industrial exhaust emissions; P_{ig} is the unit price of industrial exhaust emissions treatment; α is the coefficient of air pollution; Q_t is the total number of people; and P_t is the per capita transportation cost.

Dimensions and Factors of GNCLFRC

The construction land functions in rural communities represent a complex coupling system. The system is composed of the elements of social functions, economic functions, and environmental functions, and each function is affected by many factors. The development of a system is determined by its constituent elements, structural relations, and driving potential (responding to the external environment). GNCLFRC reflects the development status of the system of construction land functions and is affected by the development status of each subsystem, the coupling relationship between subsystems and elements, the gap between each element and the ideal state, and the resulting internal driving force for the further development of the system.

In conclusion, the GNCLFRC is jointly determined by five dimensions: the greenness of social functions (GFSO), the greenness of economic functions (GFEC), the greenness of environmental functions (GFEN), coupling coordination (CC) and the development location and potential (DLP) of functions. GFSO, GFEC, and GFEN reflect the greening level of the components of the system of construction land functions, and they are collectively called the green niche of elements (GNE). CC reflects the structural relationship among elements in the system, and DLP reflects the driving source and development potential of the system. CC and DLP are collectively called the green niche of state (GNS).

The elements and factors of the GNCLFRC based on the five dimensions are shown in Table 1.

Table 1. Elements and factors of GNCLFRC.

Dimensions	Elements	Factors	Sources
The greenness of social functions	The value of the social functions of living construction land (A_1)	The value of carrying space functions (A_{11})	[49]
		The value of social service functions (A_{12})	
	The greenness of living construction land (A_2)	Ecosystem service value of living construction land (A_{21})	[59]
		Emergy sustainability index of living construction land (A_{22})	[60]
The greenness of economic functions	The value of the economic functions of production construction land (B_1)	Per capita net income of residents (B_{11})	[42]
		The proportion of the added value of secondary and tertiary industries in the GDP (B_{12})	
	The greenness of production construction land (B_2)	Green production value (B_{21})	[61]
		Green production value index (B_{22})	
The greenness of environmental functions	The value of environmental functions of ecological construction land (C_1)	Ecosystem service value of ecological construction land (C_{11})	[49]
Coupling coordination among functions	Coupling coordination between social and economic functions (D_1)	Coupling degree between social and economic functions (D_{11})	[42]
		Coordination degree between social and economic functions (D_{12})	
		Coupling coordination degree between social and economic functions (D_{13})	
	Coupling coordination between social and environmental functions (D_2)	Coupling degree between social and environmental functions (D_{21})	
		Coordination degree between social and environmental functions (D_{22})	
		Coupling coordination degree between social and environmental functions (D_{23})	
	Coupling coordination between economic and environmental functions (D_3)	Coupling degree between economic and environmental functions (D_{31})	
		Coordination degree between economic and environmental functions (D_{32})	
		Coupling coordination degree between economic and environmental functions (D_{33})	
	Coupling coordination among social, economic, and environmental functions (D_4)	Coupling degree among social, economic, and environmental functions (D_{41})	
		Coordination degree among social, economic, and environmental functions (D_{42})	
		Coupling coordination degree among social, economic, and environmental functions (D_{43})	
The development location and potential	System self-driven development (E_1)	The development location (E_{11})	[62]
		The development potential (E_{12})	

The Function Model of GNCLFRC

GNCLFRC Model

GNCLFRC is a quantitative description of the greening level of construction land and its location and contribution to the green development system of rural communities. The function model of GNCLFRC is shown in Equation (11).

$$\begin{cases} GN = f(GNE, GNS, t) \\ GNE = f(GFSO, GFEC, GFEN) \\ GNS = f(CC, DLP) \end{cases} \tag{11}$$

where GN is the green niche of the construction land functions; f is a function of related variables and time; GNE and GNS are the green niches of elements and state, respectively; $GFSO$, $GFEC$, and $GFEN$ are the greenness of social, economic and environmental functions, respectively; CC and DLP are the coupling coordination and development location and potential of the function system of construction land, respectively; and t is the time variable.

Coupling Coordination Model

The coupling degree and coupling coordination degree are two important concepts in coupling coordination theory. The coupling degree is used to measure the mutual influence relationship among elements. The greater the coupling degree is, the closer the connection between the elements [63]. The coordination degree is used to measure the degree of coordination among elements, and it reflects the benign coupling relationship and orderly coordination state among elements [64].

The coupling coordination of the function system of construction land in rural communities reflects the structural relationship of the system and is an important method for analyzing the "state" attribute of the GNCLFRC. The functions of the coupling degree, coordination degree, and coupling coordination degree are shown in Equations (12), (13), and (14), respectively.

$$C = \begin{cases} 2\times[(u_1\times u_2)/(u_1+u_2)]^{1/2}, \; when \; n=2 \\ 3\times\{(u_1\times u_2\times u_3)/[(u_1+u_2)(u_1+u_3)(u_2+u_3)]\}^{1/3}, \; when \; n=3 \end{cases} \tag{12}$$

$$T = \begin{cases} \alpha u_1 + \beta u_2, \; when \; n=2 \\ \alpha u_1 + \beta u_2 + \gamma u_3, \; when \; n=3 \end{cases} \tag{13}$$

$$D = \sqrt{CT} \tag{14}$$

where C is the coupling degree between subsystems; u_1, u_2 and u_3 are comprehensive indexes of social, economic, and environmental functions, respectively, and the calculation method refers to Shi [63]. The indexes are the factors contained in the three dimensions of GFSO, GFEC, and GFEN in Table 1; T is the coordination index; D is the coupling coordination degree; α, β, and γ are undetermined coefficients when analyzing the coupling coordination degree between two subsystems, $\alpha = \beta = 1/2$; when analyzing the coupling coordination degree among three subsystems, $\alpha = \beta = \gamma = 1/3$.

Development Location and Potential Models

Development location and potential analysis is an important method used to research the "potential" attribute of GNCLFRC. The development location of the function system of construction land in rural communities refers to the development state of the system at a certain moment, and the formation of this state is the result of the comprehensive effects of the various elements it contains. The development potential is the difference between the actual and the ideal development location of each element in the system and is the fundamental force driving the development of the system. The development location and potential reflect the distance between the development state and the ideal state of the system of construction land functions at a certain moment and determine the development potential of the system.

The development location can be represented by the absolute state and the relative state. The absolute state refers to the absolute measurement value of the development state of each subsystem or element, such as function values and carbon emissions. The relative state refers to the value of the absolute measurement value of each subsystem or element relative to a certain reference value (such as the value of the base year, the planned target value, and the ideal state value). In this study, the ratio between the absolute value of a certain time and the ideal value in the research period is selected to calculate the development location of the system of RCL functions. The calculation method is shown in Equations (15) and (16).

$$L_j = \sqrt[n]{\prod_{i=1}^{n} L_{ij}} \tag{15}$$

$$L_{ij} = \begin{cases} x_{ij}/a_{ij}, \; when \; x_{ij} \; has \; a \; positive \; effect \\ a_{ij}/x_{ij}, \; when \; x_{ij} \; has \; a \; negative \; effect \end{cases} \tag{16}$$

where L_j is the development location of the system of construction land functions at time point j; L_{ij} is the development location of the system's component elements i (namely, the factors contained in the four dimensions of GNFSO, GNFEC, GNFEN, and CC in Table 1) at time point j; n is the number of state variables; i and j are state and time variables, respectively; x_{ij} is the absolute value of factor i at time point j; and a_{ij} is the ideal value of factor i at time point j.

The method for calculating the development potential of the system of construction land functions in rural communities is shown in Equations (17) and (18).

$$P_j = \sqrt[n]{\prod_{i=1}^{n} P_{ij}} \tag{17}$$

$$P_{ij} = \begin{cases} (a_{ij} - x_{ij})/a_{ij}, & when\ x_{ij}\ has\ a\ positive\ effect \\ (x_{ij} - a_{ij})/x_{ij}, & when\ x_{ij}\ has\ a\ negative\ effect \end{cases} \tag{18}$$

where P_j is the development potential of the system of construction land functions at time point j; P_{ij} is the development potential of the system's component elements i at time point j; n is the number of state variables; i and j are state and time variables, respectively; x_{ij} is the absolute value of factor i at time point j; and a_{ij} is the ideal value of factor i at time point j.

The Calculation Method of GNCLFRC

The function of construction land in rural communities is a multiobjective system, and there are several stable states in its evolution. Changes in elements will induce changes in the system state. A slight difference in the change path of elements in the critical state will lead to different directions of system evolution. These features are consistent with the application characteristics of catastrophe theory [65]. The entropy method is an effective way to capture objective weight, and the importance of the factors of GNCLFRC can be ranked according to this weight. Therefore, the entropy-catastrophe method was chosen to calculate the GNCLFRC. The method is as follows:

Step 1: Construct a hierarchical structure of the factors of GNCLFRC. The factors of GNCLFRC are shown in Table 1. Each element contains no more than 4 factors. The initial value of the factors should be collected.

Step 2: Construct dimensionless processing of the factors of GNCLFRC. Unify the dimension of the original data of the factors so that their value range is [0, 1].

Step 3: Rank the importance of the factors of GNCLFRC. The entropy method [45] is used to calculate the weight of the factors after dimensionless processing and rank the importance of the factors according to their weight.

Step 4: Identify the catastrophe types of the elements of GNCLFRC according to the number of factors contained in each element [66].

Results and Discussion

Changes in Construction Land Area

Land use classification and changes in Yanhe Community from 2008 to 2020 were obtained by remote sensing interpretation, iRTK and Qstar field measurements, and UAV aerial photography, which are shown in Fig. 3 and Table 2.

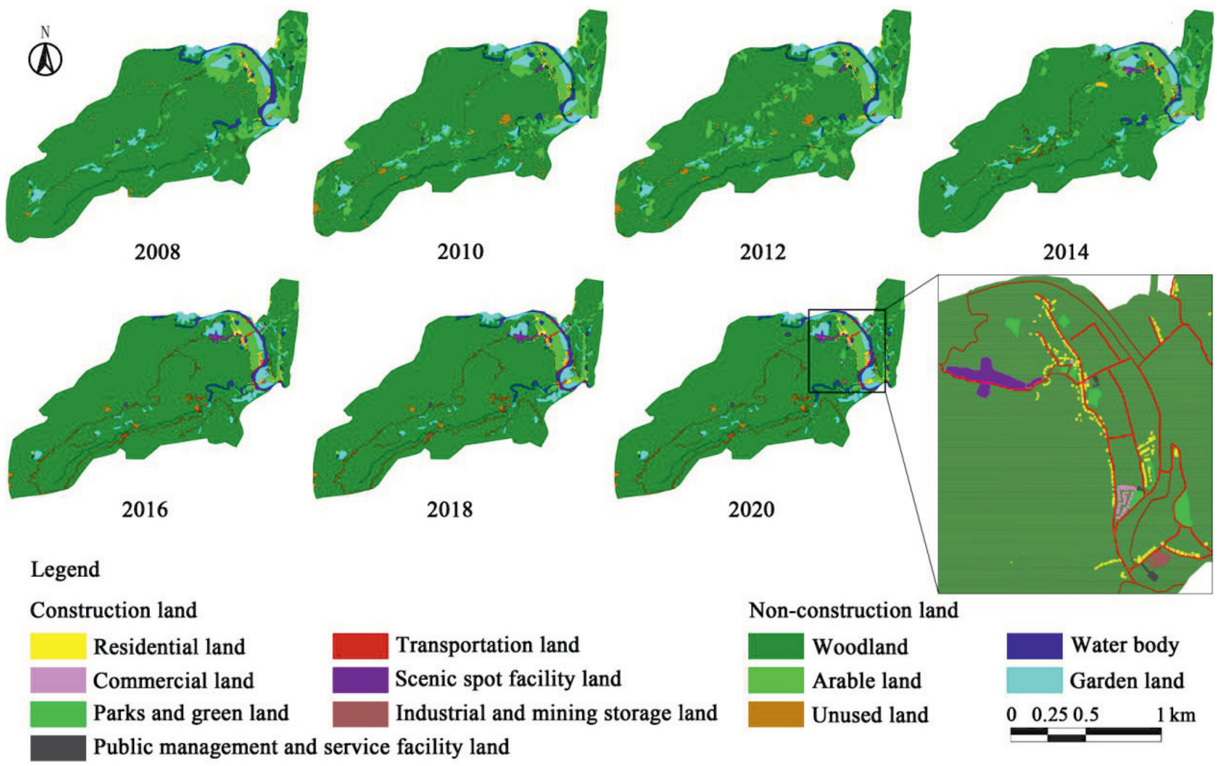


Fig. 3. Land use classification and changes in Yanhe Community from 2008 to 2020.

Table 2. The area of various construction lands in Yanhe Community from 2008 to 2020 (hm^2).

Construction land use types	2008	2010	2012	2014	2016	2018	2020
Residential land	6.02	6.02	6.05	6.05	6.05	6.05	6.05
Public management and service facility land	0.28	0.28	0.28	0.31	0.31	0.43	0.43
Industrial and mining storage land	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Commercial land	0.21	0.21	0.21	0.23	0.23	1.80	1.83
Transportation land	8.35	10.58	13.12	15.89	18.55	18.73	19.78
Scenic spot facility land	2.52	2.63	2.70	3.52	3.62	5.21	6.03
Parks and green land	2.11	2.22	2.36	3.26	3.26	3.78	3.78
Total	19.83	22.28	25.06	29.60	32.36	36.34	38.24

According to Table 2, the increase in various construction lands in Yanhe Community promotes the improvement of social, economic, and environmental functions and enhances the green niche of elements in the functional system of construction land. In terms of construction land, transportation land, scenic spot facility land, parks and green land, and commercial land increased by 11.43 hm^2, 3.51 hm^2, 1.67 hm^2, and 1.62 hm^2, respectively, which significantly improved the social, economic, and environmental functions of Yanhe Community and the green niche of various elements of the construction land function system.

Changes in Construction Land Functions

Social Functions

According to Equations (1)-(3), the social function value of construction land in Yanhe Community from 2008 to 2020 was calculated. The results are shown in Table 3.

According to Table 3, the social function value of construction land in Yanhe Community increases yearly, which promotes improvement in the green niche of the social functions. The ranking of various construction land functions indicates that the social functions of construction land in Yanhe Community are mainly used for recreation, transportation and residential carrying.

Economic Functions

According to Equations (4)-(7), the economic function value of construction land in Yanhe Community from 2008 to 2020 is calculated, and the results are shown in Table 4.

According to Table 4, the economic function of the construction land in Yanhe Community has gradually shifted toward greening, which has improved the green niche of the economic function. The green production value index of Yanhe Community is high and remains above 0.9, although it first decreased and then increased, indicating that the cost of resources and the environment of Yanhe Community first increased and then decreased. The economic function was transformed to green, and the green niche of the economic function was improved.

Table 3. The social function values of construction land in Yanhe Community from 2008 to 2020 (10^4 CNY).

Social functions		2008	2010	2012	2014	2016	2018	2020
The space carrying functions	Space carrying functions of residential land	227.03	237.01	246.98	249.31	250.51	250.51	250.51
	Space carrying functions of transportation land	2154.30	2729.64	3384.96	4099.62	4785.90	4832.34	5103.24
	Subtotal	2381.33	2966.65	3631.94	4348.93	5036.41	5082.85	5353.75
The social service functions	Employment support functions	48.00	51.00	116.00	342.00	346.00	391.70	515.00
	Public management and services functions	3.51	3.61	3.76	4.55	4.55	5.07	5.07
	Leisure and entertainment functions	3000	4000	5000	5500	6000	8000	10000
	Subtotal	3051.51	4054.61	5119.76	5846.55	6350.55	8396.77	10520.07
Total		5432.84	7021.27	8751.70	10195.48	11386.96	13479.63	15873.83

Table 4. The economic function values of construction land in Yanhe Community from 2008 to 2020 (10^4 CNY).

Economic functions	2008	2010	2012	2014	2016	2018	2020
The green production value	5100	6320	7480	8287	9220	11800	14350
The total value of secondary and tertiary industries	4691.83	5816.01	6845.22	7466.76	8387.71	10756.15	13367.34
The green production value index	0.9200	0.9203	0.9151	0.9010	0.9097	0.9115	0.9315

Table 5. ESV of construction land in Yanhe Community from 2008 to 2020 (10^4 CNY).

Construction land	Ecosystem service value (ESV)						
	2008	2010	2012	2014	2016	2018	2020
Living and production construction land	-18.40	-15.08	-18.17	-23.20	-28.59	-32.87	-36.74
Ecological construction land	18.14	18.18	19.37	24.05	24.05	27.31	27.31
Total	-0.26	3.10	1.20	0.86	-4.53	-5.56	-9.44

Environmental Functions

According to Equations (8)-(10), the environmental function values of construction land in Yanhe Community from 2008 to 2020 are calculated, and the results are shown in Table 5.

According to Table 5, the ESV of the ecological construction land in Yanhe Community increased, and the green niche of the environmental function was improved. The ESV of ecological construction land increased by 91600 CNY, while the ESV of other construction land decreased by 183400 CNY, resulting in the total ESV of construction land decreasing by 91800 CNY. Moreover, the improvement to the ecological environment from parks and green land could not compensate for the damage by other construction land.

Coupling Coordination of Construction Land Functions

According to Equations (12)-(14), the coupling coordination changes in the social, economic, and environmental functions of construction land in the Yanhe Community from 2008 to 2020 were calculated and analyzed, and the results are shown in Fig. 4.

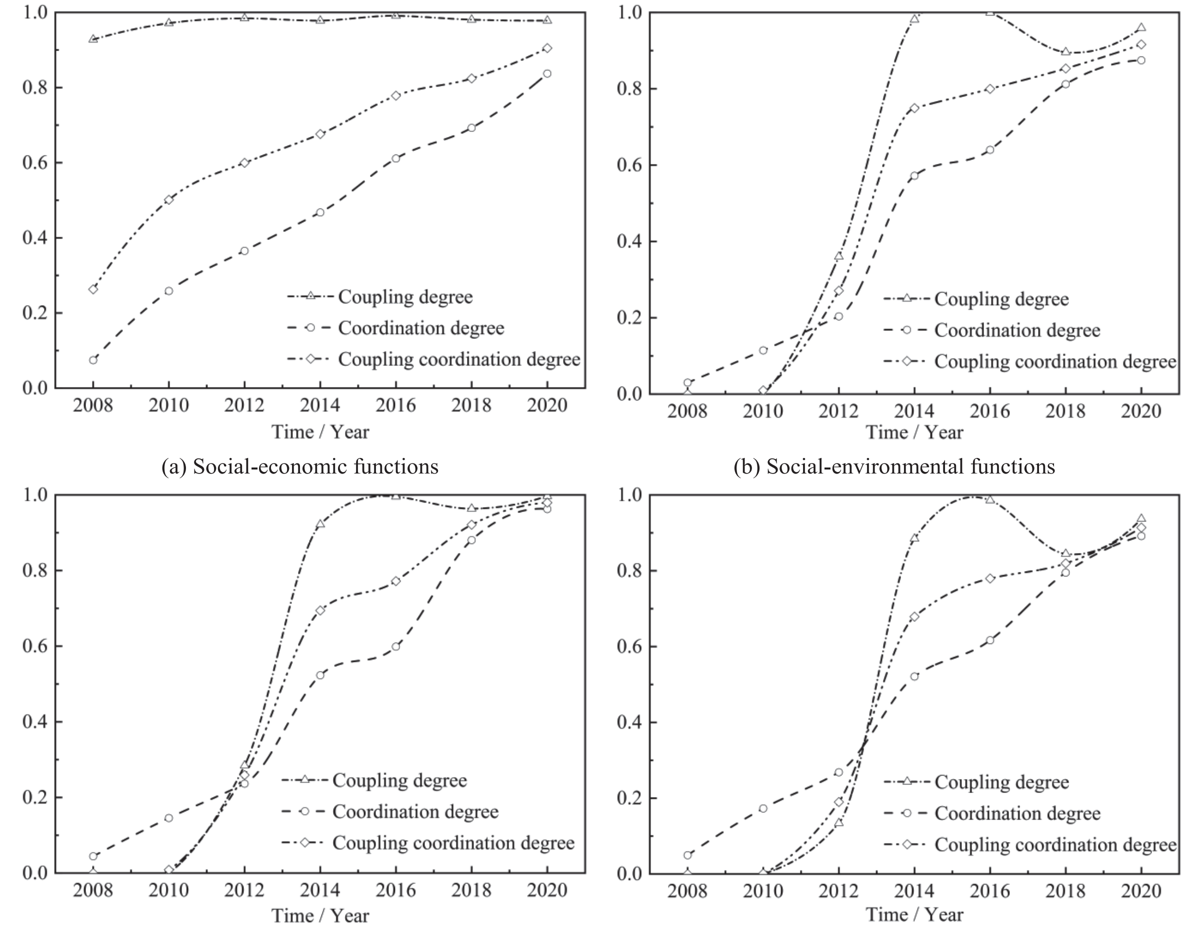
Fig. 4 shows that the degree of coupling coordination among the social, economic, and environmental functions of construction land in Yanhe Community has been increasing yearly, and their mutual promotion has strengthened, which helps to improve the GNCLFRC. The coupling degree between the social and economic functions of construction land in Yanhe Village was higher than 0.9, indicating that social and economic functions were highly correlated and had long influenced each other. The coupling degrees between social and environmental functions, economic and environmental functions, and among social, economic, and environmental functions gradually increased, which implies that the mutual influence of social, economic, and environmental functions was enhanced. The coordination degree among social, economic, and environmental functions increased yearly, which suggests that benign coupling among the three was increasing.

Development Location and Potential of Construction Land Functions

According to Equations (15)-(18), the development location and potential of the system of construction land functions in Yanhe Community from 2008 to 2020 were calculated and analyzed, and the results are shown in Fig. 5.

Fig. 5a) shows that the comprehensive development location of the system of construction land functions in Yanhe Community gradually increased, which promoted the improvement of the GNCLFRC. The development location of the system of construction land functions in Yanhe Community increased from 0.4248 to 0.7570, indicating that the development level of the system gradually increased, and the contribution of construction land functions to the green development system of Yanhe Community became increasingly prominent. From a multifunctional perspective, the development location for the social functions of construction land in Yanhe Community was higher than that for the economic and environmental functions, which suggests that social functions had a greater driving effect on the system of construction land functions, and the rapid development of the system can be promoted by greatly improving the green niche of social functions.

Fig. 5b) shows that the comprehensive development potential of the system of construction land functions in Yanhe Community gradually decreased, and the development potential was reduced. The development potential of the social, economic, and environmental functions of Yanhe Community also decreased, which signals that the gap between the current functions and the ideal value narrowed.



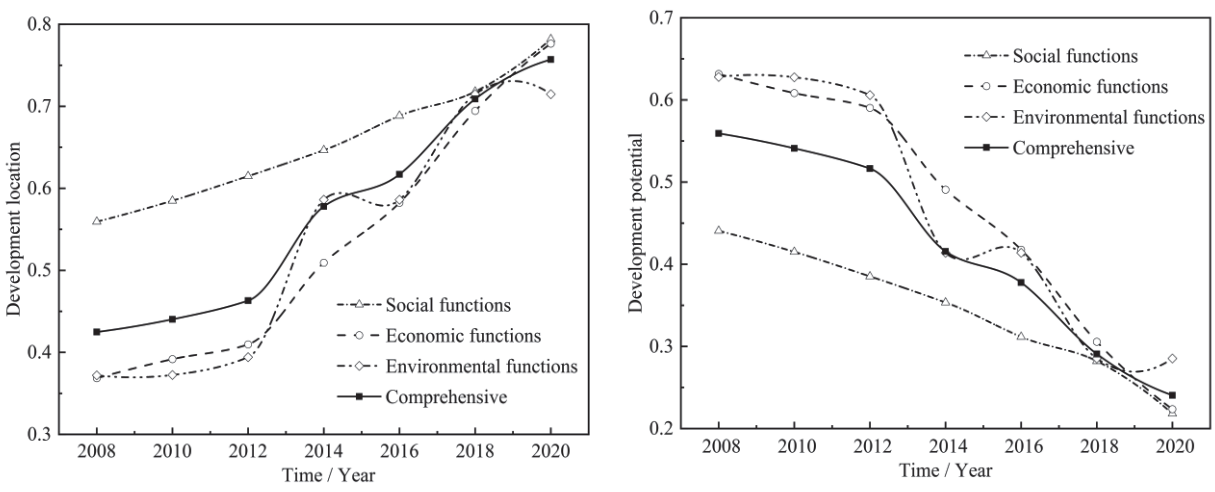
(a) Social-economic functions

(b) Social-environmental functions

(c) Economic-environmental functions

(d) Social-economic-environmental functions

Fig. 4. Coupling coordination changes of multi-functions of construction land in Yanhe Community from 2008 to 2020.



(a) Changes in the development location

(b) Changes in the development potential

Fig. 5. Changes in the development location and potential of the system of construction land functions of Yanhe Community from 2008 to 2020.

Green Niche for Construction Land Functions

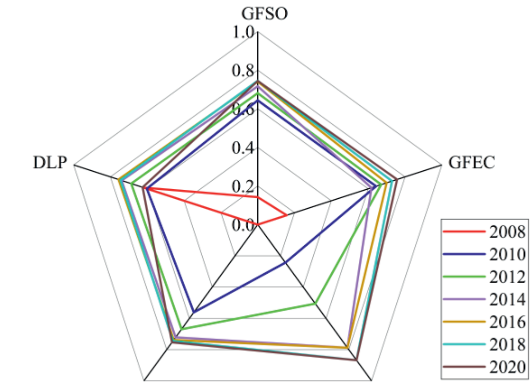
According to the proposed GNCLFRC calculation method, the changes in the green niche of construction land functions in Yanhe Community from 2008 to 2020 can be comprehensively analyzed, and the results are shown in Figure 6.

Fig. 6a) shows that each dimension saw the strengthening of its promoting effect on the green niche of construction land functions in the Yanhe Community. The greenness of social functions, economic functions, and environmental functions, coupling coordination and the development location and potential in Yanhe Community were enhanced, and the comprehensive green niche of the construction land functions was improved. In the five dimensions, the greenness of the environmental functions increased significantly, which indicates that the ecosystem service functions of the ecological construction land in Yanhe Community were enhanced.

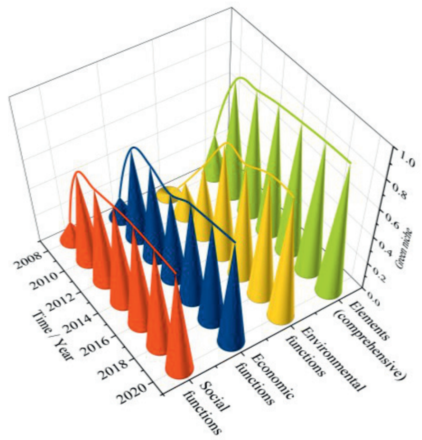
Fig. 6b) shows that the green niche of elements of the system of construction land functions in Yanhe Community increased yearly. The green niche of elements was comprehensively influenced by the greenness of social functions, economic functions, and environmental functions; although its change trend was not the same as these, it was increasing overall. The three types of functions of construction land in Yanhe Community had a dynamic influence on the green niche of the system. From 2008 to 2012, social functions played a decisive role in the green development of the system of construction land functions, while environmental functions dominated from 2012-2020.

Fig. 6c) shows that the green niche of the state of the construction land function system in Yanhe Community remains at a high level but fluctuates. The green niche of state was maintained between 0.8-0.9 for a long time, but it began decreasing in 2016. The green niche of state was comprehensively affected by coupling coordination and the development location and potential. From 2008 to 2016, the development location and potential contributed more to the green development of the system of construction land functions than coupling coordination, while the opposite was true from 2016 to 2020.

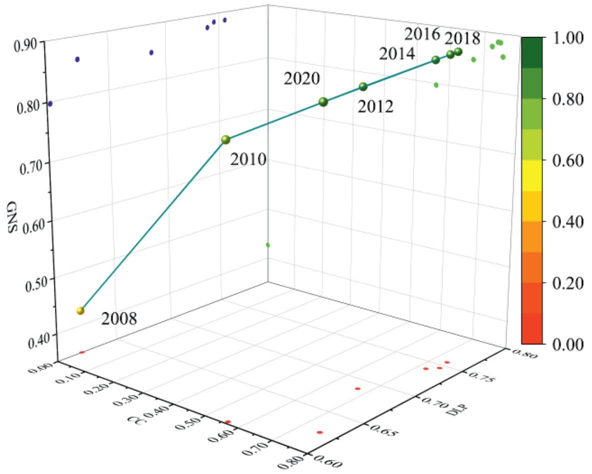
Fig. 6d) shows that the green niche of construction land functions in Yanhe Community increased yearly and remained at a high level. The green niche



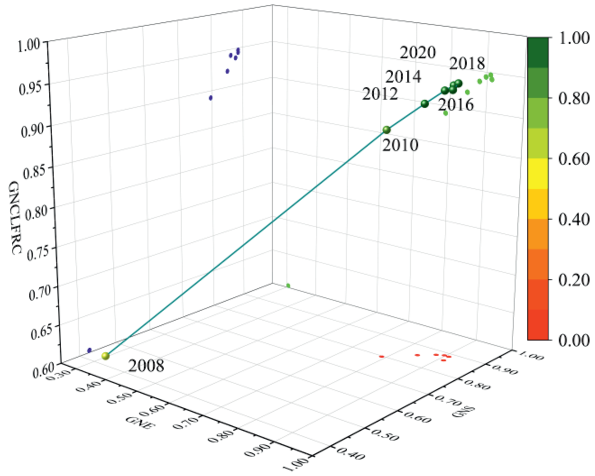
(a) Dimensions analysis of the green niche of construction land functions



(b) GNE analysis of the system of construction land functions



(c) GNS analysis of the system of construction land functions



(d) GNCLFRC analysis in Yanhe community

Fig. 6. Changes in the green niche of construction land functions in Yanhe Community from 2008 to 2020.

remained above 0.9 for many years, which suggests that the greenness of construction land in Yanhe Community was high. The green niche of construction land functions was comprehensively influenced by the green niches of elements and state. From 2008 to 2012, the green niche of the state contributed more to the green development of the system of construction land functions in the Yanhe Community, while the opposite was true from 2012 to 2020.

Discussion on The Theoretical Method of GNCLFRC

Ecological niche theory has been considered an important conceptual and technical method to systematically assess land use changes and analyze the complex ecological and social problems caused by them [46, 61]. However, the application of ecological niche theory to rural studies is insufficient [67]. In previous studies, the application of ecological niche theory in land science has mainly focused on niche change and the driving force of a single land use type [61], niche competition among various land use types [46], land structure optimization and land suitability evaluation based on niches [24, 68] in districts, cities, and regions. It is not common to analyze the greening level of construction land and the green development competitiveness of different rural communities based on ecological niches. To fill this gap, the theory of GNCLFRC, including the concept, composition, function model, and calculation method, was proposed from the perspective of a multifunctional system referring to ecological niche theory. Various findings on the key points in constructing the theory of GNCLFRC were yielded after applying it to empirical research.

First, the classification and measurement of construction land functions are the basis for analyzing the GNCLFRC. Functions are the direct result of the green utilization of construction land. By analyzing the social, economic, and environmental functions in the system of construction land functions in rural communities, the greening level of each element and the coupling coordination relationship among them can be obtained. With high function values and good coupling coordination, the greening level of construction land is high.

Second, an analysis of the driving factors is critical to the construction of the GNCLFRC. The change in the green niche of the system of construction land functions has three causes: change in the elements that make up the system, change in the coupling relationship among the elements, and change in the development potential of the system caused by impacts from the external environment. The driving factors of the GNCLFRC can be analyzed from five dimensions, including the greenness of social functions, economic functions, and environmental functions, coupling coordination and the development location and potential of functions.

Finally, the entropy-catastrophe method is effective in calculating GNCLFRC. Because GNCLFRC is a complex multiobjective system, the available analysis methods include the comprehensive index method [69], technique for order preference by similarity to an ideal solution (TOPSIS) [70], data envelopment analysis (DEA) [71], fuzzy matter-element [72], catastrophe theory [66], etc. Different analysis methods have their advantages and disadvantages, but a comparison shows that catastrophe theory is more suitable for the calculation of GNCLFRC; however, the objectivity of factor importance should be ensured. In this paper, the entropy method is used to calculate the weight of each factor, and then the factors are sorted by importance according to their weight. Combining the entropy method with catastrophe theory can effectively address its defects.

Conclusions

In this paper, a novel research approach for measuring the greening level of construction land in rural communities was proposed from the perspective of functions based on green niches. The Yanhe Community was chosen to verify the proposed method. The following conclusions can be drawn.

(1) GNCLFRC is an effective method to evaluate the green utilization of RCL. Construction land functions are intuitive expressions of human-land relationships. Assessment of the greenness of RCL function systems is an important way to clarify the relationship and the situation of land utilization. The research method for GNCLFRC can be used to quantitatively identify the greening level of construction land functions and the regional competitiveness of the green development of rural communities, thereby providing a new method for the formulation and implementation of green use planning for construction land and the improvement of the green management level of rural construction.

(2) The applicability of GNCLFRC was proven by an empirical illustration. The greenness of social, economic, and environmental functions, their coupling coordination and the development location and potential in Yanhe Community were effectively analyzed according to the proposed method. The results show that the yearly increase in GFSO, GFEC, GFEN, CC, and development location promoted the improvement of the green niche in Yanhe Community, which enhanced the greening level of construction land and green development competitiveness.

According to the conclusions, the research results of GNCLFRC have the following application prospects.

(1) The GNCLFRC analysis results can be used to identify and diagnose the constraints and bottlenecks affecting the greening level and propose optimization measures for green utilization.

(2) The GNCLFRC can provide a method for quantifying and comparing the competitiveness of green

development in various rural communities. The green development competitiveness of rural communities is an important reference index to attract external resources such as population, material, capital, and information. Rural communities with strong green development competitiveness can obtain more external resources and have greater development potential. GNCLFRC can be used to compare the green development competitiveness of different rural communities, and it reflects the location of communities in the regional green development system. The higher the green niche is, the stronger their green development competitiveness.

(3) The GNCLFRC can provide a basis for decision-making and a source of guidance for promoting rural revitalization and green development. The Chinese government clearly stated that rural revitalization should be promoted in a customized and orderly manner based on rural communities' development status and needs in the Strategic Plan for Rural Revitalization (2018-2022). GNCLFRC analysis can be used to quantify the social, economic, and environmental functions of construction land and the green niche level, identify the leading functions and greening level of construction land in different communities, and carry out the classification and regional zoning of rural communities according to the leading functions and the green niche level.

The GNCLFRC research method is suitable for the analysis of the greening of RCL during the period of green transformation development. However, empirical research on the application of the GNCLFRC was performed in only one rural community in this research. Research on its application at the multicommunity scale in regions should be conducted in the future. Moreover, the method for determining the ideal threshold of GNCLFRC factors and the correlation of the green niche of construction land functions between urban systems and connected rural systems will also be the focus of subsequent research.

Acknowledgments

This work was financially supported by the Foundation Project for Doctors' Research in HBUT (XJ2022009301) and the Innovation Demonstration Base of Ecological Environment Geotechnical and Ecological Restoration of Rivers and Lakes (2020EJB004).

Conflict of Interest

The authors declare no conflict of interest.

References

1. JIANG Y.F., LONG H.L., TANG Y.T., DENG W., CHEN K.Q., ZHENG Y.H. The impact of land consolidation on rural vitalization at village level: A case study of a Chinese village. Journal of Rural Studies, **86**, 485-496, **2021**.
2. LIU Y.S., LI Y.H. Revitalize the world's countryside. Nature, **548** (7667), 275, **2017**.
3. HUANG D.Q., LANG Y., LIU T. The evolving structure of rural construction land in urbanizing China: Case study of Tai'an Prefecture. Land, **10** (1), 65, **2021**.
4. LIU Y.S. Introduction to land use and rural sustainability in China. Land Use Policy, **74**, 1, **2018**.
5. WOODS M. Rural geography III: Rural futures and the future of rural geography. Progress in Human Geography, **36** (1), 125, **2011**.
6. YE C., MA X.Y., CAI Y.L., GAO F. The countryside under multiple high-tension lines: A perspective on the rural construction of Heping Village, Shanghai. Journal of Rural Studies, **62**, 53, **2018**.
7. VAN DIJK T., KOPEVA D. Land banking and Central Europe: Future relevance, current initiatives, Western European past experience. Land Use Policy, **23** (3), 286, **2006**.
8. ZANTSI S., PIENAAR L.P., GREYLING J.C. A typology of emerging farmers in three rural provinces of South Africa: what are the implications for the land redistribution policy? International Journal of Social Economics, **48** (5), 724, **2021**.
9. YAMASHITA R., HOSHINO S. Development of an agent-based model for estimation of agricultural land preservation in rural Japan. Agricultural Systems, **164**, 264, **2018**.
10. LEE I.H. Change of rural development policy in South Korea after Korean war. Journal of Regional and City Planning, **32** (2), 130, **2021**.
11. SALAISOOK P., FAYSSE N., TSUSAKA T.W. Reasons for adoption of sustainable land management practices in a changing context: A mixed approach in Thailand. Land Use Policy, **96**, 104676, **2020**.
12. NGUYEN H.Q., WARR P. Land consolidation as technical change: Economic impacts in rural Vietnam. World Development, **127**, 104750, **2020**.
13. LIU Y.S., WANG L.J., LONG H.L. Spatio-temporal analysis of land-use conversion in the eastern coastal China during 1996-2005. Journal of Geographical Sciences, **18** (3), 274, **2008**.
14. NGUYEN P.T., WELLS S., NGUYEN N. A systemic indicators framework for sustainable rural community development. Systemic Practice and Action Research, **32** (3), 335, **2018**.
15. WILSON G.A., HU Z., RAHMAN S. Community resilience in rural China: The case of Hu Village, Sichuan Province. Journal of Rural Studies, **60**, 130, **2018**.
16. MA W.Q., JIANG G.H., ZHANG R.J., LI Y.L., JIANG X.G. Achieving rural spatial restructuring in China: A suitable framework to understand how structural transitions in rural residential land differ across peri-urban interface? Land Use Policy, **75**, 583, **2018**.
17. MA W.Q., JIANG G.H., LI W.Q., ZHOU T., ZHANG R.J. Multifunctionality assessment of the land use system in rural residential areas: Confronting land use supply with rural sustainability demand. Journal of Environmetal Management, **231**, 73, **2019**..
18. LI L., LI X.J., HAI B.B., WANG X.F., XU J.W. Evolution of rural settlement in an inland nonmetropolitan region of China at a time of rapid urbanisation: The case of Gongyi. Journal of Rural Studies, **79**, 45, **2020**.
19. MA L.B., CUI X.J., YAO Y., LIU S.C. Gradient difference of structure of rural construction land in loess hilly region:

A case study of Yuzhong County, Gansu Province, China. Land, **10** (4), 349, **2021**.
20. ZHANG Y.Y., ZHANG, Z.S., SUN X.S. The approaches from rural construction land consolidation to sustainable rural land resource development. IOP Conference Series: Earth and Environmental Science, **508** (1), 012091, **2020**.
21. ZHANG X.R., WANG J., SONG W., WANG F.F., GAO X., LIU L., DONG K., YANG D.Z. Decoupling analysis between rural population change and rural construction land changes in China. Land, **11** (2), 231, **2022**.
22. ZOU L.L., LIU Y.S., YANG J.X., YANG S.F., WANG Y.S., CAO Z., HU X.D. Quantitative identification and spatial analysis of land use ecological-production-living functions in rural areas on China's southeast coast. Habitat International, **100**, 102182, **2020**.
23. WANG J., LI Y.R., WANG Q.Y., CHEONG K.C. Urban-rural construction land replacement for more sustainable land use and regional development in China: Policies and practices. Land, **8** (11), 171, **2019**..
24. PAN W., WANG J., QIN X.F., LI Y.R. Trends and types of rural residential land use change in China: A process analysis perspective. Growth and Change, **52** (4), 2437, **2021**.
25. CHEN Z.F., LIU X.Q., LU Z., LI Y.R. The expansion mechanism of rural residential land and implications for sustainable regional development: Evidence from the Baota District in China's Loess Plateau. Land, **10**, 172, **2021**.
26. CAI E.X., CHEN W.Q., WEI H.J., LI J.W., WANG H., GUO Y.L., FENG X.W. The coupling characteristics of population and residential land in rural areas of China and its implications for sustainable land use. Sustainable Development, **28** (4), 646, **2019**.
27. SUN D.Q., GE D.Z. The interaction mechanism of rural housing land transition and rural development: A spatial governance perspective. Growth and Change, **00**, 1, **2021**.
28. LIU Y.Q., WANG A.L., HOU J., CHEN X.Y., XIA J.S. Comprehensive evaluation of rural courtyard utilization efficiency: A case study in Shandong Province, Eastern China. Journal of Mountain Science, **17** (9), 2280, **2020**.
29. TAN S.K., HU B.X., KUANG B., ZHOU M. Regional differences and dynamic evolution of urban land green use efficiency within the Yangtze River Delta, China. Land Use Policy, **106**, 105449, **2021**.
30. YU H.S., SONG G., LI T., LIU Y.J. Spatial pattern characteristics and influencing factors of green use efficiency of urban construction land in Jilin Province. Complexity, **2020**, 1, **2020**.
31. XIE H.L., CHEN Q.R., WANG W., HE Y.F. Analyzing the green efficiency of arable land use in China. Technological Forecasting and Social Change, **133**, 15, **2018**.
32. CHAI C.Q., ZHANG B.B., LI Y.Y., NIU W.H., ZHENG W.W., KONG X.B., YU Q., ZHAO M.J., XIA X.L. A new multi-dimensional framework considering environmental impacts to assess green development level of cultivated land during 1990 to 2018 in China. Environmental Impact Assessment Review, **98**, 106927, **2023**.
33. HAN M.S., YUAN Q.Q., FAHAD S., MA T.C. Dynamic evaluation of green development level of ASEAN region and its spatio-temporal patterns. Journal of Cleaner Production, **362**, 132402, **2022**.
34. PAN X., LI J.G., WEI J., YUE Y.P., LIU L.L. Measuring green development level at a regional scale: framework, model, and application. Environmental Monitoring and Assessment, **194** (5), 343, **2022**.
35. WANG M.X., ZHAO H.H., CUI J.X., FAN D., LV B., WANG G., LI Z.H., ZHOU G.J. Evaluating green development level of nine cities within the Pearl River Delta, China. Journal of Cleaner Production, **174**, 315, **2018**.
36. WANG Y.J., CHEN H., LONG R.Y., LIU B., JINAG S.Y, YANG X.X., YANG M.H. Evaluating green development level of mineral resource-listed companies: Based on a "dark green" assessment framework. Resources Policy, **71**, 102012, **2021**.
37. QU Y.B., JIANG G.H., MA W.Q., LI Z.T. How does the rural settlement transition contribute to shaping sustainable rural development? Evidence from Shandong, China. Journal of Rural Studies, **82**, 279, **2021**.
38. LIU X.Y., XIN L.J. Assessment of the efficiency of cultivated land occupied by urban and rural construction land in China from 1990 to 2020. Land, **11**(6), 941, **2022**.
39. WIGGERING H., MÜLLER K., WERNER A., HELMING K. The concept of multifunctionality in sustainable land development. In Sustainable Development of Multifunctional Landscapes, Springer: Berlin, Heidelberg, **2003**.
40. GLP (Global Land Project). Science Plan and Implementation Strategy, IGBP Report No. 53/IHDP Report No. **19**., Stockholm, **2005**.
41. DE GROOT R. Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. Landscape and Urban Planning, **75**, 175, **2006**.
42. ZHOU D., XU J.C., LIN Z.L. Conflict or coordination? Assessing land use multi-functionalization using production-living-ecology analysis. Science of the Total Environment, **577**, 136, **2017**.
43. GRINNELL J. The niche-relationships of the California thrasher. Ornithology, **34** (4), 427, **1917**.
44. HEIDARI N. Ecological niche differentiation between Acanthodactylus micropholis and A. khamirensis (Sauria: Lacertidae) in southern Iran. Zoologia, **36**, 1, **2019**.
45. LIU X.L., GUO P.B., YUE X.H., ZHONG S.C., CAO X.Y. Urban transition in China: Examining the coordination between urbanization and the eco-environment using a multi-model evaluation method. Ecological Indicators, **130**, 108056, **2021**.
46. JING Z.R., WANG J.M., TANG Q., LIU B., NIU H.B. Evolution of land use in coal-based cities based on the ecological niche theory: A case study in Shuozhou City, China. Resources Policy, **74**, 102245, **2021**.
47. HAN B.L., WANG R.S., TAO Y., GAO H. Urban population agglomeration in view of complex ecological niche: A case study on Chinese prefecture cities. Ecological Indicators, **47**, 128, **2014**.
48. YU Z.X., XU, E.Q., ZHANG H.Q., SHANG E.P. Spatio-temporal coordination and conflict of production-living-ecology land functions in the Beijing-Tianjin-Hebei Region, China. Land, **9** (5), 170, **2020**.
49. PENG L., WANG X.X., CHEN T.T. Multifunctional land-use value mapping and space type classification: A case study of Puge County, China. Natural Resource Modeling, **32** (4), e12212, **2019**.
50. ZHU C.M., DONG B.Y., LI S.N., LIN Y., SHAHTAHMASSEBI A., YOU S.X., ZHANG J., GAN M.Y., YANG L.X., WANG K. Identifying the trade-offs and synergies among land use functions and their influencing factors from a geospatial perspective: A case study in Hangzhou, China. Journal of Cleaner Production, **314**, 128026, **2021**.

51. WANG X.M., HUA H. Green Village and Town Construction in China, Springer: Singapore, **2021**.
52. GAQSIQ (General administration of quality supervision, inspection and quarantine of the People's Republic of China), SA (Standardization administration of the People's Republic of China). Current land use classification. China standard press, Beijing, China. **2017** [In Chinese]. Available online: http://www.tdzyw.com/2017/1113/45597.html
53. HELMING K., PÉREZ-SOBA M., TABBUSH P. Sustainability impact assessment of land use, Springer: Berlin, Heidelberg, **2008**.
54. LIU D. Application and research of analytic hierarchy process in green gdp development planning of smart city. Journal of Urban Planning and Development, **147** (1), 04020051, **2021**.
55. COSTANZA R., D'ARGE R., GROOT R.D., FARBER S., GRASSOT M., HANNON B., LIMBURG K., NAEEM S., O'NEILL R.V., PARUELO J., RASKIN R.G., SUTTON P., VAN DEN BELT M. The value of the world's ecosystem services and natural capital. Nature, **387**, 253, **1997**
56. XIE G.D., ZHEN L., LU C.X., XIAO Y., CHEN C. Expert knowledge based valuation method of ecosystem services in China. Journal of Natural Resources, **23**, 911, **2008** [In Chinese].
57. PAN Y., GONG H.L., ZHOU D.M., LI X.J., NAKAGOSHI N. Impact of land use change on groundwater recharge in Guishui River Basin, China. Chinese Geographical Science, **21** (6), 734, **2011**.
58. RAO Y.X., ZHOU M., OU G.L., DAI D.Y., ZHANG L., ZHANG Z., NIE X., YANG C. Integrating ecosystem services value for sustainable land-use management in semi-arid region. Journal of Cleaner Production, **186**, 662, **2018**.
59. LI F., YE Y.P., SONG B.W., WANG R.S., TAO Y. Assessing the changes in land use and ecosystem services in Changzhou municipality, Peoples' Republic of China, 1991-2006. Ecological Indicators, **42**, 95, **2014**.
60. PENG W.J., WANG X.M., LI X.K., HE C.C. Sustainability evaluation based on the emergy ecological footprint method: A case study of Qingdao, China, from 2004 to 2014. Ecological Indicators, **85**, 1249, **2018**.
61. LIU Y.X., LIU S.L., SUN Y.X., WANG F.F., LI M.Q. Driving forces of cultivated land evolution in agro-pastoral areas on the Qinghai-Tibet Plateau based on ecological niche theory. Journal of Cleaner Production, **313**, 127899, **2021**.
62. CHEN Y., ZHANG R.Z., ZHANG J. Construction of sustainable development position theory of land use and its application in Gansu Province. Journal of Desert Research **32** (2), 574, **2012**.
63. SHI T., YANG S.Y., ZHANG W., ZHOU Q. Coupling coordination degree measurement and spatiotemporal heterogeneity between economic development and ecological environment – Empirical evidence from tropical and subtropical regions of China. Journal of Cleaner Production, **244**, 118739, **2020**.
64. LI J.S., SUN W., LI M.Y., MENG L.L. Coupling coordination degree of production, living and ecological spaces and its influencing factors in the Yellow River Basin. Journal of Cleaner Production, **298**, 126803, **2021**.
65. GHORBANI M.A., KHATIBI R., SIVAKUMAR B., COBB L. Study of discontinuities in hydrological data using catastrophe theory. Hydrological Sciences Journal, **55** (7), 1137, **2010**.
66. SHAHINUZZAMAN M., HAQUE M.N., SHAHID S. Delineation of groundwater potential zones using a parsimonious concept based on catastrophe theory and analytical hierarchy process. Hydrogeology Journal, **29** (3), 1091, **2021**.
67. CAO Y., LI G.Y., CAO Y., WANG J.Y., FANG X.Q., ZHOU L.M., LIU Y.J. Distinct types of restructuring scenarios for rural settlements in a heterogeneous rural landscape: Application of a clustering approach and ecological niche modeling. Habitat International, **104**, 102248, **2020**.
68. PAN Y.X. GIS-based niche suitability model of rice breeding and cultivation and evaluation of multi-suitability of cultivated land. Arabian Journal of Geosciences, **14** (11), 932, **2021**.
69. LI X.K., WANG X.M., LEI L. The application of an ANP-Fuzzy comprehensive evaluation model to assess lean construction management performance. Engineering, Construction and Architectural Management, **27** (2), 356-, **2019**.
70. HE C.C., HAN Q., DE VRIES B., WANG X.M., ZHAO G.C. Evaluation of sustainable land management in urban area: A case study of Shanghai, China. Ecological Indicators, **80**, 106, **2017**.
71. SU Q.M., JIANG X.Q. Evaluate the economic and environmental efficiency of land use from the perspective of decision-makers' subjective preferences. Ecological Indicators, **129**, 107984, **2021**.
72. GONG J.Z., LIU Y.S., CHEN W.L. Land suitability evaluation for development using a matter-element model: A case study in Zengcheng, Guangzhou, China. Land Use Policy, **29** (2), 464, **2012**.