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Quantitative identification and spatial analysis of land use ecological-production-living functions in rural areas on China's southeast coast

Lilin Zou [a,b], Yansui Liu [b,*,1], Jianxin Yang [c], Shengfu Yang [c], Yongsheng Wang [b], Cao zhi [b], Xuedong Hu [d]

[a] *School of Political Science and Public Administration, Huaqiao University, Quanzhou, 362021, China*
[b] *Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101, China*
[c] *School of Public Administration, China University of Geosciences, Wuhan, 430074, China*
[d] *College of Public Administration, South China University of Technology, Guangzhou, 510641, China*

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ABSTRACT

The quantitative identification of land use functions (LUFs) forms the basis of land use planning and management. Based on the widely recognized "ecological-production-living" function in sustainable development, a uniform classification and value evaluation system of LUFs for China's rural land use planning and management is established. To highlight the functions of ecological regulation, product supply and living security, the LUFs were divided into 8 primary functions and 20 subfunctions. LUF value evaluation function groups were established based on the indirect or direct value of land use. For empirical research, Fengzhou Town, a typical rural coastal area in southeastern China, was selected as an example. The results show that the values of the ecological, production and living functions account for 14.31%, 44.54% and 41.15% of the total value, respectively. This finding indicates that the primary direction of land use in the study area is oriented toward pursuing the production and living functions. The spatial distribution of the values of the production and living functions shows obvious consistency, and they are also clearly complementary with the ecological function. More than 90% of the land area is assigned double or triple functions, which indicates that the multifunctional characteristics of land use are significant, while the spatial function zoning is disordered. These findings are consistent with the socioeconomic development of the study area, demonstrating that the established classification and value evaluation system of LUFs can reliably reflect realistic land use and will provide scientific support for the multifunctional utilization and effective management of rural land in China.

1. Introduction

As an important carrier for human survival, land can provide a wide spectrum of products and services, which are collectively referred to as land use functions (LUFs; Pérez-Soba, Petit, Jones, & Bertrand, 2008). A LUF is a kind of attribute and state in which various products and services are directly or indirectly provided to human beings by different land use types (LUTs; Liu, 2018; Pérez-Soba et al., 2008). This attribute and state are related not only to land cover but also to many other factors, including the spatial arrangement and temporal intensity of land use in the landscape (Verburg, van de Steeg, Veldkamp, & Willemen, 2009). Moreover, the LUF is the basis for determining regional land organization, coordination, and allocation. It is also the key to distinguishing the structure, combination mode and dynamic tradeoff of functions in different land use systems (Slee, 2007; Wiggering et al., 2006). Therefore, the quantification of LUFs is critical to understand the complexity of the interactions among multiple land use systems to achieve sustainable development, and two key research issues should be addressed: the classification of LUFs and the valuation of LUFs.

In different types of land use systems, land is categorized into different functions. The LUF concept originated from the agricultural system (Helming et al., 2008) and mainly referred to the agricultural

* Corresponding author.
E-mail address: liuys@igsnrr.ac.cn (Y. Liu).
[1] Present address: 11A Datun Road, Chaoyang District, Beijing 100101, China.

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production function (Andersen, Vejre, Dalgaard, & Brandt, 2013). According to the Organization for Economic Co-operation and Development (OECD), the Food and Agriculture Organization (FAO), and the Common Agricultural Policy (CAP), the agricultural function is divided into the production function, the economic and social function, the ecological and environmental function, and the cultural and leisure function (Andersen et al., 2013; Bernués, Rodríguez-Ortega, Alfnes, Clemetsen, & Eik, 2015). The ecosystem service function is the foundation of the LUF (Galvanin, Menezes, Pereira, & Neves, 2019), and classification systems of this function were established by de Groot (2002), the Millennium Ecosystem Assessment (MEA; Costanza et al., 2017; MEA, 2005), the Economics of Ecosystems and Biodiversity (TEEB; Brouwer, Brander, Kuik, Papyrakis, & Bateman, 2013), and Lovell et al. (2010). In the urban system, land is the key element of physical space and the spatial carrier of functional areas. The most common function provided by the urban system is living security, for example, residence, economic output, security, and recreation (Fan et al., 2018).

Due to the different services and products provided by different land use systems, the approaches to value evaluation are different. To evaluate the agricultural functional value, three main approaches are developed. The first is the economic approach, which jointly considers the production of private and public goods (Vatn, 2002). The second is the development approach, which recognizes the many contributions of agriculture to humans, including food security, poverty alleviation, and cultural heritage (Herrero et al., 2013). The third approach concerns preservation of the agricultural landscape and sustainable rural development (Bernués et al., 2015). Researchers mainly use direct and indirect methods to evaluate the value of the ecosystem service function (Costanza et al., 2017). The former concern the market value of products and services as the approximate value of a specific function (de Groot et al., 2010). The latter take people's willingness to pay or compensate for ecosystem services as the function value, which is mainly assessed through the hedonic price method, travel cost method, and cost-benefit method (de Groot, 2006; Xue, Zheng, Zhang, & Yuan, 2015). For the urban system, the value evaluation of natural ecosystem (e.g., water, forest, wetland) services has received more attention (Kandulu, Connor, & MacDonald, 2014; Mei, Sohngen, & Babb, 2018; Xu, You, Li, & Yu, 2016).

Clearly, previous studies on LUF identification mainly referred to a single land use system (e.g., the agricultural system, the natural ecosystem, the urban system) in specific geographies (Fan et al., 2018; Hong & Guo, 2017; Liekens et al., 2013; Rallings, Smukler, Gergel, & Mullinix, 2019; Xie et al., 2010; Zhou, Xu, Wang, & Lin, 2015). However, rural areas are a complex system that includes the functions of the agricultural system and the natural ecosystem, and some functions of the urban system are also involved. Especially in the process of urban and rural transformation and development, the functions of industrial development, ecological conservation and social security in rural areas are gradually highlighted (Long & Liu, 2016; Zhu, Zhang, & Ke, 2018), as a result of which the rural regional function is the critical factor in dividing the rural regional pattern and locating the rural development status (Li, Westlund, & Liu, 2019b; Woods, 2012). In addition, the evaluated values often represent the total value on the national (Long & Liu, 2016; Ondetti, 2016), provincial (Fan et al., 2018; Qiao, Ge, Gao, Lu, & Huang, 2019), county (Xu & Fang, 2019; Zebisch, Wechsung, & Kenneweg, 2004) or village (Bernués et al., 2015) scale; however, they do so less on the scale of the parcel. A parcel is the smallest visible area under a certain scale and the smallest unit of the rural regional function. All kinds of LUFs must be spatialized to a specific parcel (El Baroudy, 2016; Xue et al., 2015). Therefore, it highly important to clarify the spatial pattern of the rural regional function at the parcel scale to accurately locate the rural development pattern and to implement a differentiated pathway of rural revitalization.

In recent years, with the popularity of the "three pillars" theory of sustainable development, many scholars have focused on the identification of LUFs from the "ecological-production-living" perspective (Xi, Zhao, Ge, & Kong, 2014; Zhou, Xu, et al., 2017). The Chinese government has also placed great emphasis on this perspective because it is consistent with the concept of the comprehensive functional zoning of land use (Huang, Lin, & Qi, 2017; Zhou, Guo, & Liu, 2019). Moreover the Chinese government has constantly emphasized the optimization of the structures of ecological, production and living functions (Long & Liu, 2016), and the identification of various LUFs and the scientific evaluation of their values are the basis of such optimization (Fan et al., 2018; Li & Fang, 2016). However, a comprehensive system for the classification and value evaluation of LUFs that covers the whole rural area is still lacking, which severely hinders the promotion of rural land use planning and management. Therefore, the objectives of this study are as follows:

(1) To build a comprehensive classification system of rural LUFs from the ecological-production-living perspective;
(2) To establish the value evaluation functions for each land use subfunction; and
(3) To quantify and analyze the LUF value at the parcel scale.

2. Classification and value connotation of land use functions

2.1. Classification system of land use functions

The rural land use system is a complex functional system that includes the subsystems of the natural ecosystem, the agricultural system, and the rural settlement system; thus, it is endowed with ecological, production and living functions (Long & Tu, 2017). Fig. 1 illustrates the relationships among the three functions of the land use system, in which the ecological function provides the guarantee for sustainable land use, the production function is the most basic LUF, and the ultimate purpose of human land use is to pursue the living function (Zhou, Xu, et al., 2017).

In general, the objectives of the ecological, production and living functions are different in contemporary China. The ecological function pursues beautiful scenery and respect for nature, which reflects the capacity of the ecological services of the rural land use system (Zhou, Xu, et al., 2017). The production function pursues intensive land use and efficient outputs, which reflects the economic output capacity of the rural land use system (Liu et al., 2016). The living function emphasizes convenient services and livability, which reflects the living security capacity of the rural land use system (Long & Liu, 2016). According to the "factor-function-valuation" framework, each LUF can be quantified according to the content and form of the products and services provided (de Groot, 2006). To quantitatively identify rural LUFs, our study proposes a three-level classification and evaluation system, as shown in Table 1.

2.2. Value connotation of land use functions

In epistemology, value is a kind of utility, benefit or effect relationship between the functions of the object and the needs of the subject (McMillen & McDonald, 2002). It can be inferred that the value of land is represented by the utility of the various functions provided to human beings by land (Verburg et al., 2009). As mentioned above, the LUF refers to the capacity of land to provide various products and services; thus, the value of the LUF refers to the utility of the products and services provided by land. Essentially, land value is a kind of functional value that depends on the existence of a land function, while LUF value is a kind of material (i.e., products and services) value that can be monetized. In other words, the value of land is the internal essence of the value of the LUF, while the value of the LUF is the manifestation of the value of land (Ando, Camm, Polasky, & Solow, 1998).

Notably, the value of the LUF should include not only the economic utility of the products and services provided by land but also ecological, landscape, and social security utility as well as other utilities (Huo & Cai,

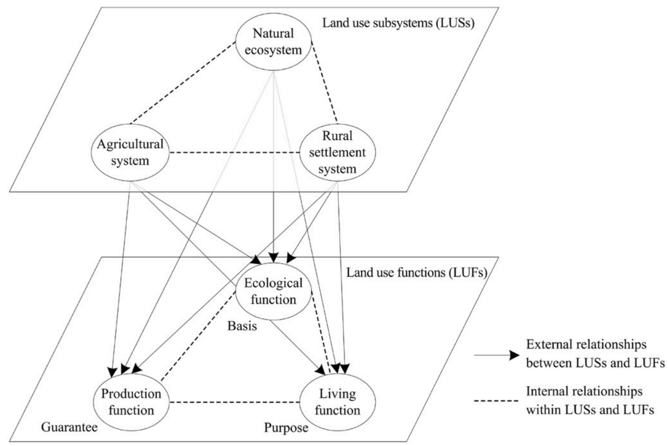

Fig. 1. Relationship between land use subsystems and land use functions.

- The ecological function refers to the capacity of the ecosystem and ecological processes to provide products and services for human survival (de Groot et al., 2012). These products and services are mainly provided by the regulation function, which serves as a gift for human beings, protecting the natural ecological environment (MEA, 2005). In this study, the regulation function mainly consists of climate regulation, hydrological regulation, soil conservation and environmental purification (Costanza et al., 1997). Notably, in addition to the regulation function, the support, supply, and culture functions of the ecosystem are correspondingly evaluated in the production and living functions.
- The production function refers to the capacity of the land use system to supply various products and services for human beings, and this capacity mainly depends on the natural outputs (e.g., freshwater, minerals) of land and outputs (e.g., agricultural products, industrial productions, commercial services) that are generated through the exertion of human labor (Jin et al., 2019). The attributes and types of the products and services provided constitute the symbolic classification of the production function (Fan et al., 2018). In this study, the production function includes the supply of resource products, biological products, industrial products, and services. According to the types of products supplied, all of these primary functions are further classified into subfunctions.
- The living function refers to the capacity of the land use system to provide living space and security for human beings, and it is the most basic function (Geoghegan, 2002). As an important production factor, land also provides a living guarantee for farmers (Plantinga & Miller, 2001). In addition, the spiritual function of land is increasingly important as people's lifestyles become diverse (de Groot, 2006). In this study, the living function is divided into housing security, social support, and spiritual security. Moreover, all of these primary functions are further classified into specific subfunctions based on regional characteristics, the urban-rural dualism, and the types of services provided. Notably, entertainment service security and tourism service supply are different. People can enjoy the latter (e.g., public scenery, regional culture) in their everyday lives for free, while the enjoyment of the latter requires payment for travel expenses.

2003). According to the view of Pearce (Pearce & Moran, 1994), combined with the characteristics of land resources, the theoretical composition of the value of the LUF should mainly include the actual utilization value, selection value and existence value. The actual use value refers to the economic returns of land use, such as the value of the agricultural products provided when land is used for agriculture. The selection value refers to the potential income of land use, which is expressed as a preference or willingness to pay for the protection of land resources, such as the travel expenses paid to enjoy a beautiful natural environment. The existence value refers to the value of land with regard to maintaining the natural landscape and ecosystem; for example, ecological land can regulate the global climate.

Table 1
Classification and evaluation system of the ecological, production, and living functions of rural land use.

Function criteria	Primary function	Subfunctions	Connotation of subfunctions
Ecological function	Regulation function	Climate regulation (*e11*)	Regulating atmospheric composition and climate.
		Hydrological regulation (*e12*)	Intercepting and accumulating precipitation.
		Soil conservation (*e13*)	Preventing soil erosion and maintaining soil nutrients.
		Environmental purification (*e14*)	Absorbing pollution, killing germs, reducing noise and blocking dust.
Production function	Resource products supply	Freshwater supply (*p11*)	Providing domestic, industrial and agricultural water.
		Mineral supply (*p12*)	Providing oil, natural gas, stone, etc.
	Biological products supply	Agricultural product supply (*p21*)	Providing food, vegetables, fruits, etc.
		Forestry product supply (*p22*)	Providing wood, bamboo, flowers, etc.
		Livestock product supply (*p23*)	Providing meat, eggs, milk, etc.
		Fishery product supply (*p24*)	Providing fish, shrimp, etc.
	Industrial products supply	Industrial product supply (*p31*)	Processing and selling shoes, clothes, furniture, etc.
	Services supply	Commercial service supply (*p41*)	Providing retail, catering, etc.
		Tourism service supply (*p42*)	Providing charged travel products and services.
		Transportation service supply (*p43*)	Providing freight and passenger services.
Living function	Housing security	Urban housing security (*l11*)	Providing a place for urban production and living.
		Rural housing security (*l12*)	Providing a place for rural production and living.
	Social support	Basic living support (*l21*)	Providing a minimum living guarantee.
		Employment support (*l22*)	Providing social insurances for unemployment.
	Spiritual security	Public service security (*l31*)	Providing services such as education, medical treatment, etc.
		Entertainment service security (*l32*)	Providing services such as leisure, culture, visits to relatives, etc.

3. Materials and methods

3.1. Study area

Fengzhou Town is located in Nan'an City, Fujian Province, with a latitude of 24°56′38″-25°01′09″N and a longitude of 118°26′54″-118°35′09″E (Fig. 2). The terrain is lower in the south and higher in the north. The annual temperature is 18°C–21 °C on average, and the average annual rainfall is 1620 mm. The main soil types include red soil, latosolic red soil, fluvio-aquic soil, and paddy soil. The forest coverage is 53.2%, and the vegetation is mainly Masson pine forest, Chinese fir forest, coniferous broad-leaved mixed forest, and a small proportion of Phyllostachys pubescens forest. There are ample water resources in Fengzhou Town, and the Jinjiang River is one of the main water sources in southern Fujian. In recent years, with the promotion of the "joint household management" policy, private enterprises have developed

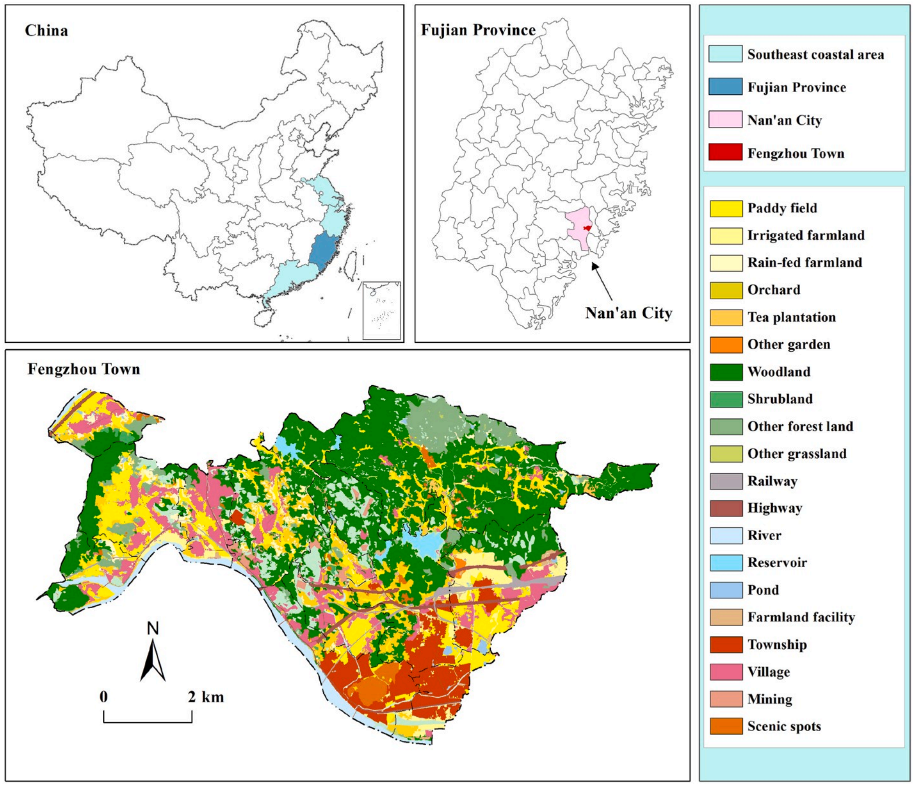

Fig. 2. Location and land use/cover of the study area in 2015.

vigorously in rural areas. The total number of enterprises was more than 180 by the end of 2015, and tourism has also been well developed.

The reasons we choose Fengzhou Town as the study area are as follows: First, as the main driver of China's economic growth, the southeastern coastal region is not only a frontier of rapid urbanization and industrialization but also a typical region for rural transformation and development (Liu, Wang, & Zhang, 2013; Long, Zou, & Liu, 2009). Second, this study area is located in the hinterland of southeast China, and the land use patterns and LUFs are becoming increasingly diversified and are quite representative of China's southeast coast (Zou, Liu, Wang, Yang, & Wang, 2019). Third, our team has long been concerned about rural transformation development on China's southeast coast, and we have a better understanding of the land use situation in this study area, as well as access to detailed data.

3.2. Data sources

The land use/cover data come from the Nan'an Land Use Survey (2015), and it is classified according to the Land Use Status Classification in the Second National Land Survey of China (Ministry of Land and Resources of China, 2007). The cultivated soil data are from the Second National Soil Survey and the Farmland Fertility Survey (2009). Other spatial data include the Shuttle Radar Topography Mission (SRTM) Digital Elevation Models (DEMs) by NASA (https://www2.jpl.nasa.gov/srtm/). The rainfall is from weather statistics, and the social and economic data are obtained from the Nan'an City Statistical Yearbook (2016). In addition, some data come field research, including the prices of freshwater and minerals, the transportation costs of freight and passengers, the annual rent of residences, commercial and industrial land and the number of tourists. Due to the small area and the difficulty of valuing the inland beach, irrigation canals and ditches, hydraulic construction land, and bare land, only 20 LUTs in the study area are included in the quantitative identification.

3.3. Value evaluation of land use functions

3.3.1. Value evaluation of the ecological function

As the most influential functional value assessment system (Costanza et al., 1997; de Groot, Wilson, & Boumans, 2002; Guo, Xiao, & Li, 2000), the value of land use ecological function is evaluated based on the indirect assessment methods in Table 2. That is, the material quantity is calculated first by biophysical measurement, and then, it is converted into a value by economic evaluation with the parameters in Appendix 1. The climate regulation function is mainly achieved by fixing CO_2 and releasing O_2. The material quantity of the regulated gases is estimated according to the equations of photosynthesis and respiration (Guo, Xiao, Gan, & Zheng, 2001). The values of fixed CO_2 and released O_2 are calculated by the afforestation cost method (Guo et al., 2001), carbon tax method and industrial oxygen production method (Guo et al., 2001), and their sum is the value of the climate regulation function.

The hydrological regulation function includes three stages: canopy interception, litter layer absorption and soil layer accumulation (Lee, 1980), and the maintained precipitation amount is related to the vegetation cover type, soil type and slope. Therefore, the "vegetation-soil-slope" combined relationship is first divided into 11 categories according to Guo et al. (2000), and then their comprehensive precipitation maintenance capacities are calculated based on the coefficients in Appendix 2. Subsequently, the material quantity of the hydrological regulation function is obtained, and finally, the value of the hydrological regulation function is calculated by the cost method.

The soil conservation function is mainly affected by the vegetation cover, roots and slope, and the amount of soil erosion is generally characterized by the material quantity. First, the amounts of potential soil erosion and actual soil erosion are calculated by the revised universal soil loss equation (RUSLE). Second, the shadow price method, opportunity cost method and cost expense method are used to calculate the values of protected soil fertility, reduced soil abandonment and reduced sediment deposition, respectively (de Groot et al., 2002; Guo

Table 2
Value evaluation function groups of land use ecological functions.

Subfunctions	Calculation formula	Explanation of parameters
Climate regulation	$V_i^{e11} = V_i^{CO_2} + V_i^{O_2}$ $V_i^{CO_2} = (P_{RCO_2} + P_{CCO_2}) \times Q_i^{CO_2}/2$ $V_i^{O_2} = (P_{RO_2} + P_{IO_2}) \times Q_i^{O_2}/2$ $Q_i^{CO_2} = 1.63 \times S_i \times NPP_i$ $Q_i^{O_2} = 1.2 \times S_i \times NPP_i$	$V_i^{e11}$is the value of the climate regulation function; $V_i^{CO_2}$is the value of fixed CO_2; $V_i^{O_2}$is the value of released O_2; $P_{RCO_2}$is the afforestation cost of per unit fixed CO_2; $P_{CCO_2}$is the CO_2 tax rate; $Q_i^{CO_2}$is the material quantity of fixed CO_2; $P_{RO_2}$is the afforestation cost of per unit released O_2; $P_{IO_2}$is industrial oxygen production cost of per unit released O_2; $Q_i^{O_2}$is the material quantity of released O_2; $S_i$is the parcel area; i is the evaluation unit
Hydrological regulation	$V_i^{e12} = Q_i^w \times C_c$ $Q_i^w = \sum_j Q_{w(p_{ij})} A_{p_{ij}}$ $Q_{w(p_{ij})} = \varepsilon_v \delta_s \eta_a Q_{w(p_0)}$ $Q_{w(p_0)} = \mu(C + L + S)$	$V_i^{e12}$is the value of the hydrological regulation function; $Q_i^w$is the material quantity; $C_c$is the cost of unit reservoir capacity; $Q_{w(p_{ij})}$is the comprehensive precipitation maintenance capacity; $A_{p_{ij}}$is the area; $j$is the "vegetation-soil-slope" combined relationship; ε_v, $\delta_s$and η_a are the type coefficients of vegetation, soil and slope, respectively; $Q_{w(p_0)}$is the largest quantity of intercepted precipitation; C, L and S are the water absorption capacity of canopy interception, litter layer absorption and soil layer accumulation, respectively; $\mu$is the precipitation equivalent coefficient
Soil conservation	$V_i^{e13} = V_i^f + V_i^c + V_i^n$ $V_i^f = A_i^c \times S_i \times C_i \times N_r \times P_r$ $V_i^c = A_i^c \times S_i \times B_i \times \rho^{-1} \times h^{-1}$ $V_i^n = A_i^c \times S_i \times \rho^{-1} \times 0.24 \times C_c$ $A_i^c = A_i^p - A_i^r$ $A_i^r = R \times K \times LS \times C \times P$ $A_i^p = R \times K \times LS$	$V_i^{e13}$is the value of the soil conservation function; V_i^f, V_i^c and V_i^n are the value of protected soil fertility, reduced soil abandonment and reduced sediment deposition; $A_i^c$is the per unit area amount of soil conservation; $C_i$is the average content of N, P and K; $N_r$is the coefficient of hydrolysable nitrogen, instant phosphorus and instant potassium converted into ammonium sulfate, potassium phosphate and potassium chloride, and $P_r$is the respective price; $B_i$is the average income; $\rho$is the soil bulk density; $h$is soil thickness; $A_i^p$is the potential soil erosion amount; $A_i^r$is the actual soil erosion amount; $R$is the rainfall erosion factor; $K$is the soil erodibility factor; $LS$is the terrain factor
Environmental purification	$V_i^{e14} = V_i^S + V_i^D$ $V_i^S = Q_i^S \times S_i \times C_S$ $V_i^D = Q_i^D \times S_i \times C_D$	$V_i^{e14}$is the value of the environmental purification function; $V_i^S$is the value of absorbed SO_2; $V_i^D$is the value of blocked dust; $Q_i^S$and $Q_i^D$are the abilities to absorb SO_2 and block dust, respectively; C_S and $C_D$are the investment cost of cutting SO_2 and cutting dust, respectively

et al., 2001). Finally, the value of the soil conservation function is estimated by adding those values.

The environmental purification function mainly includes absorbing dirt, blocking dust, killing germs and reducing noise. Based on data availability, SO_2 absorption and dust blocking are selected to characterize the regional environmental purification capacity. The material quantities of absorbed SO_2 and blocked dust are calculated based on the environmental purification capability coefficients of different LUTs according to Li (2010), and the value of the environmental purification function is achieved by the cost method.

3.3.2. *Value evaluation of the production function*

Since the value of land use production function is equal to the value of the products and services provided (Fan et al., 2018; Li & Fang, 2016), they are mainly measured by the direct income method or the cost

Table 3
Value evaluation function groups of land use production functions.

Subfunctions	Calculation formula	Explanation of parameters
Freshwater supply	$V_i^{p11} = V^w \times \varepsilon \times \alpha_i$ $V^w = \sum Y_j \times P_j$ $\alpha_i = s_i/S_i$	$V_i^{p11}$is the value of the freshwater supply function; $V^w$is the gross output value of freshwater products; $\varepsilon$is the freshwater output coefficient; $\alpha_i$is the distribution coefficient; $Y_j$is the consumption of domestic water, industrial water and agricultural water; $P_j$is the respective price; $s_i$is the parcel area; $S_i$is the respective area of LUTs
Mineral supply	$V_i^{p12} = V^m \times \chi \times \alpha_i$ $V^m = \sum Y_j \times P_j$ $\alpha_i = s_i/S_i$	$V_i^{p12}$is the value of the mineral supply function; $V^m$is the gross output value of mineral products; $\chi$is the mineral output coefficient; Y_j is the output of minerals (mainly stone); $P_j$is the respective price of minerals
Agricultural product supply	$V_i^{p21} = V^f \times \phi \times \alpha_i \times \lambda_i$ $\alpha_i = s_i/S_i$	$V_i^{p21}$is the value of the agricultural product supply function; $V^f$is the gross output value of agricultural products; $\phi$is the grain output coefficient; $\lambda_i$is the correction factor
Forestry product Supply	$V_i^{p22} = V^t \times \kappa \times \alpha_i$ $\alpha_i = s_i/S_i$	$V_i^{p22}$is the value of the forestry product supply function; $V^t$is the gross output value of forestry products; $\kappa$is the wood output coefficient
Livestock product Supply	$V_i^{p23} = V^l \times \mu \times \alpha_i$ $\alpha_i = s_i/S_i$	$V_i^{p23}$is the value of the livestock product supply function; $V^l$is the gross output value of livestock products; $\mu_i$is the livestock output coefficient
Fishery product supply	$V_i^{p24} = V^a \times \omega \times \alpha_i$ $\alpha_i = s_i/S_i$	$V_i^{p24}$is the value of the fishery product supply function; $V^a$is the gross output value of fishery products; $\omega$is the fishery output coefficient
Industrial product supply	$V_i^{p31} = V^i \times \sigma \times \alpha_i$ $\alpha_i = s_i/S_i$	$V_i^{p31}$is the value of the industrial product supply function; $V^i$is the gross output value of industrial products; $\sigma$is the industrial output coefficient
Commercial service supply	$V_i^{p41} = (Y_r^1 + Y_r^2 + Y_r^3) \times \alpha_i$ $\alpha_i = s_i/S_i$	$V_i^{p41}$is the value of the commercial service supply function; Y_r^1, $Y_r^2$and $Y_r^3$are the gross output value of the wholesale and retail industry, accommodation and catering industry and real estate industry
Tourism service supply	$V_i^{p42} = T_i^{cap} \times \frac{I_i}{T_i} \times l$ $l = L \times (1 + ae^{-bt})^{-1}$ $t = En^{-1} - 3$	$V_i^{p42}$is the value of the tourism service supply function; $T_i^{cap}$is the tourism environmental capacity; $I_i$is the tourism income; $T_i$is the numbers of visitors; $l$is the social development stage coefficient; $L$is the willingness to pay in the extremely rich phase and is equal to 1; $t$is the time variable, representing the stage of social development; a and $b$are constants equal to 1; $e$is the natural logarithm; $En$is the Engel coefficient
Transportation service supply	$V_i^{p43} = V_i^G + V_i^P$ $V_i^G = \lambda_i \times Y_g \times \rho_i$ $V_i^P = \theta_i \times Y_p \times \rho_i$	$V_i^{p43}$is the value of the transportation service supply function; $V_i^G$is the gross output value of freight services; $V_i^P$is the gross output value of passenger services; $Y_g$is the freight turnover; $Y_p$is the passenger turnover; $\lambda_i$is the freight transportation cost; $\theta_i$is the passenger transportation cost; $\rho_i$is the road length

substitution method, as shown in Table 3. Freshwater and minerals are the resource products supplied by the natural system. The values of these two functions can be evaluated by the market value method with the outputs and prices of different productions. The biological products in this study are mainly from the agriculture, forestry, husbandry, and fishery industries. Industrial products mainly refer to products produced in the secondary industry. We can query the gross output value of agriculture, forestry, husbandry, fishery, and industry in the statistical yearbooks issued by the government and take them as the values of these two functions. Based on the available data, the total output values of the wholesale and retail industry, accommodation and catering industry and real estate industry counted in the statistical yearbooks can be used to represent the value of the commercial service function. The value of the tourism service function is mainly calculated by the cost expenditure method. Transportation services refer to freight services and passenger services, and the value of this type of service is calculated according to the cost substitution method, that is, by taking the annual transport cost of freight and passenger services as the value of the transportation service supply function.

Notably, all the figures queried from the statistical yearbooks are the total value of each function. Therefore, it is necessary to decompose them to the specific parcel according to the yield coefficients in Appendix 3. For example, the total value of agricultural output is ¥19.18 million yuan, and the LUTs that provide agricultural products include cultivated land and gardens. First, the output values of cultivated land and gardens are estimated based on their area and average revenue. Then, the grain output coefficient is calculated by dividing the output value of cultivated land by that of gardens. Subsequently, the values of the agricultural supply function from cultivated land and gardens are calculated by the grain output coefficient. Finally, the value at the parcel scale is calculated by the parcel area and agricultural land grade indexes.

3.3.3. *Value evaluation of the living function*

Because the value of land use living function represents the social welfare brought by land rights (Li, 2010), it is assessed by the substituted cost or governmental expenditure. Urban housing security and rural house security refer to the LUF of providing the place of production and life for urban and rural residents. And the values of these functions are calculated by the cost substitution method; that is, the rental costs of the place are the substitution value of these functions. First, urban and rural land are divided into different LUTs according to land use, and then, the respective areas and annual rents are estimated according to the sample survey. Subsequently, the values of the urban housing security function and rural housing security function are evaluated by the corresponding formulas in Table 4.

Basic living support refers to the LUF of providing life security for humans, and its value is measured by the substitution cost to meet the minimum living standard of the population in different LUTs (He, Liu, & Liu, 2011). Employment support refers to the LUF of providing employment opportunities, and its value is calculated as the substitution cost of the unemployment insurance premium obtained by assuming that the entire agricultural and nonagricultural labor force is unemployed, which is determined by both the demand and supply coefficients of employment support. The urban demand and supply coefficients are both 1. The rural demand coefficient is inversely proportional to nonagricultural income, while the rural supply coefficient is directly proportional to land productivity (Xu et al., 2015).

Public service security refers to the function of the government, dependent on public finance, to provide public services for residents, and its value is evaluated by the expenditure on public services. The total expenditure can be queried directly from the statistical yearbook, and it can then be scaled to the concrete parcel with the correction coefficients that are estimated according to the number and grade of public services in different areas. Entertainment service security refers to the function of the land use system to meet the needs of human spiritual life, and the value of such services in the study area is evaluated based on the worldwide average value of this function specified by the TEEB (Brouwer et al., 2013).

Table 4
Value evaluation function groups of land use living functions.

Subfunctions	Calculation formula	Explanation of parameters
Urban housing security	$V_i^{l11} = V_i^1 + V_i^2 + V_i^3$ $V_i^1 = Y^R \times S_i^R \times r^R$ $V_i^2 = Y^B \times S_i^B \times r^B$ $V_i^3 = Y^I \times S_i^I \times r^I$	V_i^{l11} is the value of the urban housing security function; V_i^1, V_i^2 and V_i^3 are the total rent of residential land, commercial land, and industrial land, respectively; Y^R, Y^B and Y^I are the per unit land area rents, respectively; S_i^R, S_i^B and S_i^I are the land area, respectively; r^R, r^B and r^I are the average volume rate, respectively
Rural housing security	$V_i^{l12} = Y^R \times \lambda \times S_i^{'}$ $S_i^{'} = S_i \times \gamma$	V_i^{l12} is the value of the rural housing security function; Y^R is the rent of residential land; λ is the urban-rural income ratio; $S_i^{'}$ is the total rural homestead area; S_i is the parcel area; γ is the building density
Basic living support	$V_i^{l21} = C_i \times L \times S_i$	V_i^{l21} is the value of the basic living support function; C_i is the population carrying capacity of land; L is the minimum living standard
Employment support	$V_i^{l22} = P_i \times B \times \lambda \times k_i \times \mu_i$ $P_i = \alpha_i P_o$ $k_i = 1 - M_i/M_I$ $\mu_i = v_i/v_o$ $\alpha_i = s_i/S_i$	V_i^{l22} is the value of the employment support function; P_i is the size of the labor force; B is the standard of the unemployment insurance premium for urban residents; M_i is the per capita nonagricultural net income of the agricultural population; M_I is the per capita net income of urban residents; k_i is the correction coefficient of employment demand and when $M_i \geq M_I$, it is equal to 1; μ_i is the correction coefficient of employment ability; v_i is the net income of agricultural products; v_o is the average net income of regional agricultural products; P_o is the total labor force in the administrative village
Public service security	$V_i^{l31} = \alpha_i \sum_{j=1}^{4} \omega_{i,j} F_{i,j}$ $\alpha_i = s_i/S_i$	V_i^{l31} is the value of the public service security function; $F_{i,j}$ is the government expenditure on general public services, education services, medical services, and transportation services; $\omega_{i,j}$ is the correction coefficient of public service expenditure
Entertainment service security	$V_i^{l32} = \sum V_{i,j}$ $V_{i,j} = V_j \times \alpha_i$ $\alpha_i = s_i/S_i$	V_i^{l32} is the value of the entertainment service security function; $V_{i,j}$ is the value of the leisure entertainment function, science and education function and spiritual sustenance function; V_j is the global average value of land use services

4. Results analysis

4.1. *Value structure of land use functions*

According to Table 5, the annual value of the LUFs of Fengzhou Town is ¥870.20 million yuan. The annual values of the ecological, production and living functions are ¥124.49 million yuan, ¥387.66 million yuan, and ¥358.06 million yuan, accounting for 14.31%, 44.54%, and 41.15%, respectively. The value structure indicates that the primary direction of land use in the study area is oriented toward pursuing the production and living functions. The value proportion of the hydrological regulation function is 7.52%, which means that it is the most prominent ecological function. The proportions of resource products, biological products,

Table 5
Value structure of land use ecological, production and living function in 2015.

Ecological function			Production function			Living function		
Function type	Value	Proportion	Function type	Value	Proportion	Function type	Value	Proportion
Climate regulation	27.63	3.18	Freshwater supply	6.00	0.69	Urban housing security	177.46	20.39
Hydrological regulation	65.45	7.52	Mineral supply	4.93	0.57	Rural housing security	79.94	9.19
Soil conservation	11.95	1.37	Agricultural product supply	19.18	2.20	Basic living support	35.58	4.09
Environmental purification	19.45	2.24	Forestry product supply	1.16	0.13	Employment support	15.09	1.73
			Livestock product supply	15.63	1.80	Public service security	41.54	4.77
			Fishery product supply	0.41	0.05	Entertainment service security	8.45	0.97
			Industrial product supply	230.70	26.51			
			Commercial service supply	54.34	6.24			
			Tourism service supply	25.06	2.88			
			Transportation service supply	30.23	3.47			
Total	124.49	14.31	Total	387.66	44.54	Total	358.06	41.15

Note: the unit of value is ¥ million yuan per year, and the unit of proportion is %.

industrial products, and service products are 1.26%, 4.18%, 26.51%, and 12.60%, respectively, indicating that industrial production is the main economic source and leads to the development of the service industry. The percentages of the housing security function, social support function, and spiritual security function are 29.58%, 5.82%, and 5.74%, respectively, indicating that the land use living function mainly provides space for production and life, while social security and spiritual security are relatively weak.

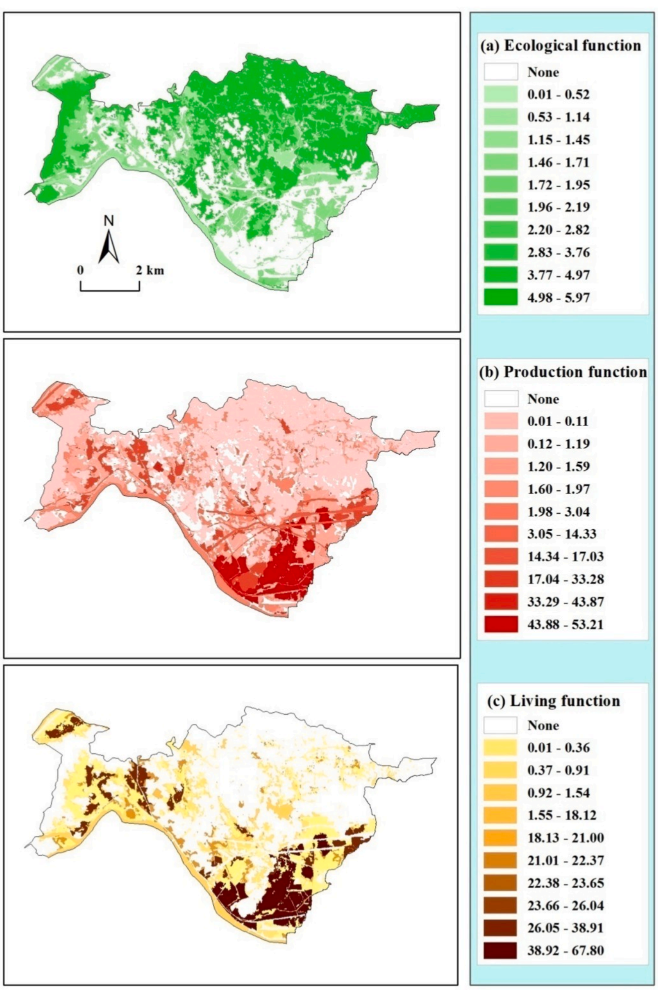

Fig. 3. Distribution of the values of land use function in 2015. The unit of value is ¥ yuan ha^{-1}.

4.2. *Spatial characteristics of the value of land use functions*

As shown in Fig. 3, the spatial distribution of the values of the ecological, production and living functions are clearly clustered. The value distribution of the production function and living function shows obvious spatial consistency and is complementary to the ecological function. Specifically, the distribution of the values of the ecological function is scattered, and the gradient characteristic between high and low values is not obvious. The areas with a higher ecological function value are mainly distributed in the less developed hilly areas in the north, and the LUT is mainly forest. The areas with a null ecological function value are mainly distributed along the river in the south and west, where human activities are intensive, and the LUT is mainly construction land. The areas with a median value are primarily distributed in the transitional areas between the high-value areas and the null-value areas, and the LUT is mainly agricultural land. The distribution of the values of the production and living functions is concentrated, and the gradient characteristic is significant. The high-value areas are mainly distributed along the southern flat valley and the important traffic corridor in the west, where the LUT is mainly residential land. The areas with low production function values basically fill the entire area except for the area with a null value, while the areas with low living function values are mainly distributed around the periphery of the high-value areas, where the LUT is mainly cultivated land.

4.3. *Functional pattern and distribution of land use types*

The function types, combined function patterns and dominant function types of different LUTs are shown in Table 6. The study area has 8 kinds of combined function patterns: the ecological function, production function, ecological-production function, production-ecological function, living-production function, ecological-production-living function, production-ecological-living function and production-living-ecological function; in Fig. 4a, they have areal proportions of 0.35%, 7.60%, 45.98%, 0.61%, 17.1%, 13.98%, 9.58%, and 4.81%, respectively. Among the 20 LUTs, there are 6 LUTs with a single function, 6 LUTs with dual functions, and 8 LUTs with triple functions. As shown in Fig. 4b, the area proportion dominated by ecological function is 60.30%, mainly covering the northeastern area. The areal proportion dominated by the production function is 22.60%, mainly filling in the middle as long strips or patches. The areal proportion dominated by the living function is 17.10%, mainly located in the south and west. More than 90% of land area has double or triple functions, which indicates that the land use in the study area is multifunctional. The adjacency and agglomeration relationships among different combined function patterns and dominant function types are complex, which indicates that the spatial distribution of LUFs in the study area is rather complicated. Therefore, it is necessary to optimize the layout of different landscape elements in rural spatial planning to enhance the matching and

Table 6
Value, function types, combined function patterns and dominant function types of different land use types in 2015.

Land use type	Ecological value	Production value	Living value	Function type	Combined function pattern	Dominant function type
Paddy field	15437	14556	2900	Triple	Ecological-production-living	Ecological
Irrigated farmland	13624	12976	2591	Triple	Ecological-production-living	Ecological
Rain-fed farmland	9317	9772	1946	Triple	Production-ecological-living	Production
Orchard	19031	21339	4654	Triple	Production-ecological-living	Production
Tea plantation	17894	18528	4046	Triple	Production-ecological-living	Production
Other garden	19419	21685	4750	Triple	Production-ecological-living	Production
Woodland	44888	559		Double	Ecological-production	Ecological
Shrubland	33899	294		Double	Ecological-production	Ecological
Other forest land	42996	159		Double	Ecological-production	Ecological
Other grassland	25612			Single	Ecological	Ecological
Railway		166667		Single	Production	Production
Highway		153970		Single	Production	Production
River	10136	24396	14387	Triple	Production-living-ecological	Production
Reservoir	7889	23996	14388	Triple	Production-living-ecological	Production
Pond	2736	17610		Double	Production-ecological	Production
Farmland facility		434719		Single	Production	Production
Township		520595	587927	Double	Living-production	Living
Village		176968	260653	Double	Living-production	Living
Mining		133944		Single	Production	Production
Scenic spots		211249		Single	Production	Production

Note: the unit of function value is ¥ yuan ha^{-1}.

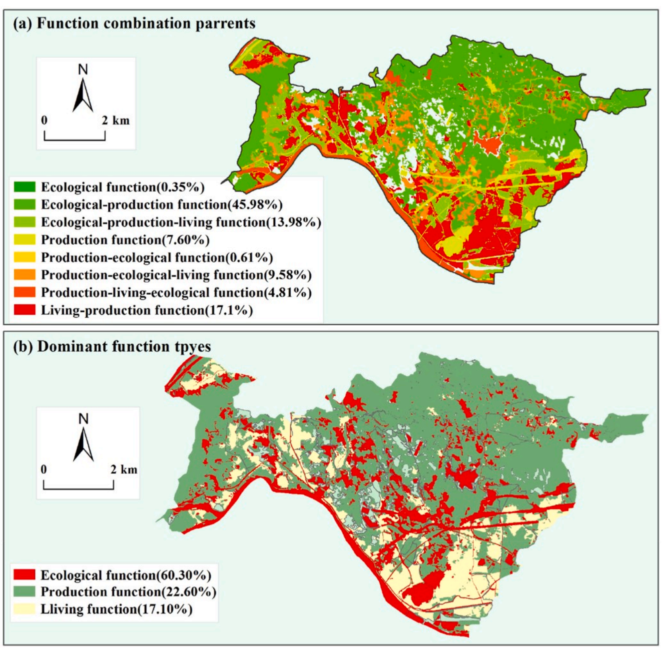

Fig. 4. Spatial characteristics of different combined function patterns and dominant function types in 2015. “Ecological function (0.35%)” in Fig. 4a indicates the land that has only the ecological function, which accounts for 0.35% of the total area. “Ecological function (60.30%)” in Fig. 4b indicates the land dominated by the ecological function, which accounts for 60.30% of the total area.

integration of spatial functions.

5. Discussion and conclusions

5.1. Practicability of the land use function classification system

The LUF classification system must be built based on practicality. At present, there are three concepts based on which LUFs are divided from the “ecological-production-living” perspective. First, based on the subjective land use intention, the dominant LUF is highlighted, and the LUFs are divided into single function types, such as the production function, the living function, and the ecological function (Chen, Zhou, Zhou, & Lv, 2015). The second concept concerns the combination of the main function and secondary function, in which LUFs are divided into combined function types, such as the ecological-production function, the production-ecological function, and the living-production function (Zhang, Xu, & Zhu, 2015). Third, based on the function intensity, LUFs are divided into 12 types: ecological land, semi-ecological land, weak ecological land, and non-ecological land; production land, semi-production land, weak production land, and non-production land; and living land, semi-living land, weak living land, and non-living land (Liu, Liu, et al., 2017). Although studies have been effective in explaining the relationship between the classification of LUFs and the land use status, they are somewhat less practical because they rely on the subjective judgment of the primary or secondary function and fail to take into account the equality of LUFs.

With the development of the social economy, the trend of multi-functional land use has gradually strengthened. However, the primary and secondary functions cannot be distinguished for every LUT, as this approach may result in deviation or negligence in land use planning and management and is not conducive to the practical application of the LUF classification system (Xie et al., 2010). For example, cultivated land is a complex “natural-economic-social” system that serves as the main source of grain production, and it can also provide the social support function and ecological regulation function (Arcidiacono, Ronchi, & Salata, 2016; Portman, 2013). In the classification of LUFs, any emphasis placed on the production function weakens the ecological and living functions. Consequently, the actual effect of the value of a function will not be accurately reflected. At present, due to the lack of a unified spatial plan in China, the problems of disordered rural LUFs have become a cause for concern for both policymakers and the public (Liu, 2018; Xie et al., 2010). To resolve such problems, the Chinese government has issued a series of policies to guide land use planning and management in an attempt to coordinate the multiple functions of rural regions instead of being dominated by a single agricultural production function (Liu, Li, & Yang, 2018; Long & Liu, 2016). This paper constructs a classification system in which all LUFs are equally weighted when linked to the land use status. Clearly, it is more practicable and operational than previous methods because it complies with current land planning and management practices.

5.2. Rationality of the value evaluation models of land use functions

Since each LUF has a specific social and economic value (Long, 2014), scientifically establishing the value evaluation functions is key to obtaining correct results. The existing literature has illustrated the prevailing view in academic circles that the value of land use ecological function is represented by part of the ecological service function value (Guo et al., 2001), but the value evaluations of the production and living functions are notably different. The market value method has been used to calculate the value of the production function. This method results in a large deviation because of its high dependence on data. For example, the annual value of the production function of paddy fields calculated in this way by Li et al. (2016) is ¥64,637 yuan ha^{-1}, which is obviously higher than the actual value. According to preliminary estimates, the annual value of the production function of cultivated land in China is ¥7500–18,000 yuan ha^{-1} (Jin, He, Wang, & Gong, 2018). For this reason, the gross value of agriculture, forestry, animal husbandry, fishery, and industry was directly obtained from the statistical yearbooks as the value of the corresponding product supply function. These data are closer to actual land values because they are informed by solid evidence.

In addition, a previous study used the land price as the value of the housing security function and corrected it by using location factors and individual factors to determine the spatial variability of the value (Li & Fang, 2016). Although this method achieves value quantification, it ignores the difference between the land price and the value of the land function. The land price refers to the currency exchanged when land is bought and sold as a commodity in the market, which is the monetized performance of land value (Kau & Sirmans, 1979). According to the fundamental asset market equation, the price of land equals the present discounted value of the stream of future rents in a competitive land market (Plantinga & Miller, 2001). As mentioned above, the value of the LUF refers to the utility of the products and services provided by land in the year. For the housing security function, the products and services concern providing living space; thus, the utility can be valued by the annual rents (Ondetti, 2016). Based on this concept, the evaluated value of the housing security function accounted for 71.88% of the total value of the living function. This result indicates that the living function of land use in the study area mainly concerns providing a place for production and living, which is largely consistent with the actual situation of rural land use in China.

5.3. Implications of the value evaluation of land use functions

The rapid development of the social economy has improved land use intensity, leading to an increase in multifunctional land use (Liu, Liu, et al., 2017). To satisfy multifunctional utilization and effective management, a uniform classification and value evaluation system of rural LUFs is established. Thus, two key problems are solved: first, previous studies referring to the classification of LUFs mainly focused on the agricultural system, natural ecosystem or urban system, while this study provided a classification system focused on the rural regional system. The multifunctionality of land use is gradually being strengthened in rural areas (Long & Liu, 2016; Zhu et al., 2018). With economic and social development, the role of China's rural areas has changed from food supply and the contribution of production factors to ecological space, cultural heritage and new consumption carriers (Li et al., 2019b). Second, the functional groups were constructed to quantitatively evaluate the values of ecological, production and living LUFs. Rural LUFs are the result of the comprehensive effect of natural, social and economic activities; thus, it is more meaningful to evaluate the value of LUFs based on the indirect values of biophysical processes and the direct values of socioeconomic processes.

The empirical analysis shows that the value contributed by rural LUFs is large, which indicates that China has transitioned from an "agricultural power" to an "industrial power" driven by the strategy of urbanization in recent decades (Li, Fan, et al., 2019). This transformation has spread from urban areas to traditional rural areas. The nonagricultural use and nongrain use of rural land and the concurrent business and citizenship of the rural population have begun to emerge and subtly change the structure and direction of land use (Liu et al., 2018). This change has also led to an adjustment in land use management strategies. For example, the Chinese central and local governments have constantly emphasized the optimization of the structures of the ecological, production and living functions in land use activities and rationally demarcated the boundaries of urban land, agricultural land, and ecological land ; (Xu et al., 2015; Zhou et al., 2017a). Notably, although the economic output of cultivated land has weakened, it is the foundation of national food security as well as the livelihood security of nearly 600 million rural people. Meanwhile, the interference of human activities in the ecological environment has endangered the sustainable use of land. Therefore, it is necessary to rationally reorder land development and optimize the "ecological-production-living" spatial structure.

5.4. Limitations of the value evaluation of land use functions

Although the established classification system and value evaluation functions of LUFs have good applicability and a scientific basis, there are still some improvements to be made, which are described as follows. (1) The regional difference in the classification of land use ecological function does not include all ecological functions. These excluded functions are weak or difficult to quantify using data collection, such as the functions of sudden event mitigation, pollination, and genetic inheritance. (2) The corresponding relationship between the classification of LUFs and land use status should be in accordance with actual land use. Because multifunctional land use continues to strengthen, traditional LUFs continue to evolve. For example, terraced fields with tourism value have both production and ecological supplement functions, and they also have important cultural functions (Jin et al., 2018). (3) The spatial scale of the value evaluation of LUFs needs to be expanded. Because the classification of LUFs varies greatly under different spatial scales, the corresponding theory and method of value evaluation should also be different. All of these issues require further theoretical and empirical studies to develop a base of scientific evidence for promoting land use planning and management.

Author statement

I have made substantial contributions to the work; AND.

I agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

All persons who have made substantial contributions to the work reported in the manuscript.

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Appendix 1. Parameters in valuing land use ecological function

Parameter	Symbols	Value	Unit	Reference
Afforestation cost of per unit CO_2 fixed	P_{RCO_2}	220.32	yuan t^{-1}	Miao, Sun, Wang, and Huang (2017)
Carbon dioxide tax rate	P_{CCO_2}	996.35	yuan t^{-1}	Su, Fu, He, and Lü (2012)
Afforestation cost of per unit O_2 released	P_{RO_2}	159.55	yuan t^{-1}	Miao et al. (2017)
Industrial oxygen production cost of per unit O_2 released	P_{IO_2}	1160.70	yuan t^{-1}	Guo et al. (2000)
Net primary productivity	NPP		t C (ha·a) $^{-1}$	GCE and (Liu et al., 2017b)
Canopy interception water absorption capacity	C	1.52	mm a^{-1}	Wen and Liu (1995)
Litter layer water absorption capacity	L	2.29	mm a^{-1}	Wen and Liu (1995)
Soil layer water absorption capacity	S	69.43	mm a^{-1}	Wen and Liu (1995)
Cost of unit reservoir capacity	C_c	6.11	yuan m^{-3}	FESFAS
Fixed costs of reducing SO_2 by the cost method	C_S	830	yuan t^{-1}	Miao et al. (2017)
Fixed costs of blocking dust by the cost method	C_D	230	yuan t^{-1}	Miao et al. (2017)

Note: all prices in this article are for 2015 unless otherwise stated. GCE is the abbreviation for the global continental ecosystem. FESFAS is the abbreviation for the Forest Ecosystem Service Function Assessment Standard issued by the Chinese Forestry Administration on April 28, 2008.

Appendix 2. Water absorption capacity coefficients of different vegetation types, soils and slopes

Vegetation type	Variable	Coefficient	Soil type	Variable	Coefficient	Slope	Variable	Coefficient
Forest land	ε_1	1.00	Red soil	δ_1	1.00	<15°	η_1	1.00
Shrub land	ε_2	0.71	Latosolic red soil	δ_2	0.98	15° –25°	η_2	0.57
Other forestland	ε_3	0.57	Fluvio-aquatic soil	δ_3	0.81	>25°	η_3	0.31
Garden land	ε_4	0.11	Paddy soil	δ_4	0.05			
Grass land	ε_5	0.35						
Cultivated land	ε_6	0.07						

Appendix 3. Output coefficients of land use production function in different land use types

Output coefficient	Variable	Land use type	Sign	Proportion
Freshwater output coefficient	ε	River, reservoir, pond	Water supply	0.722: 0.212: 0.066
Minerals output coefficient	χ	Mining	Stone type	1
Grain output coefficient	ϕ	Cultivated land, garden	Agricultural product value	0.565: 0.435
Wood output coefficient	κ	Woodland, shrubland, other forest land	Forestry products value	0.952: 0.007: 0.041
Livestock output coefficient	μ	Farmland facility	Livestock products value	1
Fishery output coefficient	ω	River, reservoir, pond	Breeding area	0.187: 0.463: 0.350
Industrial output coefficient	σ	Township, village	Industrial output value	0.638: 0.362

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