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Coordinated development efficiency between cultivated land spatial morphology and agricultural economy in underdeveloped areas in China:

Evidence from western Hubei province

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Abstract: Suitable spatial morphology of cultivated land is a basic requirement for sustaining agricultural economic development in mountainous areas. Coordinated development efficiency of cultivated land spatial morphology and agricultural economy (CECA) is of great practical significance to measure the efficiency of cultivated land use, and thereby promote regional rural revitalization. However, few studies to date have focused on coordinated development efficiency between cultivated land use and agricultural economy in mountainous areas from the perspective of cultivated land spatial morphology. Thus, the present study explores CECA with this focus using the data envelopment analysis method, and analyzes the key influencing factors via a geographical detector model in 16 counties in western Hubei province. The results show the following: (1) CECA exhibits significant spatial heterogeneity that is high in the south of the study area and low in the north; (2) scale efficiency is the primary limiting factor for CECA; (3) the insufficient output of cultivated land use mainly restricts CECA in the south of the study area, while individual county in the north suffered from input redundancy and insufficient output; and (4) population density in the southern region has the most significant effect on CECA, and gross domestic product has the greatest impact in the northern region. The results contribute to the derivation of specific measures by which to promote cultivated land use efficiency and sustainable development of the social economy.

Keywords: cultivated land spatial morphology; agricultural economy; data envelopment analysis; geographical detector model; coordinated development efficiency; western Hubei

1 Introduction

China has embarked on a new journey to build itself into a modern socialist country in all respects. In this vein, rural revitalization is an important problem that needs to be solved as a

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matter of urgency (Huang *et al*., 2020). Underdeveloped areas in China are mostly concentrated in rural areas, which have a complex topography, inefficient transportation, underdeveloped science and technology and relatively poor resource endowments. Such aspects have become important bottlenecks to economic development (Xiang *et al*., 2019b; Zhang *et al*., 2019). In addition, there has been an increasing flow in recent years of young labor into the cities (Qin and Liao, 2016). This has led to an increasing number of vacant houses and abandoned cultivated land, leading to sluggish social and economic development in underdeveloped areas (Long *et al*., 2012; Li *et al*., 2014). In response to this problem, China has implemented vigorous strategies of "targeted poverty reduction" and "rural revitalization" to promote the economic development of these areas in a holistic manner (Lo *et al*., 2016; Guo *et al*., 2019; Yin *et al*., 2019). In this context, an important issue to promote regional socioeconomic development is how to improve the agricultural economy by enhancing their vitality and self-hematopoiesis, for instance by optimizing their cultivated land spatial morphology. Central to this issue is the *coordinated development efficiency between cultivated land spatial morphology and agricultural economy* (in abbreviated form, CECA), as understanding this aspect is vital to improving cultivated land use efficiency and ensuring the sustainable development of the agricultural economy that means the economic development caused by agricultural production.

Due to differences in the spatial topography, socioeconomic development status, science and technology level, and population flow across underdeveloped areas, the spatial morphology of cultivated land varies significantly (Guo and Liu, 2022). Suitable spatial morphology of cultivated land is required in order to promote effective utilization of cultivated land and agricultural economic development. Scholars have carried out extensive research on cultivated land spatial morphology, mainly focusing on dominant morphology and recessive morphology (Long and Qu, 2018; Ma *et al*., 2020), and functional morphology and spatial morphology (Song and Li, 2019; Xiang *et al*., 2019b). Spatial morphology mainly refers to landscape patterns and management patterns (Song, 2017). Landscape patterns primarily relate to cultivated land landscape fragmentation (Qiu *et al*., 2020), diversity (Lombardi *et al*., 2019), locality (Wang *et al*., 2018), heterogeneity (Atique and An, 2020), complexity (Mohammed *et al*., 2020), and so on. For mountainous areas (Han and Song, 2019), plain areas (Wei *et al*., 2019), and hilly areas (Tang *et al*., 2019), the relationship between landscape patterns of cultivated land and ecological services has been studied from an comprehensive perspective. Management patterns mainly means the combination of cultivated land utilization that appears after the cultivated land operated by different entities (individual or organization) in a certain area. With respect to management patterns, many studies have revealed patterns of cultivated land management in underdeveloped areas and the human impact on cultivated land use transition (Cao *et al*., 2019). Such studies have primarily considered population migration and labor force loss (Xu *et al*., 2019), emerging science and technology (Deng *et al*., 2019), and wasted cultivated land (Meyfroidt *et al*., 2016). These studies have defined the connotations of cultivated land spatial morphology in detail from a range of aspects, and evaluated the characteristics of cultivated land spatial morphology in different regions. These provide a foundation for the study of cultivated land spatial morphology in underdeveloped areas.

Cultivated land is a basic resource to promote the development of the agricultural economy in underdeveloped counties. Scholars have typically studied the coordinated development relationship between cultivated land use and agricultural economy development from the perspective of changes in cultivated land quantity and spatial morphology, such as cultivated land loss contributing to built-up land occupation (Song, 2014; Li *et al*., 2019), the relationship between economic growth and cultivated land conversion (Liu and Guo, 2015), urbanization and cultivated land marginalization (Li *et al*., 2017), the relationship between quantitative change and finance (Yongle and Qun, 2007), and cultivated land quality improvement to promote the revitalization of sandy rural areas (Yuan *et al*., 2019). Studies have also covered the impact of cultivated land expansion on global agricultural markets (Yang *et al*., 2014; Huy and Nguyen, 2019), agricultural land rent (Stokstad and Krøgli, 2015), price volatility of agricultural land (Bórawski *et al*., 2019), agricultural land leasing (Mandal *et al*., 2019), the cropland rental market, and farm technical efficiency (Huy and Nguyen, 2019). These studies have explored the coordinated development relationship based on cultivated land quantity change and spatial change, which provides a basis for CECA research with regard to aspects such as the evaluation method and index system construction.

In addition, many studies have involved factor analysis of CECA (Wang and Li, 2021), mainly including ecological factors such as irrigation and salinization (Yuan *et al*., 2019) and ecological environmental constraints (Li *et al*., 2020a); economic factors such as gross domestic product (GDP) (Kuang *et al*., 2020) and the proportion of industry and service industry (Liu *et al*., 2019); and social factors such as population density (Liu *et al*., 2020) and urbanization development (Hou *et al*., 2019). Moreover, the cultivated land morphology in underdeveloped areas is often complex and diverse, which entails differences in resource endowments and palpable cultivated land fragmentation, as well as variations of scientific and technological development level (Kuang *et al*., 2020) and cultivated land protection policies (Liu *et al*., 2017a). Such hindrances to the utilization of cultivated land also lead to changes in the land's spatial morphology, which has characteristics of high fragmentation and poor agglomeration that in turn affect agricultural economic output.

However, few studies have focused on the coordinated development efficiency between cultivated land use and agricultural economy in underdeveloped areas from the perspective of cultivated land spatial morphology. Currently, many bottlenecks—such as poor transportation facilities, underdeveloped science and technology, and related national policies and measures—jointly restrict rational development of cultivated land spatial morphology, which thus fails to fully meet the needs of local agricultural economic development. Therefore, optimizing the spatial morphology of cultivated land is particularly important for promoting the rapid growth of the agricultural economy, as well as regional economic growth through the promotion of endogenous power. As such, improving CECA is an urgent and feasible requirement that could promote the effective use of cultivated land in underdeveloped areas and growth of the agricultural economy in order to facilitate rural revitalization and sustainable socioeconomic development by enhancing intraregional vitality and self-hematopoiesis.

To this end, the present study takes 16 underdeveloped counties in western Hubei as the study area. These counties represent a typical underdeveloped rural area in China (Xiang *et al*., 2019b). The area faces several problems—such as poor endowment of cultivated land resources, underdeveloped cultivation techniques, and significant wasted cultivated land—that seriously threaten attempts at rural revitalization and impede the sustainability of the agricultural economy. The aims of our study are to: (1) analyze the characteristics of CECA from 1995 to 2015, (2) identify the problem areas pertaining to coordinated development efficiency using a Data Envelopment Analysis (DEA) method, and (3) explore the influencing factors of CECA using a geographical detector method. The findings are expected to contribute to developing differentiated and precise strategies for cultivated land use, and providing scientific references for the sustainable and effective use of cultivated land, regional rural revitalization in underdeveloped counties of China, and even similar areas elsewhere in the world.

2 Research framework and methods

2.1 Research framework

Generally speaking, the spatial morphology of cultivated land is influenced by policies at the national and local levels, socioeconomic development, regional cultivated land resource endowment, location conditions, and other factors (Liu *et al*., 2019; Qu *et al*., 2019; Xiang *et al*., 2019b; Qu *et al*., 2020). First, different policies at the national and local levels act as a directional guiding factors, and frequently affect people's behaviors in managing cultivated land, leading to changes in the utilization efficiency of this land, as well as management pattern. Second, the rapid development of urbanization and structural changes in society and the economy trigger a trend of migration from rural areas to cities. This loss of young rural labors leads a decreasing capacity for cropland management, an increase in areas of wasted cropland, and inefficient utilization of the land (Li *et al*., 2014; Liu *et al*., 2017b). People prefer to choose plots with a high yield and good location that are close to their home and thus enable cultivation to be self-sufficient, which increases the degree of fragmentation of cultivated land and affects the scale and management patterns therein. Third, underdeveloped areas often have a relatively low endowment of cultivated land resources due to their complex and diverse topography, specific climate, and lack of development with regard to agricultural science and technology (Xiang *et al*., 2019b). As such, areas with high soil fertility and flat terrain are the first choice for people to cultivate. However, thus randomness of choice makes it difficult to facilitate large-scale management and intensive utilization, which affects landscape patterns and management patterns of cultivated land.

There is a direct interaction between cultivated land spatial morphology and agricultural economy. On the one hand, the regularity shape of cultivated land patches, the fragmentation or agglomeration of spatial distribution, as well as the willingness to farm, business mode and scale of farmers' operations, all directly affect the utilization efficiency of cultivated land and agricultural production, which further impacts agricultural income, the degree of prosperity of the agricultural market, and agriculture economic benefits. On the other hand, development of the agricultural economy has brought vitality to the agricultural market, while the increase in farmers' economic income has pushed them to develop more advanced modes of agricultural management, and has promoted corresponding patterns of agricultural management. Farmers are willingness to management the cultivated land with better topography and higher resource endowments are prioritized for cultivation, which promotes the agglomeration and utilization of cultivated land and the improvement of utilization efficiency. Based on the preceding discussion, Figure 1 shows the theoretical framework of CECA in underdeveloped areas.

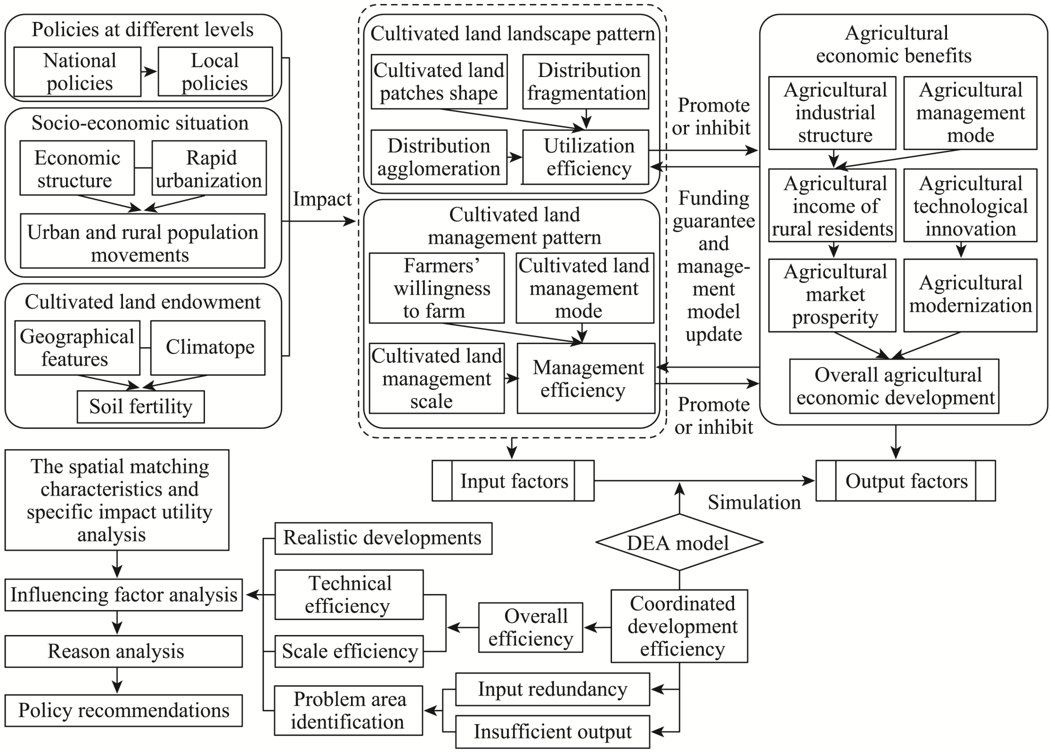

Figure 1 Research framework of CECA in underdeveloped areas

As shown in Figure 1, changes in the spatial morphology of cultivated land, which contribute to the landscape and management patterns thereof, are closely related to benefits of the agricultural economy. Therefore, we analyze CECA based on an input–output model, taking the spatial morphology of cultivated land as the input element and benefits of the agricultural economy as the output element, in order to characterize agricultural economic benefits brought about by changes of cultivated land spatial morphology and to comprehensively detail the effective spatial allocation and rational utilization of cultivated land resources. The high efficiency of coordinated development indicates that the changes of cultivated land spatial morphology are reasonable, and promote the agricultural economy.

The input–output model is characterized as a DEA model in this study. On the one hand, the DEA model enables us to identify an overall efficiency, which is then decomposed into scale efficiency and technical efficiency. Scale efficiency refers to the development efficiency affected by the size of each factor, while technical efficiency is the development efficiency affected by factors such as management and technical conditions. On the other hand, using the DEA method input redundancy and insufficient output can be calculated simultaneously. Input redundancy represents the proportion of savings that can be achieved by the indicator, or the number of excess inputs under a given output; insufficient output represents the proportion of outputs that can be increased, or the number of outputs that are missing under a given input. By comparing the input redundancy and insufficient output, we can infer the deficiencies that require further refinement, and identify aspects that affect coordinated development efficiency in order to provide recommendations for targeted regulations.

2.2 Construction of the index system

In this study, in order to build our DEA model to analyze coordinated development efficiency, we take two aspects of the spatial morphology of cultivated land—landscape pattern and management pattern—as input elements, and agricultural economic benefits as output elements. The specific indicators selected are as follows.

For the landscape pattern, cultivated land patches can be regarded as the basic unit of cultivated land and the basic elements of the landscape pattern. Patch connectivity is the premise underlying the large-scale utilization of cultivated land. As such, the landscape distribution pattern of cultivated land is characterized by the fragmentation degree and the agglomeration degree of a cultivated land patch (Wu *et al.*, 2019). At the same time, due to the staggered distribution of paddy fields and dryland in underdeveloped areas, the proportion of paddy field areas is taken to reflect the background structure of cultivated land (Xiang *et al.*, 2019a).

For the management pattern, the degree of fine fragmentation of cultivated land has a certain influence on the efficient utilization of cultivated land. The Simpson Index (Somerfield *et al.*, 2008) is used to comprehensively measure the management status of fine fragmentation of cultivated land in order to reflect the distribution of plot number and average plot size, which is assigned a value between 0 and 1. The larger the Simpson Index value, the higher the degree of cultivated land fragmentation. The per capita cultivated land and the per household cultivated land plots reflect the actual difference in cultivated land management considering population factors (Yan *et al.*, 2016; Liu *et al.*, 2019).

For the measurement index of agricultural economic benefits, the agricultural gross output value is chosen to reflect the overall economic agricultural situation, and the output variable is optimized using the index of agricultural added value to prevent a possible deviation of agricultural gross output value due to differences in regional economic policies and directions, which enhances the accuracy of the results. In addition, the per capita agricultural income for rural residents is selected to measure the income brought via agricultural production to rural residents (Xiang *et al.*, 2019b). The input–output index system used in this study is shown in Table 1.

2.3 Research methods

2.3.1 Data envelopment analysis

DEA is a common systematic analysis method that can be applied to calculate coordinated development efficiency. The method was put forward by Charnes *et al.* (1978) based on the concept of "relative efficiency" according to the input–output model (Peyrache *et al.*, 2020). The approach makes it possible to decompose overall efficiency into scale efficiency and technical efficiency (Avkiran, 2001) without assuming the weight and without determining the explicit expression of the relationship between the input and the output. It enables not

Table 1 Evaluation index system of CECA based on an input–output model

Elements	Factor	Index	Calculation	Data sources
Input elements	Landscape pattern	Cultivated land fragmentation ($X1$)	Cultivated land patch quantity / land area	Chinese County Statistical Yearbook (1995–2015), Hubei Province Statistical Yearbook (1995–2015), Resources and Environmental Sciences Data Center of the Chinese Academy of Sciences (2019)
		Cultivated land agglomeration ($X2$)	Adjacent patch quantity / cultivated land patch quantity	
		Proportion of paddy in cultivated land ($X3$)	Paddy field quantity / cultivated land quantity	
	Management pattern	Management of cultivated land fragmentation ($X4$)	Simpson Index	
		Per capita cultivated land ($X5$)	Cultivated land quantity / permanent resident population	
		Per household land plots ($X6$)	Cultivated land patch quantity / household quantity	
Output elements	Agricultural economic benefits	Agricultural output ($Y1$)	Agricultural output statistics	Chinese County Statistical Yearbook (1995–2015), Hubei Province Statistical Yearbook (1995–2015)
		Added value of agriculture ($Y2$)	Agricultural added value statistics	
		Per capita agricultural income for rural residents ($Y3$)	Agricultural income of rural residents / rural population	

only analysis of input redundancy and insufficient output, but also comprehensive discrimination of the specific factors affecting the efficiency of coordinated development (López, 2011). The definitions of overall efficiency, scale efficiency, technical efficiency, input redundancy, and insufficient output are explained in section 2.1. The calculation results based on the assumption of a constant scale reward DEA model are as follows (Sözen *et al*., 2010).

$$\begin{cases} \min \alpha \\ \text{st.} \quad \alpha \sum_{j=1}^{n} \lambda_j x_{ij} + s^- \leqslant \alpha x_0, i = 1,2,3,\ldots,m \\ \sum_{j=1}^{n} \lambda_j y_{rj} - s^+ \geqslant y_0, r = 1,2,3,\ldots,n \\ s^-, s^+, \lambda_j \geqslant 0, j = 1,2,3,\ldots,n \end{cases} \tag{1}$$

where x_{ij} and y_{rj} are inputs and outputs, respectively, of the decision-making module; x_0 and y_0 are specific input and output values, respectively; α is the set parameter; s^- and s^+ represent the relaxation variables of the input and output, respectively; and λ_j is the coefficient of the input and output. When $\alpha = 1$, $s = 0$ and $s = 0$, the DEA is effective. Therefore, there is no need to adjust the input and output, and CECA is optimal. When $\alpha=1, s_i^+ \neq 0$ or $s_i^- \neq 0$, the DEA value is weak. Therefore, the spatial variation of cultivated land under the same agricultural economic conditions is unreasonable. When $\alpha \neq 1$, the DEA is ineffective, and CECA entails a series of development problems.

Studies have shown that one of the prerequisites for the scientific application of the DEA model is that the sample size is greater than the sum of the input and output variables (Bo, 2005). For this study, the sample size is 16, and the sum of the number of input and output variables is 9, which meets this requirement and can be calculated.

2.3.2 Geographical detector approach

The geographical detector approach is a statistical method used to explore the driving forces of spatial heterogeneity, which can express the similarity and the heterogeneity between different regions (Wang and Xu, 2017). It is based on the assumption that if an independent variable has an important influence on a dependent variable, the spatial distribution of independent variables and dependent variables should be similar (Wang *et al*., 2017; Qiao *et al*., 2019). The method has been widely used to analyze the evolution of geographical distribution patterns and geographical spatial differentiation (Wang *et al*., 2016). The equation is as follows:

$$Q=1-\frac{1}{n\sigma^2}\sum_{h=1}^{m}n_h\sigma_h^2 \tag{2}$$

where n is the total number of samples in the study area; σ^2 is the discrete variance of Y values for the entire region; h is the partition number of variable Y or factor X, h=1, 2, …, m; q is the spatial heterogeneity of a certain index; and the range is [0, 1]. The larger the q value, the more obvious the Y spatial differentiation and the stronger the explanatory independent variable X to Y, and vice versa. The results are calculated using GeoDetector software. In this process, we calculate the impact utility of a single factor and the interactive influence utility of each of the two factors using the submodules of the factor detector and interaction detector.

In this study, indicators from social, economic, and ecological aspects are used to quantitatively detect the influencing factors. Social factors include population density and urbanization rate (Hou *et al*., 2019; Liu *et al*., 2020), economic factors include GDP and the proportion of value added of primary industry to GDP (Liu *et al*., 2019; Kuang *et al*., 2020), and ecological factors include forest coverage and ecological services value (Xiang *et al*., 2019b). Because it is very difficult to quantitatively measure policy factors, we do not consider these in the index system.

3 Study area and data sources

3.1 Study area

At total of 16 mountainous underdeveloped counties in western Hubei province, China, are selected as the study area (108°21′–111°21′E, 29°06′–33°16′N) (Figure 2). The altitudes of this area range from 44–3002 m, and it has a subtropical monsoon climate with an average annual precipitation of 834–1600 mm and a temperature of 15.2–16.2℃. The area is bounded by the Shennongjia forest area and can be divided into a northern area and a southern area. The northern area contains six underdeveloped counties and the south the remaining 10. In terms of topography, the average elevation in the northern region is relatively low (Figure 3a), and landforms are mainly mountainous and hilly, with a few plains and basins. The region has rich water resources. In particular, the Danjiangkou Reservoir is the primary water source of the South-to-North Water Transfer Project in China.

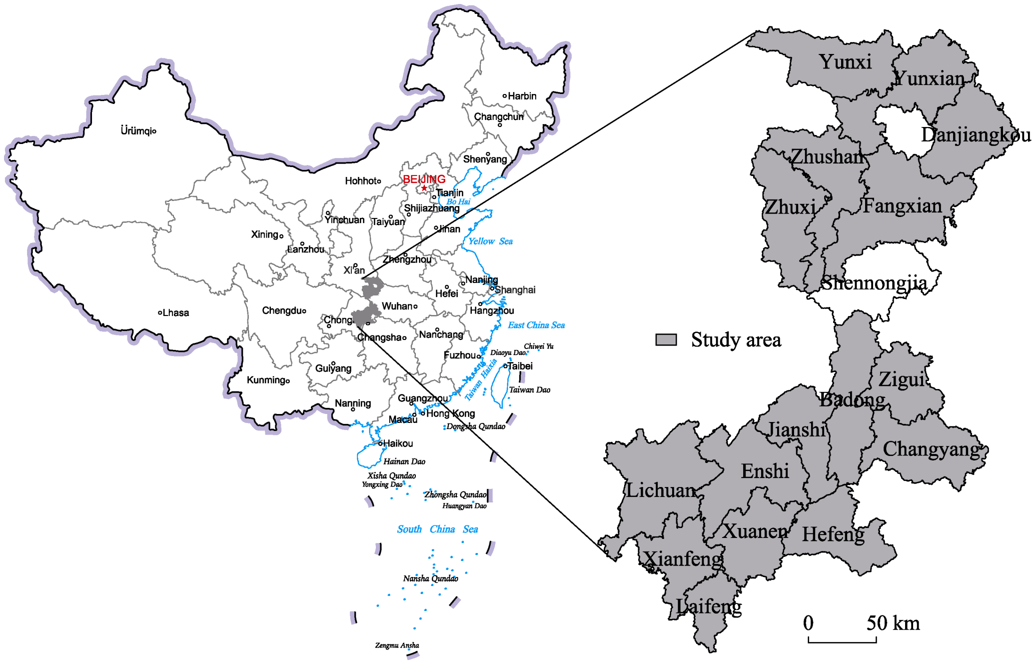

Figure 2 Location of the study area (western Hubei province, central China)

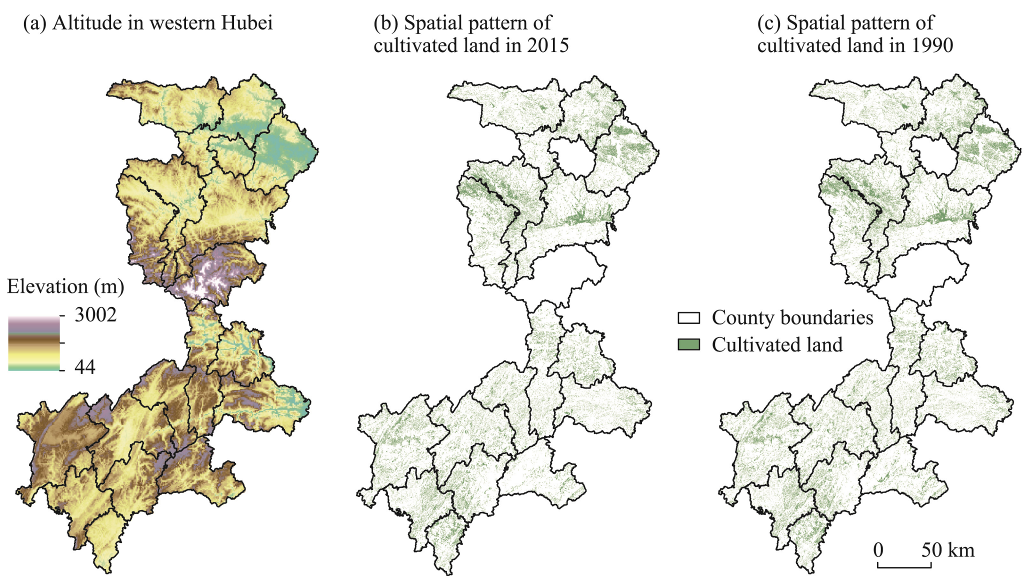

Figure 3 Altitude and spatial pattern of cultivated land in western Hubei province
(Source: Resources and Environmental Sciences Data Center of the Chinese Academy of Sciences, 2019)

The average elevation in the southern region is relatively high, and its topography is complex and diverse. High mountains cover approximately 80% of the area. In terms of spatial distribution of cultivated land (Figures 3b and 3c), there is a large continuous area of cultivated land in Danjiangkou, Zhushan, Zhuxi, and Fangxian in the northern region, where the utilization of cultivated land is relatively agglomeration. The distribution of cultivated land in the southern region has obvious characteristics of fragmentation, except in Laifeng and Lichuan, which have several large areas of continuous cultivated land. In terms of economic development, the economic structure visibly varies. The pillar industries of local economic development mainly include the automobile industry, hydropower industry, tourism industry, and ecological industry in the northern region. The southern area is primarily inhabited by ethnic minorities, with a large proportion of planting, livestock breeding, and tourism industries, and the region depends on the agricultural economy.

Most of the region is comprised of mountainous areas and hillocks (Figure 3a), which contain various forms of cultivated land that is outstanding contradiction with economic development. Because agricultural production is still the main source of local economy in the study area, it is important to consider the suitable spatial morphology of cultivated land use for regional economic development. In 2017, the average GDP of the 16 underdeveloped counties was 10.79 billion yuan, accounting for only 38.8% of the average gross regional product in Hubei province, and 37.2% of China as a whole (Xiang *et al*., 2019b). There are many problems pertaining to cultivated land utilization in this area. On the one hand, industrialization and urbanization have promoted the population flow and the loss of young workers, which has resulted in problems such as extensive occupation of cultivated land and extensive wasteland, and caused frequent changes in the spatial landscape pattern and management pattern of cultivated land. On the other hand, limitations to the natural resource endowment of cultivated land and the limited scientific and technological development have affected the region's agricultural economic growth, which has made it difficult to meet the need for sustainable and efficient utilization of cultivated land and the development of economy. Therefore, it is urgent for the studied region to promote the suitable change to the spatial morphology of cultivated land and its coordinated development with the agricultural economy.

3.2 Data sources

The research years considered in this study are 1995, 2000, 2005, 2010, and 2015. Two kinds of data are considered: vector data and statistical data. Vector data of 30 m × 30 m land use raster data based on remote sensing image interpretation are provided by the Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (RESDC, 2019), and are mainly used to calculate the fragmentation, agglomeration, and agglomeration management of cultivated land. The remaining socioeconomic data, such as agricultural output, urbanization rates, population density, and forest cover, are statistics collected from the Chinese County Statistical Yearbook (RSIDNBS, 1995–2015), Hubei Province Statistical Yearbook (HMBSNBS, 1995–2015), and the special statistical yearbooks of each county. The ecological services value is calculated by multiplying the cultivated land area and equivalent value of ecosystem services in China based on data from Xie *et al.* (2015). It is worth noting that in the process of conducting the calculations for this study, five years' worth of data are integrated to calculate a composite value of CECA using the DEA model. Correspondingly, we collect five years' worth data on influencing factors and simulate the impact utility thereof on CECA via the geographical detector model in order to explore the comprehensive development of CECA during the past 25 years.

4 Results

4.1 Spatial characteristics of coordinated development efficiency

Based on the DEA method, we calculate the overall efficiency, technical efficiency, and scale efficiency of the coordinated development of cultivated land spatial morphology and agricultural economy in western Hubei for all study years as a comprehensive value (Table 2). In terms of overall efficiency, the distribution is random, and the fluctuation range of the overall efficiency values for each county is small. Among them, the overall efficiency values of seven counties reach 1, and those for 13 counties do exceed 0.800. The overall efficiency values of Xianfeng, Yunxi, and Xuan'en counties are 0.771, 0.653, and 0.444, respectively, which shows that the overall efficiency of coordinated development in the study area is relatively low. The overall efficiency showed the distribution of high in the south and low in the north, in general. However, the discrepancy in the overall efficiency of coordinated development between cultivated land spatial morphology and agricultural economy is small, indicating strong convergence. Mitigating these discrepancies contributes to the distribution of cultivated land in each county and the adjustment of policy measures.

Table 2 Efficiency values for coordinated development

Counties	Overall efficiency	Technical efficiency	Scale efficiency	Scale gains
Yunxian	1.000	1.000	1.000	—
Zigui	1.000	1.000	1.000	—
Changyang	1.000	1.000	1.000	—
Enshi	1.000	1.000	1.000	—
Lichuan	1.000	1.000	1.000	—
Laifeng	1.000	1.000	1.000	—
Hefeng	1.000	1.000	1.000	—
Danjiangkou	0.999	1.000	0.999	Increased
Zhuxi	0.996	1.000	0.996	Increased
Zhushan	0.897	1.000	0.897	Increased
Fangxian	0.869	1.000	0.869	Increased
Jianshi	0.853	1.000	0.853	Increased
Badong	0.811	1.000	0.811	Increased
Xianfeng	0.771	1.000	0.771	Increased
Yunxi	0.652	0.999	0.653	Increased
Xuan'en	0.444	1.000	0.444	Increased

In terms of technical efficiency, except for Yunxi county, the value for each county is 1, indicating that the technical efficiency is in a good state of development despite being affected by factors such as poor management and technical issues related to CECA. However, as an integral part of comprehensive efficiency, the influence of technical efficiency on comprehensive efficiency is limited. Moreover, the scale efficiency shows high consistency with the comprehensive efficiency overall. Most of the southern counties have problems of insufficient scale efficiency, while only a few counties in the north. This indicates that the phenomenon of large scale but underutilized cultivated land exists in both the north and south, but is more prominent in the south. The spatial distribution of the scale efficiency also presented a pattern of being high in the south and low in the north. Scale efficiency is the main factor affecting comprehensive efficiency, while technology efficiency is a secondary factor. From Table 2, it can be seen that the scale efficiency values of Danjiangkou, Zhuxi, Zhushan, Fangxian, Jianshi, Badong, Xianfeng, Yunxi, and Xuan'en counties are less than 1. However, the values of comprehensive efficiency in the above areas show increasing trends to the contrary. As such, though the areas have relatively underdeveloped technology and imperfect management, the expansion and utilization of the factor's scale of cultivated land effectively enhance CECA.

4.2 Identification of problem areas

According to the above analysis, some counties lack efficiency and comprehensive coordinated development, indicating that cultivated land spatial morphology and agricultural economic development are facing a series of problems. Based on the input redundancy and insufficient output revealed by the DEA model, problem areas pertaining to coordinated development can be identified. From Table 3, it can be seen that the values of input redundancy and insufficient output in Yunxi and 11 other counties are 0, and coordinated development efficiency is correspondingly high. However, the CECA values for Jianshi, Badong, Xianfeng, Yunxi, and Xuan'en counties—which account for 31.25% of the total study area—are low due to insufficient development (Table 3). It is worth noting that the total agricultural output and added value of Xuan'en county reached at 1.181 and 1.123, respectively. The input redundancy of cultivated land spatial morphology and insufficient agricultural output in the same area indicates that the utilization efficiency of cultivated land is very low and the areas do not achieve the optimal input and output efficiency. The results show that some areas in western Hubei province still have unreasonable patterns of cultivated land utilization and low efficiency of agricultural output. There is thus a need to improve the cultivated land spatial morphology.

Table 3 Counties with problems of input redundancy and insufficient output in 16 counties in western Hubei province

Counties	Types	Location	Input redundancy						Insufficient output		
			X1	X2	X3	X4	X5	X6	Y1	Y2	Y3
Yunxi	Input redundancy and insufficient output are balanced	North of the study area	0.001	0.001	0.001	0.001	0.007	0.003	0.323	0.457	0.034
Jianshi	Insufficient output dominated	South of the study area	0.000	0.000	0.000	0.000	0.004	0.002	0.000	0.349	0.018
Badong			0.000	0.000	0.000	0.000	0.004	0.001	0.017	0.000	0.013
Xianfeng			0.000	0.000	0.000	0.000	0.001	0.000	0.215	0.614	0.007
Xuan'en			0.000	0.000	0.000	0.000	0.006	0.001	1.181	1.123	0.042

We analyze the results from two different regions divided by the Shennongjia Nature Reserve in the study area. Table 3 shows that the input redundancy and insufficient output lead to significant discrepancies between the two regions. Specifically, there is insufficient output in Jianshi, Badong, Xianfeng, and Xuan’en counties, which are located in the southern part of the study area, and input redundancy in the per capita cultivated land area and the per household cultivated land. This shows that there is a certain excess of input on the scale of cultivated land, and that cultivated land is not fully utilized. These four districts account for nearly half of the total number of underdeveloped districts in the southern area. Correspondingly, Yunxi county in the north is in a balanced state between input redundancy and insufficient output, though the presence of input redundancy and insufficient output indicates that Yunxi county has low utilization efficiency in both the cultivated land management pattern and the landscape pattern. In general, although the overall efficiency of CECA in the south is better than that in the north, there are several counties in the south that have insufficient output mainly restricts CECA, indicating that their cultivated land utilization efficiency is low, certain cultivated land inputs have not received corresponding output, and the benefits of cultivated land utilization have not been optimized. And individual county in the north both meet the situation of input redundancy and insufficient output, means it has relatively underdeveloped management and landscape patterns.

4.3 Influencing factors analysis of coordinated development efficiency

4.3.1 Spatial matching characteristics

Due to the discrepancies for CECA in the northern versus southern parts of the study area, the utilities of matching and influencing factors are measured quantitatively using the geographical detector method. The spatial matching characteristics are studied using space analysis technology via ArcGIS software. We divide the grade of influencing factors and CECA into three categories—high, medium, and low—by applying the natural breakpoint method based on their values. As such, we are able to study the basic spatial matching characteristics between CECA and influencing factors.

Figure 4 shows that the spatial matching characteristics between CECA and influencing factors in western Hubei province have obvious spatial heterogeneity, being high in the south and low in the north. As such, we can infer that the development in the southern region is superior to that of the northern region. The high coordinated development efficiency and a high factor level are mainly distributed throughout Lichuan, Enshi, Zigui, and other areas in the south. Changyang and Hefeng are mainly characterized by high coordinated development efficiency and a low element level. The north areas, such as Fangxian and Danjiangkou city, have a medium level of coordinated development efficiency and a low element level. Yunxi county has low coordinated development efficiency and middle and low element levels. The matching characteristics analysis describes general features of coordinated development efficiency and influencing factors, while the impact utility analysis further explains the quantitative effective of influencing factors on coordinated development efficiency. Additional calculations on the latter factors are provided in the next section.

4.3.2 Specific impact utility of factors

Figure 5 shows the detection values of the impact of various factors on the coordinated development efficiency. Population density, forest cover, and value of ecological services are the most effective factors in the southern region, which indicates that social and ecological elements play major roles in the southern region. In recent years, due to the migration of

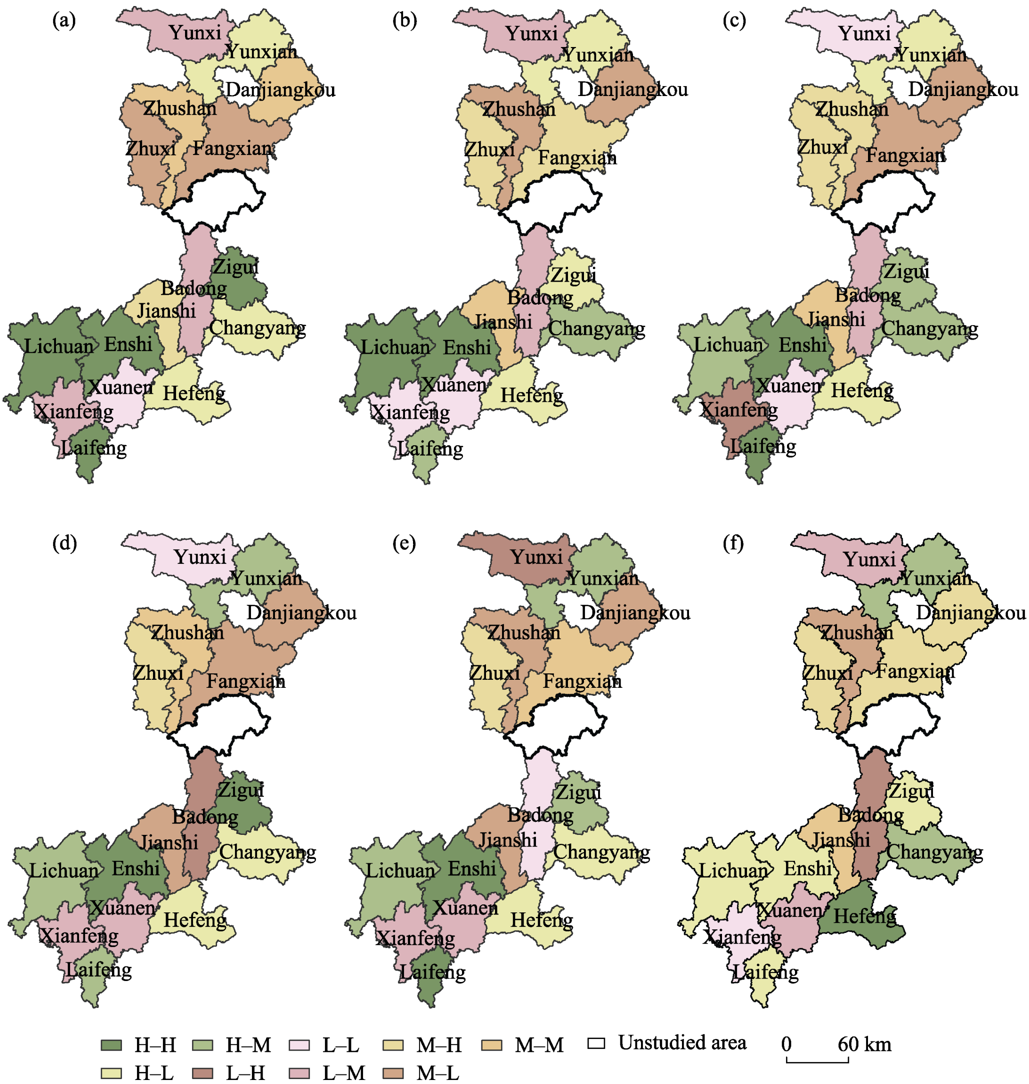

Figure 4 Spatial matching characteristics of coordinated development efficiency and influencing factors in western Hubei province

(Notes: H-H: High coordinated development efficiency and high element level; H-M: High coordinated development efficiency and medium element level; H-L: High coordinated development efficiency and low element level; M-L: Medium coordinated development efficiency and high element level; M-M: Medium coordinated development efficiency and medium element level; M-L: Medium coordinated development efficiency and low element level; L-H: Low coordinated development efficiency and high element level; L-M: Low coordinated development efficiency and medium element level; L-L: Low coordinated development efficiency and low element level; a. Population density; b. Urbanization rate; c. GDP; d. Primary industry added value as a proportion of GDP; e. Percentage of forest cover; f. Ecological services value)

urban and rural populations, a large rural labor force flows out of this underdeveloped area, which leads to a large amount of abandoned cultivated land—that is, the scale of cultivated land does not match that of the cultivated labor force, leading to a relative surplus of cultivated land. At the same time, the study area is located in a mountainous area with a large area of slope cultivated land, when these cultivated lands abandoned, may lead to shortage of the roots of trees or crops to fix the soil, and caused the soil erosion, debris flow when encountering rain and snow (Xiang *et al*., 2021), and affects the coordinated development of CECA. The coordinated development efficiency of the northern region is mainly affected by economic factors. In particular, the GDP, the proportion of primary industry in the GDP, and the urbanization rate have stronger impact utilities. The results show that though the overall development in the region is relatively good, there are many input redundancy problems in individual counties. As the embodiment of overall economic strength, an increase in GDP leads to social improvement and economic benefits in various directions, and significantly promotes the effective utilization of cultivated land and agricultural economy development, which affects the coordinated development efficiency.

Table 4 shows the results of the interaction detector results for each influencing element on the spatial distribution of coordinated development efficiency, which is used to characterize the common influence utility by combining two factors at a time. It can be seen that interaction impact of any two variables on the spatial distribution is greater than that of a single variable. Especially in the southern area, the utility of the combined effect of urbanization rate and population density is the highest; in the north, GDP has the optimal dual influence

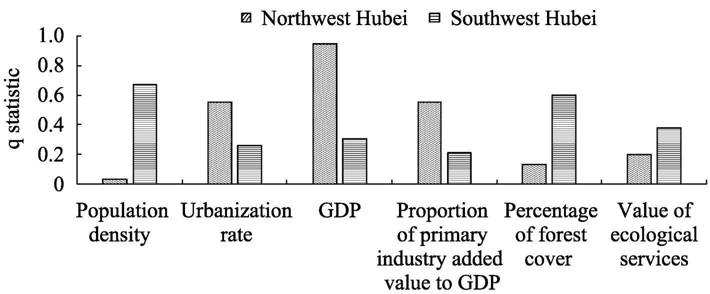

Figure 5 Detector results of influencing factors

Table 4 Interaction detector results based on different combinations of influencing factors

Region	Factor	Population density	Urbanization rate	GDP	Proportion of primary industry added value to GDP	Percentage of forest cover	Value of ecological services
Northwest Hubei	Population density	0.032					
	Urbanization rate	0.927	0.551				
	GDP	1.000	1.000	0.946			
	Proportion of primary industry added value to GDP	0.927	0.626	1.000	0.551		
	Percentage of forest cover	0.451	1.000	1.000	1.000	0.130	
	Value of ecological services	0.378	0.927	1.000	0.927	0.451	0.196
Southwest Hubei	Population density	0.668					
	Urbanization rate	1.000	0.258				
	GDP	0.967	0.945	0.300			
	Proportion of primary industry added value to GDP	0.836	0.920	0.526	0.211		
	Percentage of forest cover	0.836	0.945	0.935	0.836	0.599	
	Value of ecological services	0.803	0.865	0.990	0.521	0.713	0.373

utility with many other variables, and the dual effect of urbanization rate and forest coverage also achieve optimal impact utility. However, we find that the population density in the southern region is a matter of concern, while GDP is strengthening in the northern region.

4.4 Reason analysis of coordinated development efficiency

For a long time, the industrial structure in the north versus the south of the study area has different characteristics. These variations represent a historical reason contributing to the different spatial characteristics of CECA. For example, Shiyan county, in the north, plays an important part in the development of the automobile industry, while Enshi city, in the south, takes ecotourism and agricultural products as the pillar industries of local economic development. This indicates that more attention should be paid to promoting the effective use of arable land and economic development in the southern area.

The level of social development represents a basic reason to explain the spatial characteristics of CECA. With the rapid development of industrialization and in science and technology in China, the societal development of the northern and southern regions of the study area shows different trends. In particular, an project of "eco-cultural tourism circle" is established in the study region. As a gathering place for ethnic minorities, Enshi city's social development has national characteristics. Correspondingly, Shiyan city in the northern area is known for its relatively developed industrial economy.

Natural resources and ecological environmental conditions are also fundamental reasons for the spatial characteristics of CECA. Although the northern and southern regions are both located in highly mountainous areas, the specific ecological environment and resource endowment exhibits obvious differences. For example, Shiyan city is the host of the middle line project of China's South-to-North Water Transfer Project, with abundant water resources and a superior ecological environment. The rich reserves of selenium, which is highly important to crop cultivation, play an important role in promoting local agricultural development in the Enshi area. In addition, Enshi's unique canyon landforms bring natural advantages to local tourism development.

Finally, a series of policy measures comprise reasons for the spatial characteristics of CECA. Shiyan city is an important part of the development strategy pertaining to the Hanjiang ecological economic belt in Hubei province, which plays an important role in promoting the development of the local ecological economy. Enshi city is the core area for tourism development in western Hubei province and is key to its agriculture development. The Hubei provincial government, along with local governments, issue a series of policies and measures to promote tourism and agricultural development, which facilitate the effective use of cultivated land and led to differentiated development of the agricultural economy.

5 Discussion

5.1 Comparison with previous studies

With regard to the development of cultivated land and the agricultural economy in underdeveloped areas, previous studies have mainly focused on cultivated land quantity changes and spatial locations, including farmland abandonment (Shi *et al.*, 2018), marginalization (Wang *et al.*, 2019), cropland expansion (Minta *et al.*, 2018), land fragmentation (Tran and Vu, 2019), unique landscapes and resource endowments in underdeveloped regions, cultivated land's allowable range and spatial allocation (Cheng *et al*., 2019), and land use spatial transitions (Liao *et al*., 2019). Considering that the quantity changes and spatial distribution of these arable lands are significantly affected by human activities in addition to the influence of natural landscapes, we extend previous research on changes in cultivated land quantity to consider natural and human factors from two perspectives: landscape pattern and management pattern which is consistent with previous study (Song, 2017).

In this study, it is found that population density, ecological environment, GDP, etc. are the main factors affecting CECA in this typical mountainous area of the study area. Previous studies have found that in addition to the natural environmental factors, the utilization of cultivated land in mountainous areas is mainly affected by demographic, economic and social factors brought about by human activities (Xiang *et al*., 2019b). This is basically consistent with the results of this paper. It shows that economic, social and natural ecology are still the main factors affecting the utilization of cultivated land and agricultural development in mountainous areas.

5.2 Policy implications

With regard to the southern region of the study area, there are four counties with insufficient overall efficiency and scale efficiency, and per capita cultivated land and per household land plots indicators representing the scale of cultivated land, have redundant inputs. And labor loss, population density decreases, and ecological environmental damage caused by the rapid development of urbanization and industrialization are the primary factors affecting CECA. As such, we propose three improvement measures to migrate these problems. First, implement village renovation and accelerate urbanization. The village renovation projects which being carried out by the Chinese government should be promoted vigorously, aim at renovating the appearance of villages, the agglomeration of residential areas and promoting various industries to the direction of urbanization, so as to create more jobs opportunities, reduce labor loss and increase regional population density. Second, cultivated land should be strongly protected from ecological destruction (Liang *et al*., 2022). The study area is mountainous, and the cultivated land is vulnerable to damage such as soil erosion. For slope cultivated land, especially abandoned cultivated land, the governance of the ecological environment should be strengthened, aim to reduce the occurrence of disasters such as soil erosion, improve ecological maintenance, and enhance the value of ecological services (Liang and Li, 2019; Li *et al*., 2020b). Third, cultivated land quality should be enhanced through the application of science and technology. More efforts should be made to develop modern agriculture, to popularize mechanized applications, and to improve the productivity related to cultivated land.

With regard to the northern region of the study area, overall inefficiency and scale inefficiency are relatively positive, only Yunxi county exist this situation. GDP, proportion of primary industry in GDP, and urbanization rate are the main factors affecting CECA in the region as a whole. In terms of the development process, we provide the following recommendations. First, attention should be paid to economic development. For example, to further the existing economic development model, Shiyan city in the north should not rely only on secondary industry (Li *et al*., 2016), but also formulate relevant financial policies to develop tourism and service industries vigorously in order to improve its economic structure and promote all-round economic growth. Second, local governments should seize the development opportunities arising from ongoing urbanization. As such, the level of urbanization and people's living standards should be significantly improved (Chen *et al*., 2019). Furthermore, science and technology should be advanced along with the urbanization to improve the rational distribution and optimal utilization of cultivated land spatial morphology. Third, measures such as land renovation, land reclamation, and hill land transformation should be taken to integrate disparate farmland and improve the spatial concentration of cultivated land. This would not only promote agricultural machinery cultivation and large-scale management (Asiama *et al*., 2017; Ying *et al*., 2020), but also enhance the landscape pattern and management pattern of cultivated land.

5.3 Limitations

This study focuses on the harmonious development of cultivated land spatial morphology and agricultural economy with respect to spatial morphological features such as landscape pattern and management pattern. However, we do not consider cultivated land morphology, for two primary reasons: one pertains to the complicated and systematic changes that have occurred in the cultivated land morphology in underdeveloped areas; the other related to the fact that cultivated land morphology includes both functional and invisible morphology. Future research should fully consider the impact of these forms on agricultural economic development and the effective use of cultivated land.

Differences in development strategies and policies are also important factors impacting the CECA. For example, Danjiangkou city has relatively strong environmental protection policies because it is an important source of the South-to-North Water Transfer Project. Changyang county has led the tourism industry in recent years due to its special ecological resources of Qingjiang river. Zigui, which is the immigration county of Three Gorges reservoir area in China, has attained increasing socioeconomic development policy support. However, due to difficulties pertaining to quantitatively measuring these policies, quantitative analysis of policy impacts on CECA has not carried out in this study. Conducting such quantitative research using mathematical methods on the basis of qualitative analysis of policy impacts should be the focus of future research.

6 Conclusions

In this study, we explore CECA in 16 counties of western Hubei province, China. First, the DEA model is applied to measure CECA, analyze its spatial differentiation characteristics, and identify areas that face coordinated development problems from 1995 to 2015. Second, the impact utility of key influencing factors, which includes aspects of society, economy, and ecology, are calculated using the geographical detector model. Finally, relevant policy recommendations are put forward to promote CECA in the western part of Hubei province.

The following conclusions can be drawn based on our results: (1) CECA in the western part of Hubei province have significant heterogeneity in terms of overall efficiency, which show a spatial pattern that is high in the south and low in the north. The scale efficiency is also consistent with overall efficiency, while the technical efficiency is in a good state of development with little difference between the south and the north. (2) Scale efficiency is the main factor affecting CECA in the study area, and technical efficiency is the secondary factor. Considering that the area's technical efficiency has not yet matured, the control of farmland scale efficiency should be taken as the leading factor in the overall area of western Hubei province. (3) There are several counties in the south that have insufficient output mainly restricts CECA, indicating that their cultivated land utilization efficiency is low. And individual county in the north meet the situation of both input redundancy and insufficient output, means it has relatively underdeveloped management and landscape patterns. (4) The effect of social and ecological factors' impact utility on CECA is significant in the southern region, population density is the most prominent factor, while GDP has the most significant impact in the northern region. Each region should take specific measures to promote the effective use of cultivated land and sustainable development of the social economy.

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