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# Optimizing cropland resource allocation based on the priority of cropland non-agriculture - A case study of Wuhan metropolitan area

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ABSTRACT: Based on the regional natural resources endowment and the social and economic conditions and under the premise of guaranteeing the regional grain security, this paper adopts the partition asynchronous cellular automata model to construct the cultivated land layout optimization method system based on the regional differences of non-agricultural priority of cultivated land, and study the optimal allocation of cultivated land resources in Wuhan metropolitan area. The results show that this model could optimize the allocation of cultivated land resources, coordinate the relationship between cultivated land protection and demand growth of construction land, thus realizing the sustainable development of regional social economy.

*Keywords*: non-agricultural priority of cultivated land; partition asynchronous cellular automata; cultivated land optimization; Wuhan metropolitan area

## 1 INTRODUCTION

With the development of social economy, the process of industrialization and urbanization in China has been accelerated, and the situation of cultivated land protection has become more and more serious. Although the Chinese government has actively introduced a number of strict policies on the protection of cultivated land, they have limited effects on alleviating the contradiction between urbanization and cultivated land protection, and there are still high-quality arable land occupied by urban construction. Therefore, how to solve the contradiction between economic development and land resource protection in the process of rapid economic development and resolutely implement the basic national policy of protecting cultivated land has become the key to realize the coordinated development of the four modernizations and the inevitable requirement of building a "two-type society". Due to the differences in economic base, resource endowment and development goals, the spatial distribution of cultivated land in China and its transfer to the construction land have significant regional differences, especially in the high demand of cultivated land conversion in developed areas and the low efficiency of cultivated land conversion in less developed areas [1]. At the same time, regional differences in economic development have resulted in significant regional differences between non-agricultural pressure and non-agricultural efficiency of the cultivated farmland [2].

There are significant regional differences in natural resource endowment and social economic development level among cities in Wuhan metropolitan area. In this paper, Wuhan metropolitan area is taken as a case study area. Based on the estimation of non-agricultural priority, the partition asynchronous cellular automata model is used to carry out the optimal allocation of arable land resources and to provide decision support for optimal and sustainable land use.

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## 2 STUDY AREA AND DATA SOURCES

### 2.1 *Overview of the study area*

Wuhan metropolitan area is the first batch of resource-saving and environment-friendly society construction comprehensive reform pilot area. In this area, Wuhan is regarded as the center city, Huangshi as deputy center city. There are 9 cities, Wuhan, Huangshi, Ezhou, Xiaogan, Huanggang, Xianning, Xiantao, Tianmen, Qianjiang, a total of 34 counties, with a total area of 5.78 × 104km$^2$, accounting for 31.10% of the land area of Hubei Province. Wuhan metropolitan area is not only the core area of economic development in Hubei, but also the important strategic fulcrum of the central rise. With the economic development, population increase and urbanization in Wuhan, the cultivated land area has been decreasing year by year, the construction land area has been increasing continuously, and the regional land use changes have been significant.

### 2.2 *Data source*

The data of this paper mainly include the socio-economic data, the land use and basic geographic data of Wuhan metropolitan area. The social and economic data of Wuhan metropolitan area is mainly used to measure the priority of non-agricultural land. The data is from Hubei Statistical Yearbook in 2012 and China Urban Statistical Yearbook in 2012, which is authoritative and accurate. The land use data and basic geographic data are mainly used to calculate the key parameters of the Partition Asynchronous Cellular Automata model. The data of land use in 2000 were obtained from the Land Use Database of Resources and Environment Data Center of Chinese Academy of Sciences, and the data of land use in 2008 were obtained by manual interpretation by CBERS. The basic geographic data in this paper includes the DEM data of Wuhan metropolitan area, the distance raster data of each road, and the distance raster data of the water system. Among them, DEM data is provided by the State Bureau of Surveying with the scale of 1: 250,000. The distance raster data of each road is generated from the Wuhan metropolitan area traffic data by the Distance function of ArcGIS10. The distance raster data of the water system is generated from the Wuhan metropolitan area water system data by the distance function of ArcGIS 10.

## 3 RESEARCH METHODS

### 3.1 *Research method system*

The basic ideas of optimizing the allocation of arable land resources based on the non-agricultural priority of arable land include: the basic objective is to realize the release of non-agricultural pressure on the basis of guaranteeing the regional food security; the basic basis is the regional difference of non-agricultural priority of the cultivated land. In this paper, the partition asynchronous cellular automata model is used to optimize the allocation of cultivated land resources in the Wuhan metropolitan area. According to the demand of cultivated land in the whole region, the global termination condition of the model is determined. The asynchronous evolution rate is determined according to the non-agricultural priority, the partition evolution rules are determined according to the regional land use change law, and the optimal allocation of cultivated land resources in Wuhan urban area is realized by means of partition and asynchronous cellular automata model. The partition asynchronous cellular automata module is the core of the regional optimization model of cultivated land layout. It runs the cellular automaton model in accordance with the partition transformation rules and the asynchronous evolution rate. It automatically checks whether the iteration result satisfies the termination condition after the iteration. If the termination condition is not satisfied, the iteration will be continued; otherwise, the cellular automata model will stop running and the optimization result of cultivated land layout will be obtained.

### 3.2 *Non-agricultural priority calculation method of cultivated land*

20 indicators from the four aspects of social development, intensive benefit, economic level and industrial disparity were selected to construct the evaluation index system of farmland non-agricultural priority, and the coefficient of variation TOPSIS was used to calculate the non - agricultural priority of cultivated land in Wuhan metropolitan area. The coefficient of variation (TOPSIS) is the combination of coefficient of variation [3] and TOPSIS [4]. The main steps are shown as follows:

#### 3.2.1 *Data normalization processing*

The normalized calculation formula of the evaluation index data is [5]: Positive indicator: $y_{ij}=(x_{ij}-m_j)/(M_j-m_j)$; negative indicator: $y_{ij}=(M_j-x_{ij})/(M_j-m_j)$.

$x_{ij}$ is the actual value of the indicator, $y_{ij}$ is the standardized value of the indicator. $i$ is the evaluation object, $j$ is the evaluation indicator. $M_j$ and $m_j$ are the maximum and minimum indicators of the $j$ indicator. When the indicators are standardized, the decision matrix B is constructed.

#### 3.2.2 *Use the coefficient of variation method to determine the index weight W*

(1) Calculate the average $\overline{x}_j$ and standard deviation $S_j$ of the indicators:

$$\bar{x}_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij}\ ,\ j = 1,2,3,\cdots,m\ ;$$

$$S_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{ij} - \bar{x}_j\right)^2}\ ,\ j = 1,2,3,\cdots,m$$

(2) Calculate the coefficient of variation $V_j$ of each indicator, and normalize the coefficient of variation to get the weight $W_j$ of each indicator:

$$V_j = \frac{S_j}{\bar{x}_j}\ ,\ j = 1,2,3,\cdots,m\ ;$$

$$W_j = V_j \Big/ \sum_{j=1}^{m} V_j\ ,\ j = 1,2,3,\cdots,m\ .$$

3.2.3 *Establish a weighted normalization matrix V*

$$W = \left\{ W_1\ , W_2\ , \cdots , W_j\ \right\};$$

$$V = B \times W\ , V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1j} \\ v_{21} & v_{22} & \cdots & v_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ v_{i1} & v_{i2} & \cdots & v_{ij} \end{bmatrix}$$

3.2.4 *Determine the positive and negative ideal solutions*

The positive ideal solution:

$$V^+ = \left\{ \max V_{ij} \mid i = 1, 2, \cdots, n \right\} = \left\{ V_1^+ , V_2^+ , \cdots , V_n^+ \right\}$$

The negative ideal solution:

$$V^- = \left\{ \min V_{ij} \mid i = 1, 2, \cdots, n \right\} = \left\{ V_1^- , V_2^- , \cdots , V_n^- \right\}$$

3.2.5 *Calculate the distance*

Respectively calculate the distance $D^+$ between the evaluation vectors of different evaluation objects and the positive ideal solution and the distance $D^-$ between the evaluation vectors of different evaluation objects and the negative ideal solution.

$$D^+ = \sqrt{\sum_{j=1}^{m}\left(V_{ij} - V_j^+\right)^2} \quad \left( i = 1, 2, \cdots, n \right);$$

$$D^- = \sqrt{\sum_{j=1}^{m}\left(V_{ij} - V_j^-\right)^2} \quad \left( i = 1, 2, \cdots, n \right)$$

3.2.6 *Calculate the farmland non-agricultural priority $C_i$ of the evaluation objects*

$$C_i = D_i^- \big/ \left( D_i^+ + D_i^- \right) \quad \left( i = 1, 2, \cdots, n \right)$$

In this formula, $Ci \in [0, 1]$, so the greater $Ci$ means higher priority of the evaluation object, and vice versa. In this paper, the non-agricultural priority of cultivated land can be divided into four grades, which are used to characterize the degree of priority, while $Ci \in (0, 0.3]$, $Ci \in (0.3, 0.5]$, $Ci \in (0.5, 0.8]$, $Ci \in (0.8, 1]$, the non-agricultural priority of cultivated land is respectively in the low, moderate, good and excellent priorities. When $Ci = 1$, the non-agricultural priority of cultivated land reaches the optimal state; when $Ci = 0$, the non-agricultural priority of cultivated land is in the worst state.

### 3.3 *Optimal allocation model of cultivated land resources*

The objective of optimization of regional arable land is to realize the rational allocation of cultivated land among different regions, which can meet the needs of construction land and complete the overall goal of cultivated land protection simultaneously. According to the demand of construction land in different regions and the non-agricultural priority of cultivated land, this paper constructs and utilizes the optimal layout model of the cultivated land to achieve the optimization of the cultivated land combining with the law of regional land use change.

The most important parameter is the asynchrony evolution rate when the partition asynchronous cellular automata model is used to optimize the allocation of cultivated land in Wuhan metropolitan area. From the perspective of the whole research area, the area with higher non-agricultural priority should be given the first priority, so a higher development speed should be assigned. In this paper, the asynchronous evaluation rate of the partition asynchronous cellular automata model of the regional optimal layout of the cultivated land is determined by the non-agricultural priority of cultivated land. The asynchronous evolution rate in the model can be expressed as follows [6]:

$$v_{ij} = \frac{priority_{iy}}{priority_{\max} - priority_{\min}} \times \left( v_{\max} - v_{\min} \right) + v_{\min}$$

In the formula, $v_{ij}$ is the evolution rate of the cell $(i,j)$ determined by the non-agricultural priority of the cultivated land; $priority_{ij}$ is the non-agricultural priority of the cultivated land of the cell $(i,j)$; $priority_{\max}$ is the maximum value of the non-agricultural priority of the cultivated land in the whole area; $v_{\max}$ and $v_{\min}$ are the maximum and minimum values of the cell evolution of the whole region.

## 4 RESULTS OF THE STUDY

### 4.1 *Non-agriculture priority of the cultivated land*

Calculate the non-agricultural priority of the cultivated land in the Wuhan metropolitan area according to the calculating method of the non-agricultural priority of cultivated land. The regional differences were significant in 2011 and the polarization is obvious, including low priority, medium priority and good priority. The comprehensive priority indicator reaches its maximum value in Wuhan, up to 0.7446, belonging to a good stage. With the advantages of location and resources, Wuhan has gathered a large amount of capital, manpower and technology in the process of “two-type society” construction, which provides strong support for economic development. The construction of “two-type society” has embarked on a sound development road. The land use obtains the best overall benefit and the non-agriculture demand of farmland is exuberant. Ezhou has the secondary priority indicator, 0.3707, and the gap with Wuhan is 0.3739, followed by Huangshi and Xianning with the priority indicators of 0.3454 and 0.3126. These three cities are in the middle stage. Ezhou, as an important industrial base in Hubei Province, regards metallurgy as the pillar industry and the second industry contributes 60% of GDP, while the land intensive use is relatively high, and the non-agriculture of the cultivated land is powerful. Therefore, it is superior to other cities in this circle in the social development, intensive benefit and industrial differences. As a sub-center of Wuhan metropolitan area, Huangshi has strong economic strength. However, the intensive benefits and economic level have seriously hindered the advancement of non-agricultural land. Xiaogan, Huanggang, Tianmen, Xiantao, Qianjiang are low-level stage and their indicators are between 0.2998-0.2401 with slight difference. These five cities have little difference in social development, intensive benefit, economic level and industrial difference. Under the combined effect of various factors, the comprehensive non-agricultural priority level of the cultivated tends to be the same, which is in the backward position in the urban circle. Within the urban circle, Wuhan is the priority area, followed by Ezhou and Huangshi. Xianning, Xiaogan, Huanggang, Tianmen, Xiantao, and Qianjiang are in the disadvantaged status. It further shows that the rapid economic growth and social progress have become the direct driving force of farmland conversion.

### 4.2 *Key parameters of partition asynchronous cellular automata model*

The global termination condition of the optimal allocation of arable land resources is that the cultivated land area is not less than that required by the regional grain security. The cultivated land area is calculated by the following formula [7]:

$$Q = \frac{pop \times cpp \times rss}{ypu}$$

In the formula, $Q$ is the regional cultivated land area; *pop* is the regional total population which is obtained by the gray model forecasting; *cpp* is the per capita food consumption, which is taken as 450kg combined with the actual situation of Wuhan metropolitan area; *rss* is the self-sufficiency rate of food which is taken as 90% in this paper; *ypu* is the regional grain yield which is obtained by the prediction of a linear regression model.

According to the formula, the total cultivated land area in Wuhan metropolitan area in 2020 is $254.80 \times 10^4 hm^2$, which is taken as the global termination condition of the partition asynchronous cellular automata model. When the total cultivated land area is less than or equal to $254.80 \times 10^4 hm^2$, the model stops running and the optimal allocation result of cultivated land is obtained.

The termination condition of each city district is that the urban construction land demand is satisfied. For each city, the satisfaction degree of construction land demand has a great impact on the partition conversion rules. When the construction land of a certain area is far from being satisfied, the partition cell has a relatively high conversion probability; when the construction land of a certain area is met, the development of this area should be restricted; therefore, a lower evolution probability should be given to this area. In this paper, we use the gray model to forecast the population, calculate the per capita construction land indicator combined with the social economic development level, and determine the construction land demand of Wuhan metropolitan area in 2020 (Table 1). On this basis, the partition termination condition of zoal cellular automata model can be determined. Wuhan has the greatest construction land demand, $375469hm^2$, followed by Huanggang and Xiaogan. The demand of these three cities is more than 100,000 hectares by 2020. Huangshi, Tianmen and Xiantao, Xianning, Ezhou and Qianjiang have low construction land demand, respectively $31128hm^2$ and $26550hm^2$. Based on the socio-economic development and resource endowments of each city, the evolution rules of the partition asynchronous cellular automata model is obtained by the C5.0 decision tree algorithm [8].

### 4.3 *Optimization of cultivated land resources in Wuhan metropolitan area*

According to the global termination condition determined by the food security, the asynchronous evolution rate determined by the farmland non-agricultural priority, the partition termination condition determined by the regional construction land use demand and the regional land use change history rule, the par-

Table 1. Interregional farmland layout optimization result for Wuhan city circle in 2020

| | Wuhan | Huangshi | Ezhou | Xiaogan | Huanggang | Xianning | Xiantao | Qianjiang | Tianmen |
|---|---|---|---|---|---|---|---|---|---|
| Cultivated land ($hm^2$) | 303916 | 146558 | 671505 | 565959 | 717106 | 281442 | 150108 | 148258 | 192950 |
| Construction land ($hm^2$) | 267613 | 50958 | 31128 | 67277 | 94863 | 33341 | 37733 | 26550 | 47169 |

tition evolution rules determined by the regional socio-economic factors and natural factors, this paper adopts the Partition Cellular Automata Model to study the optimal allocation of cultivated land resources in Wuhan metropolitan area and obtain the optimal allocation results in 2020 (Table 1).

## 5 CONCLUSION AND DISCUSSION

Based on regional natural resources and social and economic conditions, and under the premise of guaranteeing the regional food safety, this paper regards the Wuhan metropolitan area as the research area and adopts the partition asynchronous cellular automata model to construct a cultivated land layout optimization method system of regional difference of non-agricultural areas of the cultivated land, and study the optimal allocation of cultivated land resources. The results show that: (1) The Partition Cellular Automata Model with regional differences in the non-agricultural priority of the cultivated land as a parameter is absolutely necessary and feasible for the optimal allocation of regional cultivated land resources. (2) The optimal allocation of the cultivated land based on the Partition Cellular Automata model could coordinate the relationship between cultivated land protection and the demand growth, thus realizing the sustainable development of regional social economy.

The method of optimizing the cultivated land layout based on the regional differences of non - agricultural priority of cultivated land could provide a reference for rational allocation of land resources and improvement of land use efficiency. However, in this paper, the measurement of the non-agricultural priority is a little simpler, and lacks vertical knowledge on the change rule. This may impact the identification of the general characteristics of farmland non-agricultural priority. In the future, it is necessary to conduct the dynamic estimation of non-agricultural priority of the cultivated land and apply it to the optimization of farmland layout model.

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