Permanent Basic Cultivated Land Delineation Based on Population Projection and Food Demand--Taking Wuhan City as an Example

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ABSTRACT: The reasonable delineation of permanent basic cultivated land is of great meaning to guarantee China's food security and promote the long-term social stability and sustainable economic development of China. This paper addresses the current problem of unreasonable delineation of permanent basic cultivated land that may result from not considering future population demand factors. Taking Wuhan city as an example, this paper derives permanent basic cultivated land's area demand based on population projections, combined with per capita food demand, and further integrates comprehensive quality evaluation of arable land to delineate the quantity and location of basic cultivated land in Wuhan city in 2035. The study obtained that: (1) the population of Wuhan GM (1,1) predicts that the population of Wuhan in 2035 is 16,041,900 and the basic cultivated land's demanded area is 239,559.55hm²; (2) the medial score of comprehensive quality of cultivated land in Wuhan is 66.23, with good comprehensive quality, and the mass of arable land varies widely among the lower districts. (3) The cultivated land with the best overall quality will be allocated as basic cultivated land, and the final area of basic cultivated land in Wuhan in 2035 will be 239,797.26hm², which can meet the population demand of Wuhan in 2035, mainly distributed in Jiangxia District, Xinzhou District and Huangpi District.

1. INTRODUCTION

Cultivated land is one of the bases of agricultural production and is a valuable land resource. Basic cultivated land is the essence which is the best mass, high-yielding and stable part [4][8]. Since 1994, when China promulgated the Regulations on the Protection of Basic Cultivated land, China has implemented special protection for basic cultivated land. Since then, China has amended the regulations several times to improve the basic cultivated land protection system. In 2019, China's territorial spatial planning designated the basic cultivated land protection red line, ecological red line and town development boundary as the "lines of control", and pointed out that the three control lines should be defined and strictly adhered to. As an effective measure to strictly adhere to the cultivated land red line of 1.8 billion mu (Chinese unit of land measurement that is commonly 0.067 hectares), scientifically delineating basic cultivated land and implementing strict protection are of great significance to maintain regional and national food security.

At different stages of social development, population size as well as the changes in industrial structure put forward different demands for agricultural products supply. For the past few years, with the acceleration of urbanization, the urban population has been growing, which has promoted the development of social economy. At the same time, it has also led to increased demand for food and land use, thus producting pressure on the protection of cultivated land resources. A scientific and rational prediction of future population size can provide an important reference for the formulation of policies and plans. Therefore, the delineation of basic cultivated land guided by the population size demand for basic cultivated land can ensure that food production can meet the demand of population, so as to ensure the stable development of society.

This paper takes Wuhan City as the study target, and intends to calculate the requirement for basic cultivated land in 2035 and determine basic cultivated land allocation's area in Wuhan City on the basis of predicting the population size using the grey GM (1,1) model. Meanwhile, constructing an index system evaluates the comprehensive quality of cultivated land in Wuhan City. Finally, the cultivated land with the best comprehensive quality will be allocated as basic cultivated land in 2035 in Wuhan City. The research is expected to provide some reference for the delineation of basic cultivated land under the background of the rapid increase of urban population.

2. RESEARCH AREA AND DATA SOURCE

2.1. Overview of the study area

Wuhan is the provincial capital of Hubei, located in the central section of the Yangtze River Basin, the eastern Jianghan Plain and the eastern Hubei Province, and situated between 113°41′-115°05′ E longitude and 29°58′-31°22′ N latitude. Wuhan's topography is mainly plain, with numerous lakes and water systems and rich cultivated land resources. As the only sub-provincial city in China's six central provinces and a hub city for inland transportation, Wuhan has a large population base and a fast growth rate, making it a megalopolis in China and a key city for future population inflow. However, with the population's quick growth and the large expansion of urban land, the area of cultivated land in Wuhan has declined sharply and protecting cultivated land is facing challenges in many aspects. Therefore, this paper selects Wuhan City as the research area, which can offer a reference to the basic cultivated land delineation under the background of rapid population growth in megacities.

2.2. Data source

The data of the paper mainly consist of land use form data from the Resource and Environment Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/). Soil spatial distribution data is from the soil datasets created by the Harmonized World Soil Database (HWSD). DEM data is from the National Earth System Data Center (http://auth.geodata.cn). The population and socio-economic data of Wuhan are obtained from the Wuhan Statistical Yearbook published by the Wuhan Bureau of Statistics (http://tjj.wuhan.gov.cn).

3. METHODS

3.1. Population size projection methods

The commonly used population size projection methods mainly include the comprehensive population growth rate method [6], logistic population block model [2], BP neural network model [11-12], grey GM (1,1) model [5][13][14] and so on. The change of population size is influenced by various factors such as social, economic and policy. The grey GM (1,1) model can predict the uncertain systems including more interference factors with better prediction results [7][15]. Therefore, the grey GM (1,1) model is chosen to forecast the future population data of Wuhan City in this paper. The construction of the grey GM (1,1) population size projection model consists of the following main steps:

Step 1: Generate the original series $X^{(0)}$ using the population size data of the study area over the years, and then obtain the time series $X^{(1)}$ after accumulating $X^{(0)}$ once:

$$X^{(0)}=\left(X^{(0)}(1),X^{(0)}(2),\cdots,X^{(0)}(n)\right) \quad (1)$$

$$X^{(1)}=\left(X^{(1)}(1),X^{(1)}(2),\cdots,X^{(1)}(n)\right) \quad (2)$$

Step 2: Construct the whitening differential equation based on the time series $X^{(1)}$:

$$\frac{dX^{(1)}}{dt}+aX^{(1)}=b \quad (3)$$

Where: a is the development grey number, and when $|a| \leq 0.3$, it indicates that the model can be used for medium- and long-term prediction; b is the control grey number.

Step 3: Calculate the parameters a and b using the least square method, and set:

$$A=(a,b)^T=\left(B^TB\right)^{-1}B^TY \quad (4)$$

Where:

$$B=\begin{bmatrix} -\frac{1}{2}\left(X^{(1)}(1)\right)+\left(X^{(1)}(2)\right) & 1 \\ -\frac{1}{2}\left(X^{(1)}(2)\right)+\left(X^{(1)}(3)\right) & 1 \\ \cdots & \cdots \\ -\frac{1}{2}\left(X^{(1)}(n-1)\right)+\left(X^{(1)}(n)\right) & 1 \end{bmatrix} \quad (5)$$

$$Y=\left(X^{(0)}(2),X^{(0)}(3),\cdots,\ X^{(0)}(n)\right)^T \quad (6)$$

Step 4: Solve the whitening differential equation (3) to obtain the function of time response series.

$$\hat{X}^{(1)}(k+1)=\left(X^{(0)}(1)-\frac{b}{a}\right)e^{-ak}+\frac{b}{a} \quad (7)$$

Cumulative subtraction once reduces the population size pormula predicted by the grey GM (1,1) model:

$$\hat{X}^{(0)}(k+1)=\hat{X}^{(1)}(k+1)-\hat{X}^{(1)}(k) \quad (8)$$

Step 5: Accuracy inspection:

The precision of the grey GM (1,1) model was tested using the relative variance ratio C to test for small probability error P, and its precision test standard is shown in Table 1.

Table 1. Accuracy level of grey GM (1,1) model

Model accuracy level	Variance ratio C	Small probability error P
Grade I	$C\leq0.35$	$P\geq0.95$
Grade II	$0.35<C\leq0.50$	$0.80\leq P<0.95$
Grade III	$0.50<C\leq0.65$	$0.70\leq P<0.8$
Grade IV	$C>0.65$	$P<0.70$

3.2. Basic cultivated land delineation methods

3.2.1. Calculation method of basic cultivated land demand

The calculation of the basic cultivated land demand in this paper mainly considers some factors such as the food demand in the study area and the food yield per unit of basic cultivated land. The calculation formula is shown below.

$$A=\frac{P_i \times N_i \times \varepsilon}{Y} \quad (9)$$

Where: A is the basic cultivated land's demand area, hm²; P_i is the population size in year i; N_i is the per capita food demand in year i, kg/person; ε is the food degree of self-sufficiency of the study area; Y is the yield of basic cultivated land per unit area, kg/hm².

According to Yu [16] and the per capita food demand in 2035 predicted by the reconstruction of Chinese residents′ dietary structure, Ni is taken as 448kg/ person. Based on the food self-sufficiency rate of Wuhan in recent years, ε is taken as 0.5. Referring to the National High-Standard Cultivated land Construction Plan (2021-2035), Wuhan City is situated in the middle and lower reaches of the Yangtze River, and the average food production per mu is required to be 1000 kg. Therefore, Y is taken as 1000 kg/mu.

3.2.2. Comprehensive quality evaluation of cultivated land

The mass of cultivated land is the main basis for classifying basic cultivated land. This paper constructs an index system from three aspects: natural quality of cultivated land, transportation location and spatial morphology to evaluate the comprehensive mass of cultivated land in Wuhan and delineate the cultivated land with the best comprehensive quality to basic cultivated land.

(1) Natural quality of cultivated land

The natural quality of cultivated land is an significant factor affecting food production. According to the Agricultural Land Quality Grading Regulations (GB/T 28407-2012), soil texture, soil thickness, and pH indexes were chosen and graded. Meanwhile, soil fertility indexes of organic material, nitrogen, phosphorus and potassium contents in soil were selected and graded by natural breakpoint method. In addition, slope was selected as an evaluation index for cultivated land terrain and graded [3][9].

(2) Transportation location of cultivated land

On the basis of the Agricultural Land Classification Regulations TD-T1005-2003, the distance from main roads and central towns are selected as the evaluation indexes of the location conditions of cultivated land, while the distance from rural settlements is used as the evaluation index of farming distance. Based on the difference of radiation influence degree of the above indexes, different grading standards are established respectively.

(3) Spatial morphology of cultivated land

The spatial morphology of cultivated land includes both spatial contiguity and regularity of cultivated land. The spatial contiguity of cultivated land can reflect the centralized scale of cultivated land. Referring to related literature [1][10] to establish a 10m buffer zone, integrate adjacent cultivated land and grade the cultivated land's area using the natural breakpoint method.

The regularity of cultivated land is an significant index to reflect whether the shape of cultivated land plots are regular. The more regular the geometric shape of cultivated land plots are, the better it is for promoting the mechanization of agricultural production and improving the efficiency of food production. The fractal dimension (FRAC) index in scenery ecology is used as the evaluation index of the regularity of cultivated land plots. The design equation is as follows:

$$FRAC=\frac{2\ln(p/4)}{\ln a} \quad (10)$$

Where: $FRAC$ is the degree of regularity of cultivated land plot; p is the block perimeter (m); a is the plot area (m²). The *FRAC index ranges from* 1.0-2.0, and the smaller the value, the more regular the cultivated land plots are.

According to the above factors, the comprehensive quality evaluation index system and grading standards of cultivated land in Wuhan were established as shown in Table 2. Using the analytic hierarchy process (AHP) assigned corresponding weights to each cultivated land comprehensive quality evaluation index, and the weights of each evaluation index were finally determined through consistency test.

Table 2. Comprehensive quality evaluation index system of cultivated land in Wuhan

Criterion layer	Indicator layer	Index evaluation standard					weight
Natural quality	Soil texture	Loam	Clay	Sandy soil	Gravelly soil	-	0.108
	Score	100	80	70	50	-	
	Soil thickness/cm	≥150	100~150	60-100	30-60	<30	0.164
	Score	100	90	70	50	20	
	Organic matter content	Grade I	Grade II	Grade III	Grade IV	Grade V	0.045
	Score	90	80	70	60	50	
	pH	6-7.9	5.5-6.0, 7.9-8.5	5.0-5.5, 8.5-9.0	4.5-5.0	<4.5, 9.0-9.5	0.032
	Score	100	90	80	50	30	
	Nitrogen content	Grade I	Grade II	Grade III	Grade IV	Grade V	0.024
	Score	100	80	60	40	20	
	Phosphorus content	Grade I	Grade II	Grade III	Grade IV	Grade V	0.017
	Score	100	80	60	40	20	
	Potassium content	Grade I	Grade II	Grade III	Grade IV	Grade V	0.021
	Score	100	80	60	40	20	
	Slope/°	<2	2~6	6~15	15~25	>25	0.079
	Score	100	80	60	40	20	

Location conditions	Distance from town/m	<500	500-800	800-1000	1000-1500	>1500	0.097
	Score	100	80	60	40	20	
	Distance from rural settlements/m	<200	200-400	400-600	600-800	>800	0.061
	Score	100	80	60	40	20	
	Distance from main road/m	<1000	1000-2000	2000-3000	3000-4000	>4000	0.152
	Score	100	80	60	40	20	
Spatial morphology	Field regularity	<1.02	1.02-1.06	1.06-1.10	1.10-1.50	>1.50	0.086
	Score	100	80	60	40	20	
	Cultivated land continuity	Grade I	Grade II	Grade III	Grade IV	Grade V	0.114
	Score	100	80	60	40	20	

4. RESULTS

4.1. Wuhan City 2035 Population Forecast

According to the grey GM(1,1) model, the original series of population size in Wuhan City during 2000-2020 are established [804.81, 813.80, 823.80, 836.80, 845.43, 858.00, 875.00, 891.00, 897.00, 910.00, 978.54, 1002.00, 1012.00, 1022.00, 1033.80, 1060.77, 1076.62, 1089.29, 1108.10, 1121.20, 1244.70], using MATLAB programming analysis, the model predicted values are compared with the actual values as shown in Figure 1. Using the least squares solution to obtain a = -0.0206 , b = 771.04 and $|a|<0.3$, which indicates that the model is able to use for medium- and long-term forecast. The GM(1,1) model time response equation for population size projection in Wuhan City is as follows:

$$\hat{X}^{(1)}\left(k+1\right)=38233.836e^{0.0206}-37429.126$$

From Figure 1, it can be seen that the population of Wuhan continues to increase during 2000 to 2020, and the grey GM(1,1) simulation curve is consistent with the actual population change. Except for 2020, the imparity between the model prediction and the actual value is small and the accuracy is high. The accuracy test of the model shows that the relative residual error Q=0.0154, the variance ratio C=0.1782, the diminutive probability error P=1, and the accuracy grade of the model is grade I, indicating that the model has high accuracy. According to the model prediction, the population size of Wuhan City is 16.0419 million in 2035.

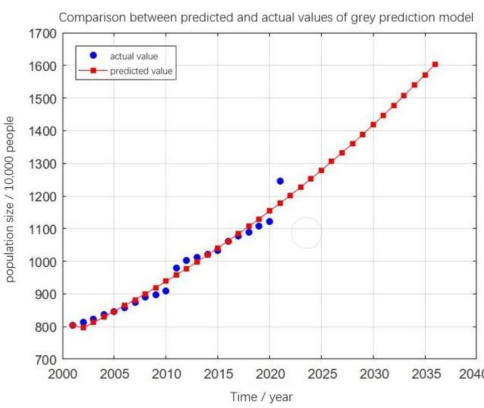

Figure 1: Comparison Wuhan population size of the predicted consequences of the grey GM (1,1) model and the actual values

4.2. Comprehensive quality evaluation of cultivated land in Wuhan

Through constructing the Wuhan comprehensive quality evaluation index system, the comprehensive mass score interval of Wuhan cultivated land is obtained as [26.25, 92.49], with an average score of 66.23, indicating that the comprehensive quality of Wuhan cultivated land is good. The specific distribution of the comprehensive mass of cultivated land is as Figure 2.

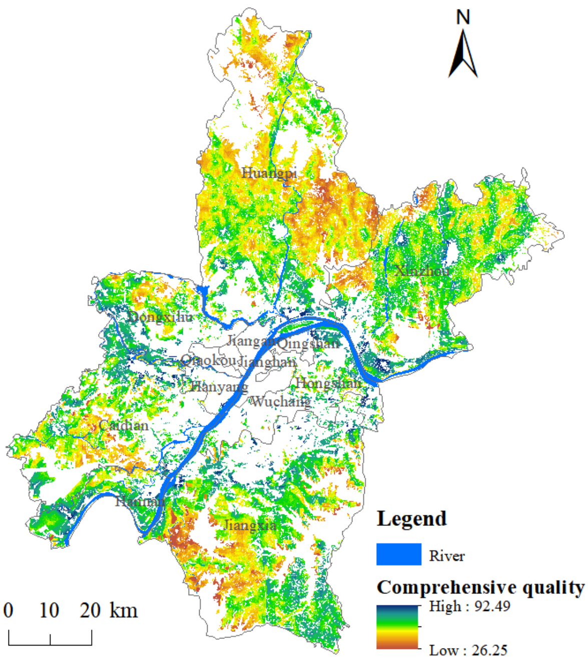

Figure 2: Comprehensive quality of cultivated land in Wuhan

In figure 2, the cultivated land with high synthetical mass in Wuhan is scattered along the Yangtze River, Han River and around the main urban area. The main reason is that the cultivated land in the above areas is close to the city and main roads, and the traffic location condition is good. In addition, the above areas have low altitude, fertile soil and high synthetical mass of cultivated land. The large areas of high quality cultivated land are distributed in the east of Jiangxia District, the south of Hannan District, the middle of Huangpi District and Xinzhou District, mainly because of the high natural mass of the cultivated land in these areas. The comprehensive mass of cultivated land in the east and north of Huangpi District and the west of

Jiangxia District is low. Because the above areas are far away from the urban areas and major roads in Wuhan City, and have poor traffic location condition and low comprehensive quality of cultivated land.

4.3. Delineation of basic cultivated land in Wuhan

Based on the population projection data and formula (9), the basic cultivated land demand area of Wuhan City in 2035 is calculated as 239559.55hm². According to the consequences of synthetical mass evaluation of cultivated land in Wuhan City, the threshold value of comprehensive quality score for cultivated land to be classified as basic cultivated land is determined to be 65.73, All cultivated land with comprehensive quality score above 65.73 is sorted out as basic cultivated land, while excluding fragmental map spots, influenced by the area of cultivated land map spots, the final basic cultivated land's area in Wuhan in 2035 is designated as 239,797.26hm² in Figure 3. The area of basic cultivated land in each administrative district is shown in Table 3.

Table 3 Area and proportion of basic cultivated land in each district of Wuhan

Administrative District	Area（hm²）	Proportion	Administrative District	Area（hm²）	Proportion
Jiangan District	157.67	0.066%	Dongxihu District	14915.71	6.220%
Jianghan District	0.00	0.000%	Hannan District	12587.93	5.249%
Qiaokou District	9.65	0.004%	Caidian District	30981.53	12.920%
Hanyang District	1018.33	0.425%	Jiangxia District	62100.44	25.897%
Wuchang District	25.78	0.011%	Huangpi District	47125.78	19.652%
Qingshan District	50.66	0.021%	Xinzhou District	60563.60	25.256%
Hongshan District	10260.18	4.279%			

As can be seen from Table 3, the largest area of basic cultivated land in Wuhan City in 2035 is Jiangxia District, followed by Xinzhou District, which is 62100.44 hm^2 and 60563.60 hm^2 respectively, and the overall area of basic cultivated land in the two districts holds 50% of the basic cultivated land's area in Wuhan. Huangpi District ranks third in basic cultivated land area with 4725.78hm^2, chiefly distributed in the southwest of Huangpi District. The basic cultivated land's area in Caidian District is 30,981.53hm^2 with a relatively scattered distribution throughout the area. The basic cultivated land area in Dongxihu District, Hannan District and Hongshan District is moderate. The remaining six administrative regions have smaller areas of basic cultivated land, mainly because they are all major urban areas with relatively small regional area and large proportion of urban construction land area, so the basic cultivated land area is small.

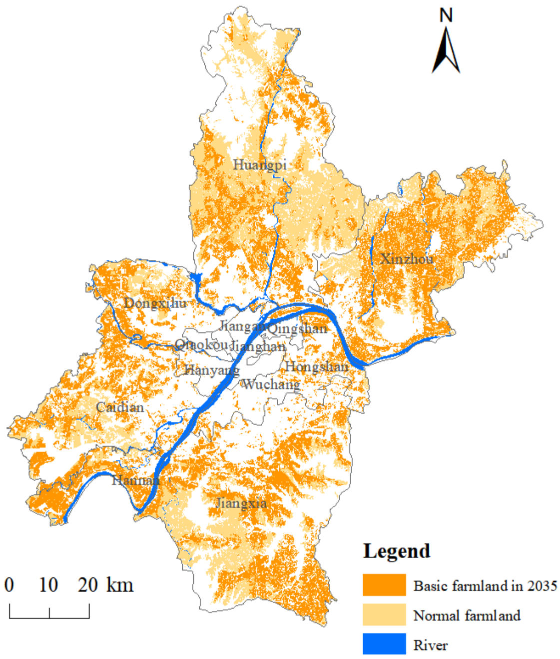

Figure 3: Basic cultivated land in Wuhan City in 2035

5. CONCLUSION AND DISCUSSION

From the perspective of meeting the food demand of urban population, this paper takes Wuhan City as the research object, determines the basic cultivated land's area demand based on the prediction of future population size projection and combining the per capita food demand, and further integrates theconsequences of synthetical mass evaluation of cultivated land to delineate the basic cultivated land. This idea can meet the food demand of cities with rapid population growth, guarantee regional food security, and can offer a certain reference for the delineation of basic cultivated land in megacities. The main conclusions are as follows:

(1) During 2000-2020, the population size of Wuhan City continues to increase. Using the grey GM (1,1) model to predict the population of Wuhan City and comparing it with the actual data, we concluded that the model has high accuracy and is able to use for medium- and long-term forecast. The forecast equation for the population size of Wuhan City is obtained, which finally predicts the population of Wuhan City to be 16.0419 million in 2035.

(2) Starting from the natural mass of cultivated land, transportation location and spatial morphology, the index system is constructed to evaluate the quality of cultivated land in Wuhan, which can mirror the comprehensive mass of cultivated land in a more comprehensive manner. The evaluation consequences indicate that the overall quality of cultivated land in Wuhan is good, but there is great difference in the mass of cultivated land among different regions.

(3) The demand of basic cultivated land in Wuhan in 2035 can be obtained based on the population projection. According to the consequenses of the comprehensive mass evaluation of cultivated land, the cultivated land with the best comprehensive quality is delineated to basic cultivated land, and the basic cultivated land's area in Wuhan in 2035 is finally delineated as 239,797.26 hm^2, which can meet the demand for food by the predicted population size in Wuhan in 2035.The basic cultivated land is mainly distributed in Xinzhou District, Jiangxia District and Huangpi District, with a small area in the main urban area.

The grey GM(1,1) model is used to forecast the population size of Wuhan city. The model precision is high, but there are still some errors. In addition, the change of population size is influenced by many uncertain factors. Therefore, future research may consider the effects of multiple drivers, so as to more accurately predict the change of population size. In the course of delineating basic cultivated land, this paper only starts from the point of view of the cropand quality and fails to consider the ecological value of cultivated land. How to consider the ecological use of cultivated land and determine the precedence of cultivated land protection and ecological protection in the region is a possible direction for the next research.

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