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Optimal Simulation of the Land-Use Structure Based on the Local Ecological Environment: the Case of Huanghua City in Hebei Province, China

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ABSTRACT: The overuse of land has resulted in a sharp decline in ecological functions, affecting the environment as it relates to the existence and sustainable development of the whole biosphere. This work aims to evaluate the ecological and economic efficiencies of the land-use structure. A simulation model, CLUE-S (Conversion of Land-Use and its Effects at Small Region Extent), and an integrated model based on the MOP (Multi-Objective Program) and CLUE-S were applied to assess the suitability of unutilized lands in Huanghua City, China. This was to simulate the optimal structure of land-use in the research zone to avoid loss of the land ecological service functions and the decreasing values with rapid changes in the land-use structure. By the year 2020, the simulation of the single model shows that the economic efficiency is expected to increase, but the ecological efficiency will decline. Depending on the evaluation of the suitability of unutilized land and the optimization results of the integrated MOP- and CLUE-S-based models, the ecological and economic efficiencies are expected to increase by 1.17 and 2.23 %, respectively, compared with those in 2012. In addition, the sum of the two land functions will increase for the integrated MOP- and CLUE-S-based model by the year 2020 compared with the single model. Consequently, the ecological efficiency will significantly increase. However, the optimization solution based on the integrated MOP and CLUE-S model is better than the one based on the CLUE-S model.

Keywords: CLUE-S model, MOP model, evaluation of suitability, ecological efficiency.

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INTRODUCTION

As the society and economy have developed rapidly in China, different demands for land have emerged during various stages of development. In addition, methods of land-use and strengths of impacts have changed. The population density in urban land is increasing; in turn, the demand for land is constantly increasing, resulting in the continuous occupation of cultivated land (Verburg et al., 2009; Leal et al., 2016). When the global economy developed to the point of industrial civilization, the overuse of land resulted in a sharp decline of ecological functions, which affected the environment as far as the existence and sustainable development of the whole biosphere (Li et al., 2016; Sica et al., 2016). Ecological service values have been considered important quantitative indices for evaluating land-use/cover changes (LUCC) (Verhagen et al., 2016); they have attracted wide attention and have been an important topic for global sustainable development.

The simulation of land-use changes and their optimization are important aspects of land science. Such simulations also scientifically guarantee the achievement of the sustainable development of land resources. Under certain constraints, this strategy is an important method for attaining the scientifically supported land use ratios and spatially optimized layout for various land resources. Moreover, experts and scholars have completed several optimal designs for land utilization, made multiple achievements, and conducted many studies about models for optimal configurations of land utilization (Hou et al., 2016; Lu et al., 2016; Sohl et al., 2016). The applications of the Markov model, neural network model, and system dynamics model have also significantly promoted the development of related land utilization research. In recent years, some Chinese scholars have combined ecological theory, mathematical models, and GIS technology to undertake spatial configuration research on land utilization (He et al., 2015; Liu et al., 2015). In China, the application of the CLUE-S (the Conversion of Land-Use and its Effects at Small Region Extent) and cellular automaton (CA) models are popular.

Many investigations (Yu and Ke, 2010; Feng et al., 2013; Zhang et al., 2014, 2016) have shown that the CLUE-S model, alone or integrated with other models, can achieve good simulation results for land-use changes for the small regional scale. The model is suitable for the simulation of the spatial-temporal dynamic changes of land-use on the county scale. Feng et al. (2013) improved the CLUE-S model and selected regions to test the simulation effects. Many large-scale studies exist, whereas few works have focused on counties and townships (Yu and Ke, 2010). Most studies have focused only on the optimization of a certain aspect of the quantitative structure or spatial layout. In addition, few works exist on the optimal configuration of land-use combined with other models and the CLUE-S model. Previous research has not considered ecology during optimization or the increase of multiple variables based on economic and ecological efficiencies. Moreover, few studies have been conducted on the optimization of the land-use structure while combining the MOP with the CLUE-S model based on land suitability evaluations (Zhang et al., 2014, 2016).

Huanghua City was selected based on the interpretation remote-sensing data from 2006 to 2012 land-use survey, as well as social and economic statistics. The driving forces for land-use change were evaluated. Moreover, an elevation model of the economic and ecological efficiencies in Huanghua City was generated. The CLUE-S model and the integrated MOP and CLUE-S model were applied to obtain the optimal configuration for the land-use structure based on the evaluation of the suitability of unutilized land and other constraints. The purpose was to analyze changes in land economic efficiency and land ecological benefits during different periods, and then to compare the effects of two kinds of calculation models on land-use change simulation. This research also proposed a new method to simulate the land-use structure based on the evaluation of the unutilized land suitability. According to the traditional land-use change optimized with the single CLUE-S model, the areas of cultivated land, garden land, and grasslands have increased somewhat, and other land types have been reduced. According to the simulation, the economic benefit of land will increase by 2.77 %; however, the ecological benefit will decrease by 1.67 %, which indicates that the local economic development damages the local ecology at the same time. Based on the two objectives, including the suitability evaluation of unutilized land and the increase of the economic and ecological benefits, the optimization results from the multiple model shown that the economic and ecological benefits of land will improve from 2012–2020. Therefore, the integrated simulation possesses and extends the advantages of the CLUE-S model, and can promote the important objective of rationally utilizing the unutilized land during the land-use simulation. Repetitions have shown that the MOP and CLUE-S-based integrated model had better simulations of land-use change, if the human factors, such as land management, were not taken into consideration. This paper discusses the maintenance of the ecological balance based on the land demands and under the condition of improving the economic efficiency, thus increasing the efficiency of land-use. Therefore, scientific bases can be provided for ecological safety and the sustainable utilization of finite land resources.

MATERIALS AND METHODS

Overview of the study area

This research uses Huanghua City as an example, which is located in the central region of the Northeast Asia economic circle, southern Hebei Province, China, and between 117.08°-117.82° E and 38.15°-38.65° N. Its total area is approximately 2,391.4 km^2.

Huanghua City is located in the Bohai Sea Ring Region in the east of Hebei Province, but the region belongs to an inland arid area, and it is dominated by dry farming. The agricultural management is relatively complex, and the local ecology has been destroyed by the rapid development of the regional economy in recent years. Huanghua City is characterized by high elevation in the southwest and low elevation in the northeast and coastal areas. Huanghua City has several soil types that are heterogeneously distributed, which are divided into three moisture types (moist, saline, and boggy soil) and seven sub-classes. In addition, Huanghua City is deficient in fresh water resources and has low groundwater resources. According to the statistical yearbook of Huanghua City, its total population has been increasing since the reform and opening-up in 1978. In 2012, the population was 454,000. Huanghua City plays an important role in the synergetic development of the Beijing-Tianjin-Hebei Region, but the changes of land-use in Huanghua City are complex. Furthermore, a long-standing vulnerable local ecology, rapid urbanization, and industrialization have resulted in serious challenges for ecological safety in this region or even in the larger-scale area. With the current policy of the promotion of rapid industrialization, developing optimized land-use plans based on the evaluation of the suitability of unutilized land is necessary.

Data collection

Data mainly include Landsat TM/ETM remote-sensing images from 2006, 2012, and 2016 in Huanghua City along with vector data and statistical and anecdotal information. The remote-sensing images were mostly collected from June to August and they were good quality, with 5 % below-average cloud cover, and a spatial resolution of 30 × 30 m. In addition, the vector data mainly included DEM data downloaded from the international scientific data platform, administrative boundary data, and linear river and road data. The statistical data were related to the total population of townships and the per capita GDP. Data were sourced from the statistical yearbook of Huanghua City, the rural statistical yearbook of Hebei Province, and the latest land-use planning for Huanghua City, which came from the second China National Land Survey launched on

July 1, 2007 and completed in 2012. The main tasks of the survey included conducting a rural land survey to identify each land type, location, scope, area distribution, and ownership. Another task was an urban land survey to identify each land boundary, scope, quantity, and usage, as well as a basic farmland investigation to put the basic farmland protection land onto a land-use map, register, and record it. A land-use database was established with a cadastral information system to facilitate Internet survey information sharing.

Data analysis

Research methods

CLUE-S simulation model

The CLUE-S model, which was developed using a visual model for spatial suitability, as well as spatial and dynamic simulations of land-use, was developed by Verburg et al. (2002) from Wageningen University in the Netherlands at the end of the twentieth century. This model consists of two core modules (Gao and Yi, 2012): the non-spatial and spatial modules.

The CLUE-S model considers both natural and socio-economic driving factors in the land-use system, reflecting the process and results of land-use change in space. Compared with other land-use models, it has greater reliability and stronger explanatory power. The model, with the grids as research units, uses land utilization types in the main land-use research units to express the land-use situation. The aim was to determine which type of farming is dominant using the probabilities calculated from each type of land-use in the research unit.

The CLUE-S model inputs include several factors. The first factor relates to areas with policy restrictions, which are allowed to change within the simulation period due to special policies or regional conditions, such as nature reserves and the basic farmland protection areas within the study area. In our study, land-use changes were simulated throughout the study area without setting up restricted areas. The second factor relates to conversion rules and conversion elasticity coefficients of land-use types. The third factor related to the land-use requirements belongs to the non-spatial analysis module in the CLUE-S model. The requirements of each land-use type during the simulation period are accounted for by referring to the annual land-use type demand data, including the land-use area in each year of the simulation from the beginning to the end of the year. The fourth factor relates to the relationship between regional location characteristics and driving factors, which means the relationship between the spatial distribution pattern of land-use and its driving factors. In the CLUE-S model, logistic regression analysis is used to calculate the quantitative relationship between the spatial pattern of land-use distribution and its driving factors.

The transformational rules among different land types were determined in accordance with the transformational rules and development targets for types of land utilization in Huanghua City regarding the trends of traditional land-use changes. In addition, the stability of the land-use type was related to the reversibility of its changes.

The spatial analysis function of the CLUE-S model applies the logistic regression method, a common strategy used to analyze land-use changes (Verburg et al., 1999). After converting the raster images, Pontius and Kangpin (2014) proposed the receiver operating characteristic (ROC) method to test the consistency of the regression results. The model test mainly consists of two tasks. The first is to test the ROC coefficient of the logistic regression analysis, which must be larger than 0.7 to satisfy the requirements for probability distribution; the second is to test the Kappa coefficient, particularly when kappa is larger than or equal to 0.75 (Liu et al., 2009). The prediction precision of the CLUE-S model is high according to ROC.

Building of the MOP model and solution of the parameters

When the spatial layout for land-use was implemented, three targets were considered, including the increase of economic efficiency. In addition, the MOP model is comprised of model variables, constraints, and target functions and can be used to obtain the quantitative structure for land-use optimization.

Based on the actual conditions of the research zone, cultivated areas, gardens, grasslands, urban, water regions, and unutilized land were selected as variables for analysis. Moreover, increases in the ecological efficiency and the economic efficiency of the land were selected as the model targets.

The standards for checking and calculating the ecological values relate to increasing the ecological efficiency and building the elevation model for the ecological service values. This research refers to China's evaluation system for ecological service values developed by Xie Gaodi. The ecological service value for Hebei Province was modified (modification coefficient 1.02), the list of the service values for the unit areas of the ecosystem in Huanghua City was obtained (Zheng et al., 2012), and the calculation models for ecological efficiency (Equations 1 and 2) were applied.

$$ESV_f = \sum_k A_k \times VC_{kf} \qquad \text{Eq. 1}$$

$$ESV = \sum_k \sum_f A_f \times VC_{kf} \qquad \text{Eq. 2}$$

In the formulas, ESV_f and ESV denote the f^{th} function and total service value, respectively. The A_k is the area of k^{th} land-use; and VC_{kf} is the service values of the k^{th} and f^{th} unit area services.

The increases in land economic functions were measured using the evaluation model for economic efficiency (Li et al., 2013), and the model is shown in equation 3:

$$B(X) = \sum_{I=1}^{6} (K_i \cdot W_i \cdot X_i) \qquad \text{Eq. 3}$$

in which: K_i is the coefficient of efficiency for land-use types and is a constant; W_i is the relative weight of land-use types including cultivated land, garden land, grassland, urban land, water land, and other lands; and X_i is the land area (ha).

In building the MOP model, the total land areas, cultivated land quantity, areas of grassland, and garden parcels in the research zone were selected as constraints to build the corresponding equation or functions and determine the constraint in target year. The original model of the MOP is equation 4:

$$\max(X) = [f_1(x), f_2(x), ..., f_p(x)]^T \qquad \text{Eq. 4}$$

in which: max (X) is denoted as the target function and $f_1(x)$ is the constraint.

Building the constraint conditions: total land area is the sum of the areas for various land-use types in Huanghua City (Equation 5):

$$X_1 + X_2 + X_3 + X_4 + X_5 + X_{6\text{-}1} + X_{6\text{-}2} + X_{6\text{-}3} = 239136.18 \text{ ha} \qquad \text{Eq. 5}$$

According to the constraint indices for land-use planning in Huanghua City, as of 2020, the area of cultivated land should not be smaller than that in 2012 and should rise to 76,875.73 ha to guarantee the safety of the regional population and food. Therefore, the constraints for the cultivated land quantity include equation 6:

$X_1 \geq 76,875.73$ ha Eq. 6

Grassland can guarantee ecological safety; thus, this area should not be smaller than that of 2012, as according to equation 7:

$X_2 \geq 114.91$ ha Eq. 7

To protect the tourist environment in offshore wetlands, the water regions in Huanghua City should not be smaller than 98 % of the 2012 regions, as according to equation:

$X_5 \geq 63,273.33$ ha Eq. 8

To guarantee the demands for social and economic development, the area of unutilized land will be smaller than that in 2012, as according to equation 9:

$X_{6\text{-}1} + X_{6\text{-}2} + X_{6\text{-}3} \leq 36,633.54$ ha Eq. 9

Garden parcels have good ecological efficiency and can result in large economic value; furthermore, people in Huanghua City usually plant jujube trees. Thus, this area should not be smaller than that in 2012, as according to equation 10:

$X_2 \geq 5364.85$ ha Eq. 10

Urban land can bring considerable economic efficiency, and it cannot be enlarged randomly; thus, the rate of increase for this area should not exceed 2 %, as according to equation 11:

$X_4 \leq 56,694.18$ ha Eq. 11

The model must satisfy the following criteria, as in equation 12:

$X_j \geq 0, j = 1, 2, \ldots, 6\text{–}3$ Eq. 12

In equations 7-13, X_j is denoted as follows: X_1 is the area of cultivated land; X_2 is the area of garden parcels; X_3 is the area of grassland; X_4 is the area of urban land; X_5 is the area of water; $X_{6\text{-}1}$ is the area of unutilized land suitable for cultivation; $X_{6\text{-}2}$ is the area of unutilized land suitable for construction; and $X_{6\text{-}3}$ is the area of unutilized land suitable for the ecosystem.

Multi-target evaluation of the suitability of unutilized land in Huanghua City (Luan et al., 2015)

Evaluation of the suitability of unutilized land in Huanghua City

When evaluating the suitability of unutilized land in Huanghua City, the Delphi method (Yu et al., 2006) was first applied to determine the evaluation indices, index weights, index quantifications, as well as to evaluate the suitability of unutilized land in the typical zone. The score zone was divided, and the suitability level was determined. Tables 1-3 show the selected indices and levels.

The comprehensive exponent method was applied to the evaluation model for the suitability of unutilized land. The calculation was as follows (Equation 13):

$$R_i = \sum_{j=1}^{n} F_{ij} \bullet W_j \qquad \text{Eq. 13}$$

in which: R_i is the comprehensive score of the i^{th} evaluation unit; W_j is the weight value of the j^{th} index; F_{ij} is the score of the i^{th} evaluation unit and j^{th} index; and n indicates the total number of evaluation indices.

Table 1. Evaluation index values for the ecosystem suitability of unutilized land

Evaluation factor	Grading standard			
	1	2	3	4
Texture of surface soil	gravelly soil	sandy soil	medium loam, clay	light loam
Configuration of soil	sandy soil/clay/sandy soil, loam/sandy soil/sandy soil, whole-body sandy soil	clay/sandy soil/clay	loam/clay/clay, loam/sandy soil/loam, sandy soil/clay/clay/	whole-body loam
Salt content of soil (g kg^{-1})	≥6	4-6	2-4	<2
Groundwater depth (m)	0-2	1.6-2.2	2.2-2.6	≥2.6
Vegetation coverage	<0.2	0.2-0.5	0.5-0.8	>0.8
Organic content (g kg^{-1})	<5	5-10	10-15	≥15

Table 2. Evaluation index values for cultivation suitability of unutilized land

Evaluation factor	Grading standard			
	1	2	3	4
Organic content (g kg^{-1})	<5	5-10	10-15	≥15
Groundwater depth (m)	0-2	1.6-2.2	2.2-2.6	≥2.6
Texture of surface soil	gravelly soil	sandy soil	medium loam, clay	light loam
Salt content of soil (g kg^{-1})	≥6	4-6	2-4	<2
Urban influence distance (m)	>3,000	2,000-3,000	1,000-2,000	<1000

Table 3. Evaluation index values for construction suitability of unutilized land

Evaluation factor	Grading standard			
	1	2	3	4
Geological disaster	highly vulnerable zone	moderately vulnerable zone	less vulnerable zone	invulnerable zone
Bearing capacity of foundation soil (kPa m^{-2})	100-200	200-300	300-400	400-500
Vegetation coverage	>0.8	0.5-0.8	0.2-0.5	<0.2
Groundwater depth (m)	0-2	1.6-2.2	2.2-2.6	≥2.6
Urban influence distance (m^{-1})	3000	2,000-3,000	1,000-2,000	<1000
Road influence distance (m)	>500	200-500	100-200	<100

Determination of the suitability of unutilized land in Huanghua City based on the trade-off model

This research properly configured the suitability of unutilized land in Huanghua City based on trade-off theory, which initially came from economics and mainly emphasizes the earnings from tax offsets when debt interests are balanced. In application to the land-use field, trade-off theory mainly focuses on establishing how to regulate the structure and efficiency of land utilization and optimize the spatial pattern. However, during detailed applications, scholars have applied various models, functions, or trade-off methods based on complicated contradictions of land utilization; they have also started from various aspects of the problem, analyzed and evaluated the problem, and finally determined the optimal solution. Hence, our research selected a genetic algorithm to obtain the optimal configuration for the suitability of unutilized land.

RESULTS

Single-model simulation based on the CLUE-S model

Based on the mathematical statistics and GIS spatial analysis method, our research analyzed the structure of land utilization, rules of change, and transformational rules for land types in Huanghua City from 2006-2016. Furthermore, we created an optimal model for land utilization in Huanghua City based on the data regarding land utilization in 2012, as interpreted by remote-sensing technology and after multiple iterations as well as simulated and measured data about land utilization in 2020. China formally completed its second national land-use survey in 2012, and the data were detailed and accurate. The simulation process and results of the CLUE-S model are shown below.

Analyses of the conditions of land utilization and the selection of driving force factors

This research analyzed the conditions of land utilization based on the current data of Huanghua City, the structure and changes of land utilization in Huanghua City from 2006-2016, a transformation matrix for types of land utilization (Table 4), and the dynamic degree of land utilization. Furthermore, ten driving factors were selected for the change of land utilization, including the GDPs of townships, distance to a level I road, distance to a level II road, distance to rivers, distance to townships, distance to rural residential areas, elevation, population density, gradient, and slope direction. The ArcGIS software was used to construct a raster diagram of the ten selected driving factors for the change of land utilization.

Transformational rules for types of land utilization and stability

Table 5 shows the matrix of transformational rules for land-use.

Table 4. Matrix of transition probabilities for land type utilizations in Huanghua City, China from 2006-2016

Type of lands	Cultivated land	Garden parcel	Grass land	Urban land	Land for water area	Other lands
Cultivated land	0.74	0.07	0.02	0.11	0.02	0.04
Garden parcel	0.44	0.27	0.06	0.13	0.01	0.08
Grassland	0.20	0.07	0.47	0.07	0.03	0.17
Urban land	0.27	0.04	0.01	0.66	0.01	0.02
Land for water area	0.27	0.04	0.01	0.13	0.52	0.03
Other lands	0.38	0.07	0.17	0.08	0.04	0.26

Table 5. Transformational rules among various types of land utilization for the single model

Transformational rules	Cultivated land	Garden parcel	Grass land	Urban land	Water area	Other lands
Cultivated land	1	1	1	1	1	1
Garden parcel	1	1	1	1	1	1
Grass land	1	1	1	1	1	1
Urban land	0	0	0	1	0	0
Water area	1	1	1	1	1	1
Unutilized land	1	1	1	1	1	1

Notes: the row indicates transforming out of a certain land-use type; the line indicates transformation into certain land-use type; “1” indicates transformation available between two types of land use; and “0” indicates transformation unavailable.

Logistic regression analysis and verification

The result indicates good simulation effects of the spatial distribution probability for six land-use types in Huanghua City. The ROC values for cultivated land, garden parcels, grassland, urban land, water regions, and unutilized land are 0.868, 0.841, 0.806, 0.913, 0.940, and 0.854, respectively. Therefore, the selected driving factors were thought to provide better explanatory capacity and to be able to satisfy the regression requirements for simulating the spatial layout of land-use in Huanghua City.

Spatial simulation of land utilization in 2020 based on the CLUE-S single model

According to the current trends of economic and social development in Huanghua City, the land-use types were transformed in accordance with the above rules. Based on the data about land utilization in 2012, related parameters such as the logistic regression results, demands of land utilization, and transformational rules were input into the model. The diagram of land-use simulation in 2020 was simulated to obtain the results of land utilization in 2020. According to the results, the areas of cultivated land, garden parcels, and urban land from 2012-2020 would increase from 76,875.73, 5,364.85, and 55,582.53 ha to 79,891.23, 7,935, and 57,011.75 ha, respectively. In addition, the urban land area would result in an increase in economic efficiency to 2.77 % from 2012-2020. However, the area of water regions would decline from 64,564.62 to 61,140.47 ha, resulting in a decrease of ecological efficiency.

Land utilization simulation based on the evaluation of the suitability of unutilized land and multiple models

Based on GIS spatial, mathematical, and statistical analysis methods and depending on the evaluation of the suitability of unutilized land in Huanghua City, the transformational rules of land-use types were reset, and a multi-target optimal model and other constraints were built. Furthermore, the optimal structure of land-use in Huanghua City in 2020 was simulated using the land-use data for 2012.

To ensure the promotion of both ecological and economic benefits after the simulation, it was necessary to revise the conversion rules and constraints repeatedly if a single simulation was not successful (Figure 1). The maximum level of land utilization could finally be accomplished based on improving overall benefits while reducing ecological services.

Building the MOP model

Expression of land economic efficiency: the key to determining economic efficiency includes the coefficient and multiplication of the corresponding weights (Chen et al., 2016). We first applied the regression analysis method to predict the per-unit yield of cultivated land. The relative weights were increased in accordance with the area of crops. The unit output values were summed and weighted with relative weights to obtain the coefficient of economic efficiency for cultivated land of CNY 17400/ha. Similarly, this method was applied to obtain efficiency coefficients for other land types, specifically CNY 20080/ha, CNY 610/ha, CNY 217395/ha, CNY 1667/ha, and 0 for garden parcels, grassland, urban land, water regions, and unutilized land, respectively. Therefore, the land's economic efficiency was expressed as in equation 14:

$$B(X) = 17400\ X_1 + 20080\ X_2 + 610\ X_3 + 217395\ X_4 + 1667\ X_5 + 0\ (X_{6\text{-}1} + X_{6\text{-}2} + X_{6\text{-}3}) \qquad \text{Eq. 14}$$

Expression of land ecological efficiency: the land's ecological efficiency was indicated by the ecological service value. According to the list of ecosystem service values in Huanghua City (Table 6), the expression for the ecological service value is stated in equation 15 below (unit of constant: CNY ha^{-1}):

$$C(X) = 6236.59\ X_1 + 13127.66\ X_2 + 19334\ X_3 + 378.82\ X_4 + 98088.71\ X_5\ (X_{6\text{-}1} + X_{6\text{-}2} + X_{6\text{-}3}) \qquad \text{Eq. 15}$$

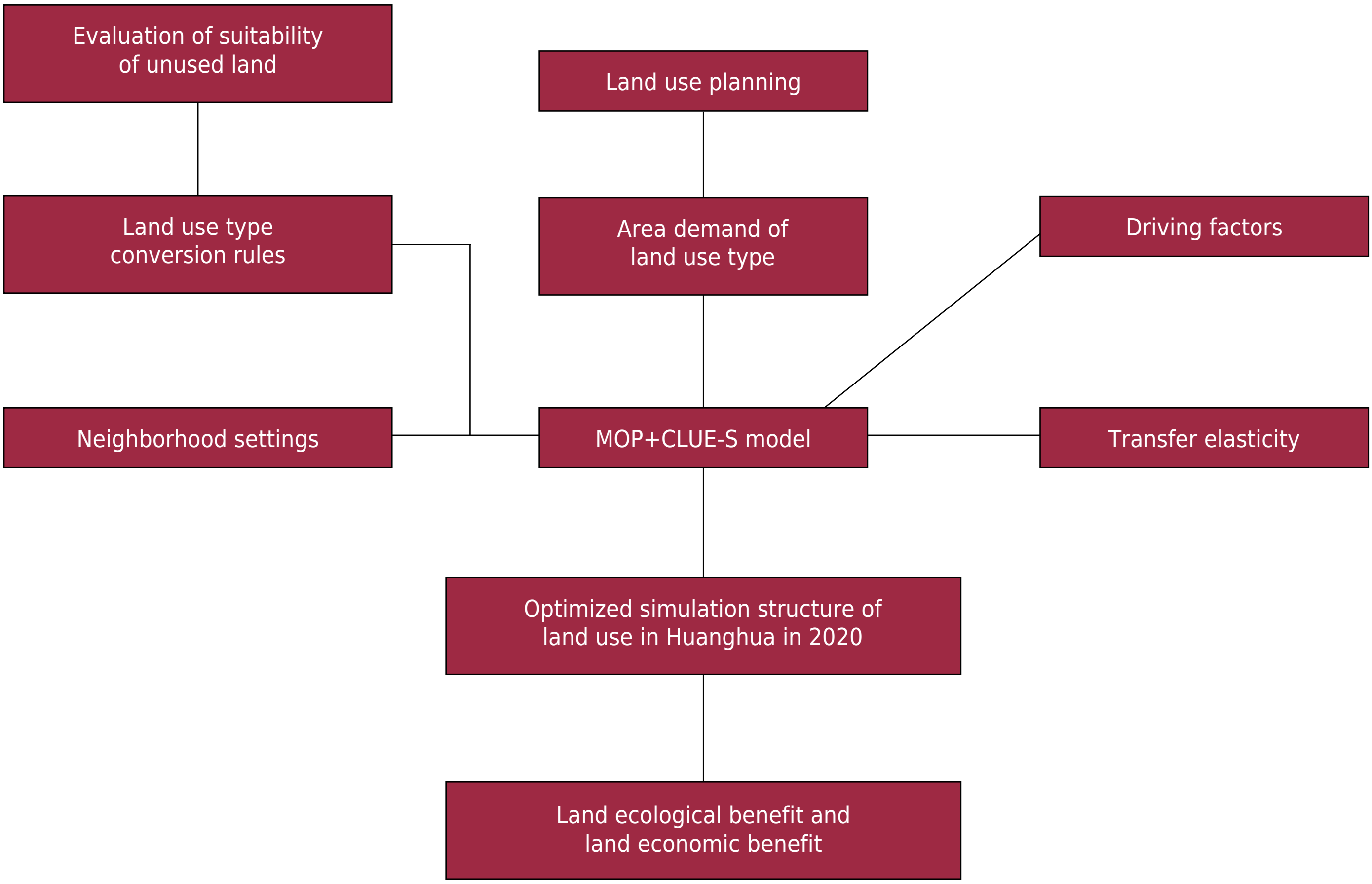

Figure 1. Route map of integrated MOP and CLUE-S-based model simulation in Huanghua City in 2020.

Table 6. List of ecosystem service values per unit area in Huanghua City, China (CNY ha·a)

Efficiencies		Cultivated land	Garden parcel	Grass land	Water area	Construction land	Unutilized land
Class I	**Class II**						
Supply service	Food production	902.6	180.54	88.5	180.54	8.98	8.98
	Raw materials	90.27	1,195.85	2,300.60	36.06	0	0
Regulation service	Gas regulation	451.25	1,940.5	3,097.00	812.28	0	0
	Climate regulation	803.25	1,624.61	2,389.10	7,924.33	0	0
	Water conservation	541.52	1,805.09	2,831.50	1,6191.68	27.03	27.03
	Waste disposal	1,480.22	1,182.38	1,159.20	16,408.33	8.97	8.98
Support service	Maintain soil	1,317.74	2,639.96	3,450.90	776.17	18.05	18.05
	Maintain biodiversity	640.76	1,963.04	2,884.60	2,251.91	306.82	306.82
Cultural service	Provide aesthetic landscape and cultural entertainment	8.98	595.68	1,132.60	4,463.06	8.97	8.98
	Total	6,236.59	13,127.66	1,9334.0	98,088.71	378.82	378.83

Based on measuring the economic and ecological efficiencies for each land-use type, the target expression for the MOP is given below in equation 16:

$$Z = \max[B(X)\lambda_1+C(X)\lambda_2] = \max [(17400\ X_1 + 20080\ X_2 + 1310\ X_3 + 217395\ X_4 + 1667\ X_5 + 0\ X_{6\text{-}1} + 0\ X_{6\text{-}2} + 0\ X_{6\text{-}3})\ \lambda_1 + (17400\ X_1 + 26000\ X_2 + 15300\ X_3 + 5900\ X_4 + 44300\ X_5 + 9600\ X_{6\text{-}1} + 9600\ X_{6\text{-}2} + 9600\ X_{6\text{-}3})\ \lambda_2] \quad \text{Eq. 16}$$

In the above formula, X_j is denoted as follows: X_1 is the area of cultivated land, X_2 is the area of garden parcels, X_3 is the area of grass land, X_4 is the area of urban land, X_5 is the area of water regions, X_{6-1} is the area of unutilized land suitable for cultivation, X_{6-2} is the area of unutilized land suitable for construction, and X_{6-3} is the area of unutilized land suitable for the ecosystem.

Considering the development orientation over ten years and the target of simultaneously improving the economic and ecological efficiencies in Huanghua City, the weights were set as $\lambda_1 = 0.45$ and $\lambda_2 = 0.55$.

Based on the equation 16 for the MOP model and constraints, Lingo Software was applied to solve the multi-target planning model. In addition, the optimal results of the quantitative structure for land-use in 2020 were obtained.

According to the calculation results, the areas of cultivated land, garden parcels, and urban land increase from 76,875.73, 5,364.85, and 55,582.53 ha to 80,937.16, 7,345.84, and 56,471.33 ha, respectively, from 2012-2020, whereas no significant change was observed for the areas of grassland and water. In addition, the area of unutilized land has declined to 29,717.07 ha, and most declined regions are suitable for development, indicating that large areas of unutilized land have been developed into cultivated land, garden parcels, or other land types.

Transformational rules for land types

Based on the targets for improving the economic and ecological efficiencies of land in Huanghua City, the driving forces and model methods were selected in the same way as above, and the transformational rules for land-use types under new targets were reset (Table 7).

Optimal simulation for multi-model land utilization

In the multi-target scenario, based on the land utilization data for 2012, the related parameters that were reset, such as the logistic regression results, land utilization demands, and transformational rules, were entered into the model. After multiple iterations, the optimization results of the MOP model and the simulation of CLUE-S were utilized to obtain the results for land utilization in 2020.

Table 7. Transformational rules among various types of land utilization for the dual model

Transformational rules	Cultivated land	Garden parcel	Grass land	Urban land	Water area	Unutilized land suitable for cultivation	Unutilized land suitable for construction	Unutilized land suitable for ecosystem
Cultivated land	1	1	0	1	0	0	0	0
Garden parcel	1	1	1	1	1	0	0	0
Grass land	0	1	1	0	0	0	0	0
Urban land	1	1	1	1	0	0	0	0
Water area	0	0	0	0	1	0	0	0
Unutilized land suitable for cultivation	1	1	0	0	0	1	1	1
Unutilized land suitable for construction	1	0	0	1	0	1	1	1
Unutilized land suitable for ecosystem	0	0	1	0	1	1	1	1

Notes: The row indicates transforming out of a certain land-use type; line indicates transformation into a certain land-use type; “1” indicates available transformation between two types of land use; and “0” indicates unavailable transformation.

DISCUSSION

On the basis of the suitability evaluation of the unutilized land in Huanghua City, using the GIS, MOP, and CLUE-S models, the results showed the model integrating MOP and CLUE-S continued and strengthened the advantages of the CLUE-S model. The integrating model reflected the inherent development trends and the consistency of land utilization as well as determining important targets for developing unutilized land properly during the simulation of land utilization.

The comparison between the simulation solution for the natural development conditions of the CLUE-S single model and the optimization solution of the multi-model showed that the CLUE-S single model was optimized in accordance with the trend of changes for land economic efficiency (Figure 2a). The cultivated land, garden plots, grasslands, and urban land areas increased, but the water area and unused land area decreased. Although the economic efficiency was increased significantly (growth rate 2.77 %) and the total efficiency value increased, the ecological efficiency value decreased (-1.67 %), indicating damage to the local ecology during local economic development.

Based on the evaluation of the suitability of unutilized land and the multi-model optimization for ecological and economic efficiencies from 2012-2020 (Figure 2b), the increase in the areas of cultivated land, garden parcels, and urban land contributes to the improvement of the land economic functions (Table 8). Moreover, the increases in the areas of garden parcels and grasslands will likely improve the ecological efficiency and maintenance of ecological balance in Huanghua City.

Comparing the two simulation results above, there was optimal simulation with the single CLUE-S model, despite the economic efficiency of the land leading to a decrease of ecological efficiency, indicating that the ecosystem service function of the land had been reduced. The optimization results from the integration of multiple models would improve both regional economic and regional ecological efficiencies, indicating that the ecosystem service function was improved while the local economy was vigorously developed. These results illustrate that the multiple-model integration outperforms the single model as far as optimization.

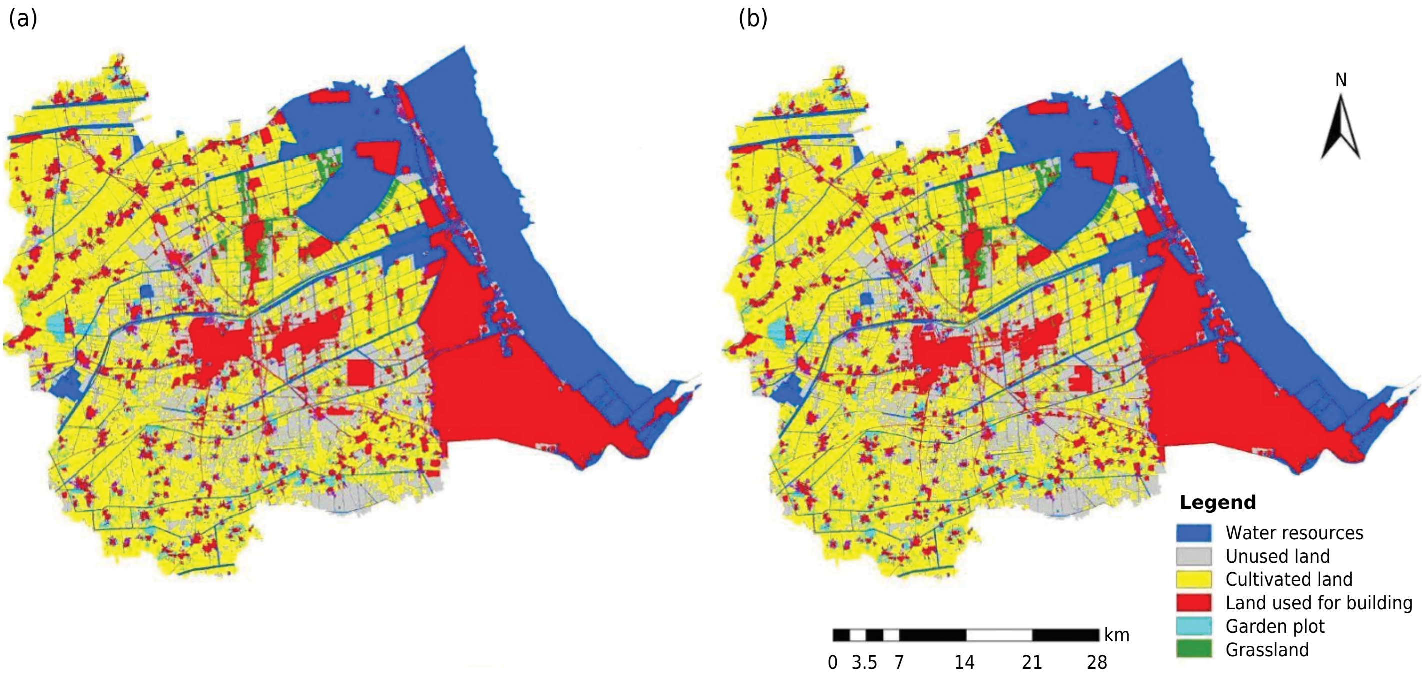

Figure 2. Diagram of the comparison of economic efficiency with the simulation of land utilization between the single model (a) and the multi-target dual model (b) in Huanghua City in 2020.

Table 8. Comparison of optimization simulations between the CLUE-S single model and the multi-objective integrated MOP and CLUE-S model

Variables	2012	Simulation solution for optimization of CLUE-S single model		Simulation solution for integration and optimization of dual model	
		2020	Rate of change	2020	Rate of change
			%		%
Area of cultivated land (ha)	76875.73	79891.23	3.92	80937.16	5.28
Area of garden parcel (ha)	5364.85	6357.42	18.50	7345.84	36.93
Area of grass land (ha)	114.91	174.01	51.43	177.52	54.49
urban land (ha)	55582.53	57011.75	2.57	56471.33	1.60
Water area (ha)	64564.62	61140.47	−5.30	64487.26	−0.12
Total area of unutilized land (ha)	36633.54	34561.3	−5.66	29717.07	−18.88
Ecological efficiency (CNY 10 million)	501.87	493.47	−1.67	507.73	1.17
Economic efficiency (CNY 10 million)	1363.64	1401.39	2.77	1394.00	2.23

The CLUE-S model for land-use optimization simulation could achieve good results; however, the land-use uncertainty would increase due to the land-use structures being influenced by the climate and many other factors. The water area of wetlands and suchlike will become smaller and smaller, especially with global warming and population growth. In addition, since Huanghua City is located in the Bohai Economic Development Zone, China, the land-use will be influenced by economic policies, especially land-use planning policies.

CONCLUSIONS

The optimization for the integrated MOP and CLUE-S model could be applied to simultaneously improve the economic and ecological efficiencies. The model could improve upon the advantages of the CLUE-S model. However, the land-use uncertainty would increase due to the land-use structures being influenced by the climate and many other factors. The accuracy of the model simulation and optimization would be improved if the regional policy factors and other human-factor data were spatialized.

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