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Land use structural optimization of Lilin based on GMOP-ESV

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Abstract: Land use structural optimization is an effective approach to realize land sustainable utilization and allocate limited land resource rationally. Grey multiple objectives programming (GMOP) model based on China terrestrial ecosystem service value was constructed and applied to Lilin town. The result shows that GMOP model has more practical applicability and takes ecologic, social and comprehensive benefit into consideration. There are three programs after optimization. Program I is comprehensive improvement and constructing ecological economy type, program II is gross cultivated land dynamic balance type and program III is compromise type. There are still problems in programs II and III, such as distribution in disorder, land left unused or abandoned. Based on the benefits above, Program I>Program III> Program II. Program I is the optimal case. Its comprehensive benefit is 8.43208×10^7 RMB yuan/a.

Key words: land use structure optimization; grey multiple objective programming; ecosystem service value; Lilin town

1 Introduction

Land is the material base for human beings to live and develop. With the development of economic society, the demand for land keeps increasing. But the restriction of limited land and scarce supply lead to the unlimited increase of economic society demand and series problems of extensive or inefficient land use. It becomes the bottleneck to restrict the economic society development, ecological environment improvement and human's living level. Land use structure optimization is an effective approach to solve this contradiction [1], which can realize the land resource optimal distribution in different industries, departments and areas. It can promote the economical and intensive use of land resource in order to give full play to different land resource advantages. It has important theoretic and realistic meaning to realize harmonious and sustainable regional economic society.

Current research mainly focuses on the macro or medium scopes of land use, but township level in micro level is less. Town is the basic subdivision of the administrative system in rural areas of China, and it is the basic unit in land use. Because the rational planning and management are insufficient for a long time, there are problems such as inharmonious land use, unreasonable land structure, unused or abandoned land and deteriorated ecological environment. Research of land use structural optimization is needed to realize the allocation of limited land resource rationally. In this work, the model combined with GMOP and ESV applied to Lilin town was constructed. It aims to realize structural optimization of land use, allocation of regional land resource rationally and give reference to the revising and compiling of the new round township level general land use.

2 Overview of research area and data resource

2.1 Overview of research area

Lilin town lies in the east of Jiyuan, and is called the east door of Jiyuan. It is at longitude of 112°40′−112°45′ east and latitude of 35°07′−35°12′ north. The total area of Lilin is 56.5 km^2 and the per capita is 0.091 hm^2. The population is 42000 and GDP is 711.98 million RMB yuan in 2005. The town is flat, high in the north and low in the south. The soil is mainly composed of soil and red clay. Its fertility is high and the water-retaining property and fertility preserving properties are good. Qin River, Mang River and Guangli

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canal for irrigation cross the town. The transportation network of Lilin forms "5 verticals, 5 transverses and 1 annular". The Erguang highway and Changji highway cross it. As the development of economic society and increasing unreasonable land use, the contradiction between human and land is sharp, the land use construction in certain area is inharmonious, and the land resource and ecological are damaged. So, land use structural optimization is needed.

2.2 Data resource

The relevant economic social data information was mainly from the 12th Five-year plan of Jiyuan, Jiyuan statistical yearbook, general land use planning of Jiyuan (2006−2020) and general land use planning of Lilin (2006−2020). The land data was from the second land survey data of Jiyuan and land use change survey data.

3 Research methods

3.1 GMOP model

The information is incomplete in the land use system, which is a grey system. From the grey multiple objective programming, the optimal structure under the set condition [2] and the developing trend of the optimal structure are obtained. It is an effective approach of land use structural optimization [3].

GMOP model is used and ESV is integrated to construct the land use structural optimization model based on GMOP-ESV.

The target function is

$$\text{optif}(\boldsymbol{x}) = \otimes(c)\boldsymbol{X}^{\mathrm{T}} \rightarrow \max(\min) \tag{1}$$

where $\otimes$ is the grey index and

$$\otimes(\boldsymbol{c}) = [\otimes(c_1), \otimes(c_2), \cdots, \otimes(c_n)] \tag{2}$$

The constraint condition is

$$\otimes(A)\boldsymbol{X} \leq \otimes(B) \tag{3}$$

$$\otimes(A) = \begin{bmatrix} \otimes(a_{11}) & \otimes(a_{12}) & \cdots & \otimes(a_{1n}) \\ \otimes(a_{21}) & \otimes(a_{22}) & \cdots & \otimes(a_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ \otimes(a_{m1}) & \otimes(a_{m2}) & \cdots & \otimes(a_{mn}) \end{bmatrix} \tag{4}$$

$$\otimes(B) = [\otimes(b_1), \otimes(b_2), \cdots, \otimes(b_{\mathrm{m}})] \tag{5}$$

$$\boldsymbol{x}=[x_1, x_2, \cdots, x_n]^T \tag{6}$$

where $\boldsymbol{x}$ is the variable needed; $\boldsymbol{c}$ is the coefficient matrix of target function and $\otimes(\boldsymbol{A})$ is the grey index matrix under the constraint condition.

3.2 Variable set

The variable set is based on the land use classification. The work combines the land use feature of Lilin and general demands of land use planning. The set variables reflect the gross cultivated land dynamic balance and the requirement of land use control. There are 14 variables shown in Table 1.

Table 1 Land use structural optimization variable set

Land type	Variable	Land type	Variable
Cultivated land	x_1	Mining lease	x_8
Garden plot	x_2	Scenic spot and special land	x_9
Forest land	x_3	Communication and transportation land	x_{10}
Other rural land	x_4	Hydraulic structure land	x_{11}
Urban land	x_5	Water area	x_{12}
Rural settlement	x_6	Tidal marsh	x_{13}
Independent industrial and mining district	x_7	Nature reserve	x_{14}

3.3 Ecological service value index

According to different terrestrial ecosystem unit area ecological service value proposed by XIE et al [4] and relevant findings by other researchers [5−8], the reality of Lilin and the estimate method proposed by COSTANZA [9] are combined to make the land use ecological service value index table of Lilin Town (Table 2). The equation is

$$E_{\mathrm{SV}} = \sum_{k=1}^{14} A_k \times V_{ck} \tag{7}$$

where E_{SV} is the total ecological service value (RMB yuan); A_k is the k type land area (hm^2); V_{ck} is the ecological service value index (RMB yuan/(hm^2·a))

Table 2 Ecological service value index

Number	Land use type	V_{ck}/(RMB yuan·hm·a^{-1})
x_1	Cultivated land	4035.2
x_2	Garden plot	7607.2
x_3	Forest land	11179.1
x_4	Other rural land	6653.0
x_5	Urban land	−2250.0
x_6	Rural settlement	0.0
x_7	Independent industrial and mining district	−2250.0
x_8	Mining lease	−2250.0
x_9	Special land	0.0
x_{10}	Communication and transportation land	0.0
x_{11}	Hydraulic structure land	28473.2
x_{12}	Water area	40676.0
x_{13}	Tidal marsh	53819.0
x_{14}	Nature reserve	371.4

3.4 Target function

Based on the principle of unification of economy, society and ecology, the optimal targets of Lilin are constructed as economic target, social target and ecological target.

1) The economic benefit target function is

$$f_1(x)_{\max}=\sum_{i=1}^{n}c_j x_i\ ,\ i=1,\ 2,\ \cdots,\ n;\ j=\ 1,\ 2,\ \cdots,\ n \tag{8}$$

Different land type economic output of Lilin from 1997 to 2005 is referred. The first industry output is set as farmland economic output, the second and third industry outputs are set as construction land economic outputs. It combines the research before and reality of Lilin to set the relative right coefficient. By analyzing the output of different land type of Lilin from 1997 to 2005 and combining different land type output of Lilin in 2005, the relative right coefficient W_i of different land type in 2020 is set: W_i=(0.08, 0.1, 0.035, 0.07, 0.15, 0.05, 0.15, 0.15, 0.012, 0.15, 0.046, 0.003, 0.002, 0.002).

So, the unit cultivated land benefit in 2020 is

C_1=0.11C=9940, so C=124250

C_j=(9940, 12425, 4349, 8698, 18638, 6213, 18638, 18638, 1491, 18638, 5716, 373, 249, 249).

The economic benefit target function is

$$f_1(x)=9940x_1+12425x_2+4349x_3+8698x_4+18638(x_5+x_7+x_8+x_{10})+6213x_6+1491x_9+5716x_{11}+373x_{12}+249(x_{13}+x_{14}) \tag{9}$$

2) Based on the ecological service value index, the ecological benefit target function is

$$f_2(x)=4035.2x_1+7607.2x_2+11179.1x_3+6653x_4-2250(x_5+x_7+x_8)+28473.2x_{11}+40676x_{12}+53819x_{13}+371.4x_{14} \tag{10}$$

3) Land use has clear sociality. Index measuring regional social benefit contains urban construction land per capita, cultivated land per capita, ect. Furthermore, transportation land, hydraulic structure land and special land still play a role in guaranteeing the social development. So, the social benefit target function is

$$f_3(x)=x_1+0.8x_2+0.8x_3+x_5+x_6+x_7+x_8+x_9+x_{10}+x_{11} \tag{11}$$

3.5 Constraint condition

To insure the dynamics of general land use planning of Lilin, the constraint factor a_{ij} and constraint constant b_i are set by grey dynamic model GM (1, 1), Delphi method, overall balance method, etc. Qualitative analysis is used to get the whitening value and constraint the target year 2020.

1) Constraint total land area

The sum of different land type area is the total land area (5648.7 hm^2). That is

$$x_1+x_2+\ \cdots\ +x_{14}=5648.7 \tag{12}$$

2) Constraint total population

Based on the average population density GM (1, 1) of rural land (rural settlement) and urban land, the bearing population of rural land and urban land of Lilin should be less than the planned population in 2020. That is

$$7.3(x_1+x_2+x_3+x_4+x_6)+83x_5\le 48300 \tag{13}$$

3) Constraint cultivated land area

The cultivated land possession is less than the superior set target. That is

$$x_1\ge 3\ 842.2 \tag{14}$$

4) Constraint construction of land area

The construction of land scale, urban industrial and mining district of Lilin, is strictly limited by the superior, which cannot break the target. That is

$$\sum_{i=5}^{11}x_i\le 870.5 \tag{15}$$

$$x_5=127.9 \tag{16}$$

$$x_5+x_7+x_8\le 201.7 \tag{17}$$

$$x_5+x_6+x_7+x_8\le 7582 \tag{18}$$

$$89.9\le x_{10}+x_{11}\le 112.2 \tag{19}$$

In the planning of Lilin, the independent industrial and mining district is protected. Town and township enterprises and other industry are relative concentrated. Industry land becomes industrial park in order to increase the land use ratio. This industry land is not higher than 56.9 hm^2 in the planning period. That is

$$x_7\le 56.9 \tag{20}$$

5) Constraint land ecological environment

The constraint is based on the fact of Lilin, that is

$$x_3\ge 164.4 \tag{21}$$

$$x_2\ge 116.1 \tag{22}$$

$$89.6\le x_{12}\le 121.1 \tag{23}$$

$$65.8\le x_{13}\le 98.3 \tag{24}$$

$$x_{14}=1.1 \tag{25}$$

6) Constraint negative

The variable has reality meaning, which is not negative. That is

$$x_i\ge 0,\ i=1,\ 2,\ \cdots,\ 14 \tag{26}$$

4 Results and analysis

4.1 Optimize result

As the benefit coefficient, technical coefficient and constraint coefficient are grey in dynamic GMOP model,

this work is based on the model demand, related coefficient elastic range and developing trend, which chooses appropriate value in coefficient limited interval and makes the target function fit the fact of Lilin and get different optimal programs (Table 3).

Table 3 Land use structure optimization (Unit: hm^2)

Variable	Number	Program		
		I	II	III
Cultivated land	x_1	3913.50	3871.70	3842.20
Garden plot	x_2	125.80	117.10	116.10
Forest land	x_3	191.60	171.40	164.40
Other rural land	x_4	383.10	407.20	453.3
Urban land	x_5	127.90	127.90	127.90
Rural settlement	x_6	513.20	556.90	556.5
Independent industrial and mining district	x_7	56.90	56.90	56.90
Mining lease	x_8	16.90	16.90	16.90
Special land	x_9	2.80	2.80	2.80
Communication and transportation land	x_{10}	111.20	108.60	102.90
Hydraulic structure land	x_{11}	0.80	0.80	0.80
Water area	x_{12}	105.60	121.10	121.10
Tidal marsh	x_{13}	98.30	88.30	85.80
Nature reserve	x_{14}	1.10	1.10	1.10

4.2 Analysis

The economic benefit, ecological benefit, social benefit and comprehensive benefit of land use structure optimization can be got from Table 3 and the land use structure optimal target function (Table 4).

Table 4 Land use optimal program benefit of Lilin (Unit: 10^4 RMB yuan/a)

Benefit type	Program		
	I	II	III
Economic benefit	5372.12	5350.12	5354.57
Ecological benefit	3059.46	3035.38	3038.65
Social benefit	0.4997	0.4931	0.4973
Comprehensive benefit	8432.08	8386.00	8393.72

From Tables 3 and 4, the urban land of the three programs after optimization increases 31.11 hm^2. The independent industrial and mining district increases by 56.9 hm^2. The nature reserve keeps constant, which fits the index demands of general land use plan of Jiyuan 2006−2020. The three programs have certain advantages and operability, but the emphases are different. From the point of benefits above, Program I>Program III>Program II.

Program I is comprehensive improvement and constructed ecological economy type. Its comprehensive benefit is 8.43208×10^8 RMB yuan/a. The increase of cultivated land, garden plot, forest land, communications and transportation land is bigger than the other two programs. The decrease of rural settlement and water area is also bigger than the others. Compared with 2005, the cultivated land increases by 71.34 hm^2, forest land increases by 27.17 hm^2, garden plot increases by 9.67 hm^2, other rural land decreases by 135.31 hm^2, rural settlement decreases by 70.34 hm^2. These are realized through comprehensive renovation of rural settlement and other rural land, and the method of linking the increase with the decrease between urban and rural land. Increasing cultivated land, garden plot and forest land is to solidify the agriculture production and improve the ecological environment. Properly increasing the urban land, independent industrial and mining district and communications and transportation land are to supply necessary land support for the development of economic society.

Program II is gross cultivated land dynamic balance type. Its comprehensive benefit is 8.3860×10^8 RMB yuan/a. Cultivated land area after optimization keeps constant, which reflects the gross cultivated land dynamic balance. The garden plot and forest land remain stable. Other rural land decreases by 65.11 hm^2. Rural settlement decreases by 27.04 hm^2 and tidal marsh decreases by 12.47 hm^2. The cultivated land occupied by construction is got from the comprehensive improvement of rural settlement, other rural land and development of tidal marsh.

Program III is compromise type. Its comprehensive benefit is $8.3937.2\times10^8$ RMB yuan/a, which is between program I and Program II. Compared with 2005, cultivated land increases by 29.54 hm^2, which increases moderately. Forest land increases by 6.97 hm^2, which plays a role in changing ecological environment. Other rural land decreases by 111.21 hm^2, rural settlement decreases by 26.64 hm^2 and tidal marsh decreases by 9.97 hm^2. Program III adjusts the land use structure, guaranteeing cultivated land and forest land increasing properly and least disturbing the land use structure. But it does not get the maximum of benefits. It does not renovate the rural settlement with the maximum potential. Furthermore, it leads to some problems such as layout messy, land left unused or abandoned and so on.

5 Conclusions

1) Empirical study was made on Lilin by constructing GMOP-ESV model. The model considers the multiple targets of land use and the competitiveness

of different land use type. It makes overall plans of economic benefit, ecological benefit, social benefit and comprehensive benefit. It gives reference to reasonable and effective regional land use.

2) There are three programs after the optimization. Program I is comprehensive improvement and constructing ecological economy type. Program II is gross cultivated land dynamic balance type. Program III is compromise type. Program II and Program III do not get the maximum of benefits. They do not renovate the rural settlement with a maximum potential.

3) Based on economic, ecologic, social and comprehensive benefit, Program I>Program III>Program II. Program I is the optimum, the comprehensive benefit of which is 8.43208×10^7 RMB yuan/a. Program I considers both land development and use, and comprehensive improvement and protection. It avoids overexploitation, improves land use efficiency and benefit, realizes land use intensively and economically, protects and improves the land ecological environment.

4) In Program I, cultivated land, garden plot, forest land and communications and transportation land increase. Rural settlement and water area decrease. These are realized through comprehensive renovating rural settlement and other rural land and the method increases linking with decrease of land between urban and rural.

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