Asian Agricultural Research 2018, 10(11): 52 –57 DOI: 10.19601/j.cnki.issn1943 –9903.2018.11.010

Optimization of Urban Land Use Structure Based on the Perspective of GMOP-GA——A Case Study of the Urban Districts of Hohhot

Tongyu TIAN * , **Mei YU**, **Hong SU**

College of Geographical Science, Inner Mongolia Normal University, Hohhot 010022, China

Abstract Taking the urban districts of Hohhot as the study area, using the classification data of land use change and relevant socio-economic statistical yearbook data in 2001 –2016, taking the dual targets of economic-ecological and related constraint factors as the optimal decision of optimization of land use structure, using the Grey Multi-objective Programming (GMOP) and Genetic Algorithm (GA) to estimate the intervals of predictive threshold value of the factors and inequality constraint equations, and on the basis of it to designed two schemes for optimization of land use structure for the study area in 2030 and made them in comparison and optimization. The results show that in contrast to the primitive land use structure, the optimized scheme based on the economic-ecological comprehensive benefit is better than the current land use structure as the two aspects of the overall land output benefit and the scale combination of single type land use and the current land use structure.

Key words Urban land use; GMOP-GA; The urban districts of Hohhot

1 Introduction

Land use is a long-term dynamic process of human beings developing, transforming and protecting the land through the development of corresponding multi-sector economic activities based on the various natural or economic attributes attached to land resource entities, and the issue optimal allocation of land resources has developed into a multi-objective uncertainty decision problem[1]. At present, studies on urban land use structure optimization under uncertainty conditions are mainly in the optimal allocation of natural resources in the given area from the economic or ecological perspective, such as: pay attention to research that formulate and develop land use plans by using genetic algorithm, mainly through applied two optimization criteria that resulting land use patch by a kind of suitability and the shape-regularity prospective[2]; To optimized and analyzed the land use structure by using the grey linear programming method based on the optimized area of land resources and the minimum carrying capacity of water resources[3]; Using a series of models such as objective optimization and spatial zoning and it like, so that achieved to establish a land use structure optimization model for one given region[4]; However, there are few analyses of optimization of urban land use types from the perspective of economic benefits.

Taking the maximization of economic-ecological benefits as the only decision target and using the spatial analysis operating platform such as ArcGIS and the proper implementation tool of multi-objective optimization genetic algorithm such as MATLAB, and by these tools respectively to finish the spatial vectorization of the urban land use layout and estimated the optimized value of the various types of specific types of non-construction land and construction land in the urban districts of Hohhot, finally obtained the grey intervals of corresponding factor constraint conditions. The results are expected to provide certain reference value for effectively solving the problem of the urban land use of Hohhot, especially the construction land layout, so that make the different types of land resources can be optimally distributed.

2 Study methods and data source

2.1 Study methods

2.1.1 Remote sensing image classification. Remote sensing image classification refers to the various features of remote sensing image spectral information and spatial information analysis, and then selects the characteristics of ground objects and according to one rule or algorithm of the image to divide each pixels of the image into different categories, furthermore get in the remote sensing images and the actual features of the corresponding information, so as to acquire the classification of remote sensing images[5]. Meanwhile, the supervised classification of remote sensing image refers to a kind of classification method that form a prior knowledge of the category attributes of some ground objects in the remote sensing images through visual interpretation or field investigation before divide the display objects of image into new categories, then identify the unknown classification pixels based on the sample pixels of the recognized categories[6]. According to the situation of urban land structure in the study area and the land use classification standard from *Current Land Use Classification* (GB/T21010-2017), and screening 12 types of urban land use, such as farmland (x_1), garden land (x_2), forest land (x_3), grass land (x_4), waters (x_5), residential land (x_6), commercial and service land (x_7), public administration and public service land (x_8), industrial land (x_9), transportation land (x_{10}), special land (x_{11}) and unused land (x_{12}).

2.1.2 Grey multi-objective programming. The model of grey

Received: September 13, 2018 Accepted: November 11, 2018

Supported by Inner Mongolia Normal University Graduate Students' Research & Innovation Fund (CXJJS17098).

* Corresponding author. E-mail: imnu_ttongyu@126.com

multi-objective programming by the composition of grey systematic model (GM (1,1)) and multi-objective programming, GM (1,1) is a dynamic model consisting of a first-order differential equation established by accumulation of univariate original data by a series of processing[7], and the multi-objective programming method refers to the study of the optimal value of multiple objective functions on a given interval, whose main content includes that set the optimal objectives and some related constraint factors of the model, and calculate the threshold value of interval of the constraint factors' index and the like[8]. The basic form of GMOP model is as follows[9]:

Objective function: $\max f(x) = a_1x_1 + a_2x_2 + \cdots a_ix_i$;

Constraint conditions: $\begin{cases} \sum_{i=1}^{n} c_ix_i \leqslant (=\geqslant) \otimes \hat{b}_i \\ x_i \geqslant 0 \end{cases}$

where x_j ($i = 1, 2, \cdots, n$, $n = 12$) represents the decision variables of each kind of urban land use; a_i is the normalized economic and ecological benefit coefficient of the objective function; $\otimes \hat{b}$ and c_i respectively expresses threshold predicted value of the constraint grey interval and the given coefficient of the constraint conditions. To determine the grey constraint threshold value $\otimes \hat{b}_i$ in the specific time period t in the future, it is essential that needed to construct the GM(1,1) model based on the historical data of corresponding indexes in the past time t_0, so that we obtained the predicted value $\otimes \hat{b}_i(t_0 + t)$ in the time period $(t_0 + t)$.

In view of the problems such as prominent contradiction between supply and demand of land resources, and increasing conflict of the demand of land use among the main urban economic departments set forth in the *Overall Land Use Plan of Hohhot* (2006 – 2020)[10], we made a grey model prediction for factors restricting the optimization of land use structure, including the total population, agricultural land area, the least farmland area and construction land area and the like, and take the predicted value based on the GM(1,1) is set as the upper threshold value of the limit interval of the corresponding constraint factor. The special expressions of economic-ecological benefit objective function and the given constraint conditions as follows:

(I) Construction of objective function

(i) Economic benefit objective function. In the objective function, the weight a_j ($i = 1, 2, \cdots, 12$) of land use economic benefit coefficient corresponding to decision variable of various types of land use x_j ($i = 1, 2, \cdots, 12$) can be determined through calculating the normalized ratio value of each type of land use current output value of 2016 to the total area of current land use, the specific function expression as follows:

$$\mathrm{Max}\ f(x) = 0.0017x_1 + 0.0027x_2 + 0.0003x_3 + 0.0002x_4 + 0.0025x_5 + 0.1037x_6 + x_7 + 0.0728x_8 + 0.2131x_9 + 0.0621x_{10} + 0.0049x_{11}$$

where a_i denotes the coefficient of economic benefits expressed in 10^4 yuan/ha, and x_i is the area of various types of land use, expressed in ha.

(ii) Ecological benefit objective function. When the weight a_j ($i = 1, 2, \cdots, 12$) of land use ecological benefit coefficient corresponding to decision variable of various types of land use x_j ($i = 1, 2, \cdots, 12$) can be determined through calculating the normalized ecosystem service value of per unit area of 2016 for each type of non-construction land use[11], namely:

$$\mathrm{Max}\ f(x) = 0.0209x_1 + 0.3385x_2 + 0.2820x_3 + 0.0860x_4 + x_5 + 0.0403x_{12}$$

where a_i denotes the coefficient of ecological benefits expressed in 10^4 yuan/ha, and x_i is the area of various types of land use, expressed in ha.

(II) The expressions of constraint conditions

(i) Total land use constraint. The total area of the four districts of Hohhot has been maintained at 205 400 ha from 2001 to 2016, so the sum of area of various types of land should not be greater than the total area of the study area, namely, $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} \leqslant 205\,400$.

(ii) Constraint of area of agricultural land. The current value of total area of agricultural land in municipal districts of Hohhot in 2016 and the predicted value of 2030 was 164 866.53 ha and 155 959.16 ha, respectively; considering the demand of social and economic development for basic agricultural resources, the area of agricultural land in 2030 should be not lower than the current value, namely: $155\,959.16 \leqslant x_1 + x_2 + x_3 + x_4 + x_5 \leqslant 1\,648\,66.53$.

(iii) Constraint of farmland protection area. According to the requirement that the farmland protection area should not be lower than 574.29 ha specified in *Overall Land Use Plan of Hohhot* (2006 – 2020)[10], the constraint equation of farmland protection area was set as: $x_1 \geqslant 57\,429$.

(iv) Constraint of area of construction land. In order to ensure the reserve of urban agricultural land and maintain the urban ecological environment, and appropriately adjust the overall scale of construction land to meet the requirements of planning and construction, such as stipulated the predicted value of area of construction land in 2020 must be not exceeded 41 689 ha from the *Overall Land Use Plan of Hohhot* (2006 – 2020), so that the upper and lower limits of the construction land area should be based on the planned value and the current value, respectively, namely: $41\,064.52 \leqslant x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} \leqslant 41\,689$.

(v) Constraint of area of unused land. With the expanding of urban land use development scale, which made that the unused land was gradually decreasing. Thus, the constraint area of unused land in the end of 2030 should be lower than the current value, *i. e.*: $x_{12} \leqslant 13\,748$.

(vi) Non-negative constraint. The corresponding constraint non-negative equation can be expressed as: $x_i > 0$ ($i = 1, 2, \cdots, 12$).

2.1.3 Genetic algorithm. Genetic algorithm as a kind of global search algorithm, puts up the key characteristic of high parallel in the aspect of solving problem[12]. Its feature correspondingly means that the problem of the optimal result of multi-objective programming calculated by genetic algorithm performs a kind of disaggregation in nature, rather than a single calculation. Therefore, considering the problem of the optimal allocation of urban land use represents the problem of economic-ecological overall optimal of land use benefit, so that it is suitable to use genetic algorithm measure to deal with multi-objective optimization of land use structure. In a word, based on the above basic principles and contents of mathematical modelling of multi-objective optimal problem, the research intends to build a multi-objective optimal model with the special constraint conditions, and using the mathematical modelling software such as MATLAB R2016a to invoke the implementation tool of Genetic algorithm. Then the calculations obtained should also be a set of the optimal solutions, which is known as Pareto solutions[13]. On the basic of characteristics of solution sets, transform the problem of multi-objective optimization into the single-objective optimization by taking the weight coefficient conversion method, and respectively calculate one optimal set of solutions based on the objective of economic-ecological integrated benefit.

2.2 Data source The data used in this study included spatial data of the urban land use and related statistical data on development area such as socio-economic construction and Chinese land ecosystem service value and so on. Specifically, the classification of spatial vector data on the change of urban land use layout were mainly based on the remote sensing images that includes three types of time sections as 2001,2010,2016, and search number of the reference base image respectively represents as 126-31,126-32,127-31and 127-32 from Landsat TM/OLI. The remote sensing images were taken proper geometric correction by ENVI 5.0, and carried out with ArcGIS 10.3, Google Earth Pro tools to achieve the visual interpretation of the three-phase remote sensing images. As for the source of statistical data, it mainly collected from *China Urban Construction Statistical Yearbook*, while the data of social economic construction were mainly collected from *Statistical Yearbook of Inner Mongolia* and *Economic Statistical Yearbook* of Hohhot of the years of 2001 – 2016.

3 Results and analysis

3.1 The characteristics of Changes of urban land use in the study area In the land use top-level structure, there are two land use categories: non-construction land which includes agricultural land use and unused land, and construction land. The two land use categories can takes as the basic perspective of qualitative classification and quantitative evaluation, combined with the spatial statistical data of relevant land categories of area under the districts of Hohhot in 2001, 2010 and 2016, then respectively analyzed and evaluated the change characteristics and trend of overall structure of three land use categories and each category of subdivided land use, especially pay attention to research the spatial pattern change of each type of subdivided construction land. From the perspective of the transfer of urban construction land area and its relationship with the change of non-construction land area, there is a clear corresponding relationship between the changes in urban land use layout and the urban economic construction activities of the departments. The adjustment of the requirements of urban economic construction and development will inevitably lead to changes in the proportion of urban construction land use types[9]. Hence, under the premise of fixed total land area, the sector division and scale expansion of the urban economic departments will inevitably deteriorate the development trend of continuously declining proportion of non-construction land and increasing constantly proportion of construction land since 2001. As shown in Table 1, in the aspect of the land source composition of increase area for all kinds of urban construction land from 2001 to 2016, farmland became an important source for urban construction land area constantly increased, especially it had accounted for the largest proportion in the land source of most of increased construction land types, and occupied a larger proportion in the increased area composition of industrial land, transportation land and public administration and public service land in turn. Accordingly, the number of construction land structure change reflected in the spatial layout, which can be characterized by the distribution of industrial land and public administration and public service land were concentrated with the edge of urban build-up area.

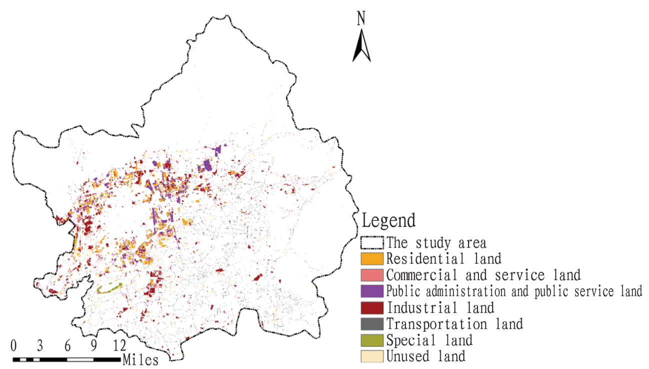

Fig. 1 The spatial transfer pattern of increased scale of urban land use from 2001 to 2016

As shown in Fig. 2, from the characteristics and development trend of subdivided land use type of non-construction land and construction land, the farmland, grassland and forest land in the overall land structure accounted for a large proportion, up to 32.53%, 25.28% and 20.40% respectively by the end of 2016; these types of non-construction land suffered a great decline from 2001 to 2016, especially the largest reduction of types of non-construction land as farmland, and it declined totally by 9.04%; Though the proportion of grassland and forest land respectively accounted for more than 20% and slightly less than 20% in the overall land use structure, both of them the decline was small, the decline of grassland proportion was slightly greater than that of forest land by 0.29%. The proportion of area of waters and gardens was smaller than other agricultural land and the decline rate was almost to zero, and it could be maintained at a relatively stable level of change. Without considering some artificial improvement measures, it is predicted that the farmland area will be rapidly reduced to a large extent in the future. On the contrary, the differences of the magnitude and trend of land use proportion among each type of construction land were larger than all kinds of non-

Table 1 The transfer matrix of urban land use from 2001 to 2016 %

Value	Residential land	Commercial and service land	Public administration and public service land	Industrial land	Transportation land	Special land
Farmland	22.08	21.79	27.58	79.14	31.55	17.63
Garden land	0.06	0.03	0.06	0.16	0.47	0.17
Forest land	0.24	0.21	0.09	0.29	0.75	0.64
Grassland	0.18	0.30	0.22	0.27	1.50	0.84
Waters	0.07	0.11	0.38	0.08	0.42	0.00
Residential land	67.50	14.50	5.68	4.56	8.97	0.17
Commercial and service land	1.00	37.07	0.99	0.71	2.90	0.53
Public administration and public service land	0.95	2.36	41.40	0.48	4.83	2.15
Industrial land	0.55	1.42	1.62	1.11	0.28	0.00
Transportation land	3.64	10.79	9.39	4.24	44.65	3.21
Special land	0.00	0.04	0.23	0.00	0.12	50.67
Unuse land	3.73	11.36	12.36	8.95	3.55	24.00

construction land. By the end of 2016, the proportion of residential land and transportation land which were related to the residential basic activities, separately accounted for 11.16% and 51.60% of the overall land use area and overall construction land area, but the total average change in the proportion of land use was slightly from 2001 to 2016, up to 2.74% and −3.24% respectively. Compared with the above two types, the proportion of industrial land in the total construction land area accounted for 12.98% merely, but the growth rate was the fastest, and it went up annually 88.26%. However, the proportion of commercial and service land area was smaller in the construction land use structure and the growth rate was relatively slower. It could be deemed as the development scale of the second industry was excessive large, which leads to the third industry and the new industry is restrained to some extent in the study area at present. Hence, it will be necessary to strengthen the intensive use of construction land and the centralized layout of various functional zones while meeting the reasonable demand of economic development for construction land, so as to provide some essential conditions to diversified development of urban economy.

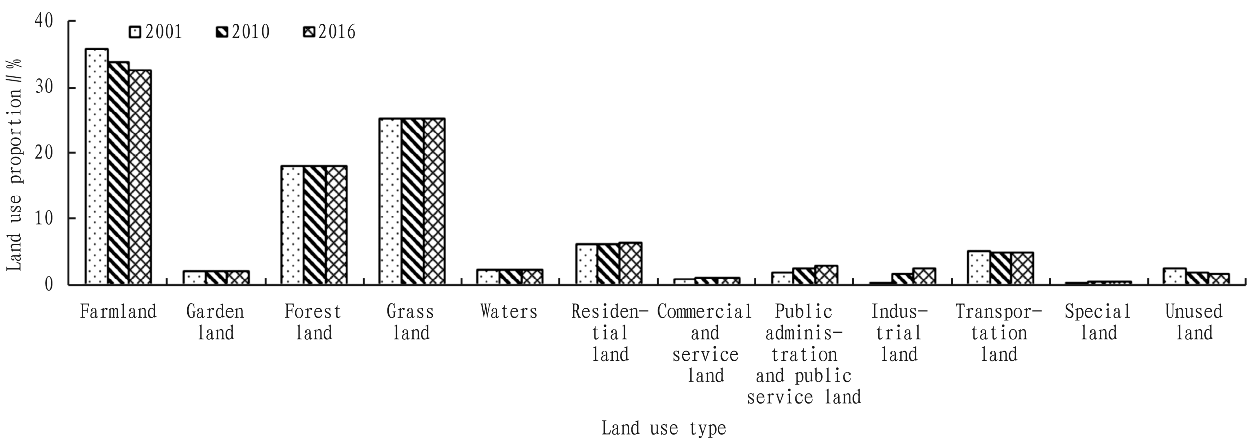

Fig. 2 Changes in land use structure in the districts of Hohhot City in 2001, 2010 and 2016

3.2 Optimization decision of urban land use structure in the study area According to the grey interval upper and lower limits of total land use area, single land use area, and total population in the end of the year , and the benefit objective functions in the above stated GMOP content, economic and ecological benefit goal function of related constraint elements were taken respectively, forming the Scheme 1 with the economic benefit maximization as the basis and the Scheme 2 with the ecological benefit maximization as the basis calculated by the general objective programming function model. In addition, set the transferred weight of economic-ecological benefit objective referred to 0.5 both of them and designed the comprehensive benefit scheme on the basis of it by multi-objective genetic algorithm, the calculation results as shown in Table 2. From the perspective of the overall output benefits of the land use structure, the maximum output benefit that can be achieved through Scheme 1 is 9 613.64 million yuan, while the maximum economic benefit of Scheme 2 is 20 199.42 million yuan, and Scheme 3 refer to 16 295.22 million yuan, so that the ecological benefits of Scheme 2 will be greater than the others. From the perspective of suitability of land use combination, the overall land area among the all kinds of benefit objective schemes were 1 205 400 ha, and the proportion of farmland, grassland and forest land in agricultural land is larger than 10%, especially farmland accounted for more than 45% among the all kinds of schemes. As for proportion of subdivided construction land based on Scheme 1, among them residential land and industrial land in construction land is large and reaches 3.71% and 3.23% respectively, while the proportion of commercial and service land is small, which will be not favorable for the transformation of urban economic industrial structure and overall land use output benefits of the study area. In Scheme 2, the area of forest land and commercial and service land is 6 139 ha and 822 ha higher than that of Scheme 1, respectively, which provides sufficient land support for both ecological benefits and urban economic continuous construction. In addition, the proportion of commercial and service land based on Scheme 3 refer to reach 4.98%, which was large than the corresponding type of construction land in the others, it also convenience to generate a significant effect on the multiple evolution of urban economic departments. In summary, due to it possibility of achieving regional economic, social and environmental benefits based on the scheme of ecological benefit objective is much higher than that of the others. Thus, Scheme 2 is taken as the decision scheme for optimization of land use structure.

Table 2 Scheme for optimization of land use structure in the districts of Hohhot

Land use types	Scheme 1 (economic benefit)		Scheme 2 (ecological benefit)		Scheme 3 (comprehensive benefit)	
	Area of land use//ha	Proportion of land use//%	Area of land use//ha	Proportion of land use//%	Area of land use//ha	Proportion of land use//%
Farmland	99 513	48.45	95 740	46.61	98 627	47.53
Garden land	1 200	0.58	1 268	0.62	2 198	1.06
Forest land	22 353	10.88	28 492	13.87	26 423	12.73
Grassland	23 394	11.39	22 774	11.09	23 084	11.13
Waters	9 496	4.62	7 428	3.62	6 542	3.15
Residential land	7 617	3.71	9 329	4.54	9 473	4.57
Commercial and service land	6 291	3.06	7 113	3.46	10 341	4.98
Public administration and public service land	6 629	3.23	6 857	3.34	4 743	2.29
Industrial land	6 578	3.20	5 419	2.64	5 398	2.60
Transportation land	6 633	3.23	5 826	2.84	6 230	3.00
Special land	5 840	2.84	6 521	3.17	5 180	2.50
Unused land	9 855	4.80	8 633	4.20	9 244	4.46

From the perspective of the current land use structure and the feasibility of optimizing the land use structure, compared with the composition of various land types in 2016, the proportion of construction land in the optimized land use structure in 2030 has increased significantly, in other words, part of non-construction land are transformed into construction land, which provides a lot of land space support for the layout of regional industrial sectors and the transformation of industrial structure, so that the overall homogeneity and rationality of land use structure are improved to some great extent. From the perspective of the proportion of magnitude changes of single type of land use, the largest increase in non-construction land use as the optimized land use structure is the farmland, which is 14.08% higher than that in 2016, and the larger increased magnitude of the proportion in the construction land use structure refer to special land and commercial and service land, which reached 2.74%, 2.39% respectively. For the decline in proportion of land use, the largest is grassland, which reach the decline magnitude of 14.19%, followed by the forest land. In addition, different from the development trend of the general decline in the proportion of various types of agricultural land in the land structure after optimization, the proportion of area of farmland and waters after optimization has increased, and the land for carrying the function of eco-tourism such as special land in the kind of the construction land category, which has also increased by a certain proportion compared with that before optimization. These are greatly helpful for realize the integrated regional development.

Table 3 Optimization of land use structure in the districts of Hohhot %

Land use types	Current value of proportion of land use	Optimized value of proportion of land use	Change of proportion of land use
Farmland	32.53	46.61	14.08
Garden land	2.10	0.62	-1.48
Forest land	18.03	13.87	-4.16
Grass land	25.28	11.09	-14.19
Waters	2.34	3.62	1.28
Residential land	6.27	4.54	-1.73
Commercial and service land	1.07	3.46	2.39
Public administration and public service land	2.86	3.34	0.48
Industrial land	2.56	2.64	0.08
Transportation land	4.89	2.84	-2.05
Special land	0.43	3.17	2.74
Unused land	1.64	4.20	2.56

5 Conclusions

(i) According to the development and changes of land use structure in the urban area of Hohhot in 2001 – 2016, the proportion of non-construction land in the overall structure as of 2016 still accounts for 80.27%, so that the total structure still much higher than the proportion of construction land. However, the overall proportion of non-construction land has shown a declining trend with an annual decline of 0.26%, while the proportion of construction land has increased with fluctuation and the average annual growth rate is up to 1.26%. In the non-construction land, the proportion of farmland shows great decline, up to 9.04% in total; in the construction land, the proportion of industrial land, public administration and public service land and commercial and service land shows great increase. These changes exert a certain positive effect on increasing the economic benefits of urban land use and promoting the sound development of the economic sector system.

(ii) In view of the construction and selection of the optimal allocation scheme for land use structure in the urban area of Hohhot in 2030, focusing on the viewpoint and method of dynamic system optimization, and using the grey objective programming method and multi-objective optimization genetic algorithm, we designed the scheme and made a comparative selection for the optimization of land use structure in the study area. Through selecting the single economic benefit goal, the ecological benefit goal and the economic-ecological comprehensive benefit goal of the grey interval, we designed three schemes for urban land use structure optimization. Through comparison, it is found that the Scheme 2 with the ecological benefit as the basis is better than the others in the overall economic benefits and land use function combination. Thus, the Scheme 2 is taken as the optimization scheme for land use structure.

(iii) Through comparative analysis of the optimization of land use structure in 2030 and the current land use structure in 2016 on the coordinated development of the economic and ecological benefits, it is found that the optimized land use structure is more significant than the current land use structure in the land use uniformity. Besides, the proportion of various types of construction land in the optimized land use structure has increased, so that the land use size and the structural changes are more suitable for demands of modern urban economic construction.

References

[1] HAO RM, ZHAO M. Study on the function of land use landscape ecosystem in Hohhot City[M]. Beijing: Minzu University of China Press, 2012. (in Chinese).

[2] PORTA J, PARAPAR J, DOALLO R, et al. High performance genetic algorithm for land use planning[J]. Computers, Environment and Urban System, 2013,37(5):45 – 58. (in Spain).

[3] DUAN YY, LIU XL. Optimization of land use structure based on water resources carrying capacity in Minqin Oasis, Gansu, China[J]. Journal of Desert Research,2011,31(1):174 – 179. (in Chinese).

[4] LIU YS. Family models used in optimal allocation of regional land use [J]. Progress in Geography,1999,18(1):26 – 31. (in Chinese).

[5] DENG SB, CHEN QJ, DU HJ, et al. The processing method of ENVI remote sensing image (2nd Edition)[M]. Beijing: Higher Education Press,2014. (in Chinese).

[6] JIN J, ZHU HY, LI ZX, et al. Comparison of several supervision classification methods in ENVI remote sensing image processing[J]. Water Conservancy Science and Technology and Economy,2014,20(1):146 – 148. (in Chinese).

[7] WANG XX, ZU PF, ZHAO BJ, et al. The GM(1,1) prediction on GDP of Mudanjiang and grey relative analysis on its affecting factors[J]. Mathematics in Practice and Theory,2013,43(8): 42 – 49. (in Chinese).

[8] YU HR, PU CL, LI Y, et al. Study on multi-objective optimization of land use in oasis cities——Taking Kuitun city in Xinjiang as an example [J]. Journal of Chinese desert,2013,33(4): 1267 – 1272. (in Chinese).

[9] CAO YE, TIYIP T, WANG XJ, et al. Land use planning research based on SD-GMOP model[J]. Journal of Anhui Agricultural Science,2011,39(25): 15563 – 15566. (in Chinese).

[10] The People's Government of Hohhot. Overall land use plan of Hohhot (2006 – 2020)[EB/OL]. http://huhhot.nmggtt.gov.cn/zwgk/ghjh/tdlygh/201510/t20151010_426447.html, 2011-12-10. (in Chinese).

[11] XIE GD, ZHANG CX, ZHANG CS, et al. The value of ecosystem services in China[J]. Resources Science,2015,37(9):1740 – 1746. (in Chinese).

[12] HU GQ. Genetic algorithm for multi-objective optimization and its implementation[J]. Journal of Chongqing University of Arts and Sciences (Natural Science Edition), 2008,27(5): 12 – 15. (in Chinese).

[13] HUANG H. Genetic algorithm for multi-objective optimization of land use structure[J]. Mountain Research,2011,29(6): 695 – 700. (in Chinese).