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CASE REPORT

Spatial optimal allocation of land resources in Fengweihan, Kaishan, Laos

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ABSTRACT

Abstract: **Objective:** Through the spatial optimal allocation of land resources to improve the efficiency of land use, promote the rational layout of various industries and infrastructure, and provide a theoretical basis for the comprehensive development of regional social economy. **Methods:** Combining GIS spatial analysis technology, logistic regression analysis method and CLUE-S model, taking Kaishan Fengweihan City, Laos, as the research area, the research on the spatial optimal allocation of land resources was carried out. Under the constraints of spatial suitability and quantitative structure, the spatial optimal allocation of land resources in Fengweihan city of Kaishan is carried out based on the land demand, limiting factors, conversion rules and spatial characteristics. **Results:** Urban construction land and paddy fields expanded to suitable areas on the original basis, and the forestry land with sparse distribution was reduced correspondingly due to development and utilization, while other land types did not change significantly in quantity and space. **Conclusion:** Urbanization construction and agricultural development can provide the foundation and support for the economic development of Kaishan Fengweihan city. At the same time, it is necessary to give consideration to ecological protection and promote the overall, coordinated and sustainable use of land resources.

Keywords: Land Use; Space Optimization; CLUE-S Model; Fengweihan City, Kaishan, Laos

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1. Introduction

The optimal allocation of land use space is conducive to the rational and efficient use of limited land resources, thereby promoting the sustainable development of regional economy. How to realize the optimal allocation of land resources in space is still a hot issue in the field of land spatial planning. At present, scholars at home and abroad have carried out a lot of research in this field[1-3], mainly including land use change research based on multi-source data fusion[4,5], spatial analysis based on GIS (Geography Information System)[6], optimal allocation based on suitability evaluation[7], land use simulation[8,9], optimization algorithm research[10], the research content has been deepened[11-13], and the research methods have been improved[14-16].

As the economic center of Laos and the second largest city after the capital Vientiane, Kaishan Fengweihan has an important strategic position in the regional development and future planning of Laos. In recent years, the urbanization of Fengweihan city in Kaishan has developed rapidly. The construction of grain production base and the development of special economic zones urgently need reasonable land planning to provide guarantee. However, at present, its land planning lags behind and the planning system is imperfect. At the same time, there are few studies and practical explorations on land allocation carried out around Kaishan Fengweihan city at home and abroad[6,17,18]. Although these studies provide methods and data support for the land use of Kaishan Fengweihan city and Laos to a certain extent, the results are still relatively scarce, which is not enough to provide sufficient support for its planning practice. As the premise and foundation of economic development, the rational allocation of land resources is still a key scientific problem to be solved urgently in the land and economic fields of Kaishan Fengweihan city.

Based on the relevant experience at home and abroad, this study combines GIS spatial analysis method with CLUE-S model to carry out the research on the spatial optimal allocation of land resources. At the same time, considering the actual situation of Laos, the control indicators of different types of land use scale are based on the suitability of natural conditions, and constrained by the restrictions of local land use policies and land use development goals, to promote the development and rational use of land resources, and provide a reliable guarantee for local economic development.

2. Overview of the study area and data sources

2.1 Overview of the study area

Located on the southern border of Laos and on the left bank of the Mekong River, Kaishan Fengweihan is the second largest city in Laos, the capital of Savannakhet Province, and the economic center of Laos. Kaishan Fengweihan city is also known as “Savannakhet city”, which means “city in heaven”. In 2005, it was renamed Kaishan Fengweihan city in memory of the second president of Laos Kaishan Fengweihan, with a population of 1.20×10^5, and a land area of 650.51 km^2.

2.2 Data source

The basic data of the study includes three types: land use data, socio-economic data and questionnaire survey data. Among them, the land use data comes from the land use status data (2006), relevant planning data (2006–2015) provided by the Lao government department, the remote sensing image data of the study area (2015–2020) provided by the geospatial data cloud of the Chinese Academy of Sciences, and the field survey and test data of the study area (2015); the socio-economic data are from the statistical yearbook of the study area (2005–2013); the questionnaire data comes from expert consultation and scoring in the field of land planning and social economy (2019–2020).

3. Research methods

3.1 Model construction

Based on GIS spatial analysis technology and CLUE-S model, the data of land use status, suitability, optimal quantitative structure, driving factors, limiting factors and so on are converted into corresponding model input parameters according to the format requirements of the model, and the model operation is carried out to obtain the spatial optimal allocation scheme of land resources in Fengweihan City, Kaishan. The model consists of four input modules: transfer rules, limiting factors, land demand, spatial characteristics, and a spatial layout allocation module[16].

(1) Transfer rules. The transformation rules between different land classes are defined and realized through the transition matrix. See **Table 1** for the transition matrix. Where the value of 1 means that it can be transferred, and the value of 0 means that it cannot be transferred. The specific assignment is obtained by collecting the opinions of relevant experts, local governments and residents in multiple rounds according to the methods of policy research, field survey in the study area in 2015 and expert consultation in 2020 (**Table 1**).

(2) Limiting factors. Restrictive factors include regulatory constraints such as nature reserves. In the CLUE-S model, the allocation of land use pattern is affected by the setting of restrictive factors. There are two types of restrictions: regional restrictions and land type restrictions. For example, the land

Table 1. Transfer matrix between secondary land types in Fengweihan City, Kaishan, Laos

Project	**Paddy field**	**Garden plot**	**Grassland**	**Crop planting**	**Other agricultural land**	**Forestry land**	**Urban construction land**	**Land use for rural construction**	**Land of water resources**	**Other land**
Paddy field	1	0	0	0	0	0	0	0	0	0
Garden plot	1	1	0	1	1	0	0	0	0	0
Grassland	1	1	1	1	1	1	1	1	1	0
Crop planting	1	1	0	1	1		0	0	0	0
ther agricultural land	1	1	0	1	1	0	0	0	0	0
Forestry land	1	1	0	1	1	1	1	1	1	0
Urban construction land	1	0	0	0	0	0	1	0	0	0
Land use for rural construction	1	0	0	0	0	0	1	1	0	0
Land of water resources	0	0	0	0	0	0	0	0	1	0
Other land	1	1	1	1	1	1	1	1	1	1

within the protected area is not allowed to be transferred to other types of land, which belongs to the restriction of specific areas; whether the transfer between different classes is allowed belongs to the land class restriction.

(3) Land demand. The land demand is obtained by fuzzy prediction calculation and used to limit the change of each land type in the simulation process. A positive value of land demand indicates an increase in the number of land, a negative value indicates a decrease in the number of land, and the total change of all land types is zero, that is, the total area of each land type is constant. Kaishan Fengweihan city has an important strategic position in the regional development and future planning of Laos. Its demand for construction land and agricultural land should not only consider the factors such as population growth, economic development and food supply in the study area, but also consider the role and contribution to the development of the whole region. Therefore, regional factors should be considered in the prediction of land demand.

(4) Spatial features. Based on the principle that all land use types are allocated at their most likely positions, the quantitative relationship between the changes of land use types and the driving factors leading to the changes is analyzed through logistic regression operation, and the spatial distribution probability of each land use type is obtained[19]. The specific calculation expression is as follows:

$$\ln\left(\frac{P_i}{1-P_i}\right)=B_0+B_1\,X_{1i}+B_2\,X_{2i}+\cdots+B_nX_{ni} \quad (1)$$

Where: P_i represents the probability that a grid unit may become a land type i; B_0 is the constant of regression equation; B is the regression coefficient of each driving factor; X is the driving factor.

(5) Space allocation. Spatial allocation is based on the analysis of land use conversion rules, limiting factors, spatial characteristics and other elements. According to the order of the total probability of land allocation from large to small, through multiple iterative operations, the land demand is allocated in space in turn.

3.2 spatial feature analysis

(1) Binary processing of raster data. In order to improve the efficiency of data processing, this study uses the sampling method for regression analysis[3]. First, the grid data of each land use type is binarized, and the grid unit whose attribute is a certain land

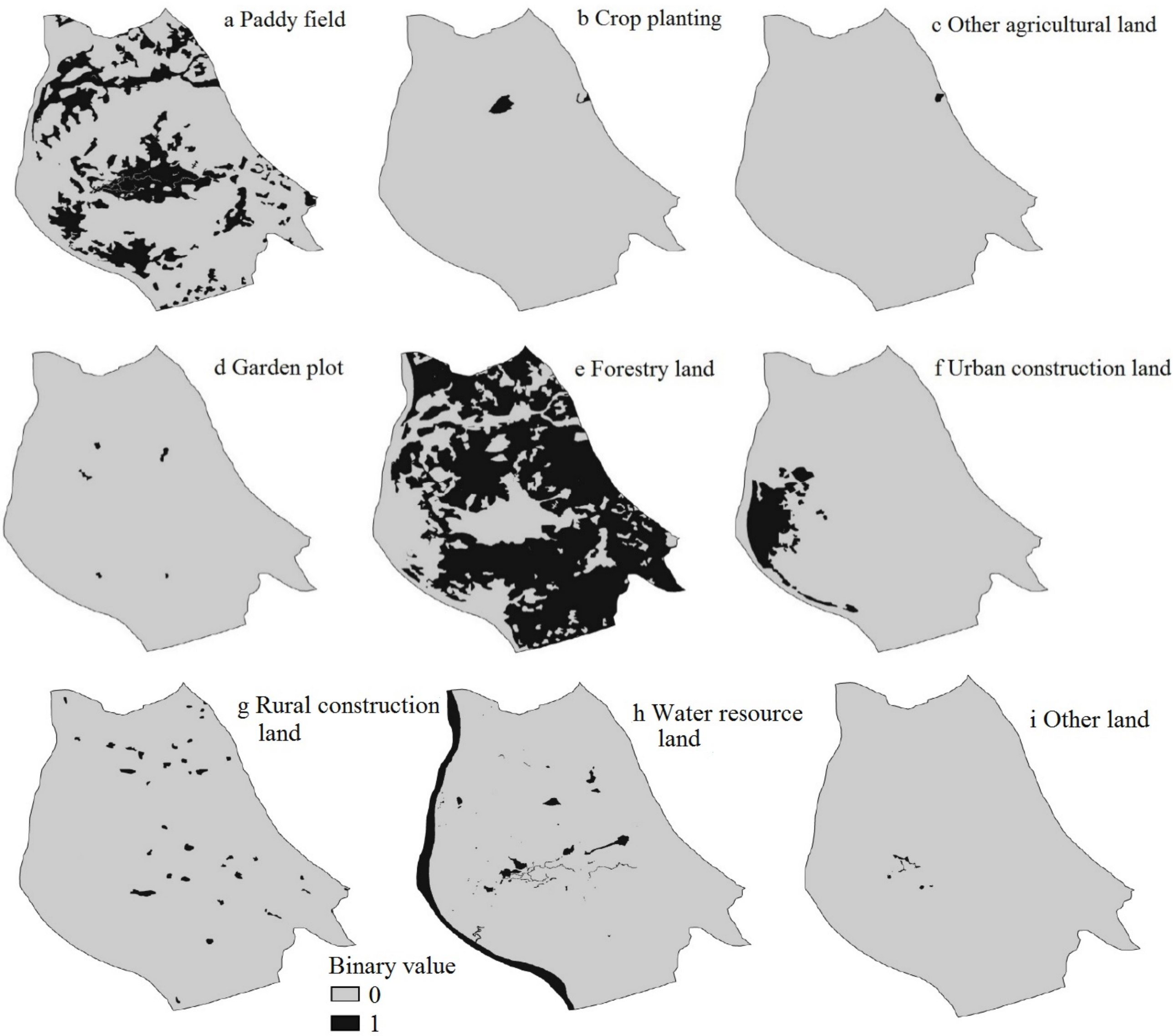

Figure 1. Binary grid map of various land uses in Fengweihan City, Kaishan, Laos.

use type is assigned as 1, and the grid unit whose attribute is not this land use type is assigned as 0, generating grid data with a value of 0, 1 (**Figure 1**).

(2) Random sampling and reclassification. After binarization of each land use type, use the Create Random Raster function of ArcGIS to generate a random grid of the coverage area for random sampling of each land use type and each driving factor. During the sampling process, the closer the percentage correction between cases with cell value of 0 and cases with value of 1 is to 50%, the better the sampling result is. Therefore, it is necessary to reclassify the random grid according to a certain proportion, so that the sampling proportion of each land type is kept at 1, 0, and the number of samples is basically the same. For example, the number of paddy field grids in Kaishan Fengweihan city is 169,022, and the number of non paddy field grids is 553,735. The ratio of the two is about 1: 3. Then the random grids covering Kaishan Fengweihan city are reclassified according to the proportion of 30%, and the reclassified random grids are multiplied by the non paddy field grid layer by using the grid calculator. The number of non paddy field samples randomly sampled at the proportion of 30% is 166,615, which is close to the number of paddy field samples. According to the sampling results, the percentage correction results of random sampling of each land type are maintained between 50.0% and 62.0%, and the sampling data is relatively reliable.

After reclassifying the random grids with cell values of 0, 1 for each land use type, according to the reclassification results, use the sample tool of ArcGIS to sample each driving factor in turn, and the sampling data obtained are the independent variable (each land use type) and dependent variable (driving factor) of regression analysis. Among them, the driving factors are selected from 12 suitability evaluation indicators. Among the 12 indicators, the land use type factor and the protected area factor are repeatedly constrained in other modules in the model, so these two indicators are removed from them, and a total of 10 driving factors are set, including elevation (X_1), slope (X_2), aspect (X_3), soil type (X_4), soil organic matter content (X_5), soil pH value (X_6), distance from water source (X_7), distance from road (X_8), distance from residential area (X_9), and vegetation coverage (X_{10}). By regression analysis between land use types and driving factors, the regression coefficients of each land use type in the model can be obtained.

(3) Binary logistic regression analysis. Through binary logistic regression analysis of their variables and dependent variables, the correlation between land use type changes and driving factors, regression coefficients, regression equation constants and land type conversion probability and other parameters are obtained. See **Table 2** for regression equation coefficients and constants of various land use in Kaishan Fengweihan city.

(4) Regression equation fitting test. The fitting degree of regression equation is generally tested by ROC curve. ROC value is the area under the curve, which is generally between 0.5 and 1. The larger the value, the better the fitting degree and the more accurate the land use allocation when the model is running. After testing, the ROC values of all land types are greater than 0.85, the fitting degree of the regression equation is good, and the spatial simulation results are more accurate.

4. Results and analysis

4.1 Land use changes before and after optimal allocation of land resources

Through the prediction of land demand, the analysis of limiting factors, the study of transformation rules and the analysis of spatial suitability characteristics, the solution is based on the CLUE-S model, and the results of the spatial optimal allocation of land use in the study area are obtained. The results show that the main land types in Kaishan Fengweihan city are agricultural land, forestry land, construction land and water resources land. All kinds of land develop outward with the current distribution area as the center, and are centralized and contiguous. The results of the optimal allocation of land resources are shown in **Figure 4a**.

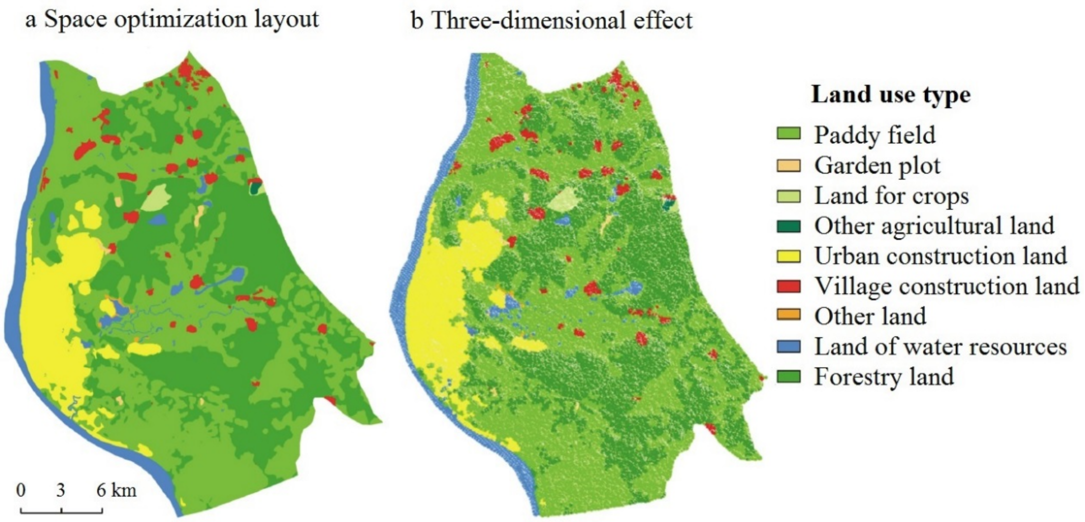

Figure 4. Spatial optimization layout and three-dimensional effect of land resources in Fengweihan City, Kaishan, Laos.

Table 2. Regression equation coefficients and constants of various land types in Fengweihan City, Kaishan, Laos

Evaluating indicator	Regression coefficient and constant								
	Paddy field	**Garden plot**	**Grassland**	**Crop planting**	**Other agricultural land**	**Forestry land**	**Urban construction land**	**Land use for rural construction**	**Land of water resources**
Elevation X_1	-0.0946	-0.0729	0.1030	0.0411	0.0706	0.0938	-0.0393	-0.0128	-0.5212
Slope X_2	-0.0473	-0.0308	0.0401	0.2485	0.0324	0.0220	0.0820	-0.0835	0.1530
Slope aspect X_3	-0.0012	-0.0013	-0.0015	-0.0027	0.0010	0.0004	-0.0022	-0.0078	-0.0029
Soil type X_4	0.3148	1.1999	-2.4874	-25.1250	0.8649	1.3648	-3.6264	-13.2591	3.7399
Soil organic matter content X_5	-0.2366	-6.4933	-3.2705	4.1104	1.1748	1.2019	-5.0435	-15.8272	16.7407
Soil ph X_6	1.9907	2.5433	-1.6280	-11.9041	-0.1215	-0.0474	-0.0611	-15.3831	0.5957
Distance from water source X_7	0.0001	0.0002	-0.0002	0.0130	-0.0001	-0.0013	0.0005	-0.0018	0.0004
Distance from road X_8	0.0003	-0.0065	0.0003	-0.0144	0.0001	-0.0014	-0.0004	0.0014	0.0043
Distance from residential area X_9	0.0003	0.0011	-0.0033	-0.0223	0.0005	-0.1571	-0.1392	-0.0047	-0.0010
Vegetation coverage X_{10}	-2.9888	-0.6348	25.6287	114.0542	5.1558	-1.0185	6.0541	1.5090	-24.2563
Constant	4.9313	1.1928	-16.9324	-205.4083	-16.9483	-8.6652	14.4926	100.8256	24.8889

Table 3. Land use changes before and after optimal allocation of land resources in Fengweihan City, Kaishan, Laos

Land type name	Current situation in 2020		2035 Planning		Difference between planning and current situation	
	Area/km^2	**Proportion/%**	**Area/km^2**	**Proportion/%**	**Area/km^2**	**Proportion/%**
Paddy field	152.06	23.38	299.78	46.08	147.72	22.71
Garden plot	1.70	0.26	1.57	0.24	-0.13	-0.02
Crop planting	3.53	0.54	3.53	0.54	0.00	0.00
Other agricultural land	0.61	0.09	0.61	0.09	0.00	0.00
Forestry land	407.48	62.64	221.40	34.03	-186.08	-28.61
Urban construction land	33.25	5.11	69.12	10.63	35.87	5.51
Land use for rural construction	13.12	2.02	16.60	2.55	3.48	0.53
Land of water resources	37.90	5.83	37.90	5.83	0.00	0.00
Other land	0.86	0.13	0.00	0.00	-0.86	-0.13
Total	650.51	100.00	650.51	100.00	0.00	0.00

The change of land use type is mainly the transformation of forestry land and other land to paddy field and construction land (**Table 3**). The land use mode is to develop and utilize sparse barren forest land with good water and soil resources and other land with the development potential of cultivated land and construction land. On the premise that the ecological land meets the requirements of regional ecological protection, improve the land use efficiency, ensure food production, and promote the development of urbanization.

4.2 Three-dimensional visualization of spatial allocation scheme of land resources

Using the digital elevation model data of the study area, through the ArcGIS platform, it is superimposed with the spatial optimal allocation data of land resources to generate a three-dimensional effect map of land use. Through the construction and analysis of the three-dimensional landscape pattern, it can provide convenient, intuitive, multi perspective and all-round decision-making basis for the planning and design at the micro level and the project layout.

The three-dimensional visualization process of the optimized configuration scheme is as follows: (1) converting the land of each county into vector data composed of regular grids of equal size of 100 ×100; (2) the data center points of the regular grid are extracted and intersected with the results of the spatial optimal allocation of land resources in each county to generate a point layer composed of regular point markers with land use attribute data; (3) this layer is superimposed with the digital elevation model of each county, and the three-dimensional visualization parameters are set to form a three-dimensional effect map of the spatial optimization layout of land resources in Fengweihan City, Kaishan (**Figure 4b**).

4.3 Space optimization results and analysis

The results show that the growth of construction land and paddy field scale and the reduction of forestry land scale are obvious, and the change range of other land is small. Kaishan Fengweihan has natural advantages in natural geography, such as water and soil resources and topography in Savannakhet plain and along the Mekong River, and has great potential for developing agricultural production. At the same time, as the provincial capital of Savannakhet Province, the second largest city of Laos and the economic center of Laos, Kaishan Fengweihan city has policy advantages in urbanization development and economic construction. The construction of grain production base and the development of special economic zones need to make a reasonable layout of its land resources to provide a foundation and guarantee for national and regional development.

In terms of spatial layout, the area where the forestry land in the study area is reduced is sparse trees, and the construction land and agricultural land expand to the undeveloped and sparsely distributed forestry land along the traffic and water system on the basis of the original useful land. The order of expansion space is controlled by the suitability, and the expansion scale is controlled by the results of structural optimization. The expansion area of construction land can be developed into new areas and special economic zones, and the expansion area of agricultural land can be developed into food production bases.

In terms of quantity structure, the planned paddy field area occupies the largest proportion, accounting for 46.08% of the total area of the study area; the second is forestry land, accounting for 34.03% of the total area of the study area; the third is construction land, accounting for 13.18% of the total area of the study area. The planned land use structure is relatively reasonable, which is in line with Laos' industrial development characteristics dominated by agriculture, and is conducive to giving full play to industrial advantages such as rice planting; at the same time, the proportion of ecological land is high. Through planning to improve the quality and ecological service value of the existing forestry land, we can create a good living environment in the region; in addition, appropriately expanding the scale of construction land to provide space for the construction of special economic zones and the development of urbanization is conducive to promoting the development of regional social economy and the improvement of residents' living standards.

In addition, through the three-dimensional visual expression of the results of the optimal allocation of land use space, it can more intuitively guide the micro land use decision-making and facility layout, so as to provide data support for the connection of various plans, and further provide data support for the urban construction and urban service functions of Kaishan Fengweihan City.

5. Conclusions and suggestions

5.1 Conclusion

This study combines suitability analysis, quantitative optimization and spatial optimization, and realizes the optimal allocation of land resources in the study area based on GIS spatial analysis technology, logistic regression analysis method and

CLUE-S model, providing decision support for accurately controlling land layout, preventing land resource waste and ecological environment damage.

Through the optimal allocation of land resources, the construction land and agricultural land in the study area have expanded to regions with better natural and regional conditions based on the current situation, and the scale has increased significantly. The scale of forestry land with poor quality is reduced and used more reasonably, so that the quality of all kinds of land is improved, the efficiency of land use is significantly improved, and it is conducive to the effective management of land resources.

The three-dimensional visual expression of the optimized configuration scheme is conducive to assisting in the construction site selection, industrial layout, transportation planning, engineering pipeline facilities layout, as well as the irrigation and drainage facilities layout of agricultural land, so as to provide a reference for the development of three-dimensional space in land use planning.

5.2 Suggestions

(1) While optimizing the spatial layout of forestry land, agricultural land and construction land in Kaishan Fengweihan City, we need to take into account the protection of the ecological environment. (i) Replan the low and sparse forestry land into street trees and shelter forests; (ii) from the perspective of regional overall planning, while developing special economic zones, food production bases and ecological protection in the region, we should implement the conversion of farmland to forests, afforestation and interregional collaborative planning in other suitable areas outside the region; (iii) draw strict protection red lines and implement special protection. Through the above measures, the current disordered forest land will be transformed into ecological forest dominated by tall trees, so as to improve land use efficiency, achieve the purpose of regional coordinated development, and promote the orderly management and zoning protection of land resources.

(2) Learn from the advanced experience of other countries and regions, establish and improve the planning management guarantee mechanism. With the continuous and in-depth cooperation between China and countries along the "Belt and Road", the development experience of China's special economic zones and grain production bases can be used for reference for Laos. At the same time, combined with the development status, characteristics, needs and future development goals of Kaishan Fengweihan City, on the basis of the research on the optimal allocation of land resources, the special economic zones, grain production bases and ecological protection areas should be rationally distributed, and a sound planning, management and guarantee mechanism should be established toromote the coordinated development of regional economic construction, agricultural production and ecological protection, and truly give play to the advantages of the study area as the economic center of Laos.

(3) Develop special economic zones by taking advantage of regional advantages, develop green agriculture and characteristic industries such as rice, coffee and tea by taking advantage of terrain and water and soil resources, and layout irrigation and drainage facilities and transportation facilities. Through the feedback of agriculture, tourism and other industries, we should promote the construction of agricultural modernization and mechanization, change the original agricultural production mode in some areas, improve agricultural production efficiency, liberate productivity, form a benign development model of mutual promotion among land, industry and productivity, and promote the development of regional economy.

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Conflict of interest

The authors declared no conflict of interest.

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