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Land-Use Pattern Evaluation Using GeoSOS-FLUS in National Territory Spatial Planning: A Case Study of Changzhi City, Shanxi Province

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Abstract: Land-use patterns have always been affected by urban development, and their structural optimization is of great significance to high-quality urban development. However, since the establishment of the spatial planning system, there are still a lack of methods for optimizing the land-use structure. To this end, the research proposes an analysis framework, and proposes the direction of land-use structure adjustment through the status analysis, potential evaluation, and LUCC simulation model, and provides a new idea and method of spatial planning. The research uses an analytical framework to analyze the case of Changzhi City, Shanxi Province, puts forward the problems existing in the process of its land use, and further proposes the direction and focus of the adjustment of the land-use structure. Results show that the spatial distribution of land in Changzhi City presents a "forest-farm-forest" characteristic, and forest land, farmland and grassland account for 85% of its total area. From 2010 to 2018, the grassland area in Changzhi City decreased the most to 3486.13 hm^2, and the comprehensive degree of land use increased from 235.88% to 236.73%; however, the cultivated land showed a downward trend. The construction land intensive utilization of Changzhi City is low, and the potential for rural construction land consolidation is high. In addition, the conversion probability of cultivated land in the Tunliu district and the conversion probability of construction land close to Luzhou district are relatively higher, which can be used as crucial areas for the future development of Changzhi City. In the process of urban development, cultivated land protection and construction land demand should be balanced.

Keywords: land use; spatial planning; framework; GeoSOS-FLUS; Changzhi

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1. Introduction

Rapid urbanization and economic development have resulted in a series of problems, including soil pollution, land degradation, and low land-use efficiency [1,2], which have a significant impact on the land and the environment [3,4]. Furthermore, sustainable land use and urban development pose a considerable challenge [5,6]. Given that land use is an artificial way of adjusting the land surface, it plays a vital role in the shaping of ecosystem functions [3]. Thus, many studies on land-use changes, driving mechanisms, and scenario simulations have been conducted [7–9].

With continuous economic and social development, different countries have explored and formed various types of spatial planning systems in the process of urbanization and industrialization. Since China's experience of problems such as human–land contradiction have become prominent, the urban area is rapidly expanding, the imbalance in regional development has intensified, and unreasonable land-use impedes the improvement of land-use efficiency and is not conducive to resource-intensive use and sustainable development [10]. Its territorial spatial pattern is also changing rapidly. In the process, China

has also gradually explored a variety of plans that fit the local situation. However, multiple management problems and a lack of overall space control have been experienced. To address these problems, the state implemented institutional reforms and decided to build the National Territory Spatial Planning System to promote the intensive use of land resources and sustainable development [11–14]. Making spatial planning in line with national conditions has become the focus of the current planning task. The optimization of land-use structure, as a part of the spatial planning system, balances social, economic, and ecological development goals, minimizes the conflicts between land uses, and further optimizes the use of space [15]. Optimizing the structure of land use and realizing the intensive use of land is vital to regional sustainable development [2].

The theory, method, and research scale of space optimization have attracted widespread attention. Koomen et al. [16] explored the supporting and guiding role of land-use change patterns for spatial planning based on land-use patterns in macro-planning policies. Todes [17] studied the use of spatial planning to solve decentralized problems in urban development in Johannesburg, South Africa. Studies in many countries mainly focus on the application of and relationship between land use and spatial planning. China's research on land-use optimization and its application in planning started relatively late. In recent years, the research results have been enriched, and land-use allocation and optimization and territorial spatial function zoning have been gradually developed and innovated. Several scholars have conducted studies on land use to achieve economic, ecological, economic–ecological, and other goals [18,19]. Their research objects include not only large-scale cities (such as urban agglomerations), semi-arid areas, and typical watersheds, but also the administrative scale of provinces, cities, and counties [20]. It also combines ecological functions and landscape patterns for research [21,22]. An increasing number of optimization methods have been developed with the deepening of study, including multi-objective programming, cellular automata (CA), and gray linear programming models [23]. Although there are various research methods of land-use structure optimization, most of them are single-model methods, especially in the spatial planning system, which has not formed a systematic framework and cannot provide a unified and applicable method system for the construction of spatial planning. Therefore, in the process of implementing spatial planning, the optimization of the land use structure in various regions increasingly requires a unified analysis process to identify the problems existing in the current land use, and then put forward suggestions on the critical directions of land use.

This study explores an analytical framework (Figure 1) to provide methodological support for understanding the existing problems in spatial planning land use and further optimizing critical directions. This analytical framework explores the characteristics and problems of current land use through the analysis of the current situation of regional land use. The framework analyzes the change rate of land use of various types through the dynamic degree of land use and uses the comprehensive index of land use to explore the degree of land use. At the same time, the intensive utilization degree, development potential and remediation potential of land use are obtained through potential analysis. Moreover, it uses the LUCC simulation model to simulate the land-use change. According to the existing research [24], the LUCC simulation model is divided into four categories: change description model, quantity prediction model, process-based simulation model, and hybrid simulation model. Researchers can choose different potential evaluation methods and LUCC simulation models according to their own needs. Based on this, the critical directions of regional land use are clarified. The analytical framework helps to better understand the mechanism and future development trend of regional land use change, to clarify the direction of critical use, and to provide scientific support for the adjustment of land use structure.

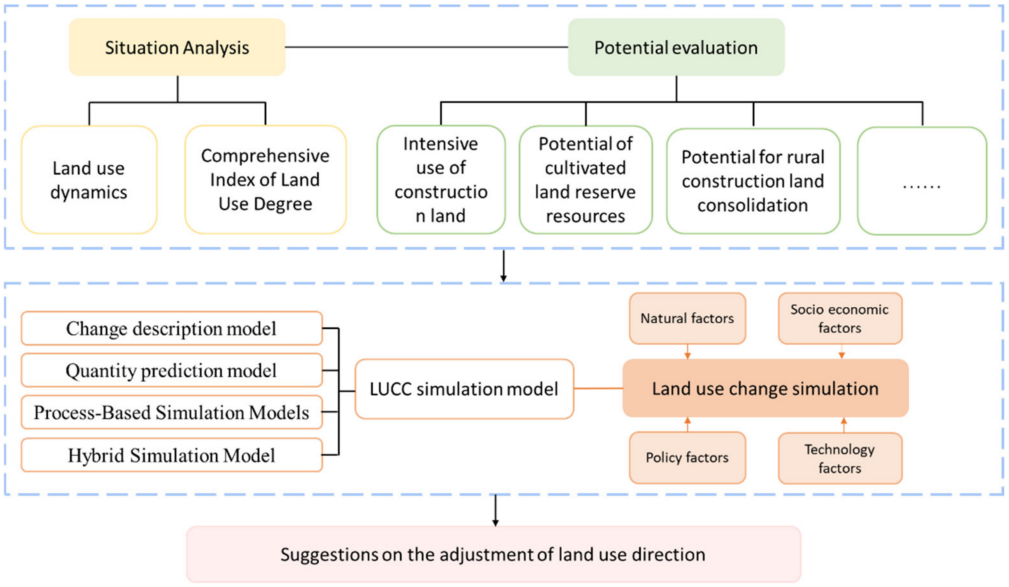

Figure 1. Analysis framework.

To this end, the study selects Changzhi City, Shanxi Province as a case to explore the feasibility of this framework. The purpose of the research is: (1) to analyze the current situation and structure of land use in Changzhi City; (2) to evaluate the potential of land use in Changzhi, and to discuss the problems of land use in Changzhi; (3) to explore the future land use situation of Changzhi City, and to propose critical directions for future land use. The research is beneficial to local ecological protection and urban development, as well as to optimizing land use. Utilization patterns and strengthening regional land-use efficiency can provide new ideas for optimizing land-use structures in spatial planning [25–27].

2. Materials and Methods

2.1. Study Area

As a significant coal province, the land-use structure and ecological problems of Shanxi Province have attracted great attention. Changzhi City is the selected research area. As a central regional city in the southeast of Shanxi Province, Changzhi is characterized by rapid economic development and rich mineral resources [28] and has an ideal ecological environment. Some areas exhibit conflicts between the ecology, minerals, land, and cities. The study uses an analytical framework to explore and analyze the problems existing in the process of land use, and to evaluate the potential of its land use. At the same time, GeoSOS-FLUS is used to explore the evolution probability of different land types to further clarify the critical directions of land use. This helps to improve the regional land-use efficiency, optimize the land-use pattern, protect the regional ecological environment, and at the same time provide a new idea for the optimization of land structure in spatial planning. Therefore, exploring the critical directions of land use in Changzhi is of great significance to improving its land-use efficiency and economic benefits, and to achieve sustainable use of land resources.

Changzhi City is located in the southeast of Shanxi Province, roughly between 35°49′ N and 37°08′ N, 111°58′ E and 113°44′ E (Figure 2). The total area of this region is 13,955 km^2, accounting for 8.90% of the total area of the province. After adjusting administrative divisions in 2018, Changzhi City has four districts and eight counties under its jurisdiction. Luzhou District, Lucheng District, Shangdang District, and Tunliu District constitute the scope of "one city and four districts". In addition, Changzhi is located in the "Golden Habitat Zone," with a typical warm temperate, semi-humid continental monsoon climate, with no severe cold in winter and scorching heat in summer. The city is located on the southeastern edge of the Loess Plateau, with a complex topography and undulating

mountains. Changzhi is mainly composed of two landform units, the Changzhi Basin and the surrounding mountainous areas, and straddles the two major basins of the Haihe River and the Yellow River. The region has many rivers, is rich in mineral resources, and is one of the critical coal-producing cities in the country. In the planning of Shanxi's territorial space development and utilization pattern, Changzhi, as the central regional city in the southeast, is not only the core area of subregional economic development in Shanxi Province, but also an important portal and carrier for Shanxi Province to open, connect, and integrate with the national strategic region.

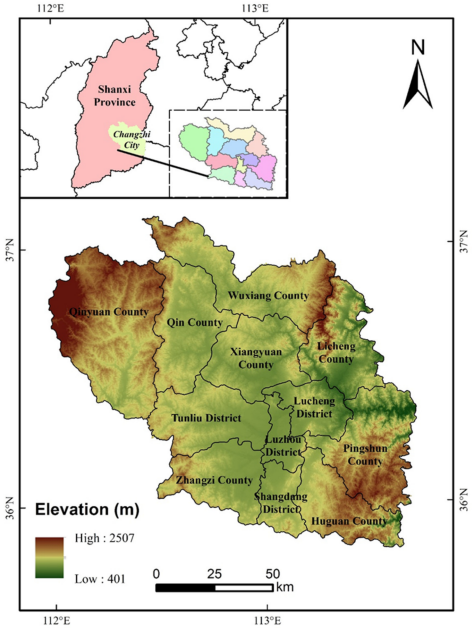

Figure 2. Location of the study area.

2.2. Data Sources

The land use data, population density, economic intensity, and other socio–economic data of Changzhi City in 2010, 2014, and 2018 were obtained from the Shanxi Provincial Statistical Yearbook (http://tjj.shanxi.gov.cn/tjsj/) (accessed on 15 October 2021). The city's land use types include cultivated land, garden land, forest land, grassland, urban village and industrial and mining land, transportation land, water area, water conservancy facility land, and other land. The land cover raster data were obtained from the resource and environmental science and data center of the Chinese Academy of Sciences (https://www.resdc.cn/Default.aspx) (accessed on 17 October 2021) platform. The classification scheme of the platform is cultivated land, garden land, forest land, grassland, water area, towns, villages, industrial and mining land, transportation land, waters and water conservancy facilities land, and other land. Altitude, slope, aspect, river, residential area, road, GDP, population distribution, and spatial distribution data were obtained from the National Catalogue Service for Geographic Information (https://mulu.tianditu.gov.cn/commres.do?method=dataDownload) (accessed on 18 October 2021).

2.3. Methods

2.3.1. Land-Use Dynamics

This study uses a single land-use dynamic degree (1) [29] (k) to study the rate of land use change in Changzhi City from 2010 to 2018. k can characterize the rate of change of a particular land use type in a specific period. If the absolute value k of is significant, then the land type change is fast. The calculation results are shown in Table 1.

$$k = \frac{(u_b - u_a)}{u_a} \times \frac{1}{T} \times 100\% \quad (1)$$

Table 1. Changes in land use types and areas in Changzhi City from 2010 to 2018.

Land Type	2010		2014		2018	
	Area (hm^2)	Proportion (%)	Area (hm^2)	Proportion (%)	Area (hm^2)	Proportion (%)
Cultivated land	360,765.48	25.85	358,926.58	25.72	358,483.27	25.69
Garden land	12,861.84	0.92	12,688.11	0.91	12,629.23	0.91
Forest land	497,616.79	35.66	496,796.20	35.60	496,417.95	35.57
Grassland	327,748.68	23.49	325,771.78	23.35	324,262.55	23.23
Towns, villages, and industrial and mining land	81,317.72	5.83	84,722.25	6.07	86,181.70	6.18
Transportation land	20,175.47	1.44	21,597.62	1.55	22,470.49	1.61
Waters and water conservancy facility land	19,242.87	1.38	19,041.36	1.36	18,970.50	1.36
Other land	75,793.55	5.43	75,978.50	5.44	76,106.71	5.45
Total	1,395,522.40	100	1,395,522.40	100	1,395,522.40	100

In the Formula (1), k represents the dynamic degree of single land use, u_a and u_b respectively represent the land area at the beginning and end of the research period of this type of land, and T represents the period time from the beginning to the end.

2.3.2. Comprehensive Index of Land Use Degree

The comprehensive index of land use degree (2) [30] is used to characterize the degree of land use in Changzhi City. Its size reflects the level of land use. The value range is 100–400. The larger the L value is, the higher the degree of land use will be.

$$L = \sum_{i=1}^{n} (A_i \times C_i) \times 100 \quad (2)$$

In the Formula (2), L represents the comprehensive index of land use degree, A_i represents the i-th level land-use classification index, C_i represents the percentage of the i-th level land area in the total land area of the year, and n is the land-use degree classification number. A_1 is other land, A_2 includes forest land, grassland, water area, and water conservancy facilities, grassland and water body, A_3 is cultivated land and garden land, and the land for towns and villages, industrial and mining land, and transportation land belong to A_4.

The change in the degree of land use in a specific area is the result of the changes in multiple types of land use. The degree of land use and its transformation can quantitatively reflect the comprehensive level of land use in the region. If ΔL_{b-a} (3) is greater than 0, the land use in this area is in the development period; otherwise, it is considered to be in the adjustment or decline period.

$$\Delta L_{b-a} = L_b - L_a \quad (3)$$

In the Formula (3), L_b and L_a are the comprehensive indexes of the degree at the beginning and end of the study period, respectively.

2.3.3. Potential Evaluation

The development of urbanization has led to the continuous expansion of construction land, and more and more attention has been paid to how to expand it more reasonably and effectively and improve its intensive utilization. In the process of urbanization, the population continues to migrate to the cities, which makes the population in rural areas gradually decrease, and much construction land is idle, so it is necessary to remediate the idle land. At the same time, the protection of cultivated land is crucial to food security. Therefore, the research selects the evaluation of construction land intensive use, the potential evaluation of cultivated land reserve resources, and the evaluation of rural construction land consolidation potential to evaluate the land-use potential of Changzhi.

(1) Evaluation of Intensive Use of Construction Land

The conservation and intensive use of construction land is evaluated to grasp the situation comprehensively and potential of the conservation and intensive use of regional and urban construction land, scientifically manage and rationally use construction land, improve land-use efficiency, and formulate land policies and regulations for the state and governments at all levels. Measures provide a scientific basis for formulating land use and related plans. Using the relevant requirements in the "Guidelines for the Compilation of Municipal Land and Space Master Plan (for Trial Implementation), based on the technical steps and technical methods of "Construction Land Conservation and Intensive Utilization Evaluation Regulations" [31], evaluation indicators were selected, an evaluation index system was established, and the intensive utilization of construction land in Changzhi City was evaluated.

Evaluation Procedures for Economical and Intensive Utilization of Construction.

This evaluation selected nine indexes, namely, the Population Density Index (PUII), the Economic Intensity Index (EUII), the Construction Intensity Index (CUII), the Population Growth Index (PGCI), the Economic Growth Land Consumption Index (EGCI), the Population Land Elasticity Index (PEI), the Economic Land Elasticity Index (EEI), the Population Contribution Index (PCI), and the Economic Contribution Index (ECI), and ten sub-indexes as evaluation indicators, and their weights were calculated. These indicators can reflect construction land-use intensity, growth land consumption, land use flexibility, and the contribution of population and economy, and are scientific and feasible.

(2) Evaluation of the Potential of Cultivated Land Reserve Resources

The development of cultivated land reserve resources is an important issue related to food security, and the evaluation of the development potential of cultivated land reserve resources is essential for developing cultivated land reserve resources. The standard cloud model and the entropy weight method are introduced into the evaluation of the development potential of regional cultivated land reserve resources, and an evaluation index system that comprehensively considers the three aspects of ecology, nature, and social economy is established to quantitatively measure the development potential of regional cultivated land reserve resources. The evaluation of the cultivated land reserve resource development potential, with cultivated land reserve resources as the evaluation object, and districts and counties as the evaluation unit, provides qualitative and quantitative descriptions of the complex and diverse cultivated land reserve resources of Changzhi City and various districts and counties.

Based on the natural and ecological conditions and the development characteristics of the social economy in Changzhi City, according to the principles of hierarchy, scientificity, completeness, comparability, data availability, and operability followed in the assessment of cultivated land reserve resources, the complex relationship of evaluation factors in the evaluation of cultivated land reserve resources development potential is fully considered. Meanwhile, based on the latest relevant research results [32], an evaluation index system of three levels is established, namely, the target, criterion, and index levels, and four indicators in the evaluation of the development potential of cultivated land reserve resources in Changzhi City.

Using the established evaluation index system and the evaluation criteria for the development potential of cultivated land reserve resources in Changzhi City, which correspond to the evaluation index data of the development potential of cultivated land reserve resources in various districts and counties of Changzhi City, the scores of every single factor of each district and county are calculated. Then, according to the weight of the evaluation index, the comprehensive score of the development potential of the cultivated land reserve resources of each district and county is calculated. On the basis of the comprehensive evaluation of the typical cloud model, the evaluation results of the development potential of cultivated land reserve resources in Changzhi City can be obtained.

(3) Evaluation of the Potential for Rural Construction Land Consolidation

According to the current situation of cultivated land utilization in Changzhi City, the area of agricultural land to be reorganized in the city is determined as the cultivated land to be reorganized, and statistical and spatial analyses are performed to assess the scale of agricultural land that can be reorganized [33].

Administrative villages are taken as a unit to investigate the area of auxiliary production and sporadic lands, such as rural roads, ditches, and ridges, in the agricultural land to be reorganized. Their proportion to the total area of the area to be reorganized and determine the differences based on the completed agricultural land reorganization projects. he unit's auxiliary production land standard coefficients are used to calculate the area of cultivated land that can be increased through consolidation. This study uses the difference between the current per capita rural construction land area and the nationally specified 150 m^2 for calculation.

2.3.4. GeoSOS-FLUS

Currently, the commonly used models for land-use change simulation include the system dynamics model (SD), CA–Markov model, CLUE-S model, etc. Still, they have poor ability to describe the spatial pattern of land use and fail to fully consider the multi-factor driving of land use. Impact and other issues (Xueran Wang et al., 2021). The FLUS model [34], based on the coupling of the system dynamics model (SD), neural network (ANN), and cellular automata model (CA), can show the probability of land conversion under the combined action of natural and human activities. The evolution of landscape patterns can be deeply analyzed [35,36].

The research intends to use the selected geographic simulation software (GeoSOS-FLUS) [34] to simulate the land use pattern of Changzhi City. GeoSOS-FLUS can use an artificial neural network (ANN) algorithm to obtain the conversion probabilities of various land use types within the research scope through the first phase of land use data and various driving factors, including human activities and natural effects. The output layer of the neural network will generate a value representing the probability of occurrence of the first land use type in the grid unit. A high value indicates that a particular grid unit has a high probability of conversion to the target land use type. In the case of training time, the occurrence probability of the land use type on the grid unit can be expressed as follows (4):

$$Pp,k,t = \sum_j w_{jk} \times sigmoid(net(p,t)) = \sum_j w_{jk} \times \frac{1}{1+e^{-net(p,t)}} \quad (4)$$

where $P(p,k,t)$ represents the probability of suitability of the k-th type of land at time t in grid p; $net(p,t)$ is the signal received by the neuron in the hidden layer; w_{jk} is the adaptive weight between the hidden and output layers and calibrated during the training process; *sigmoid* connection between the hidden and output layer is determined by the activation function.

Based on land use raster data, combined with natural background data and socio-economic statistical data, the research carried out probabilistic reasoning on the evolution of land use patterns in Changzhi City. The study aims to explore and analyze the formation and evolution process of land-use landscape patterns. On the basis of referring to similar studies [36,37] and considering local conditions, the study selects two types of driving force factors that characterize the impact of natural terrain and socio–economic effects (Figure 3). The natural topography influencing factors include altitude, slope, aspect, and distance from rivers, and the socio-economic influencing factors include distance from residential areas, distance from roads, gross domestic product, and population distribution.

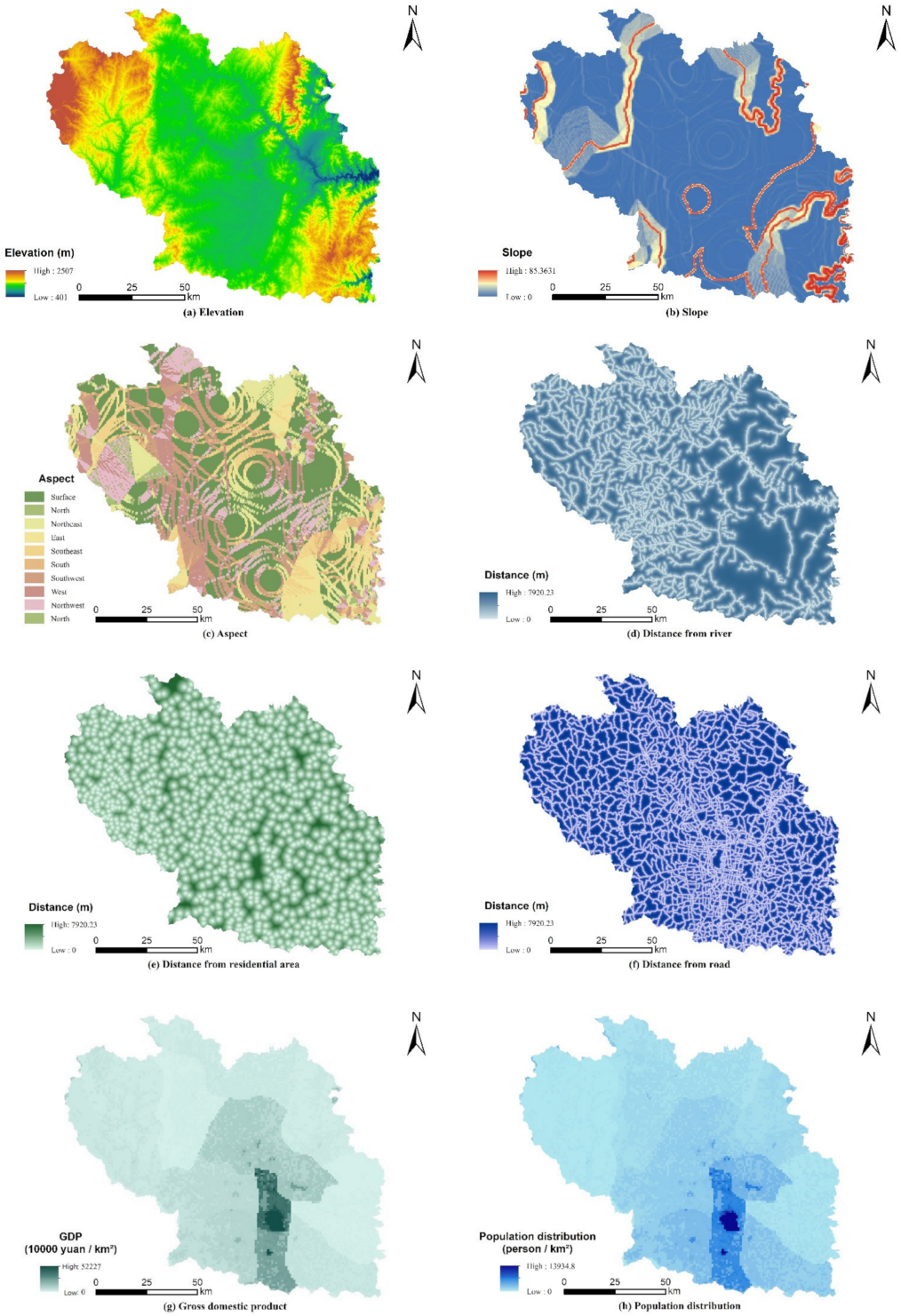

Figure 3. Driving factors. (**a**) Elevation; (**b**) Slope; (**c**) Aspect; (**d**) Distance from river; (**e**) Distance from residential area; (**f**) Distance from roads; (**g**) GDP; and (**h**) Population distribution.

3. Results

3.1. Changes in the Amount of Land Use

Tables 1 and 2 show that the change trends of the various land types in Changzhi City during the periods of 2010–2014 and 2014–2018 are the same. The main types of land use are forest land, cultivated land, and grassland, accounting for 85% of the total land-use area of Changzhi City. From 2010 to 2018, the areas of cultivated land, garden

land, forest land, grassland, water area, and water conservancy facilities declined, and the dynamic degree of land use was negative. Among them, grassland area decreased the most to 3486.13 hm^2, and the area of garden land decreased the least to 232.61 hm^2. Compared with the 2010–2014 period, the land-use dynamics of cultivated land, forest land, and grassland in 2014–2018 changed from −0.13, −0.04, and −0.15 to −0.03, −0.02, and −0.12, and their area decline decelerated. The area of urban villages, industrial and mining land, transportation land, and other land areas showed an upward trend from 2010 to 2018, and the dynamic degree of land use was positive. Among them, urban villages, industrial and mining land, and transportation land were the most significant, with an increase of 4863.98 hm^2 and 2295.02 hm^2 in 2010–2014 and 2014–2018, respectively, but their growth rates decreased from 1.05 and 1.76 in 2010–2014 to 0.43 and 1.01 in 2014–2018, while other land exhibited a relatively small increase of 313.16 hm^2.

Table 2. Dynamic degree of single land use.

Land Type	2010–2014		2014–2018	
	Amount of Change ($hm^{2)}$	Dynamic (%)	Amount of Change (hm^2)	Dynamic (%)
Cultivated land	−1838.90	−0.13	−443.31	−0.03
Garden land	−173.73	−0.34	−58.88	−0.12
Forest land	−820.59	−0.04	−378.25	−0.02
Grassland	−1976.90	−0.15	−1509.23	−0.12
Towns, villages, and industrial and mining land	3404.53	1.05	1459.45	0.43
Transportation land	1422.15	1.76	872.87	1.01
Waters and water conservancy facilities land	−201.51	−0.6	−70.86	−0.09
Other land	184.95	0.06	128.21	0.04

3.2. Changes in Land Use

Table 3 shows that the comprehensive degree of land use increased significantly from 2010 to 2018. Among them, the utilization of urban villages, industrial and mining land, and transportation land increased significantly, especially in 2010–2014. The utilization of other land increased slightly. Different land types, such as cultivated land, showed varying degrees of decline. Although the comprehensive degree of land use in Changzhi City showed an increasing trend from 2010 to 2018, the cultivated land with the highest degree of comprehensive land use exhibited a downward trend, mainly due to the decrease in the area of cultivated land, which significantly reduced its utilization. This phenomenon also shows that in urban construction and planning, if the land type transformed from cultivated land cannot be fully developed and utilized, it will be unable to provide the equivalent value of its historical use (Figure 4).

Table 3. Index of the comprehensive degree of land use in Changzhi City from 2005 to 2015/%.

Land Type	2010	2014	2018
Cultivated land	77.55	77.16	77.07
Garden land	2.76	2.73	2.73
Forest land	71.32	71.20	71.14
Grassland	56.98	46.70	46.46
Towns, villages, and industrial and mining land	23.32	24.28	24.72
Transportation land	4.76	6.20	6.44
Waters and water conservancy facilities land	2.76	2.72	2.72
Other land	5.43	5.44	5.45
Total	235.88	236.43	236.73

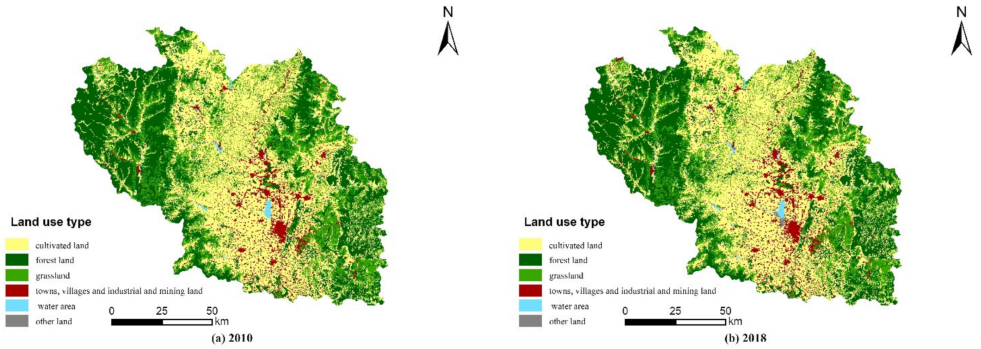

Figure 4. Land use types of Changzhi City in 2010 (**a**) and 2018 (**b**).

According to the calculation result of the degree of land use in Formula (3), the change in the degree of land use in Changzhi from 2010 to 2018 can be easily obtained as $\Delta L_{b-a} = 0.85 > 0$. On this basis, the land use of Changzhi can be considered to be in the development period (Table 3).

3.3. Potential Evaluation

Table 4 and Figure 5 reflect the potential evaluation of districts and counties in Changzhi City. "Low, Lower, Medium, Higher, High" in the figure represents the height of the potential size, and the higher the value, the greater the potential value.

Table 4. Potential Evaluation of Districts and Counties in Changzhi City.

Administrative District Name	Intensity of Construction Land	Cultivated Land Reserve Resource Potential	Rural Construction Land Consolidation Potential
Luzhou District	0.65	0.47	2545.60
Lucheng District	0.31	0.52	3696.08
Shangdang District	0.64	0.50	211.42
Tunliu District	0.27	0.30	5543.13
Huguan County	0.40	0.30	3959.63
Xiangyuan County	0.26	0.51	6998.42
Licheng County	0.22	0.64	1387.21
Pingshun County	0.23	0.33	603.09
Qinyuan County	0.42	0.07	1668.58
Qin County	0.19	0.38	2979.43
Wuxiang County	0.26	0.26	3483.17
Zhangzi County	0.14	0.26	5089.33

Table 4 and Figure 5a show that Luzhou District has the highest construction land intensive utilization degree, that is, 0.65, followed by Shangdang District's construction land intensive utilization degree of 0.64. By referring to relevant literature [38] and using the Delphi method, the intensive utilization of construction land in Changzhi City is divided into different types according to the degree of construction land intensity. The value 0.7 is more intensive; X < 0.5 is extensive. Overall, Changzhi City has no intensive construction land area. Only Luzhou District and Shangdang District are more intensive, and the rest of the districts and counties are extensive construction land areas. Thus, the intensive utilization of construction land in Changzhi City is relatively low, and its level of intensive utilization must be improved.

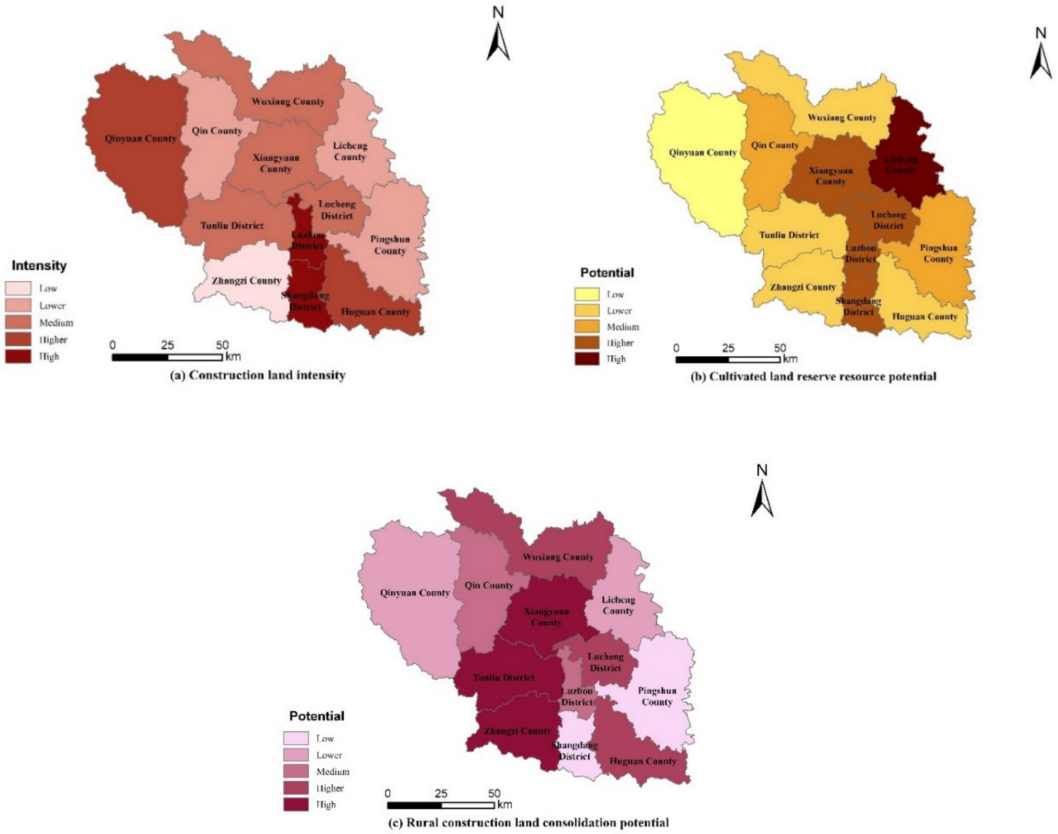

Figure 5. Potential distribution.

The reserve resources of cultivated land in Changzhi City generally have medium development potential (Table 4, Figure 5b), but specific regional differences exist. Among them, Licheng County has the highest development potential of cultivated land reserve resources, which is 0.64., followed by Lucheng District, Xiangyuan County, Shangdang District, and Luzhou District. The reserve resources of Wuxiang County, Qin County, Pingshun County, Tunliu District, Huguan County, and Zhangzi County have medium potential for the development of cultivated land reserve resources. The development potential of cultivated land reserve resources in Qinyuan County is 0.07, which is the lowest in Changzhi City.

The overall potential of rural construction land consolidation in Changzhi City is relatively high (Table 4, Figure 5c), and a large room for consolidation exists. Among them, Xiangyuan County has the most significant potential for construction land consolidation, followed by Tunliu District, with 6998.42 and 5543.13, respectively. Within the scope of "one city and four districts," the rural construction land consolidation potential of Shangdang District is the lowest at only 211.42. Although the construction land intensive utilization degree in Luzhou District is relatively high, an enormous potential for rural construction land consolidation remains. In the subsequent planning, low-utility and idle lands should be integrated to promote the economic and intensive use of land.

3.4. Probabilistic Evolution Reasoning

The probability of occurrence module of GeoSOS-FLUS is used to explain the probability of land use pattern evolution. Cultivated land, woodland, grassland, construction land, water area, and other land are mainly simulated, and the result is shown in the figure.

The cultivated land conversion probability map (Figure 6a) shows that the areas with high cultivated land evolution probability are mainly distributed in Tunliu District and Xiangyuan County in the central part of Changzhi City. The existing cultivated land in these two areas is higher than that of the other districts and counties. The area of urban and

rural construction land in Luzhou District and Lucheng District is high, and the probability of cultivated land conversion is low.

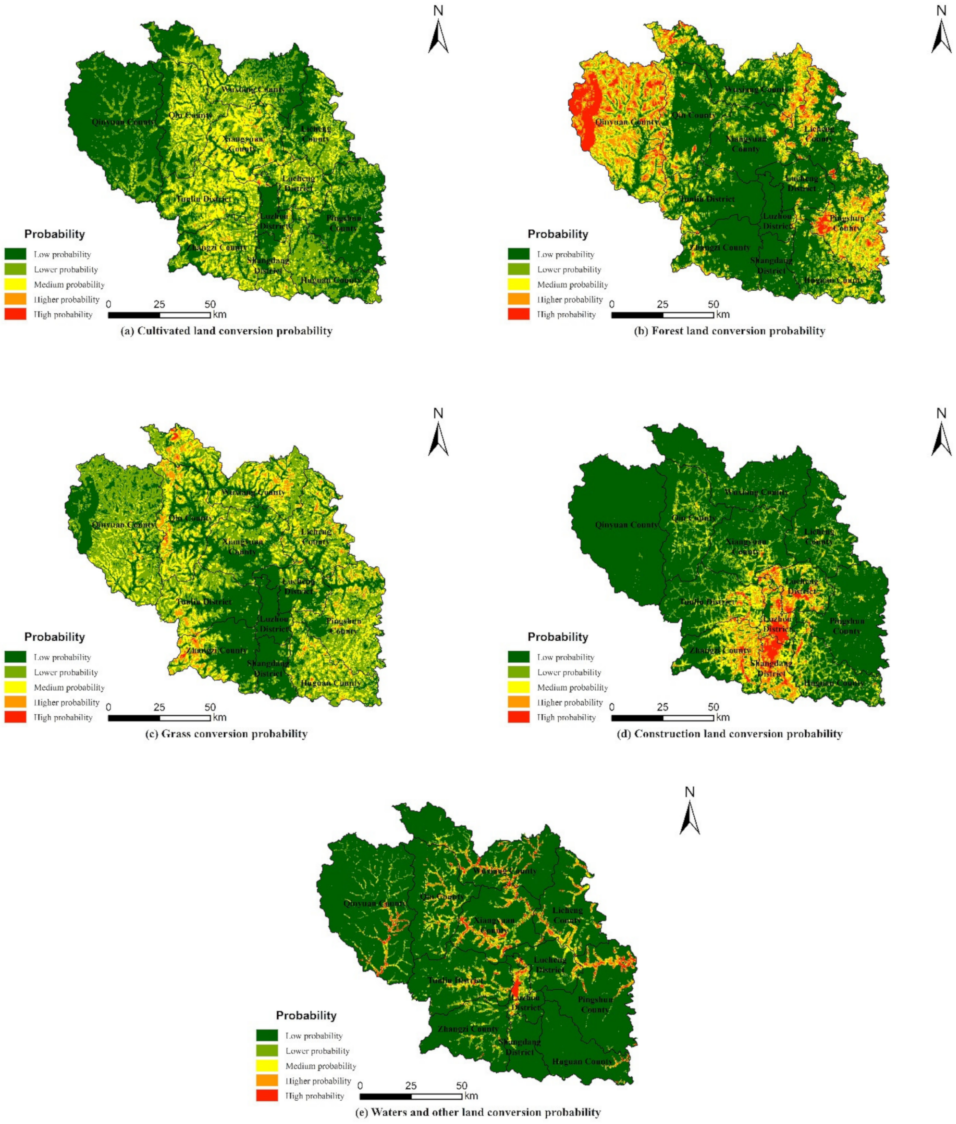

Figure 6. Probability distribution of land conversion: (**a**) Cultivated land conversion probability; (**b**) Forest land conversion probability; (**c**) Grass conversion probability; (**d**) Construction land conversion probability; (**e**) Water and other land conversion probability.

The forest land conversion probability map (Figure 6b) shows the woodland conversion probabilities and their differences in different regions. Qinyuan County, Licheng County, and Pingshun County have many high probability areas. Changzhi City is surrounded by mountains and has more mountains than plains. Forest land is the principal land type in this city. Under the constraints of natural conditions and the red line of ecological protection, forest land is expected to remain the primary land type in Changzhi for a long time. The distribution characteristics change slightly.

The grassland (Figure 6c) and the water and other land conversion probability maps (Figure 6e) show that the high-probability area is still on the same land type plate, and the number of conversions from other land types is small. Among them, the conversion probability of grassland within the scope of "one city and four districts" is the lowest, and the high probability areas are mainly concentrated in the Qinxian and Tunliu districts.

The construction land conversion probability map (Figure 6d) shows that the existing construction land area of land within the "one city and four districts" area is the largest,

and the high conversion probability area accounts for the largest proportion. As a relatively active land use type, the conversion of construction land shows an "expansion" trend.

4. Discussion

4.1. Overall Spatial Pattern of Changzhi City

According to the current state of the land and space structure of Changzhi City, the development and protection of land and space in Changzhi City present an overall pattern of "one center, one circle, two rivers, and three districts." "One center" means one city and four districts. "One center" is the growth pole of urban development and the core of building a central regional city in the southeast region of Shanxi Province and participating in regional competition and cooperation. "One circle," namely, the Changzhi metropolitan area, is the main body of building a central regional city in the southeast of Shanxi Province and the main area of population and urban economic agglomeration. "Two rivers" refer to the ecological corridors of the two major water systems of the Qin River and the Zhuozhang River that strengthen the river basin governance and enhance ecological functions. "Three districts" refer to the two environmental barrier areas of Taihang Mountain and Taiyue Mountain and the agricultural area of the Zhanghe River Valley Basin.

The main function area plan is divided into the national agricultural product main production, provincial agricultural product main production, regional urbanization development, and provincial critical ecological function areas. The main agricultural production areas are areas that have good agricultural production conditions and provide agricultural products as the main function. The main national agricultural production areas include Tunliu District, Zhangzi County, Xiangyuan County, and Qin County, and the main provincial agricultural production areas are in Wuxiang County, and these areas have large, cultivated land and grain output, which ensure the supply of grain and other agricultural products. The provincial-level urbanization development zones mainly include Luzhou District, Lucheng District, and Shangdang District. These areas are densely populated and have a high development intensity, a large construction land, and a relatively developed economy. The critical provincial ecological function areas include Pingshun County, Licheng County, Huguan County, and Qinyuan County. The forest land and grassland area are relatively large, and the biodiversity and the ecological protection are good.

The area of the ecological red line designated by Changzhi City accounts for approximately 19% of the entire city, which is mainly distributed in the western region of Qinyuan County, the northwest of Qinxian County, Pingshun County, and Huguan County, and the junction of Licheng County, Wuxiang County, and Xiangyuan County. Among them, the core areas of nature reserves are mainly distributed in the Shanxi Lingkong Mountain National Nature Reserve in the west of Qinyuan County, the Shanxi Mianshan Provincial Nature Reserve, the Shanxi Zhuozhang River, the Provincial Nature Reserve in Qinxian County, and the Shanxi Central Mountain Provincial Nature Reserve in Licheng County. Permanent basic cultivated land is designated in the whole city, accounting for approximately 21% of the entire city and mainly distributed in Tunliu District, Changzi County, Xiangyuan County, Qin County, Wuxiang County, and other areas with a large, cultivated land area. The urban development boundary mainly delimits the centralized construction and flexible development zone at the present stage. The urban development boundary delimited by Changzhi City is primarily concentrated in Luzhou District and its junction with surrounding districts and counties and the central area of other counties.

The land use of Changzhi City should focus on the development of urban construction within the scope of "one city and four districts" but pay attention to avoiding basic farmland and nature reserves within the urban area, and do an excellent job in related protection work. It is necessary to combine the planning of main functional areas, give full play to regional advantages, ensure the supply of agricultural products, and pay attention to ecological protection during economic development to form a characteristic regional economy.

4.2. Land Use Problems in Changzhi City

The above analysis indicates that the land use in Changzhi City is dominated by agricultural land, such as forest land, cultivated land, and grassland, and shows apparent spatial distribution characteristics of "forest-cultivation-forest" from west to east. Forest land is mainly distributed in the west, the east, and the northeast, cultivated land is primarily distributed in the middle of Changzhi City. Construction land is primarily distributed in the urban centers of various districts and counties, of which Luzhou District is the most obvious. The area of construction land in Changzhi City is relatively small, reflecting the small scale and urban capacity of the city center of Changzhi. Therefore, the development and construction of the city will still be accelerated in the future. In addition, nearly half of the other land in the city is bare land. Rivers, lakes, and tidal flats account for more than 90% of Waters and water conservancy facilities land. Few other lands have development potential. Intensification should be strengthened in the process of land use to utilize to improve the degree of land utilization. From an overall point of view, the scope of construction land continues to expand to the periphery. As an important development area, "one city and four districts" has the most construction land in Changzhi City and a large amount of cultivated land around the construction land. With continuous deepening, the occupation of cultivated land is inevitable. From 2010 to 2018, the comprehensive degree of land use in Changzhi City showed an increasing trend. Still, the cultivated land with the highest comprehensive degree of land use showed a downward trend, mainly because the reduction of cultivated land significantly reduced its utilization. This phenomenon also indicates that in urban construction and planning, if the land type transformed from cultivated land cannot be fully developed and utilized, it will be unable to provide the equivalent value of its historical use. Therefore, ensuring the amount of cultivated land and completing the conversion between different land types in the specific planning also requires further discussion.

The exploration of the characteristics of land use in Changzhi City reveals that many problems remain in its current land use. First, the amount of cultivated land decreased by a significant amount, and apparent contradiction between people and land. As the population continued to increase, the large decrease trend in cultivated land was not effectively controlled, and the total cultivated land and per capita cultivated land continued to decline. From 2010 to 2018, the city's population increased by 55,900 annually, while the city's cultivated land decreased by an average of 2662.48 ha per year; the city's per capita cultivated land was 0.10 ha, and notable contradictions between human and cultivated land. Second, the land use structure was unreasonable, and it has a weak land ecological environment. The land reclamation rate in Changzhi City is relatively high. In contrast the ratio of forest (fruit) animal husbandry land is relatively small, and the proportion of forest land in the forest is small, the coverage rate of forest and grass vegetation is low, and the land-use structure is not reasonable enough. Thus, the city's comprehensive land production potential and advantages are not fully utilized; in mountainous and hilly areas, except for some natural forest concentrated areas where the natural vegetation coverage is relatively high, other areas have serious soil erosion and a fragile ecological environment, which affect the land ecological environment of the city. Third, the land use is relatively extensive, and the degree of intensive use is low. Among the used lands, the problems of comprehensive land use and low degree of economy and intensiveness remain. The main manifestations are as follows. First, regarding agricultural land and its utilization, the proportion of low- and medium-yield fields and orchards is relatively large, and the phenomenon of land abandonment is still relatively serious. Second, construction land is still mainly extended by extension, and a certain amount of idle land and inefficient use of stock construction land can be observed within it.

4.3. Suggestions on Critical Directions of Land Use

To shape a high-quality territorial space, promote the modernization of territorial space governance system and governance capabilities on the basis of the premise of coordinating

supply and demand, and improve both ecological and economic benefits, the critical directions of land use are clarified on the premise of coordinating supply and demand and aiming at the dual improvement of ecological and economic benefits. Cultivated land, forest land and various construction land are still the focus of future land use. Using the analysis framework to analyze the status quo of land use, potential evaluation and probabilistic evolution reasoning in Changzhi City can provide a reference for the adjustment of land use direction to a certain extent.

Changzhi City has more mountains than plains, and forest land is the primary land type. With the gradual combination of ecological civilization and planning, forest land is expected to remain the main land type in Changzhi City for a long time, and the distribution characteristics show little change. The intensive utilization of construction land in the counties and districts of Changzhi City is low. This finding can be attributed to its low level of urbanization and small economic aggregate, and the land use is basically in the transition stage from extensive to intensive use. In addition, noticeable regional differences exist in the level of intensive use of construction land in Changzhi City. The uneven economic development and different local natural conditions have led to the uneven construction use land in Changzhi City. Luzhou District and Shangdang District, which have high economic development levels, have intensive construction land use. The level is also high. Therefore, the economically underdeveloped regions should be active in their economic development level, learn from the experience of developed areas, and strive to improve the level of intensive use of their construction land. The areas with a high potential for cultivated land resources in Changzhi City are primarily located in Licheng County, Xiangyuan County, and other areas. However, Qinyuan County has a large forest land area and is affected by ecological protection and other planning. The county's cultivated land development is subject to certain restrictions, so the development potential of its cultivated land reserve resources is low. The rural construction land consolidation potential of Changzhi City is relatively high, and a large room for remediation exists. The rural construction land consolidation potential in Shangdang District is the lowest, and its construction land intensive utilization degree is high, indicating that the level of intensive use of the construction land of Shangdang District is relatively high. Although Luzhou District has a relatively high degree of construction land intensiveness, a large potential space for rural construction land consolidation remains. In future planning, inefficient and idle lands should be integrated, and land use supervision and management should be strengthened.

Overall, the suggestions for adjusting the direction of land use in Changzhi are as follows. First of all, "one city and four districts" should be regarded as critical areas. Among them, Tunliu District, as an area that has just been included in the construction scope of the main urban area, has a considerable amount of arable land, a high conversion probability of arable land, and a large potential space for rural construction land consolidation. Intensive utilization of land is low; however, as a critical development area in the process of urbanization, it should integrate low-efficiency land and idle land within it, and expand the scope of construction land. In addition, the conversion probability of construction land in Tunliu District, which is adjacent to the old city Luzhou District, is higher, which is consistent with the general urban expansion law. However, as the main production area of national agricultural products, the protection of cultivated land is very important. Therefore, in the process of urban expansion, it is necessary to pay attention to the development and utilization of land in Tunliu District and coordinate the protection and development of cultivated land for construction land demand, etc. Secondly, the conversion probability of cultivated land in Licheng County and Xiangyuan County is relatively high, and the development potential of cultivated land reserve resources is large. The existing cultivated land should be further protected, and other land types in the region that can be reclaimed into cultivated land should be developed, expanding the guarantee of food supply. In addition, Xiangyuan County and Changzi County have high potential for rural construction land consolidation, and there are many inefficient and idle land in the region,

which can be reclaimed into arable land to provide more guarantee for food security or can be converted into arable land as needed. Other land types will further improve the efficiency of land use. As for Changzi County and Qin County, which have a low degree of construction land intensiveness, in the subsequent adjustment, they should focus on improving their degree of intensification to ensure the effective use of land.

4.4. Deficiencies and Prospects

The research analyzes the land use situation in Changzhi City and puts forward suggestions for the future land use direction, which not only provides scientific support for regional development, but also provides ideas for building a unified land-use optimization analysis process. The research only proposes the general direction of land-use structure in space, but still lacks the prediction and analysis of the quantity of different land use and does not quantify the specific prediction situation. The follow-up should focus on the quantitative prediction of land use types and build the best method of land use quantification in the long-term planning process. At the same time, the evaluation of regional potential should be further refined, the smaller administrative regions should be evaluated, the specific potential scope should be clarified, and the direction of land use should be more carefully judged. In addition, in the following research, we combine landscape evaluation with ecological evaluation to more comprehensively determine the direction of critical adjustment of land use structure, which is widely used in spatial planning.

5. Conclusions

This study used ArcGIS spatial data analysis methods with land use dynamics, the land-use the comprehensive index, and other methods to analyze the characteristics and problems of the current land use in Changzhi City. Using GeoSOS-FLUS to explore the suitability probability distribution of various land types and combining the construction land intensiveness, cultivated land reserve resource, and rural construction land consolidation potential evaluation results, the direction of land spatial structure adjustment in Changzhi City is proposed. Changzhi cultivated land, forest land and grassland accounted for more than 85%, and their area decreased from 2010 to 2018. Luzhou District has the highest construction land intensity at 0.65. Licheng County (0.64) has the highest development potential for cultivated land reserve resources. Xiangyuan County and Tunliu District have the most significant potential for construction land consolidation, 6998.42 and 5543.13, respectively. In Changzhi, there are problems such as a large reduction of cultivated land in land use, prominent contradictions between man and land, and a low degree of intensive land use. Combined with the suitability probability distribution of each land use type, it is recommended to expand construction land with Luzhou District as the center, and Tunliu District as the center. In the area adjacent to Luzhou District with a large amount of construction land, the coordination of land use should be the focus of planning. The characteristics of this research are mainly reflected in the use of combined methods to explore the land use structure of Changzhi City, providing a new perspective on the optimization of the land use structure of Changzhi's long-term development, providing a new approach to the planning and design of land and space.

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