Research on Land Use Change Prediction in Harbin Based on PLUS Model

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Abstract: This study simulates and predicts land use changes in Harbin urban area in 2029 based on the PLUS model. Using two periods of Landsat8 OLI remote sensing image data in 2015 and 2022, change analysis of land use types is carried out. Fourteen driving factors such as natural and human factors are selected for driving force analysis, and the land use distribution of Harbin in 2029 is predicted. The research results show that the land use pattern of Harbin in 2029 presents "five parts of cultivated land, four parts of forest land, and half part of construction land". Urban expansion will mainly be concentrated around the main urban area. This study provides data reference and scientific basis for land use resource planning and natural ecological environment protection of Harbin.

Keywords: PLUS Model; Simulation; Land Use; Prediction; Research on Driving Forces

1. Introduction

Land use change has important impacts on social and economic development, ecological environment protection and other aspects [1]. Land use change research can help planners understand the rational use of land resources, the evolution of the ecological environment and the impact of urbanization on land use [2], and provide a reasonable scientific basis for formulating reasonable land use policies. Balance the relationship between population, development and the environment, scientifically and rationally allocate and utilize limited land resources, and achieve green sustainable development. This is not only related to food security and ecological environment issues, but also related to the long-term stable and sustainable development of local economy and society.

This paper uses the PLUS model and driving force analysis based on driving factors to analyze the land use change trend of Harbin, understand the causes of land type changes, and predict land use changes in 2029, which is of great significance for the future urban construction pattern and the rational use of land resources.

2. Review of the Current Research Situation

The LUCC model simulates and predicts the process and results of land use change by establishing mathematical or computer models. It provides important scientific support for land planning, resource management and sustainable development.

In 2021, Liang X and others proposed a cellular automata (CA) model based on raster data [2], namely the PLUS model, which is specifically used to simulate land use/land cover (LULC) changes at the patch scale [3]. The PLUS model combines the rule mining method of land expansion analysis (LEAS) and the CA model of multi-type random seed mechanism in order to explore the relationship between land expansion and driving factors more deeply and simulate and predict the evolution process of land use at the patch level. This innovative combination enables the PLUS model to provide more accurate and comprehensive simulation and prediction capabilities for land use/land cover changes, making the simulation and prediction capabilities more accurate and the data processing accuracy higher [4].

The organic combination of the two modules of PLUS model, LEAS and CARS, can deeply analyze the internal mechanism of land use change, significantly improve the accuracy and reliability of simulation [5], and provide strong support for sustainable land use.

3. Introduction to the Research Area and

Data

The terrain of Harbin urban area and its surrounding areas is mainly plain and is a part of the Northeast Plain. The terrain is relatively flat and open, with an average altitude of about 150 meters. There are local hilly landforms in the east and southeast. It belongs to a mid-temperate continental monsoon climate. The winter is long and cold. It is a famous "ice city" in China. The average winter temperature is around -20°C. The summer is short and cool. The average temperature in July is around 23°C, and the temperature difference between day and night is relatively large [6].

The research data selected in this paper are divided into remote sensing image data, social and economic data, climate and environmental data. The data sources and types are shown in **Table 1.**

Table 1. Data Sources and Types

Category	Data	Data Source
Remote sensing image data	Landsat8 OLI remote sensing image in 2015	Geospatial Data Cloud
	Landsat8 OLI remote sensing image in 2022	Geospatial Data Cloud
Social and economic data	Population	Resource and Environment Science and Data Center
	GDP	Resource and Environment Science and Data Center
	Highway	National Geographic Information Resource Directory Service System
	Railway	National Geographic Information Resource Directory Service System
Climate and environmental data	Soil type	Resource and Environment Science and Data Center
	Annual average temperature	Resource and Environment Science and Data Center
	Annual average precipitation	Resource and Environment Science and Data Center
	Elevation	Geospatial Data Cloud
	Slope	Generated from elevation
	Adjacent open water	National Geographic Information Resource Directory Service System

4. Current Status of Land Use

Based on the land use status maps of Harbin in 2015 and 2022, use ArcMAP software to perform necessary processing on the data and calculate the area and proportion of six types of land use [7], as illustrated in **Figure 1.**

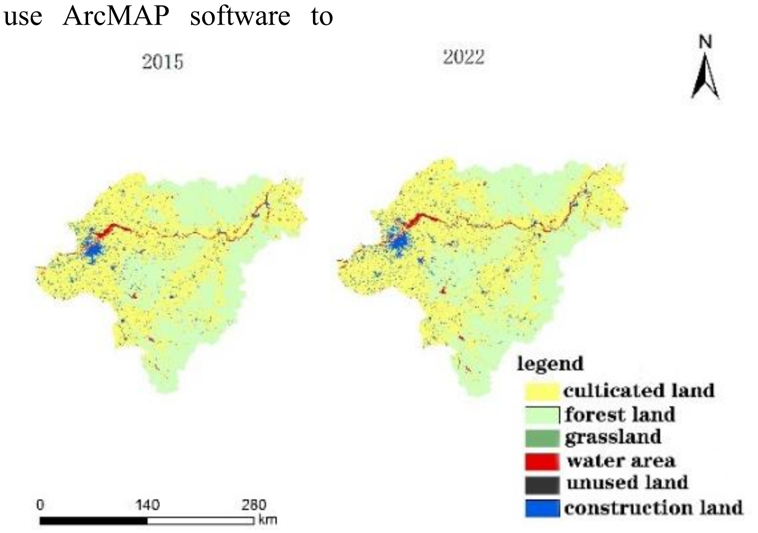


Figure 1. Land Use Changes

Woodlands are mainly distributed in areas such as Acheng, Shuangcheng, Binxian, and Mulan on the outskirts of the urban area, presenting a pattern of surrounding the city. Grassland resources are rather scattered throughout the city, mainly concentrated in Acheng, Shuangcheng, Binxian and other places, often interspersed with woodlands. Compared with 2015, it decreased by 0.03% in 2022. Cultivated land is mainly distributed in the suburbs and counties such as Siping, Wuchang, and Acheng, with a contiguous distribution. There is less cultivated land inside the city, while water system resources are abundant. The main ones include the Songhua River, Ashi River, Mulan River, etc., which run through the whole city. Its proportion decreased by 0.03% in 2022. Construction land is highly concentrated in the main urban area, distributed in strips along the main traffic arteries, with an increase of 0.49% in eight years. Unutilized land is mainly distributed in the outer suburbs and counties, mostly consisting of sandy land, tidal flats, wasteland, etc. as shown in **Table 2.**

Table 2. Various Land Areas in Harbin in 2015 and 2022

Land use type	2015	2022	Change amount
Cultivated land	51.98	52.54	0.56
Forest land	42.32	41.31	-1.01
Grassland	0.08	0.05	-0.03
Water area	1.58	1.52	-0.06
Unused land	0.007	0.03	0.023
Construction land	4.01	4.50	0.49

Based on the theory of Markov process, the dynamic change rules of land use in Harbin City are described through the transition probability matrix, as shown in the **Table 3.**

The comprehensive index of land use in Harbin City, Heilongjiang Province has shown an increasing trend in the past eight years. Due to national policy requirements and geographical location, Harbin City, Heilongjiang Province has abundant land resources and black soil. To ensure a good grain output and serve as the ballast stone for China's grain, the cultivated land area in Harbin City has gradually and steadily increased since 2015 to 2022. The land area of cultivated land in Harbin City is also gradually increasing. However, in recent years, with the vigorous development of the real estate industry, the area of construction land in Harbin City has steadily increased during this period. Human factors have played a positive and active role in the structural adjustment of land use [8]. Generally speaking, the degree of land resource development and utilization in Harbin City is at a medium level, and there is still considerable space for development and utilization.

Table 3. Land Use Area Transfer Matrix from 2015 to 2022

2015 \ 2022	cultivated land	woodland	meadow	water area	unused land	construction land	total
cultivated land	30062323	259045	17326	34782	253	267571	30641300
woodland	831437	24097572	714	2032	1	10278	24942034
meadow	23969	2675	14808	185	217	6983	48837
water area	45935	495	688	848516	16306	20521	932461
unused land	627	1	74	296	1753	1705	4456
construction land	293	0	9	14935	212	2350311	2365760
total	30964584	24359788	33619	900746	18742	2657369	

The characteristics of land use transfer in Harbin City are mainly the conversion into cultivated land and construction land, and mainly the conversion out of forest land. The area of forest land converted into other land types is 844,462 hectares, and the area of forest land converted into cultivated land is 831,437 hectares. The changes in cultivated land are mainly the conversion into forest land and construction land, with the converted areas being 259,045 hectares and 267,571 hectares respectively.

The Kappa coefficient was used to test the classification results. The accuracy of the Kappa coefficient of the classification results was 0.89069, and the overall accuracy was 0.939932. It was proved that the 14 selected driving factors, as well as the parameter settings of the LEAS module and the CASR module, fully met the requirements of this land use prediction experiment.

5 Analysis of the Driving Forces of Land Use Changes

Before predicting land use changes, appropriate driving factors should be selected according to the principles of availability, quantifiability, representativeness, relevance, and interpretability. The factors selected in this study mainly include the following 14 items,as shown in **Table 4.**

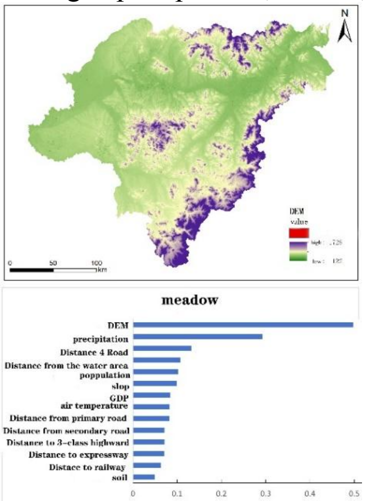
Table 4. Selected Driving Factors and Their Meanings

Data Classification	driving factor	description	function
socio-economic data	population	The population density of the unit grid	Represents the population spatial distribution
	GDP	GDP of the unit grid	Represents the spatial distribution of the economy
	railway	The distance between the unit grid and	Represents the accessibility of the

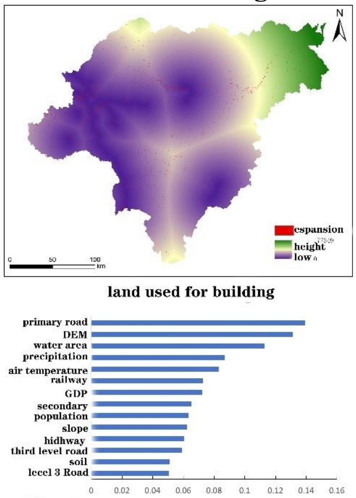
		the nearest railway	railways
	Highway (Class 1-4)	The cell grid is far away from the nearest grade highway	It indicates the accessibility of all grades of roads
	expressway	The unit grid is far away from the nearest highway	Represents the accessibility of the highway
Climate and environmental data	agrotype	Soil type of the unit grid	Represents the surface soil texture
	mean annual temperature	Aannual temperature per unit grid	Show climate conditions
	mean annual precipitation	Annual annual precipitation value per unit grid	Show climate conditions
	altitude	The elevation value of the unit grid	Topographic representation
	falling gradient	Slope value in the unit grid	Topographical ups and downs
	Nearby open waters	The unit grid is far away from the nearest water area	It means the ease of access to water resources

In this paper, the types of driving factors are divided into two major categories: socio-economic data and climate and environmental data. The driving factors of socio-economic data include eight driving factors (population, GDP, first-class roads, second-class roads, third-class roads, fourth-class roads, railways, expressways). The driving factors of climate and environmental data include six driving factors (soil type, annual average temperature, annual average precipitation, DEM, slope, proximity to open water bodies) [9,10]. The coordinate systems and spatial resolutions of the 14 driving factors are consistent with those of the land use data.

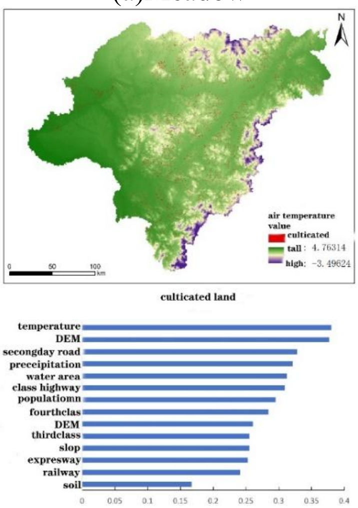
Add these 14 driving force factors to the LEAS module to explore their contribution degrees to the changes of six land types. Then, use the root mean square error value to verify the accuracy of the results. The contribution degree maps of driving factors for different land types are shown in the **Figure 2.**



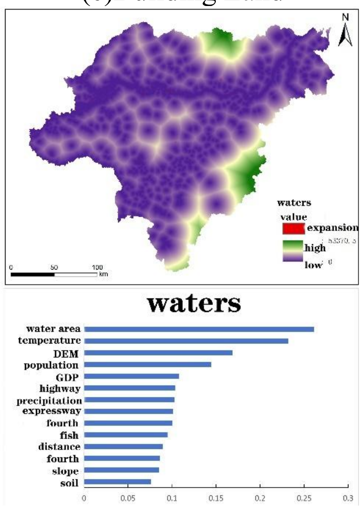
(a)Meadow



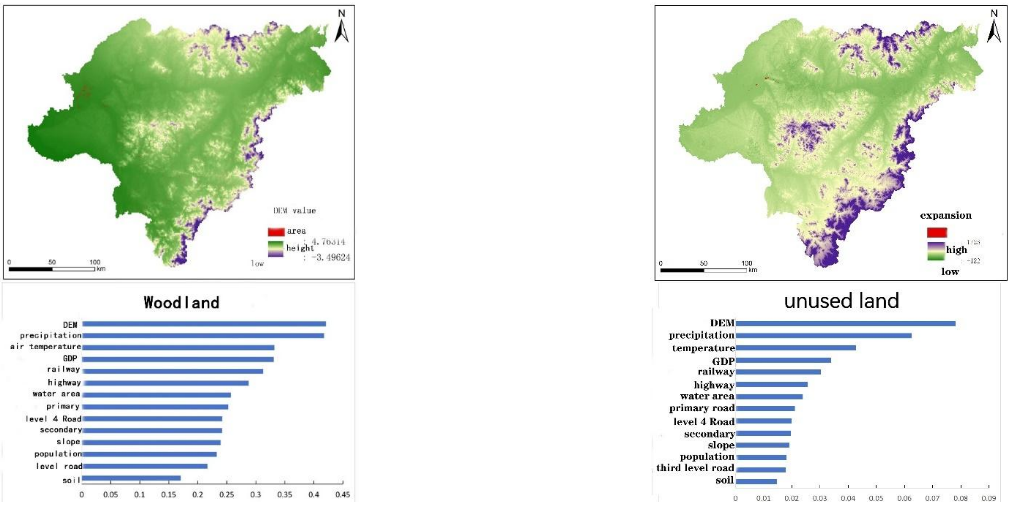
(c)Building Land



(b)Cultivated land



(e)Waters



(d)Woodland (f)Unused Land

Figure 2. Contribution Degree Map of Driving Factors of Six Land Types

6. Simulate the Land Use Changes in 2029

Based on the land use change data of Harbin City in 2022 and by making use of the development potential data of six land types from 2015 to 2022, the CARS model was run with the neighborhood weight parameters and transition matrix parameters set, so as to simulate and predict the land use data under the linear regression scenario and the Markov scenario in 2029, as illustrated in **Figure 3.**

To optimize the working process of the module, we take the following measures: Overlay the land use data of two different periods and identify the grid cells with state changes, where the grid cells are represented as the conversion areas of land use types. Mark the samples of the expanding land types as "1" and the rest of the samples as "0" to construct a training data set for the expanding land types. Then, apply the random forest classification algorithm to analyze the associations between the training data set and the 14 driving factors, thereby revealing the laws of changes in land use types.

Under the simulation of the two scenarios, in 2029, the areas of cultivated land, water areas, and construction land in the land use type structure of Harbin City all show an upward increasing trend, while the areas of forest land, grassland, and unutilized land are all on a downward trend.

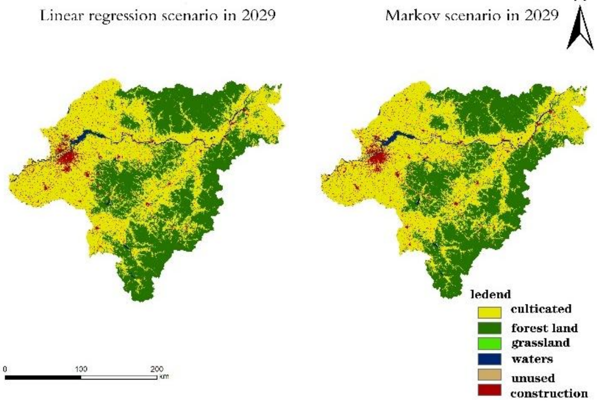


Figure 3. Land Use Change Prediction Map in 2029

7. Conclusion

Based on the PLUS model, this study predicted the land use pattern of Harbin City in 2029. The land use structure of Harbin City will undergo significant changes in the next seven years. The area of urban construction land will continue to increase, rising from 4.5% in 2022 to 5% in 2029, mainly concentrated in the main urban area and its surrounding regions. The area of agricultural land will show an upward trend, increasing from 52.54% in 2022 to 53% in 2029. The area of forest land shows a downward trend, decreasing from 43.31% in 2022 to 40.38% in 2029. The change in the area of other land types is relatively small, and the area of natural ecological land is relatively stable with little change in the future.

Analysis of the land use pattern in Harbin City shows that the land as a whole presents a pattern of "five-tenths of cultivated land, four-tenths of forest land, half a tenth of construction land and unutilized land". The forest land has the largest decreasing trend, while the cultivated land and construction land have the largest increasing amplitudes. It can be seen from the transfer matrix that the conversion mainly occurs from forest land to cultivated land and from cultivated land to construction land. The transfers are mainly the mutual conversions among cultivated land, forest land and grassland. This is based on the cultivated land protection policies in Harbin City. Heilongjiang is required to play the role of a ballast stone for food, and there are also policies in Harbin that clearly stipulate that agricultural land should be the main type.

Judging from the accuracy of the PLUS model in predicting the data of land use in Harbin City in 2022, the PLUS model has excellent accuracy in predicting the land use data of Harbin City and is scientifically reasonable. Continuing to use the parameter settings, the prediction results show that cultivated land, forest land and construction land are the main types. Among them, the growth amplitude of cultivated land is the largest, the forest land shows a decreasing trend, and the construction land also shows an increasing trend. From the perspective of distribution, the places where the cultivated land increases are mainly the areas bordering on the forest land, mainly encroaching on the forest land. The increase in construction land is concentrated on the expansion outward around the towns. The construction land in Harbin City is inclined to the western region. By 2029, the cultivated land and construction land in Harbin City will dominate, while the forest land will be significantly reduced.

Acknowledgments

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References

[1] Liu Y S. Urban-Rural Transformation Geography. Sustainable Development Goals Series, 2021. DOI: 10.1007/978-981-16-4835-9.
[2] Wu X, Shen C, Shi L, et al. Spatio-temporal evolution characteristics and simulation prediction of carbon storage: A case study in Sanjiangyuan Area, China. Ecological Informatics, 2024, 80. DOI: 10.1016/j.ecoinf.2024.102485.
[3] Huang P, Xie H, Yang Y, et al. Spatiotemporal variation in rice water requirements and area in the cold rice cultivation region of China: Past and Future. Agricultural Water Management, 2024, 298. DOI: 10.1016/j.agwat.2024.108858.
[4] Shi Y Z, Fan M Y, Liu H J, et al. Land use/land cover prediction based on land change modeler approach//International Conference on Environmental Protection and Sustainable Ecological Development. 2015.
[5] Deng X. Modeling the Dynamics and Consequences of Land System Change. Higher Education Press,2011.
[6] Yu J W, Jiang Y Q, Yan Y Q. A simulation study on heat recovery of data center: A case study in Harbin, China. Renewable Energy, 2018, 130:154-173. DOI: 10.1016/j.renene.2018.06.067.
[7] Wang T, Yang M H. Land use and land cover change in China's loess plateau: The impacts of climate change, urban expansion and grain for green project implementation. Applied Ecology and Environmental Research, 2018, 16(4):4145-4163. DOI: 10.15666/aeer/1604_41454163.
[8] Ponnambalam S G, Parkkinen J, Ramanathan K C. Communications in Computer and Information Science. 2012, 10.1007/978-3-642-35197-6(Chapter 32): 288-295. DOI: 10.1007/978-3-642-35197-6_32.
[9] Zhang J, Ding H, Xu J, et al. A Simulation-Based Prediction of Land Use Change Impacts on Carbon Storage from a Regional Imbalance Perspective: A Case Study of Hunan Province, China. Land, 2024, 13. DOI: 10.3390/land13101721.
[10] Liu K, Guo X, Lei B, et al. Relationships between land use pattern and surface water quality in Beijing. IEEE, 2014. DOI: 10.1109/IGARSS.2013.6723369.