Study on Spatial and Temporal Characteristics of Construction Land Expansion in Hohhot City Center, 1992-2022

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Abstract: Based on CLCD LULC data, this paper uses the ArcGIS 10.8 platform to analyze spatial data and discusses the expansion rate, expansion intensity, expansion direction, expansion type, and land use structure changes of construction land in Hohhot. The results show that the construction land area of Hohhot increased from 103.02 square kilometers in 1992 to 343.41 square kilometers in 2022, with an average annual expansion rate of 7.75 square kilometers and an expansion intensity index of 7.53. The city's expansion shows a staged character, with 2002 to 2012 as the period of rapid expansion. The direction of expansion is mainly concentrated in the northeast, southeast, east, and southwest directions, which is closely related to the city's economic development, natural conditions, and planning control. In terms of expansion types, infill expansion has dominated from 1992 to 2002, while marginal expansion has dominated from 2002 to 2012 and from 2012 to 2022. The land use structure has changed significantly, with a significant decrease in the area of arable land and grassland, a continuous increase in the area of construction land, and a slight increase in the area of forested land. During the 30 years, 242.51 square kilometers of land of various types have been converted into construction land, with arable land being the most converted, accounting for 71.51% of the total amount of converted land. The study concludes that urban land expansion in Hohhot is characterized by obvious spatial and temporal differences and phases, and strict land management methods need to be implemented to ensure the rationality and sustainability of land use. At the same time, arable land and the ecological environment damaged by urban expansion should be protected and restored through ecological compensation mechanisms.

Keywords: Urban Land Expansion; Spatial and Temporal Characteristics; Expansion Pattern; Hohhot City

1. Introduction

Over the past three decades, China has experienced an urbanization process of unprecedented speed and scale in human history [1-2], China's urbanization process is unique, extensive, and complex [3]. The rapid development of the urbanization process has caused many cities to face a huge demand for land. This has led to large-scale urban land expansion, accompanied by the waste of land resources and the destruction of the ecological environment. An in-depth study of urban land expansion and the changes in spatial and temporal characteristics is of great significance in revealing the multidimensional complexity of China's urbanization process and also provides strong theoretical support for the government to formulate urban planning and land management policies, which is of great academic and policy significance for the effective regulation of urban expansion and the optimal allocation of land resources. The study of urban spatial expansion has thus become a hot spot in the study of the urbanization process by many scholars. A large number of in-depth studies have been carried out on the urban land expansion model [4], the driving force mechanism [5], the ecological effect [6], the delineation of the urban growth boundary [7], and the spatial simulation prediction, etc. For Hohhot, Sun has conducted a series of in-depth studies. For Hohhot, Sun Zexiang et al. [8] analyzed the impacts of urban expansion on ecosystem services in the Hubao-Eqiu urban agglomeration; Dongmei et al. [9] monitored and analyzed the dynamics of urban expansion in Hohhot by using remote sensing imagery; Yang Yangguang et al. [10] discussed the

influencing factors of Hohhot's urbanization process in terms of economy and policy, and Zhen Jianghong [11-12] analyzed the expansion of Hohhot's urban land use and its drivers in detail and discussed the impacts of construction land expansion on the urban growth of Hohhot. Currently, most of the existing studies are based on certain time intervals, but there are few studies on the characteristics of changes based on longer consecutive years, and there is a lack of targeted studies on the economic development zones connected to the central city in the selection of the study area. Therefore, based on the land use data of Hohhot City, this paper analyzes five indicators, namely, expansion rate, expansion intensity, expansion direction, landscape expansion index, and land use structure, to characterize the spatial and temporal characteristics of urban expansion in Hohhot City, to provide examples and scientific support for the optimization of the spatial structure of land use in the future of the city.

2. Materials and Methods

2.1 Overview of the Study Area

Hohhot City is located in the central part of Inner Mongolia, China, with geographic coordinates between 110°46′-112°10′ east longitude and 40°51′-41°8′ north latitude, and has a mid-temperate continental monsoon climate. The territory is mainly divided into two major geomorphologic units, namely, the mountainous terrain in the northern Daqing Mountains and the southeastern Manhan Mountains, and the plain terrain in the southern and southwestern part of the Tumochuan Plain, with the topography gradually sloping from north-east to south-west. Hohhot is the capital of the Inner Mongolia Autonomous Region, one of the center cities of the Hohhot-Baotou-Ordos City Cluster, an important bridge connecting the Yellow River Economic Belt, Asia-Europe Continental Bridge, and Bohai Economic Rim, and also an important border opening center city of China opening to Mongolia and Russia. The study area is composed of 4 districts, namely Huimin District, Yuquan District, Xincheng District, and Saihan District, and their towns, as well as the Taigemu town of Tumotezuo Banner (including Jinchuan Economic Development Zone and Jinshan Economic Development Zone), with a total built-up area of 343.4km² in 2022.

2.1 Data Sources and Pre-processing

In this paper, the land cover data from 1992 to 2022 are selected from CLCD LULC, and the spatial resolution is 30m [13]. All the spatial data calculations are completed on the Arcgis10.8 platform. It should be noted that the urban construction land in this study refers to non-agricultural construction and production land that has been completed according to the layout of the urban construction plan, including the construction land for people's production and life in the urban area, and the rest of the construction land in the suburban areas that have a close connection with the city.

3. Research Methodology

3.1 Index of Time-varying Characteristics of Urban Building Land

In this paper, indicators such as expansion rate and expansion intensity are selected to study the expansion of the central city of Hohhot.

1) The rate of construction land expansion reflects the growth rate of construction land area expansion on the time series. The expression is:

$$V = \frac{S_{end} - S_{sta}}{T} \quad (1)$$

2) The Urban Expansion Intensity Index (UEI) is commonly used to assess the rate and intensity of urban growth in terms of land use for construction over a certain period, as well as the extent of the impact of urbanization on the surrounding area. Its expression is:

$$U = \frac{S_{end} - S_{sta}}{S_{sta} \times T} \times 100\% \quad (2)$$

In Eq. S_{end} , S_{sta} represents the construction land area at the end and beginning of the study period, respectively; T is the study time interval. The grading of the expansion intensity index is shown in Table 1 [14].

3.2 Index of Time-varying Characteristics of Urban Building Land

Types of urban built-up land expansion usually refer to the patterns of increase in built-up land area and changes in spatial distribution in the process of urban development. These types reflect the strategies and patterns of urban expansion and their relationship with socio-economic factors [15-17].

In this paper, the expansion direction, Landscape expansion index (LEI) is chosen to quantitatively identify the urban spatial expansion process. The LEI expression is:

$$LEI = 100 \times \frac{S_0}{S_0+S_V} \quad (3)$$

where LEI takes the value in the range of [0-100]. is the area of the expansion patch buffer coinciding with the original patch, and is the difference between the area of the expanded plaque buffer and the area of the original plaque, and the difference between the area of the expanding patch buffer and the original patch. The types of urban spatial expansion are divided into three types: enclave type, edge type, and infill type, as shown in Table 2.

Table 1. Extended Strength Index Grading

Extended Strength Class	High-speed Expansion	Rapid Expansion	Medium Speed Expansion	Low speed Expansion
Extended Intensity Index	9<U	6<U<9	3<U<6	0<U<3

Table 2. Classification of Urban Spatial Expansion Types

typology	LEI Range	clarification
enclave	0	Separation of new construction land patches from existing construction land patches
borderline	(0,50)	New building land patches expand along the edges of existing building land patches
filled	[50,100]	New building land patches infill within existing building land patches

4. Results and Analysis

4.1 Characterization of Temporal Changes in Building Land in Downtown Hohhot

This paper produces the urban land use change map of Hohhot city for the period of 1992-2022 (Figure 1), and extracts the number of 30-year construction land area in the central area of Hohhot city (Figure 2). The results show that the construction land area of Hohhot City increased from 103.02km² to 343.41km² from 1992-2022, with an annual expansion rate of construction land of 7.75km² and an expansion intensity index of 7.53; with time, the expansion of the construction land area was significant, among which the expansion area was the most between 2002 and 2012, with an expansion The amount is 110.44km².

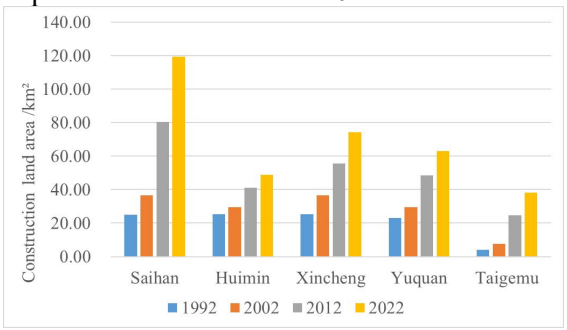

Figure 2. Map of Changes in Construction Land Area in the Study Area

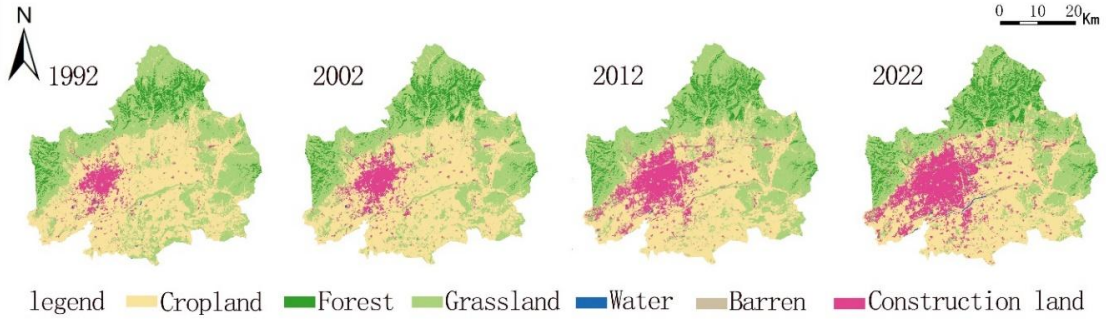

Figure 1. 1992-2022 Study Area Land Use Map

The expansion intensity of each district is consistent in different periods, but there are internal differences, with stage characteristics. In 1992-2002, the built-up area increased by 37.05 km² with an expansion intensity index of 3.60, which belongs to the period of medium-speed expansion; in 2002-2012, the built-up area increased by 110.44 km² with an

expansion intensity index of 7.88, which belongs to the period of rapid expansion; in 2012-2022, the built-up area increased by 92.91 km^2 with an expansion intensity index of 3.71, which belongs to the period of medium-speed expansion. From 2002 to 2012, the built-up area increased by 110.44 km^2, and the expansion intensity index was 7.88, which is a period of rapid expansion; between 2012 and 2022, the built-up area increased by 92.91 km^2, and the expansion intensity index was 3.71, which is a period of medium-speed expansion (Table 3). It can be seen that the expansion of built-up land in Hohhot presents a significant stage characteristic. Especially after 2000, with the implementation of the Western development strategy, the foundation stone of the Jinchuan Development Zone in Hohhot was laid in 1992, and the construction of the Jinshan Economic and Technological Development Zone started in March 2002. With the acceleration of infrastructure construction, the urban space has been expanding continuously, which has provided an opportunity to accelerate the urbanization process of the city.

Table 3. Construction Land Expansion Rate, Intensity Index and Type by District

administrative district	1992-2002			2002-2012			2012-2022			1992-2022		
	expansion rate	Extended Intensity Index	Extension Type	expansion rate	Extended Intensity Index	Extension Type	expansion rate	Extended Intensity Index	Extension Type	expansion rate	Extended Intensity Index	Extension Type
Saihan	1.14	4.58	medium speed	1.21	12.10	high speed	1.21	4.83	medium speed	3.05	12.19	high speed
Huimin	0.42	1.65	low speed	0.39	3.88	medium speed	0.39	1.83	low speed	0.75	2.95	low speed
Xincheng	1.14	4.49	medium speed	0.52	5.16	medium speed	0.52	3.34	medium speed	1.58	6.23	rapid
Yuquan	0.65	2.78	low speed	0.64	6.40	rapid	0.64	2.98	rapid	1.29	5.55	medium speed
Taigemu	0.36	8.69	rapid	2.20	22.04	high speed	2.20	5.43	medium speed	1.09	26.58	high speed
Hohhot	3.71	3.60	medium speed	11.04	7.88	rapid	0.79	3.71	medium speed	7.75	7.53	rapid

4.2 Characterization of Spatial Changes in Construction Land Use in Downtown Hohhot City

During the study period, Saihan District led the way in terms of expansion area, while Huimin District was relatively small, and Xincheng District and Yuquan District, as well as Taige Mu town, were located in both, indicating that there are spatial differences in the speed and intensity of urban land expansion.

Analyzing the results of urban expansion in each period shows that between 1992 and 2022, northeast, southeast, east, and southwest are always the four main directions of urban expansion in Hohhot, among which the construction land expands the most to the southwest and northeast, followed by east and southeast, and less to the south and west, and the least to the north and northwest. It can be seen that Hohhot's urban expansion is characterized by obvious directional differentiation (Figure 2). 1992-2002, construction land expansion was higher in the northeast and north directions; in 2002-2012 and 2012-2022, construction land expansion was higher in the northeast, southeast, east, and southwest directions. land expansion is predominant. In summary, this is closely related to Hohhot's economic development, natural conditions, and planning control, and is in line with Hohhot's urban development strategy of "controlling in the north, optimizing in the east, expanding in the south and linking in the west, concentrating into a piece and developing on a large scale".

The results of the spatial analysis of the types of urban built-up land expansion show that the pattern of built-up land expansion varies in different time periods, with infill and fringe dominating the study area from 1992 to 2022. Among them, the urban expansion pattern from 1992 to 2002 is dominated by infill type, while the urban expansion pattern from 2002 to 2012 and from 2012 to 2022 is dominated by edge type (Figure 4 and Table 4).

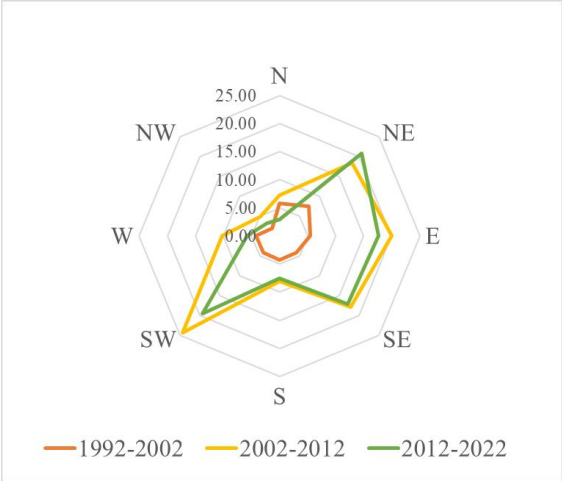

Figure 3. Radar Map of the Area of Expansion of Construction Land by Time Period

These changes reflect adjustments in urban development strategies, changes in land use policies, and different stages of land demand in the urbanization process.

Overall, in the 1992-2022 time period: the cumulative proportion of enclave-type expansion is relatively low in all districts, with a minimum of 12.32% in Yuquan District and a higher proportion of 27.51% in Taigemu Town; fringe-type expansion dominates in the 30-year period, especially in Xincheng District and Taigemu Town, with cumulative proportions as high as 75.00% and 71.93%; infill extensions had a relatively low cumulative percentage over the entire time period, but accounted for a higher percentage in Huimin District and Xincheng District, at 18.62% and 19.33%, respectively.

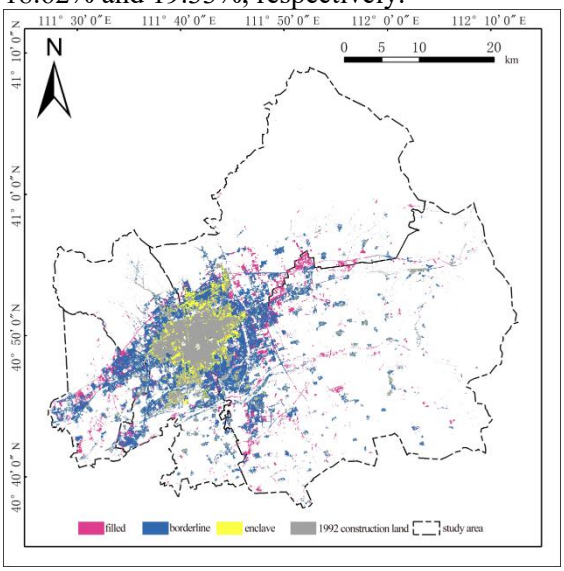

Figure 4. Distribution of Building Land Expansion Patterns, 1992-2022

Table 4. Number and Area (km²) Share of Patches with Different Types of Expansion Patterns

Aera / Types		Saihan		Huimin		Xincheng		Yuquan		Taigemu	
		area	percentage	area	percentage	area	percentage	area	percentage	area	percentage
enclave	1992-2002	1.89	16.44%	0.41	9.78%	0.92	8.13%	0.58	8.82%	1.12	31.25%
	2002-2012	6.63	15.03%	0.53	4.58%	2.45	12.98%	1.00	5.20%	2.06	12.10%
	2012-2022	4.14	10.34%	0.16	2.10%	1.85	9.94%	0.61	4.11%	1.43	10.61%
	1992-2022	28.06	29.33%	3.16	13.54%	11.47	23.45%	5.00	12.32%	9.36	27.51%
borderline	1992-2002	5.08	44.15%	1.07	25.40%	1.96	17.26%	1.83	28.04%	2.45	68.10%
	2002-2012	34.51	78.25%	7.58	65.78%	9.76	51.60%	15.00	77.96%	14.15	83.29%
	2012-2022	28.21	70.42%	3.40	44.91%	13.53	72.62%	8.45	56.92%	8.16	60.73%
	1992-2022	62.87	65.71%	15.81	67.84%	27.99	57.22%	30.45	75.00%	24.47	71.93%
filled	1992-2002	4.54	39.41%	2.73	64.83%	8.48	74.61%	4.12	63.14%	0.02	0.65%
	2002-2012	2.96	6.72%	3.41	29.64%	6.70	35.42%	3.24	16.85%	0.78	4.60%
	2012-2022	7.70	19.24%	4.01	52.99%	3.25	17.45%	5.78	38.96%	3.85	28.67%
	1992-2022	4.75	4.96%	4.34	18.62%	9.45	19.33%	5.15	12.69%	0.19	0.56%

4.3 Changes in Land Use Structure Analysis

According to the statistics of different types of land area in different years in the study area, it can be seen that: from 1992 to 2022, the area of cultivated land decreased by 169.81km², the area of grassland decreased by 139.44km², and both of them shrunk significantly; the area of forest land increased by 65.76km; and the area of construction land increased by 240.39km². Throughout the study period, arable land and grassland were the main land types in the four major urban areas of Hohhot City and Taigemu Town in the early stage of the study, and the area of forest land is larger than the area of construction land. During the 30-year period, although the area of construction land and forest land are both growing, the area of

construction land grows at a faster rate, and it becomes the third type of land with the third share of the area, and the area of construction land in 2022 will be about 1992's 3.3 times, a reflection of rapid urbanization. While waters and unutilized land have different degrees of change, the area fluctuation is not large.

The area transfer of each type of land use in the study area from 1992 to 2022 is shown in Figure 5. The mutual transfer of cultivated land, forest land, and grassland as well as the conversion of cultivated land and grassland into construction land during the 30-year period are the main ways of land transformation of each type of land. Successively, 242.51km² of various types of land were transformed into construction land. Among them, arable land has been transformed the most, with 173.43km², accounting for 71.51% of the total amount of transformation; followed by grassland, with 67.89km², accounting for 28% of the total amount of transformation. Among the time periods, the largest amount of conversion is from 2002-2012, followed by 2012-2022. It can be seen that the encroachment of arable land by the expansion of construction land in Hohhot is particularly prominent after 2002.

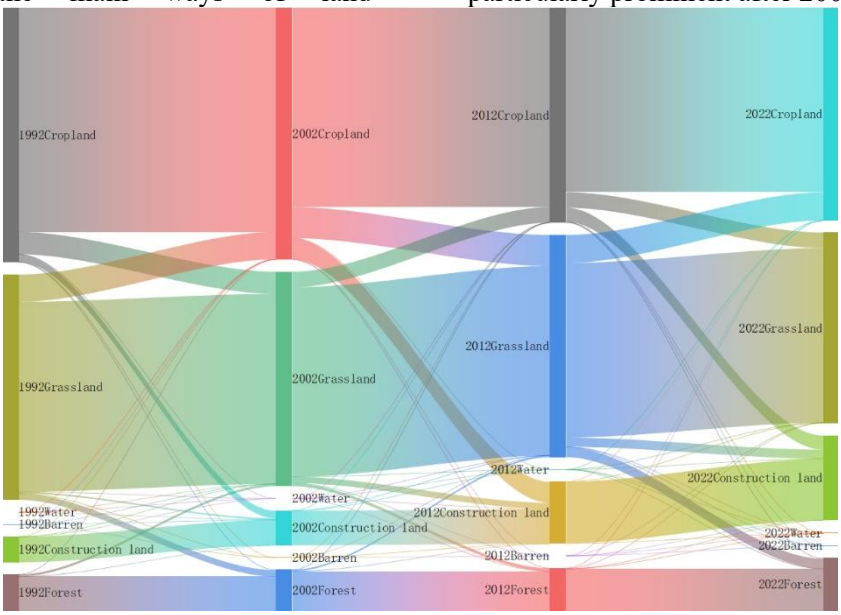

Figure 5. Hohhot Land Use Area Transfer Map, 1992-2022

5. Conclusions of the Study

Based on the spatial characterization of construction land expansion in Hohhot from 1992 to 2022, the following conclusions are drawn.

(1) The built-up area of Hohhot increased from 103.02km² to 343.41km², an increase of 3.3 times, with an annual expansion rate of 7.75km², and an expansion intensity index of 7.53, which is a strong momentum of expansion with significant spatial and temporal differences. Among them, 1992-2002 belongs to the period of low-speed expansion; 2002-2012 and 2012-2022 belong to the period of rapid expansion. The direction of construction land expansion is
mainly northeast, east, southeast, and southwest.

(2) The 1992-2022 urban expansion pattern is dominated by infill and fringe but differs by phase: 1992-2002 urban expansion is dominated by infill, 2002-2012 and 2012-2022 urban expansion is dominated by fringe. The 1992-2002 urban expansion pattern is infill-dominated, while the 2002-2012 and 2012-2022 urban expansion patterns are edge-dominated.

(3) In terms of land use structure, the land type transformation is more frequent, with arable land and grassland decreasing continuously, construction land increasing continuously, and forest land increasing slightly; during the 30 years, 242.51km² of various types of land have been transformed into construction land. Among them, arable land has been transformed the most, amounting to 173.43km², accounting for 71.51% of the total amount of transformation; followed by grassland, with the amount of transformation of 67.89km² accounting for 28% of the total amount of transformation. The encroachment of

construction land into arable land is serious.

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