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Analysis of Urban Land Use Changes in Xingtai City from the Year 2000 to 2020 for Urban Development Planning

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Land use changes as a result of urban development are inevitable. This study is based on three aspects: spatial and temporal land use changes, spatial distribution characteristics, and the state of land resource development today. In this study, the land use status of Xingtai City over the previous 20 years is systematically examined using the global and local Moran's I value, information entropy for land use structures, and land use extent models. The results indicate that, firstly, the built-up land in Xingtai City has rapidly increased while farmland land has continued to decline, with a decrease of 9.93% in farmland and an increase of 84.16% in built-up land. Secondly, the utilisation rate of land resources in Xingtai City has increased annually, as has the l information entropy for land use structures, the extent of land use, and the comprehensive land use dynamic extent index. Qiaoxi District and Qiaodong District have the most significant upward trend. And thirdly, the land use types in the study area exhibit spatial aggregation characteristics, and single land use type cold and hot spots demonstrate spatial clustering.

Keywords: The extent of Land use; land use structures; Cold spots; land use spatial pattern

I. INTRODUCTION

With the growing economic development of society, urbanisation is also increasing. Changes in human lifestyles affect the urbanisation process as well as changes in land use (Dewan *et al*., 2009). In retrospect, the formation of rural areas was a precursor to urbanisation. During this period, the type of land in its natural state rapidly transformed into farmland. As society and the economy grew, the countryside turned into more towns and cities, and the farmland around the towns became building land, which made the farmland grow. It also led to the constant growth of city edges, small towns into big cities, and the formation of metropolitan areas. As a result of urban development, many land-related problems have arisen. People have also started to pay attention to and look into the problems caused by changes in land use caused by urban development. Land Use and Land Change (LULC) studies of the past are needed to scientifically explain and understand how land is used and covered now or to predict how it will change in the future (Hu & Li, 2012).

Since IGBP and IHDP made and published the LULC Scientific Research Plan in 1995, many international organisations, experts, and scholars have researched LULC (Li, 1996). At this point, the research on LULC can be roughly divided into the following areas: Firstly, the researchers analyse the spatial and temporal changes and driving forces analysis of LULC. For example, Hou (2021) investigated land use, land cover changes, and driving forces in Asia and Europe's low- and mid-latitude coastal zones. Fu (2020) studied land use changes and driving forces on the southern slope of the Qilian Mountains from 1980 to 2018. Secondly, it is the researcher's investigation of LULC at various spatial scales, which can currently be broadly categorised into three different scales:

a. global scale, which is mainly devoted to studying LULC changes on a global scale (Turner *et al*., 1994).

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b. regional scales are broken up into administrative jurisdictions, functional areas, and natural units. In which the administrative jurisdictions can be divided into three different directions, 1. national (Kuang *et al.*, 2022; Sun *et al.*, 2012; Ning *et al.*, 2018), 2. provincial regions (Shi *et al.*, 2020), and 3. prefecture-level cities (Wang *et al.*, 2015; Zhang *et al.*, 2022a). Based on the division of functional areas, there are two distinct directions: urban agglomerations (Wang *et al.*, 2021; Shan *et al.*, 2020) and nature reserves (Xin *et al.*, 2023). Moreover, based on the natural units, there are three different directions: watersheds (Wulandari *et al.*, 2019), plateaus (Zhang *et al.*, 2021), and mountains (Poyatos *et al.*, 2003; Xystrakis *et al.*, 2017).

c. Local scales include counties (Karimi *et al.*, 2018; Cheruto *et al.*, 2016), villages, etc. (Yin *et al.*, 2020).

Thirdly, researchers study the impact of LULC changes on ecosystem functions. For example, the effect of land use change on soil erosion (Romshoo *et al.*, 2021), the impact of LULC change on the hydrological responses of rivers (Naha *et al.*, 2021), and the impact of LULC change on natural habitat quality and ecosystem function (Mengist *et al.*, 2021). In recent years, many international scholars have been updating the results of LULC research.

Xingtai City is located in north China, south of Hebei Province, and is an important transportation hub (Figure 1). It is one of the important energy-producing regions in northern China and also one of the significant agricultural-growing regions (Chen, 2016). There are more and more problems with how land resources are used in the region, and whether or not they are used wisely directly affects urban development and the population's quality of life. In recent years, research on land use change in Xingtai City has been in its infancy. Most researchers have only examined the impact of a single land use change or the effect of land use change on the ecological function of the area. Huo (2020) studied the driving factors of arable land transfer in Xingtai. Yang (2009) studied the impact of land use change on water resources in Xingtai. Wang (2019) studied the relationship between rural revitalisation and the development and utilisation of land resources in Xingtai's impoverished areas. Xingtai City needs a systematic study and analysis of land use changes. This study analysed the quantity, structure, change characteristics, and spatial distribution of land use types in Xingtai City between 2000 and 2020 and the area's land use changes. This study aims to determine the land use change rules in Xingtai City under the influence of natural and human activities to provide theoretical guidance for optimising the land resource allocation and rational development and utilisation of land resources in the area. This study also establishes a 20-year land use change database in Xingtai City to facilitate the study of ecosystem service functions in the region.

II. MATERIALS AND METHOD

A. Overview of the Study Area

Xingtai City's administrative area has a total area of 1.24 km^2. According to the seventh national census data, Xingtai City had approximately 7.11 million residents by the end of 2020. As an important central city in the Beijing-Tianjin-Hebei region, Xingtai is adjacent to Shanxi Province in the west, faces Shandong Province across the Grand Canal in the east, and is surrounded by Shijiazhuang City, Hengshui City, and Handan City. The terrain is generally more mountainous in the west and flat in the east, with mountains, hills, and plains in that order from west to east. The eastern foothills of Taihang Mountain lie in the west, which consists of mountainous regions and piedmont hills. Alluvial piedmont plains dominate the region's centre. The alluvial plain of the Ziya River and the ancient Yellow River system are located in the east. In Xingtai City in 2020, farmland accounted for 65.90%, forest accounted for 6.57%, scrub-grassland accounted for 8.83%, and built-up land accounted for 16.47%. The warm temperate continental monsoon climate and the complex and diverse types of land resources in Xingtai City are conducive to the comprehensive development of agriculture, forestry, animal husbandry, sideline, fishing, and the selection of diverse land use types (Overview of Xingtai, 2022).

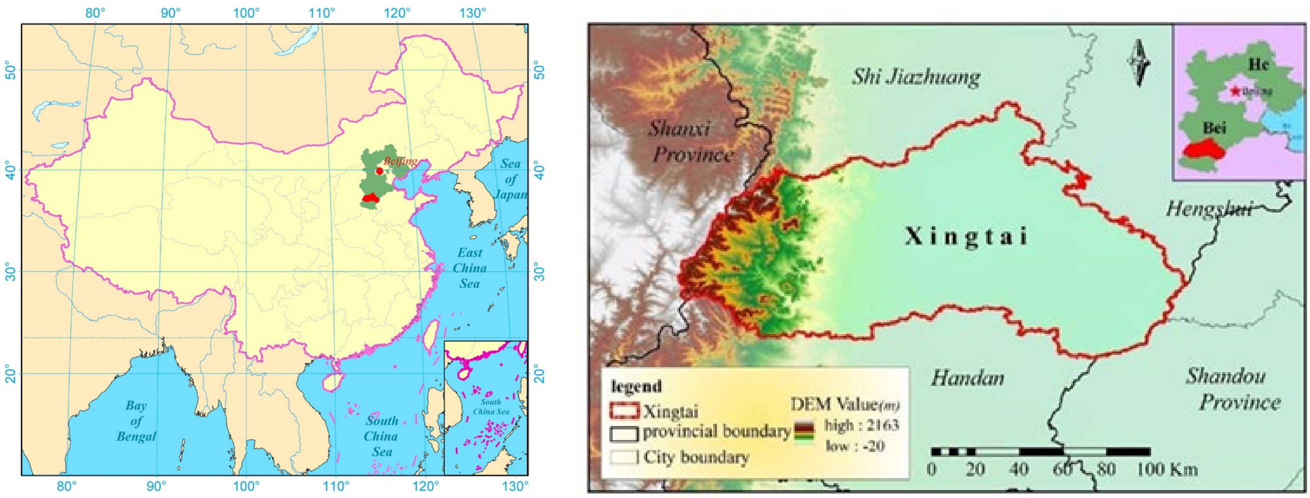

Figure 1. Maps of China (on the left) and Xingtai City (on the right).

B. Data Source

This study used NASA Landsat-TM remote sensing image data (Wenchao, 2014) for 2000 and 2010, and Landsat 8 OLI remote sensing image data for 2020. There are a total of 3 phases, with imaging occurring in July, August, and September. The Chinese Academy of Science's Resource and Environment Science Data Centre provided the remote sensing images. This study classified the area into six major categories, namely Farmland, Forest, Grassland, Water, Built-up land, and Bare land, based on the three-level classification system of Chinese land use/cover data. The accuracy of remote sensing interpretation of land use/cover types after random sampling of field survey points and random sampling of Google Maps was 85.7% (Figure 2).

C. Methods

This study utilised ArcGIS 10.2 to analyse and process LULC data and draw maps (Fu *et al.*, 2020). LULC in Xingtai City has changed dramatically over the past two decades; therefore, it is necessary to analyse these changes from multiple perspectives. In order to comprehend the spatial and temporal changes of LULC in the study area, we have selected the five indicators described below.

1. The extent of comprehensive land use dynamics (LC)

Land use dynamics (LC) analyses changes in land use types and the extent of change from a macro perspective by comparing two periods of land use data.

LC depicts the change in the number of land use types in the study area over a specified time frame.

$$LC = \left(\frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2\sum_{i=1}^{n} LU_i}\right) \qquad (1)$$

LU_i represents the area of the initial land use type; ΔLU_{i-j} represents the absolute value of the converted land use type area.

2. Information entropy analysis of land use structure (H)

Information entropy analysis of land use structure (H), an indicator used to measure system complexity, is employed in land use structure analysis to determine the degree of equilibrium in the distribution of land use types. This study utilised the information entropy formula (Equation 2) to quantify the degree of structural land use change within the study area.

$$H = -\sum_{i=1}^{n} P_i \, LnP_i \qquad (2)$$

The magnitude of H describes the uniformity and orderliness of each land use type's area distribution. The higher the H value, the lower the orderliness. P_i is the proportion of the i-th land use type's area to the total land area.

3. The extent of land use(L)

The extent of land use(L), the evaluation of the extent of land use, can provide valuable information and decision support for land use management and planning. For quantitative land analysis, this paper employs Liu's formula (2010) to measure the degree of land use according to land use type or land cover status.

$$L = 100 \times \sum_{i=1}^{n} A_i \times C_i \qquad (3)$$

A_i is the regional land use extent grading index, C_i is the proportion of regional land use extent at each level, and L is the integrated index of regional land use extent, which ranges from 100 to 400. The degree classification is based on Liu Jiyuan's research findings (Table 1).

Table 1. Classification of land use types.

Type	Bare Land	Scrub-Grassland, Forest, Water Body	Farmland	Built-Up - Land
Grading index	1	2	3	4

4. Analysis of spatial autocorrelation

Spatial autocorrelation analysis is used to identify correlations and trends in spatial data and the presence or absence of spatial autocorrelation in the data. Spatial autocorrelation typically consists of global and local autocorrelation, with global autocorrelation used to determine land use change at the macro level, using Global Moran's I statistic to measure spatial autocorrelation based on element location and attribute values. Local autocorrelation is used to identify statistically significant hot spots, cold spots, and spatial outliers at the micro level using Local Moran's I statistic (Fu *et al.*, 2018) based on the similarity of land use change in each region.

$$Global\ Moran's\ I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\bar{x}_i)(x_j-\bar{x}_j)}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \qquad (4)$$

$$Local\ Moran's\ I = \frac{n(x_i-\bar{x}_i)\sum_{j=1}^{n} w_{ij}(x_j-\bar{x}_j)}{\sum_{i=1}^{n}(x_i-\bar{x}_i)^2} \qquad (5)$$

Where n denotes the total number of cells, x_i and x_j denote the attribute value of an element in region i and region j (i≠j), and w_{ij} denotes the spatial weight matrix. I > 0 denotes a spatial distribution that is positively correlated, I < 0 denotes a spatial distribution that is negatively correlated, and I = 0 enotes a spatial distribution without any correlation. $\bar{x}_i$, $\bar{x}_j$ is the average of x_i,x_j.

5. Hotspot analysis

Hotspot analysis, also known as "hotspots," is used to identify areas of high-value aggregation in spatial data. It is used to identify areas or locations that appear more frequently in the data set. It applies to various fields, including urban and traffic planning. In this study, Getis-OrdGi* is used to detect the statistically significant spatial clustering of hot and cold spots using the following equation (Fu *et al.*, 2018):

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}x_j - w_i^*\bar{x}}{s\sqrt{[nS_{1i}-(w_i^*)^2]/(n-1)}} \qquad (6)$$

x_j denotes the attribute value of element j; w_{ij} stands for the spatial weight of elements i nd j; and S represents the standard deviation of the elements. $\bar{x}_j$ is the average of xj.

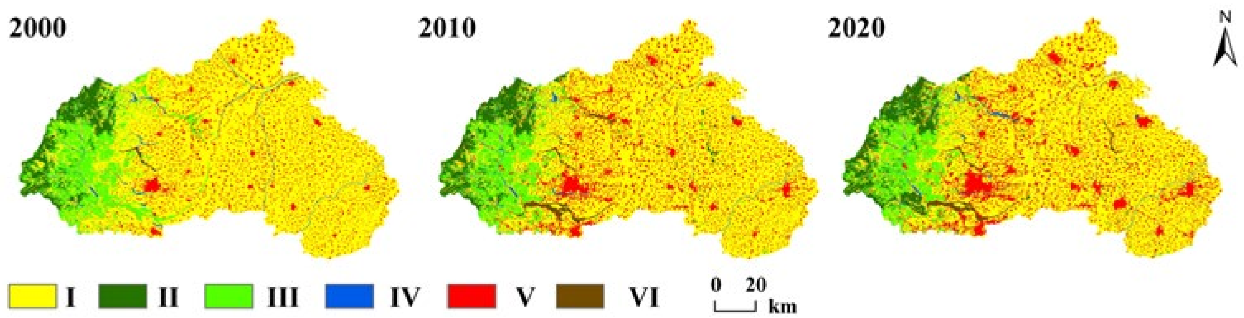

Figure 2. 2000-2020 Xingtai City land use type map. In this paper, Ⅰ: Farmland; Ⅱ: Forest; Ⅲ: Grassland; Ⅳ: Water; Ⅴ: Built-up land; Ⅵ: Bare land.

III. RESULT AND DISCUSSION

A. Temporal and Spatial Changes in LULC

1. Spatial distribution characteristics of LULC

China's Xingtai is known as the "grain warehouse and cotton sea" (Yang *et al.*, 2020) for its high-quality grain and cotton cultivation. Figure 2 reveals that, except for the western mountainous region, the majority of arable land in Xingtai is located in the eastern plains. The main urban area and county towns of Xingtai City are also distributed in the eastern plain. The built-up land area has expanded rapidly due to population growth and economic development, and the main urban area and county town show clear signs of outward expansion. Most forests and grasslands in the study area are located in the western region, dominated by mountains, and unsuitable for agriculture and human habitation. However, due to the area's improved natural environment and thriving woodlands, it is an essential water-containing area in Xingtai City.

2. Land use/land cover change (LULC) analysis

It can be seen that urban land is expanding rapidly, while farmland continues to decline, with farmland accounting for 73.16 percent of the land area in 2000 and 65.9 percent in 2020, a decrease of 7.26 percent with a change rate of -9.93 percent (Table 2 T, P). The built-up land share increased from 8.94% in 2000 to 16.47% in 2020, representing an increase of 84.16%. In 20 years, the area of forested land grew by 0.7%, at a rate of change of 12.03%. The proportion of water in the study area is negligible, the rate of change is slight, and the area is essentially stable at about 1%. Notably, the bare land area has increased by 708,91 % since 2000, a significant growth rate. However, because the overall percentage of the bare land area is small, it will only account for 1.09 % of land use in 2020.

Table 2. The LULC matrix from 2000～2020 in Xingtai City.

		I2	II2	III2	IV2	V2	VI2	T1(km2) P1(%)
I_1	A	79322.9	386.87	768.67	448.79	9820.44	293.86	91041.53
	B	-	3.27	6.53	3.81	83.90	2.49	
	C	-	28.41	80.37	72.55	91.04	24.63	73.16
II_1	A	199.23	6815.53	153.82	7.27	122.76	0.12	7298.73
	B	41.24	-	31.87	1.51	25.38	-	
	C	7.36	-	16.07	1.17	1.14	0.01	5.87
III_1	A	790.97	959.43	10031.39	147.76	741.32	729.73	13400.6
	B	23.47	28.48	-	4.38	22.00	21.68	
	C	29.45	70.45	-	23.89	6.88	61.18	10.77
IV_1	A	304.45	8.68	24.44	802.40	103.28	162.76	1406.02
	B	50.42	1.44	4.05	-	17.12	26.97	
	C	11.35	0.66	2.53	-	0.95	13.65	1.13
V_1	A	1386.48	6.44	10.07	14.80	9702.33	6.26	11126.37
	B	97.34	0.47	0.70	1.02	-	0.47	
	C	51.84	0.48	1.03	2.39	-	0.52	8.94
VI_1	A	-	-	-	-	-	168.25	168.25
	B	-	-	-	-	-	-	
	C	-	-	-	-	-	-	0.13
$T_2(km^2)$		82004.03	8176.93	10988.4	1421.03	20490.14	1360.96	124441.5
P_2(%)		65.90	6.57	8.83	1.14	16.47	1.09	100
P_3(%)		-9.93	12.03	-18.00	1.07	84.16	708.91	

Note: V_1-VI_1 was the land use type in 2000; V_2-VI_2 was the land use type in 2020. T1 was the area of each land use type in 2000; T2 was the area of each land use type in 2020. P1 was the area proportion of each land use type in 2000. P2 was the area proportion of each land use type in 2020. P3 was the comparison of the 2020 percentage change of the area of each land use type in 2000, where a positive value indicates an increase in area, and a negative value indicates a decrease in area. A is the area that was transferred from land use type i to land use type j in 2000. B is the proportion of land transferred from land use type I in 2000 to land use type j in 2020, excluding the case where i=j. C represents the proportion of land type j in 2020 that was transferred from land type I in 2000, excluding i=j, i= 1, 2, 3, ...,6).

The process of land use change transfer from Xingtai City between 2000 and 2020 is depicted as follows: 83.9% of the transfer out of farmland is built-up land; the transfer out of forest land is primarily toward farmland, grassland and built-up land; the transfer out of grassland is mainly toward farmland, forest land, built-up land, and bare land; and the main transfer out of water is toward farmland, bare land, and built-up land; Most built-up land is transferred to farmland, accounting for 97.34 percent of the transfer out (Table 2, B). The expansion of towns in the study area is evident. The spatial distribution is pushed from the centre of towns to the periphery, with farmland on the periphery of towns experiencing the most expansionism. The area of bare land increased significantly in 2020, and judging by the increase in bare land, the primary cause of the bare surface is grassland degradation (Table 2, C, Figure 3).

B. Analysis of Land Use Spatial Distribution Characteristics in the Study Area

1. Spatial autocorrelation of land use

• Global Moran's I value for a single land use type:
Global autocorrelation is a macro-level evaluation of whether or not land use change is aggregated across the entire study area. A positive value of Moran's I indicate an aggregation-like trend. A negative value indicates a dispersion-like trend, and a higher value indicates a higher degree of aggregation or dispersion.

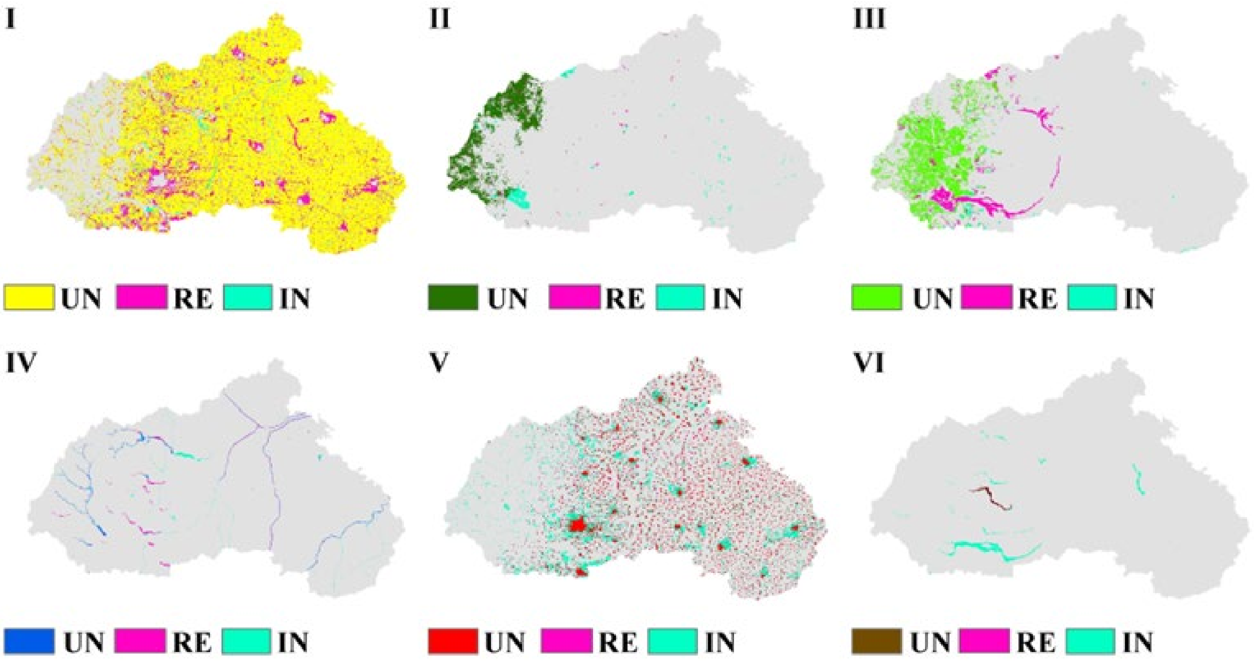

Figure 3. Land use type conversion map for Xingtai City from 2000 to 2020, where UN denotes Unaltered, RE denotes a Reduced, and IN denotes an increase.

Table 3. Global Moran's I value for a single land use type.

Year	LULC	Moran's I	z	P
2000	I	0.715215	23.298	0.0000**
	II	0.807623	26.606	0.0000**
	III	0.840908	27.505	0.0000**
	IV	0.292211	9.703	0.0000**
	V	0.563933	18.693	0.0000**
	VI	0.226431	10.111	0.0000**
2010	I	0.704992	22.963	0.0000**
	II	0.799125	26.316	0.0000**
	III	0.862609	28.235	0.0000**
	IV	0.259854	8.798	0.0000**
	V	0.585596	19.254	0.0000**
	VI	0.445145	15.296	0.0000**
2020	I	0.686657	22.366	0.0000**
	II	0.784717	25.804	0.0000**
	III	0.845713	27.702	0.0000**
	IV	0.262085	8.857	0.0000**
	V	0.657993	19.325	0.0000**
	VI	0.471724	16.031	0.0000**

The global Moran's I value of the area proportions of different land use types in the study area were all greater than 0, and the Z-statistics values ranged from 8.798 to 28.235, all of which passed the significance test, indicating that the spatial distribution of land use types was not random. The spatial distribution shows aggregation characteristics (Table 3). The Moran's I value of farmland, forest land, grassland, and water area all exhibit varying degrees of yearly decline, indicating that their spatial aggregation is gradually diminishing and that their spatial totality is gradually dividing and becoming more discrete. The increasing trend of the Moran's I value of built-up land and bare land from year to year indicates that their spatial aggregation degree is gradually increasing, and their spatial distribution is developing in an aggregated trend.

• Spatial distribution of local Moran's I value for different land use types:

In this study, the local spatial autocorrelations of various land use types in 2000, 2010, and 2020 were tallied and categorised into five groups. HH, HL, LH, LL, NS, where HH represents statistically significant high-value clusters, and LL represents statistically significant low-value clusters. HL and LH represent spatial data outliers with statistical significance; HL represents a high value surrounded by a low-value region, LH represents a low value surrounded by a high-value region, and NS represents an insignificant region. Here, the spatial distribution characteristics of HH and LL are analysed in detail.

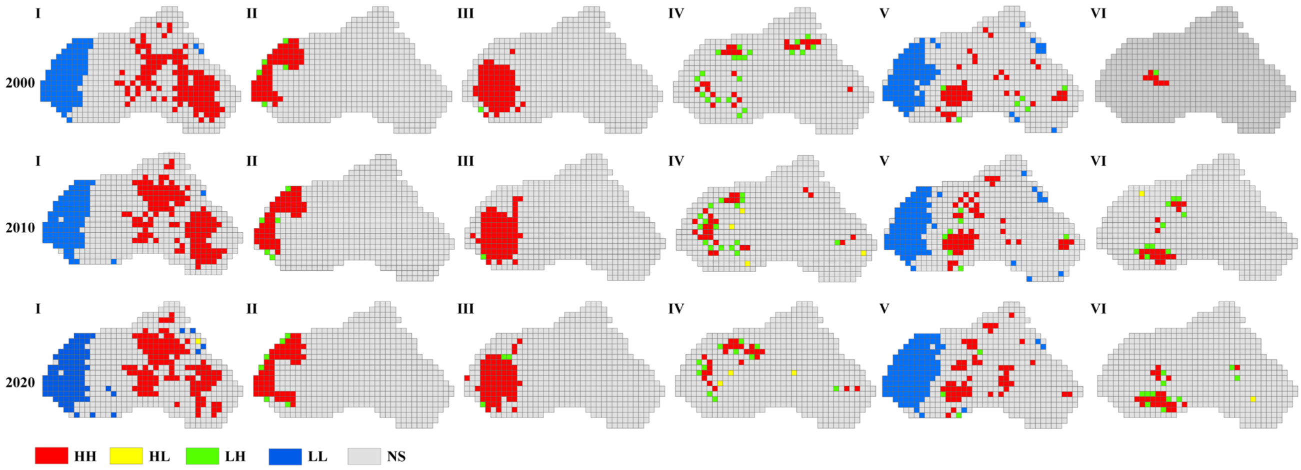

Figure 4. 2000-2020 spatial distribution of the local Moran's I value of single land use in Xingtai City. HH: High-high agglomeration; HL: High-low agglomeration; LH: Low-high agglomeration; LL: Low-low; agglomeration; NS: Not significant.

The study demonstrates that the HH aggregation status of farmland is primarily distributed in the eastern plains of the study area (Figure 4). In contrast, the LL aggregation status is revealed in the western mountainous areas, indicating that farmland is scarce and dispersed in the western mountainous areas (Figure 4). The HH aggregation of forest land and grassland is mainly distributed in the western mountainous areas of the study area, and the number of HH aggregation areas has not changed significantly over the past 20 years, indicating that there has been little human intervention in the forest land and grassland and that the area is less developed. The spatial distribution of water areas is of the meandering linear type. Meanwhile, as a result of the natural diversion of rivers, changes in the cycle of water rise and depletion, and human interference, the spatial aggregation distribution of water areas fluctuates more than other types over 20 years. Even though it can still be seen that the western portion of the area is rich in water resources, the eastern portion is relatively poor in water resources. Built-up land is closely related to urban development, and there is no significant adjustment in administrative areas at all levels, so the spatial aggregation distribution is relatively stable. The spatial distribution of bare land shows an increasing trend of spatial aggregation distribution year after year.

2. Land use hot and cold spots spatially clustered

This study of land use cold and hot spots analysis identified statistically significant spatial clusters of high values (hot spots) and low values (cold spots). Features in the HS and CS reflect statistical significance with a 99 percent confidence level; features in the SCS and SHS reflect a 95 percent confidence level; features in the TCS and THS reflect a 90 percent confidence level, and the clustering for features in NS is not statistically significant. The change of land use in hot and cold spots can directly reflect the change of a single land use type in space. Moreover, the spatial change of hot and cold spots reflects the change in the proportion of a specific land type in the area, which can indirectly reflect the current land resource development situation.

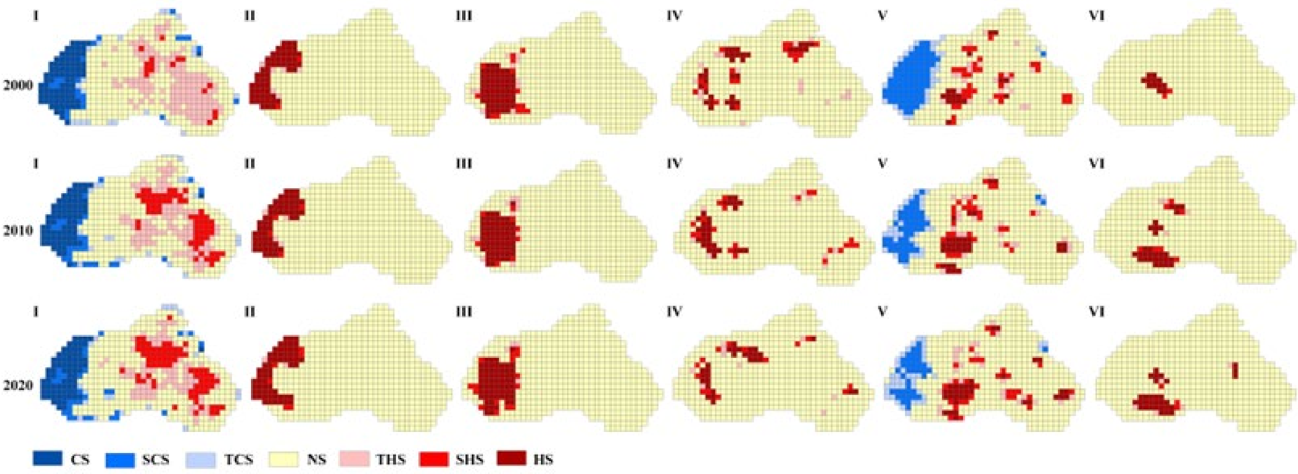

Figure 5. 2000-2020 spatial distribution of hot and cold spots for single land use in Xingtai City. Where, CS: cold spots***; SCS: second cold spots**; TCS: third cold spots*; HS: hot spots***; SHS: second hot spots**; THS: third hot spots*（*** p<0.01, ** p<0.05, * p<0.1）.

Under the premise that the farmland area in the study area is decreasing annually, the farmland hotspot areas are increasing annually (Figure 5). This phenomenon indicates that the farmland areas in the study area have been spatially optimised, and the areas with cultivation advantages have been strengthened. The SHS areas have increased from 16 in 2000 to 76 in 2020. Forestland, grassland, and water areas are generally stable. Built-up land hotspots are primarily concentrated in the central urban area of Xingtai City, where the proportion of built-up land is relatively high and increasing year by year, with HS areas increasing from 17 in 2000 to 34 in 2020. Furthermore, the CS and SCS areas of built-up land in the western mountainous areas are decreasing yearly, indicating that the proportion of built-up land in the area is gradually increasing.

3. Changes in the spatial pattern of land use

The land use and cover mean centre migration model provides a spatially appropriate description of the evolution of land use and cover types (Table 4). The mean centre is a point constructed from the mean x and y values of the input elements' centres of mass to identify the geographic centre (or density centre) of a set of elements. Standard deviation ellipses are created to summarise the spatial characteristics of geographic elements, including their central, discrete, and directional trends.

Table 4. Mean centre change of land use types.

LULC	2000		2010		2020		2000-2010	2010-2020
	X (°)	Y (°)	X (°)	Y (°)	X (°)	Y (°)	D（km）	D（km）
I	37.217	114.956	37.221	114.967	37.224	114.963	1.117	0.421
II	37.255	114.036	37.253	114.101	37.230	114.084	5.733	2.968
III	37.153	114.177	37.149	114.147	37.158	114.140	2.693	1.182
IV	37.254	114.655	37.230	114.608	37.242	114.698	5.000	8.157
V	37.214	114.975	37.203	114.891	37.196	114.907	7.530	1.679
VI	37.181	114.414	37.071	114.435	37.064	114.489	12.295	4.935

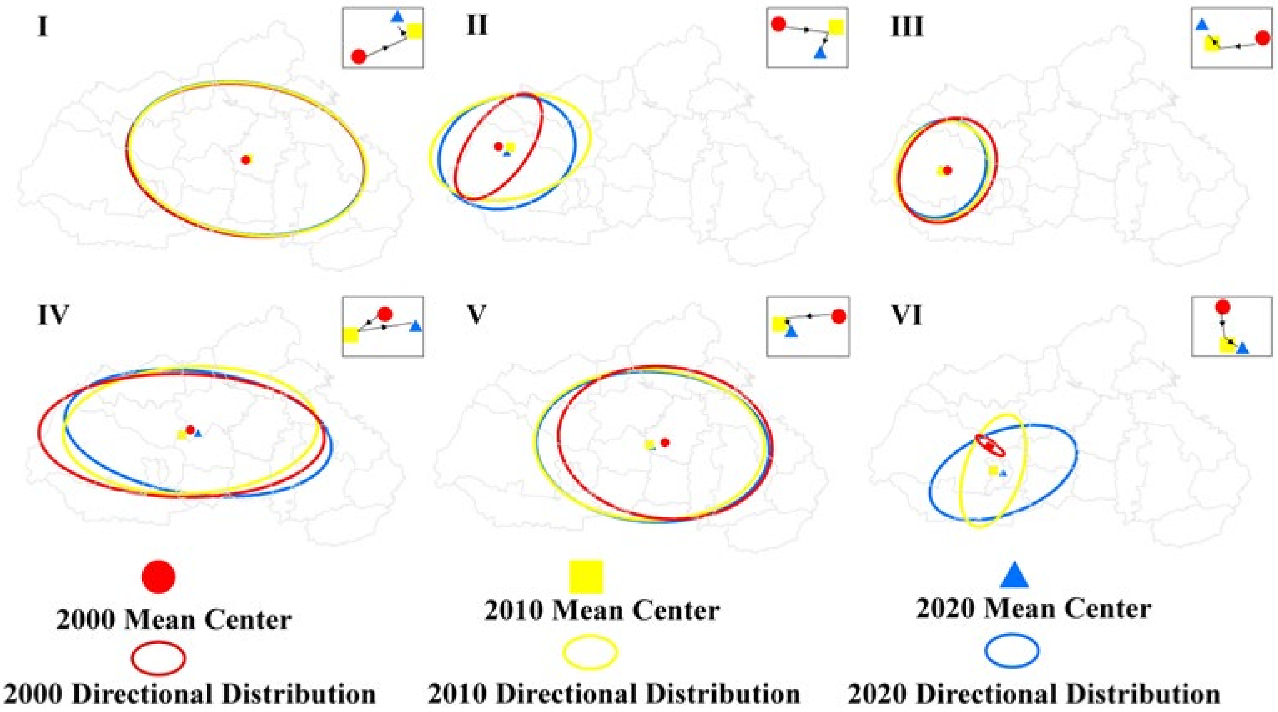

Figure 6. Characterisation of spatial changes of different land uses.

In this study, the mean centres and directional distributions of the various land use types exhibited varying degrees of movement (Table 4, Figure 6). The ellipse of the standard deviation of farmland does not change significantly, and the central trend, discrete trend, and directional trend change slightly, the average central migration path is 1.117km to the northeast, followed by 0.421km to the northwest. The ellipse of the standard deviation of forest land changes more obviously, and the range shows a trend of annual increase, indicating that forest land has a tendency to expand outward in spatial extent, and the average central migration path is 5.733km to the south of east and then 2.968km to the southwest. The spatial pattern of grassland varies little, with minimal changes in central, discrete, and directional trends and an average central migration path of 2.693 km to the south of the west, followed by 1.182 km to the northwest. The change in the standard deviation ellipse for water is more pronounced, and there is a gradual eastward migration trend. The average migration path of the centre is 5 km to the southwest, followed by 8.157 km to the north of east. The ellipse of the standard deviation of build-up land has a clear westward trend, and the average centre migration path is 7.53 km south of the west and 1.67 km south. The standard deviation ellipse of bare land has the most significant change, with noticeable expansion and directional change, and the average central migration path is 12.295km to the south and then 4.935km to the southeast.

C. Land Use Analysis of the Study Area

1. Information entropy analysis of land use structure (H)

The information entropy of land use structural is a characteristic quantity that reflects the significant state of the land use system. Entropy always tends to increase as a system develops, and the information entropy value of land use structure rises as land type diversity increases (Huang *et al.*, 2016). This study analyses the information entropy value of land use structure for 19 districts (county) administrative regions (Table 5). The results are categorised into ten classes to reflect the characteristics of each regional change more accurately. The analysis revealed that the information entropy values of all 19 administrative districts increased gradually over time. Moreover, the information entropy value of land use structure in the western part of the study area was significantly greater than that in the eastern part of the study area at the start of the statistics. This phenomenon was primarily due to the diversification of land use types in the western counties of Lincheng, Neiqiu, Xingtaixian, and

Shahe, which included forest, grassland, farmland, and built-up land. In contrast, the eastern portion of the study area consists primarily of arable farmland and developed land, so its H-value is lower than that of the western portion at the start of the statistics.

Table 5. Information entropy of land use structure of each county (city) district in Xingtai.

Administrative District	2000	2010	2020	Administrative District	2000	2010	2020
Linxi	0.30	0.41	0.52	Xingtaixian	1.23	1.09	1.39
Shahe	1.11	1.40	1.45	Julu	0.43	0.52	0.52
Nanhe	0.45	0.56	0.66	Nangong	0.36	0.49	0.52
Xiangdu	0.69	0.63	0.53	Neiqiu	1.13	1.22	1.25
Xindu	0.92	0.98	0.95	Longyao	0.59	0.61	0.63
Qinghe	0.42	0.56	0.66	Xinhe	0.47	0.43	0.50
Pingxiang	0.41	0.49	0.53	Lincheng	1.17	1.29	1.31
Renxian	0.43	0.48	0.57	Baixiang	0.47	0.52	0.55
Weixian	0.38	0.48	0.57	Ningjin	0.43	0.48	0.51
Guangzong	0.37	0.95	0.66				

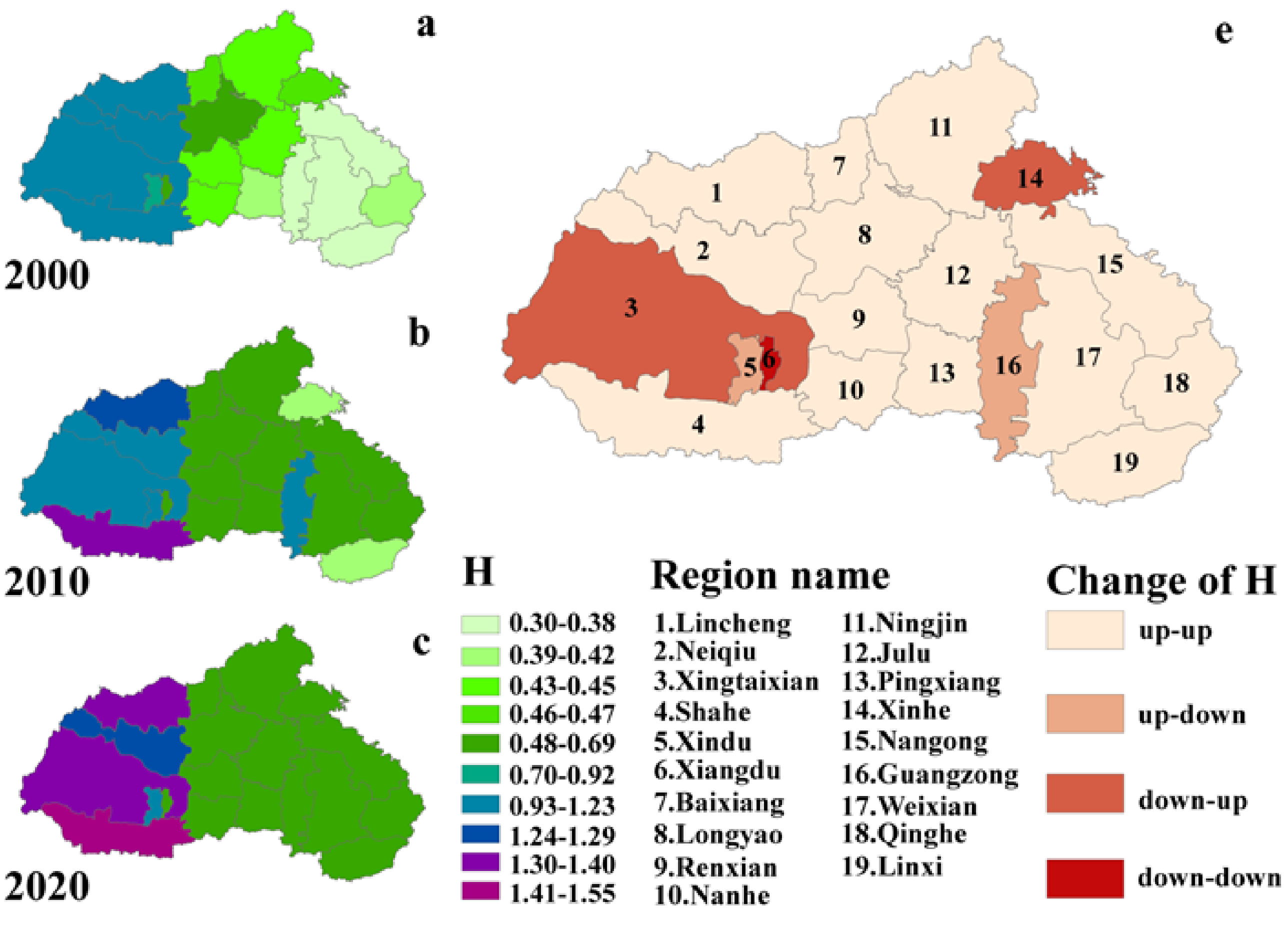

Figure 7. 2000-2020 LULC information entropy of Xingtai City. Figures a-c depict the spatial distribution of H-value for each year; Figure e depicts the spatial change of H-value for each decade from 2000-2010, 2010-2020; up represents up, down represents down; and so on.

During urban development, the number of land functions in a region increases, and the H-value first rises and then stabilises. Nevertheless, if the region has a comprehensive range of urban functions from the start. The H-value decreases initially, then increases, and then stabilises. We use the information entropy (H) to evaluate the extent of order or complexity of land use. The higher the H value, the greater the land use complexity and the lower the degree of order in a region. In 14 of the 19 administrative regions (Figure 7), the H value increases continuously (up-up); in 2 regions, it rises and then falls (up-down); in 2 regions, it falls and then rises (down-up); and in 1 region, it falls continuously (down-down).

1. *Extent of Land Use Analysis (L&LC)*

The integrated index of regional land use extent (L) expresses the depth and breadth of land use and the combined effect of human activities and natural factors. The extent in comprehensive land use dynamics (LC) can analyse the land use change in a specific region over a specific period. In this study, these two indices were calculated for each of Xingtai City's 19 administrative districts, and the results are presented in Table 4. The larger L value indicates that the greater the extent of land resource exploitation in the area, the greater the influence of human activities on land use change. The higher the LC value, the greater the land use change and the greater the rate of change in the area.

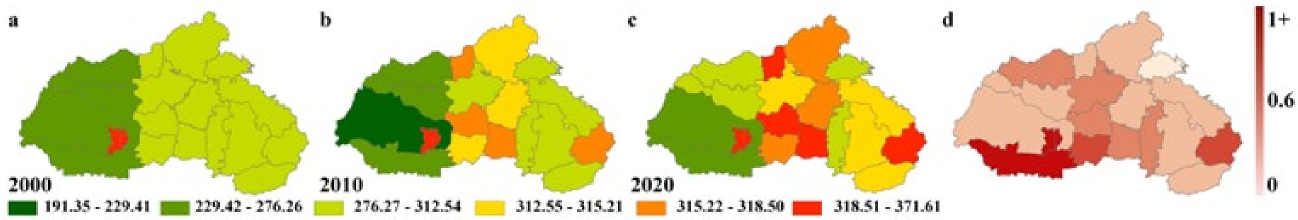

Figure 8. 2000-2020 LULC extent in Xingtai City, a-c is the integrated index of regional land use extent (L), d is the extent in comprehensive land use dynamics (LC) from 2000 to 2020.

Most of the administrative regions in the study area show a trend of increasing L-values year by year, indicating that the current land use change stage in Xingtai is still in the development stage. The results show that the top 5 regions with the highest L-values are Xiangdu, Xindu, Qinghe, Pingxiang, Renxian, respectively. The top 5 regions with the highest LC-values are Xindu, Xiangdu, Shahe, Qinghe, and Nanhe (Table 6, Figure 8).

Table 6. The extent of land use in each county (city) of Xingtai City.

Administrative District	2000	2010	2020	Lc	Administrative District	2000	2010	2020	Lc
Linxi	309.04	311.35	314.09	0.40	Xingtaixian	243.16	229.41	249.40	0.40
Shahe	266.91	266.85	272.34	1.14	Julu	311.47	313.99	316.20	0.25
Nanhe	308.70	315.21	316.37	0.60	Nangong	310.34	311.87	314.51	0.33
Xiangdu	355.12	371.61	379.46	1.35	Neiqiu	271.83	276.26	277.04	0.33
Xindu	322.04	344.69	348.70	1.75	Longyao	305.03	312.54	315.10	0.42
Qinghe	310.75	317.24	321.94	0.66	Xinhe	307.19	309.31	310.91	0.16
Pingxiang	311.77	317.36	320.24	0.41	Lincheng	267.61	275.37	277.24	0.47
Renxian	310.67	318.50	319.92	0.50	Baixiang	311.84	317.32	319.30	0.34
Weixian	309.36	310.97	314.59	0.38	Ningjin	309.36	315.19	317.26	0.35
Guangzong	308.97	310.45	312.52	0.56					

D. Discussion

1. Exploration of urban economic development cold and hot spots based on land use change

Land is the spatial carrier of human economic and social activities, and land use changes are intimately related to regional economic and social development. The evolution of urban industrialisation and urbanisation has resulted in alterations to the structure of land use. Researchers can also investigate the historical process of urban development via land use changes.

From the calculation model, it is evident that the land use extent (L) magnitude is closely related to the region's combination and proportion of land use types (Zhu & Li, 2003). Moreover, this method is widely utilised in the study of land use extent at larger scales in numerous provinces and cities. Gao (1990) calculated the extent of land use in China using this grading index; Liu (2006) calculated the extent of land use in Jiangsu Province; Jiang (2010) calculated the extent of land use in Mianyang City and Chongqing City, respectively. If the ratio of farmland to built-up land in the area is larger, the L value of the area will be larger. Farmlands and built-up land represent the impact of human activities on the area (Ah *et al.*, 2022;). The extent of land use in the high-value (hot spot) region is distributed in the region of intensive human activities. In contrast, the vegetation cover is more concentrated in the low-value (cold spot) region. The districts with the highest L values were Qiaodong and Qiaoxi, with values of 379.46 and 348.70, respectively. These districts are also the main urban areas of Xingtai City, with urban built-up areas comprising nearly 95% of the area and the areas with the most active economic activities. The forested and grassland areas within the jurisdictions of Xingtai County, Shahe City, Neqiu County, and Lincheng County are relatively extensive, and the area's topography is undulating and mountainous, resulting in a low L value. Therefore, in practice, the extent of land use depends on the impact of human activities on the land and is also related to the geomorphological features (Ibanez *et al.*, 2019). The degree of land use dynamics can visually reflect the amplitude and velocity of a particular land use/cover change. It is a scientific method for revealing the response of land use change to human activities (Zhu, 2020). It can also objectively reflect the land use activity in a region, with a higher LC indicating more land use type changes.

Table 7. The regression equation of LC\L\DD change and GDP growth.

Factor	Regression equation	R^2
L	y = 0.1525x - 1.5251	0.7365
LC	y = 0.1441x - 1.4413	0.6579
UED	y=0.225x+0.4183	0.9273

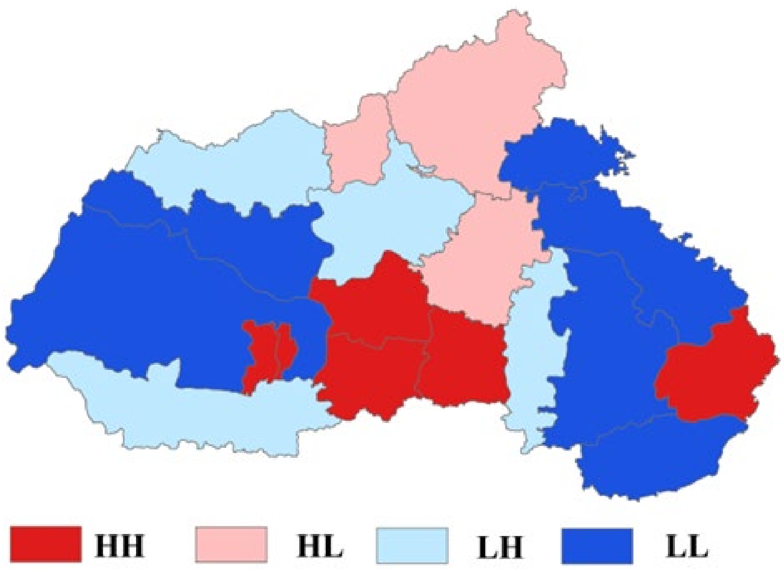

Figure 9. Cold and hot spot analysis of urban economic development (UED) in Xingtai City. HH: high L - high LC; HL: high L - low LC; LH: low L -high LC; LL: low L - low LC.

The most direct reflection of the exploitation of land resources is the change in a region's gross domestic product (GDP), while an increase in GDP indicates the region's economic vitality. In this study, a linear fit was performed for 19 administrative districts in conjunction with the GDP growth of each district and county in the most recent year (Table 7), and the results indicated that the UED value was closely correlated with the GDP growth of each district, with R2 equalling 0.9273.

Thus, the comprehensive index (UED) of the extent of land use(L)and the extent of comprehensive land use dynamics (LC) can reflect urban economic development's cold and hot spots. The impact of L on GDP is more significant than LC. The first H indicates a high L level in the region, while the second H indicates a high level of LC. According to the changes in L and LC values in 19 administrative districts in the study area, the urban economic development status can be divided into four classes: HH, HL, LH, and LL (Figure 9). The analysis reveals that the study area contains 6 HH areas, including Qiaoxi District and Qiaodong District, where the main urban area of Xingtai City is located, as well as Nanhe County, Qinghe County, Pingxiang County, and Ren County. The study area has four HL regions: Shahe City, Guangzong County, Longyao County, and Lincheng County. Furthermore, Julu County, Baixiang County, and Ningjin County are LH regions. The LL regions are Wei County, Xingtai County, Nangong City, Neqiu County, Xinhe County, and Linxi County.

2. Research contribution and future prospects

This study uses Xingtai City as the study area. Based on remote sensing image data from three time periods in 2000, 2010, and 2020, we studied the land use change in Xingtai City and created a database of land use change in Xingtai City from 2000 to 2020. This database can serve as a valuable data source for further scientific research. The findings of this study can offer more precise geographic information for regional solutions to issues with ecology, resources, the environment, and agricultural production. The content of the database of land use changes in Xingtai City can be continuously expanded on a temporal and spatial scale as we conduct further research, and we can continue to pay attention to the local land use changes and improve and update its content. With spatial and temporal variations in LC, H, L, and other indicators, this study also examines the underlying causes of land use change. It offers theoretical recommendations for maximising the allocation of land resources and rational development and utilisation in this region.

Additionally, this study innovatively introduces the idea of "Cold and Hot Spots Analysis of Urban Economic Development (UED)," which offers a new research idea and methodology for the influence of land use on economic development. The UED index is a combination of the LC and L index for exploring the relationship between land use change and economic development. The findings demonstrate that the UED index strongly correlates with the GDP figures for the various counties in the study area. The R^2 is as high as 0.9273, which is significantly better than the correlation between the L and LC indices and GDP. As a result, the index can be used to measure the economic growth of urban areas.

This dataset currently only has a 30 m spatial resolution, which is only highly useful for research on land data surveys and environmental ecology. Due to its low spatial resolution, it cannot satisfy commercial demand and has not produced economic benefits. Future studies should focus on enhancing spatial accuracy and creating a system for classifying land data that has some commercial value and can supply usable geographic data for local real estate development, land value assessment, and other fields.

3. Limitations of information entropy of land use structure

Information entropy was originally a physical quantity. In 1948, Shannon, an American mathematician, proposed the concept of information and gave an expression when studying communication problems. Since then, the relationship between physical and information entropy (Yang *et al.*, 2021) has been the subject of much debate. The information entropy of land use structure is frequently used to characterise the degree of order and evolutionary direction of land use structural changes. The higher its value, the faster the land use type conversion, the more balanced the structure tends to be, and the more chaotic the system (Chen *et al.*, 2020). Numerous scholars have used the information entropy model as a significant research method to conduct many studies on the spatial and temporal changes of land use structures across various regions and spatial scales (Liu *et al.*, 2005). Zhang (2022b) utilised the information entropy of land use structure in high-altitude areas. This study also utilised land use structural information entropy to analyse the spatial and temporal evolution of land use changes in the study area. The results properly represent the changes brought about by the development of land resources in the area.

In the course of this study, it was found that the degree of order or complexity of land use can be expressed in terms of information entropy (H). Nevertheless, the information entropy can only reflect the quantitative relationship between regional land use types. To illustrate, squares a and b have the same shape and size, and we use different colours to differentiate between various land use types (Figure 10). The internal structure of a is much simpler than that of b. However, the two figures' information entropy (H) values are identical, demonstrating the inadequacy of information entropy (H) for describing the difference in land use change complexity. The H values of both c and d are equal, although the spatial distribution and occupancy of the three land use types are distinct (Figure 10). This illustrates that in actual life, different types of land use have distinct effects on ecological protection and socioeconomic development. In addition, the information entropy does not represent the differences between land use types in terms of land characteristics and functions. Even though the information entropy of the two regions may be identical, the actual land use status may be vastly different.

In addition, different statistical scales also affect the results of the H-value's calculation, and the results of the same area at different scales are contradictory. Using H-value as a single variable to reflect the orderliness and complexity of regional land use will result in some errors because the administrative regions included in this study have different areas.

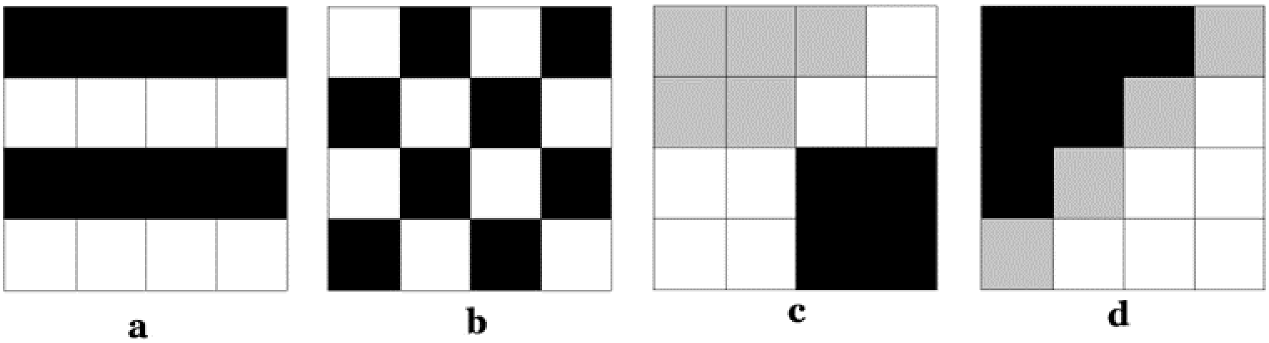

Figure 10. Schematic diagram of land use types. The black, white, and grey grids represent the three distinct land use categories.

Although H-value has some limitations when it reflects land use change, it can still express the trend of land use change in a particular region. In order to compensate for the limitation of land use structure information entropy, we use LC-value and L-value to compensate for the limitation brought by H-value when researching land change and conducting a comprehensive analysis of land development laws in the area.

IV. CONCLUSION

This paper investigated the land use change situation in Xingtai City and conducted an in-depth analysis of the land use situation in the study area, leading to the following conclusions:

There is a rapid increase in the amount of land used for construction while the amount of land used for agriculture continues to decline. By the end of 2020, the area of farmland will have decreased by 9.93% compared to 2000, while the built-up land area will have increased by as much as 84.16%. The forest cover increased by 12.03%, while the grassland cover decreased by 18%. The study area has a small portion of water and bare land—1% of the total area—which is not very significant.

Land use types show spatial aggregation characteristics. The global Moran's I value of built-up land and bare land increases year over year, and the spatial distribution develops in an aggregated manner. The global Moran's I value of other land use types decreases annually, and their spatial distribution spreads out gradually. Based on local Moran's I, the research investigated the spatial distribution of high-value clustering of single land use significance. Farmland was mainly located in the eastern plains, forestland, grassland, and water areas were primarily located in the western mountainous regions, built-up land was distributed in the central region of the study area, and farmland was distributed in the central and southern regions.

Cold and hot spots of a single land use type exhibit spatial clustering. Farmland SHS areas increased from 16 in 2000 to 76 in 2020. The number of HS areas for built-up land rose from 17 in 2000 to 34 in 2020. Forest land, grassland, water, and bare land cold and hot spots are spatially stable and experience minimal change.

The status of land resource utilisation improves annually. Except for Qiaodong District, the information entropy of land use structure (H) increases annually in 18 of the 19 administrative districts. The land use degree (L) of 19 administrative districts shows an upward trend from year to year, with the highest values being 379.46 and 348.8 in Qiaodong District and Qiaoxi District, respectively, as the main urban area of Xingtai City. These two districts also have the highest degree of dynamic land use (LC), 1.35 and 1.75, respectively.

This study reveals the effects of natural and human activities on Xingtai's land use. This study establishes a comprehensive dynamic monitoring system of land use with the changes of L, LC, H, UED, and other indicators. It offers a solid theoretical foundation for urban land resource allocation, rational development, and construction.

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