International Journal of Environment, Agriculture and Biotechnology
Vol-9, Issue-4; Jul-Aug, 2024
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

The Study of the Spatiotemporal Evolution of Land Use and Landscape Patterns in Maoming City

Chenlu Wei, Ruei-Yuan Wang*

School of Sciences, Guangdong University of Petrochem Technology (GDUPT), Maoming 525000, China
*Corresponding Author

Received: 15 Jul 2024; Received in revised form: 08 Aug 2024; Accepted: 16 Aug 2024; Available online: 22 Aug 2024

Abstract*— This study analyzes the changes in land use and the evolution of landscape patterns in Maoming City from 2000 to 2020, revealing the dynamic changes in land use and their ecological effects during urbanization. The results show a significant decrease in cultivated land area, a notable increase in construction land, and a slight decrease in grassland area during this period, indicating that the ecosystem faces certain pressures. The fluctuations in the number of patches (NP) and patch density (PD) reflect a trend of landscape fragmentation in Maoming. The number of patches in cultivated land and woodland has decreased, and the Interspersion and Juxtaposition Index (IJI) and Aggregation Index (AI) indicate that patch distribution tends to be disordered and uneven. At the overall landscape level, diversity has decreased, and the Shannon's Evenness Index (SHEI) has remained relatively stable but is insufficient to offset the negative impacts of reduced diversity. The Landscape Disturbance Index (LDI) shows that landscape interference in Maoming peaked in 2010 and then declined, suggesting that ecological protection and integrated management measures have been effective. The mean disturbance index (MLDI) is higher in the southern Maonan and Dianbai districts, mainly due to higher urbanization, population density, and active economic activities, while the northern Xinyi City, with lower urbanization and fewer human activities, exhibits a lower disturbance index.

Keywords*— Land Dynamics Degree; Land Use Transition Matrix; Landscape Pattern Index; Landscape Disturbance Index (LDI); Maoming City.

I. INTRODUCTION

Land resources are a crucial factor influencing human social development. The types of land use and their spatiotemporal changes profoundly impact human production and lifestyle [1]. Landscape patterns are considered the most significant manifestation of land use changes and are a primary focus of landscape ecology. These patterns include the spatial arrangement of patches of different sizes, quantities, and shapes [2], reflecting the ecological environment formed by the synergistic interaction between humans and nature. With the acceleration of urbanization and rapid economic transformation, the efficient and rational use of land resources and the improvement of the ecological environment have become issues of widespread social concern.

Many scholars have conducted extensive research on land use and landscape ecology patterns. Notably, in the study of land use, scholars have employed land use dynamics [3], land use Markov matrices [4], and models such as GeoSOS-FLUS and PLUS for predicting future land use [5-6].In terms of landscape patterns, various indices and models have been used, including the Landscape Disturbance Index (LDI) [7-8], the Landscape Vulnerability Index [9–10], and the Ecological Risk Model [11–12]. However, these studies typically focus on ecologically sensitive watersheds [12–13] or large cities with significant populations, such as Nanning [14] and Beijing [15]. Additionally, some scholars have analyzed landscape patterns and ecological environments from a broader perspective, such as studying the fragmentation of cultivated land in China [16] and the spatiotemporal evolution of landscape ecology in Jiangsu Province [17].

In summary, while there is extensive research on land use and landscape ecology with applications across various scenarios, smaller-scale and less developed cities have not received as much attention. The economic transformation and environmental changes have already impacted provinces, cities, and counties across China. Therefore, this paper focuses on Maoming City as the study area to narrow the research scope. It explores the spatiotemporal changes in land use in Maoming from 2000 to 2020 and how these changes respond through landscape ecological patterns. The aim is to provide some meticulous thinking for land use and ecological environmental protection in Maoming.

II. STUDY AREA

Maoming City is located in the southwestern part of Guangdong Province, bordering Guangxi to the north and facing the South China Sea to the south. Its latitude ranges from 21.67°N to 22.17°N, and its longitude ranges from 110.58°E to 111.38°E (Figure 1). Situated south of the Tropic of Cancer, Maoming experiences a subtropical monsoon climate, characterized by warm and humid weather. Located along the coast of the South China Sea, Maoming boasts abundant mineral and marine resources and serves as an important agricultural base in Guangdong Province. The city's diverse topography includes extensive plains, hills, and mountains, along with numerous rivers and lakes [18].

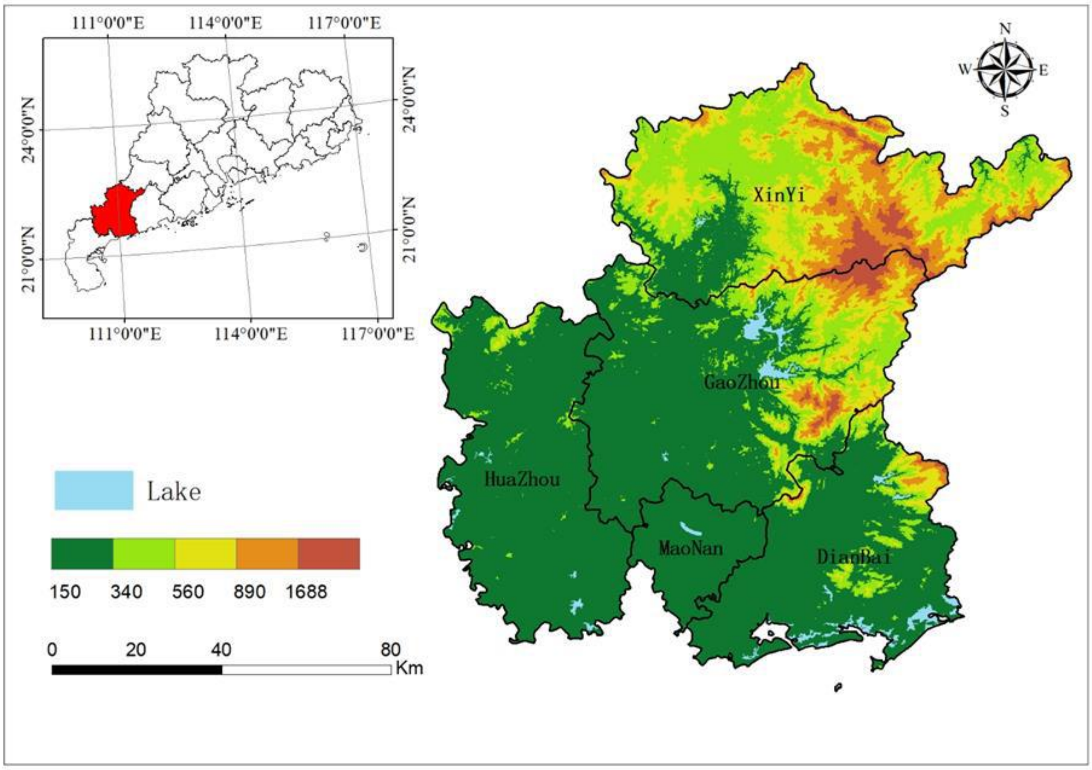

Fig.1 The map of the location and topographic in Maoming

III. DATA SOURCES AND METHODS

3.1 Data Sources

This study uses land use data with a resolution of 30m × 30m for the years 2000, 2010, and 2020, obtained from the Resource and Environment Science Data Center (RESDC) of the Chinese Academy of Sciences (CAS) (http://www.resdc.cn). After reclassification, the data were categorized into six types: cultivated land, woodland, grassland, water, construction land, and unused land.

3.2 Research Methods

This study analyzes land use data for Maoming from 2000 to 2020, employing land use dynamics and land use transition matrix methods to assess changes in land use types. The transformation processes of land use types are visualized using Sankey diagrams. The study selects several landscape pattern indices at the patch level, including Patch Density (PD), Number of Patches (NP), Aggregation Index (AI), and Interspersion and Juxtaposition Index (IJI). At the landscape level, the selected indices include Area-Weighted Mean Shape Index (AWMSI), Area-Weighted Mean Patch Fractal Dimension (AWMPFD), Shannon's Diversity Index (SHDI), and Shannon's Evenness Index (SHEI), to analyze landscape patterns. Finally, the LDI and the MLDI are calculated to assess the extent of disturbances to the ecosystem caused by human and natural activities (Figure 2).

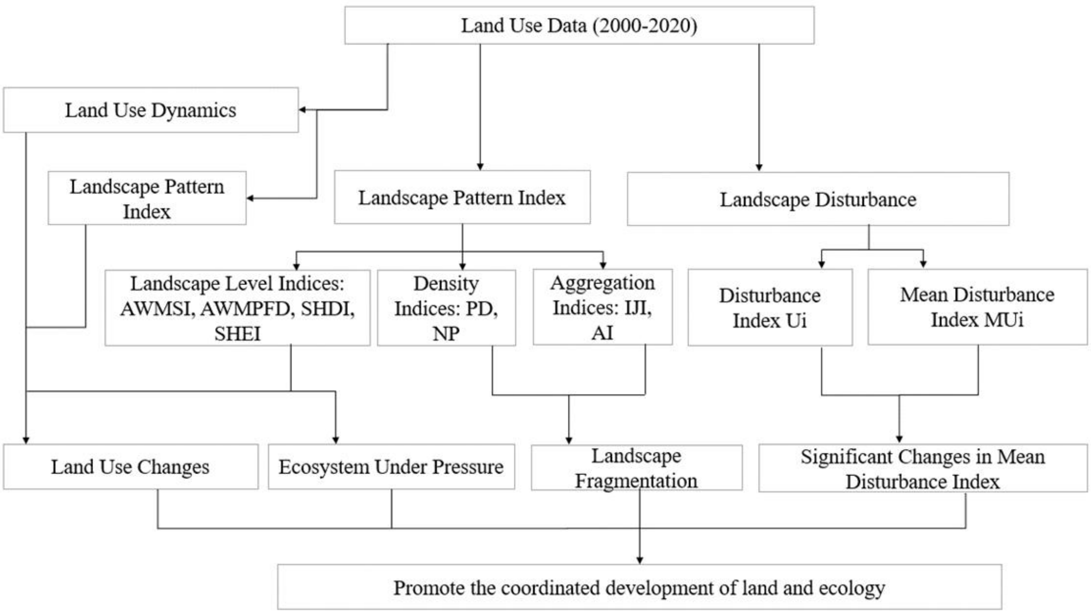

Fig.2 the Map of Technical Route

3.2.1 Land Use Dynamics

Land use dynamics refer to the degree of change in the area of a specific land use type over a particular period. It reflects the degree of dynamic change in land use types, including both comprehensive and single land use dynamics. The larger the value, the stronger the land use change. The calculation method is shown in Equation (1) [19].

$$K_I = \frac{Sit_2 - Sit_1}{Sit_1} \times \frac{1}{t_2 - t_1} \times 100\% \qquad (1)$$

where K_i is the degree of land use change during the period from t_2 to t_1, and S_{it2}, S_{it1} represent the area of a certain land type at times t_2 and t_1, respectively.

3.2.2 Land Use Transition Matrix

The land use transition matrix, also known as the Markov transition matrix model, can visually represent the quantity and direction of mutual conversions between different land use types within a specific period. In this study, the land use transition matrix is used to analyze the conversion relationships of land use in Maoming. It solves the transition matrix based on the changes in the time series, thereby analyzing the change patterns and trends of land use during this time series [20].

If P is the land use transition matrix from time T_0 to T_1, it has the following properties:

1. Normalization: the sum of the probabilities of a

certain land use type converting to other land types is 1.

2. Non-negativity: the transition probability between any two land use types cannot be less than 0, $0 \leq p_{ij} \leq 1$; The expression is:

$$P = \begin{pmatrix} P_{12} & \cdots & P_{1n} \\ \vdots & \ddots & \vdots \\ P_{n1} & \cdots & P_{nn} \end{pmatrix} \quad (2)$$

In the formula, represents the area of land type i converted to land type j, where i and j denote two different land use types, and n is the total number of land use types.

3.2.3 Sankey Diagram Analysis

The Sankey diagram, also known as the Sankey energy balance diagram, is a special type of flow chart used to describe the flow direction from one set of values to another [21]. It has clear and intuitive utility for data visualization and analysis. To reflect the transformation process of various land use types in Maoming, Origin2024 software was used to visualize the land use changes from 2000 to 2020, constructing a trajectory model of land use changes.

3.2.4 Landscape Pattern Indices and Ecological Significance

Landscape pattern indices can reflect changes in landscape form and distribution and are widely used in landscape analysis and ecological value assessment (Table 1). These indices are categorized into three hierarchical levels: patch level, class level, and landscape level. This study selects four indices at the class level: Patch Density (PD), Number of Patches (NP), Interspersion and Juxtaposition Index (IJI), and Aggregation Index (AI). At the landscape level, four indices were selected: Area-Weighted Mean Shape Index (AWMSI), Area-Weighted Mean Patch Fractal Dimension (AWMPFD), Shannon's Evenness Index (SHEI), and Shannon's Diversity Index (SHDI). These indices were used to analyze the evolution of landscape patterns in Maoming.

The main methodology involved in putting the land use data from 2000 to 2020 in tif format into the Fragstats 4.2 software to calculate the various indices is [22-23]. Finally, the calculated class-level and landscape-level indices were imported into ArcGIS 10.7 software, and natural break classification was used for visualization analysis.

Table 1 Ecological Significance of Landscape Pattern Indices

Level	Landscape Index	Ecological Significance
Class	Number of Patches (NP)	Represents the total number of patches of a type, reflecting landscape heterogeneity and fragmentation.
Class	Patch Density (PD)	Represents the density of a land use type per unit area, directly reflecting the degree of human intervention.
Class	Aggregation Index (AI)	Represents the degree of aggregation of patches.
Class	Interspersion and Juxtaposition Index (IJI)	Reflects the distribution status of patches, indicating the connectivity and distribution of patches.
Landscape	Area-Weighted Mean Shape Index (AWMSI)	Represents the complexity of patch shapes.
Landscape	Area-Weighted Mean Patch Fractal Dimension (AWMPFD)	Reflects the influence of patch shape complexity on human activities.
Landscape	Shannon's Diversity Index (SHDI)	Reflects landscape diversity.
Landscape	Shannon's Evenness Index (SHEI)	Reflects the evenness and dominance of the landscape composition.

3.2.5 Calculation of the LDI

The LDI reflects the degree of disturbance to the landscape structure caused by human activities or natural factors [24], measuring the extent of ecosystem disturbance in the landscape pattern, including both natural and human disturbances. The index is established using the Landscape Fragmentation Index (Pi), Landscape Isolation Index (Di), and Landscape Fractal Dimension Index (Fi). The calculation formula is:

$$LDI_i = W_1 \times P_i + W_2 \times D_i + W_3 \times F_i \quad (3)$$

where W_1, W_2, and W_3 represent the weights of the Landscape Fragmentation Index, Landscape Isolation Index, and Landscape Fractal Dimension Index, respectively. The value i refers to a specific land use type. Based on relevant studies and the actual situation in Maoming, this study assigns weights of 0.5, 0.3, and 0.2 to the three main landscape indices [25]. Using the moving window calculation method in Fragstats 4.2 software, a window size of 3000 meters was selected for the calculations [26], resulting in the Landscape Fragmentation Index, Landscape Isolation Index, and Landscape Fractal Dimension Index. The calculations were then performed using the ArcGIS raster calculator, and the natural break classification method was used to visualize the LDI.

IV. RESULTS AND ANALYSIS

4.1 Analysis of Land Use Dynamics

4.1.1 Temporal Scale

The analysis of land use dynamics shows that the degree of change in cultivated land was the most intense during the period 2010–2020, consistently showing a downward trend (Table 2). From 2000 to 2010, the change in area was small, about 11.68 km²; however, from 2010 onwards, the cultivated land area decreased by 613.95 km², with a dynamic degree of -1.87%. In contrast, the woodland area showed a growing trend. From 2000 to 2010, the Woodland dynamic degree was 0.04%, indicating a slow increase; from 2010 to 2020, the dynamic degree rose to 0.77%, with the woodland area increasing by 521.15 km². This increase is due to the implementation of the "Returning Farmland to Forest" policy, which facilitated effective ecological restoration in Maoming. Moreover, the dynamic degrees of grassland and water were relatively small, at 0.20% and 0.65%, respectively, from 2010 to 2020. Overall, from 2000 to 2010, the dynamic degree of grassland was -0.32%, and for water, it was 0.25%, indicating a slow but steady increase in the area of water. In contrast, the grassland area decreased at first and then increased, but overall, the increase in grassland area was less than the decrease.

Additionally, the dynamic degree of construction land was relatively high, indicating significant land use changes. As shown in Table 2, construction land accounted for 6.05% of the total land area in 2000, decreased to 5.97% in 2010, and then expanded again to 6.62% in 2020. Unused land experienced the most significant change in land use dynamics from 2000 to 2020. Although the change in area was relatively small, the degree of utilization greatly increased.

Table 2 Dynamics and Change of Land Use in Maoming City from 2000 to 2020

Year	2000		2010		2020		2000-2010		2010-2020	
Type	Area / km²	Ratio / %	Area / km²	Ratio / %	Area / km²	Ratio / %	Change / km²	Dynamics / %	Change / km²	Dynamics / %
Cultivated	3296.80	29.08	3285.12	28.97	2671.17	23.55	-11.68	-0.04	-613.95	-1.87
Woodland	6714.12	59.22	6739.99	59.44	7261.14	64.03	25.86	0.04	521.15	0.77
Grassland	343.81	3.03	337.21	2.93	344.01	2.99	-6.60	-0.32	6.80	0.20
Water	285.22	2.52	292.25	2.58	311.15	2.74	7.03	0.25	18.91	0.65
Construction	685.60	6.05	676.87	5.97	750.27	6.62	-8.73	1.08	73.40	1.08
Unused	12.97	0.11	12.67	0.11	6.95	0.06	-0.30	-0.23	-5.73	-4.52

4.1.2 Spatial Scale

The analysis shows significant changes in the cultivated land area in Maoming from 2000 to 2020. The regions with the most substantial decrease in cultivated land are concentrated in the central part of Maonan District, the northwest of Dianbai District, and the southern part of Gaozhou City (Figure 3). Due to the need for returning farmland to forests and grasslands, as well as urban construction, the sources of construction land in Maonan District and Gaozhou City are primarily from cultivated land. Some cultivated land has been converted to ecologically more significant woodland and water. Thanks to the active ecological protection efforts, the areas of these two land use types have increased, mainly in Maonan District, Dianbai District, and Gaozhou City.

Changes in water are concentrated in Maonan District, while changes in woodland are distributed in the northwest of Dianbai District, the east of Maonan District, and the south of Gaozhou City. Grassland areas showed fluctuations, with some grasslands disappearing in the northwest of Gaozhou and the central part of Huazhou between 2000 and 2010. Afterward, grassland areas slowly increased and were relatively evenly distributed, but overall, the increase was not significant, leading to a decline in grassland area. The increase in construction land is most notable in the central Maonan District and the southern part of Gaozhou.

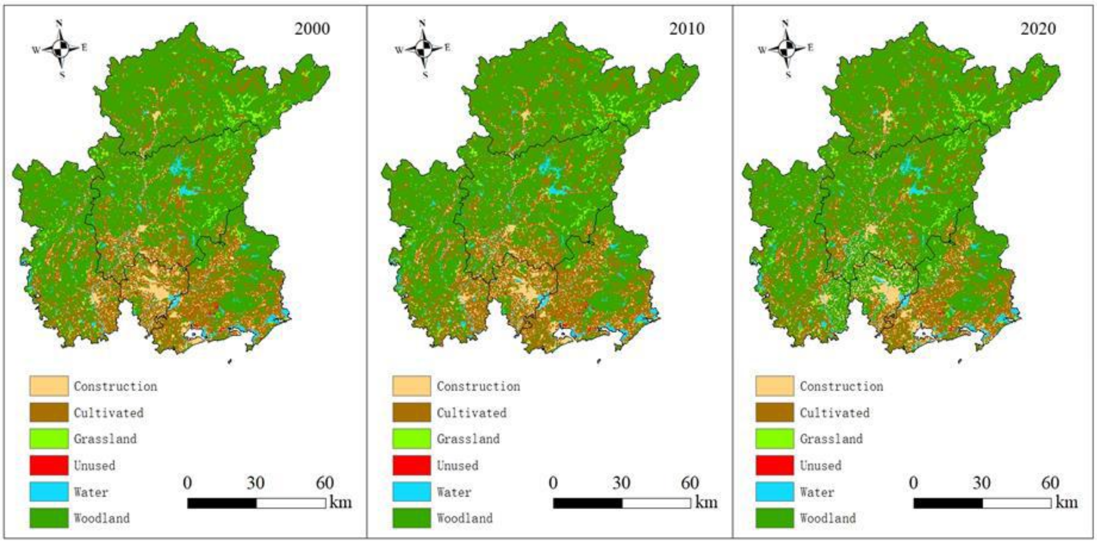

Fig.3 Land Use Changes in Maoming from 2000 to 2020

Since 2010, construction land in Maonan District has expanded significantly, and although the growth area of construction land in Gaozhou is smaller than in Maonan District, its distribution is more extensive. Unused land is distributed in the southeast of Dianbai District. From 2000 to 2010, the change in unused land area was minor, but by 2020, rapid development and construction in Dianbai District increased land use efficiency and developed some of the unused land.

4.2 Analysis of Changes in Land Use Types

From the results of land use type transitions in Maoming from 2000 to 2020 (Table 3), it can be seen that the primary land use changes involve the mutual transformation of cultivated land, woodland, and construction land. From 2000 to 2010, the total transfer of cultivated land reached 3296.61 km², with 19.69 km² converted to construction land and 42.38 km² converted to woodland. Construction land had a total transfer of 685.57 km², primarily converting to woodland (16.50 km²) and cultivated land (21.12 km²). The total transfer of woodland was 6713.43 km², with 30.51 km² and 11.63 km² converted to cultivated land and construction land, respectively. Grassland had a total transfer of 343.73 km², mainly converted to cultivated land and woodland.

This period's land use changes indicate an urbanization trend, with cultivated land being extensively converted to construction land, significantly impacting agricultural land. Some construction land was converted to woodland, possibly due to urban greening and ecological restoration measures. However, the conversion of grassland to cultivated land and woodland reflects a reduction in natural vegetation, which could lead to decreased ecosystem services such as soil and water conservation and biodiversity.

From 2010 to 2020, the total transfer of cultivated land was 3284.38 km², with 84.23 km² converted to construction land and 664.68 km² to woodland. Compared to the previous decade, the pattern of construction land transfer remained similar, still primarily converting to woodland and cultivated land, but with increased conversion areas of 25.56 km² to woodland and 41.10 km² to cultivated land. Woodland transferred to cultivated land and construction land at 106.25 km² and 52.34 km², respectively, showing significant changes. Woodland also converted to grassland at 20.05 km², the largest conversion of grassland area in 20 years. The total transfer of water was 291.62 km², primarily converting to construction land and cultivated land; unused land was mainly converted to grassland and construction land, while grassland was mainly converted to woodland and cultivated land.

These changes indicate a more pronounced trend of urban expansion during this period. Cultivated land continued to be extensively converted to construction land, putting more pressure on agricultural land. The significant increase in woodland converted to construction land could negatively impact the region's carbon storage and climate regulation functions. The large-scale conversion of grassland to woodland, while increasing vegetation cover, could also lead to the degradation of grassland ecosystems. Additionally, the transfer of water to construction land could affect regional water resource management and water quality protection.

Table 3 Land Use Transition Matrix in Maoming City from 2000 to 2020 (Unit: km²)

Year	Land Use Type	Grassland	Cultivated	Construction	Woodland	Water	Unused Land	Total
2000-2010	Grassland	323.48	1.29	0.53	17.66	0.77	0.00	343.73
	Cultivated	1.18	3282.98	19.69	42.38	6.27	0.11	3296.61
	Construction	0.09	21.12	643.94	16.50	3.90	0.01	685.57
	Woodland	7.66	30.51	11.63	6659.70	3.85	0.08	6713.43
	Water	0.21	1.84	0.46	7.44	279.83	0.02	285.10
	Unused	0.00	0.11	0.31	0.08	0.03	12.43	12.96
	Total	332.62	3340.56	676.56	6739.97	291.64	12.65	11337.40
2010-2020	Grassland	308.56	4.06	2.15	16.08	2.12	0.00	332.42
	Cultivated	4.40	2508.44	84.23	664.68	22.34	0.27	3284.38
	Construction	2.15	41.10	701.90	25.56	11.08	0.03	781.82
	Woodland	20.05	106.25	52.34	6532.16	25.85	0.26	6736.91
	Water	2.02	10.12	1.28	19.13	248.88	0.11	291.62
	Unused	2.02	0.36	3.47	0.01	0.19	6.65	12.69
	Total	339.21	2670.46	749.72	7257.91	310.45	6.93	11334.67

The Sankey diagram in Figure 4 intuitively displays the trajectory of land use quantity changes in Maoming from 2000 to 2020, revealing shifts among different land use types over the past 20 years. The diagram shows that cultivated land has been predominantly converted into woodland, followed by construction land.

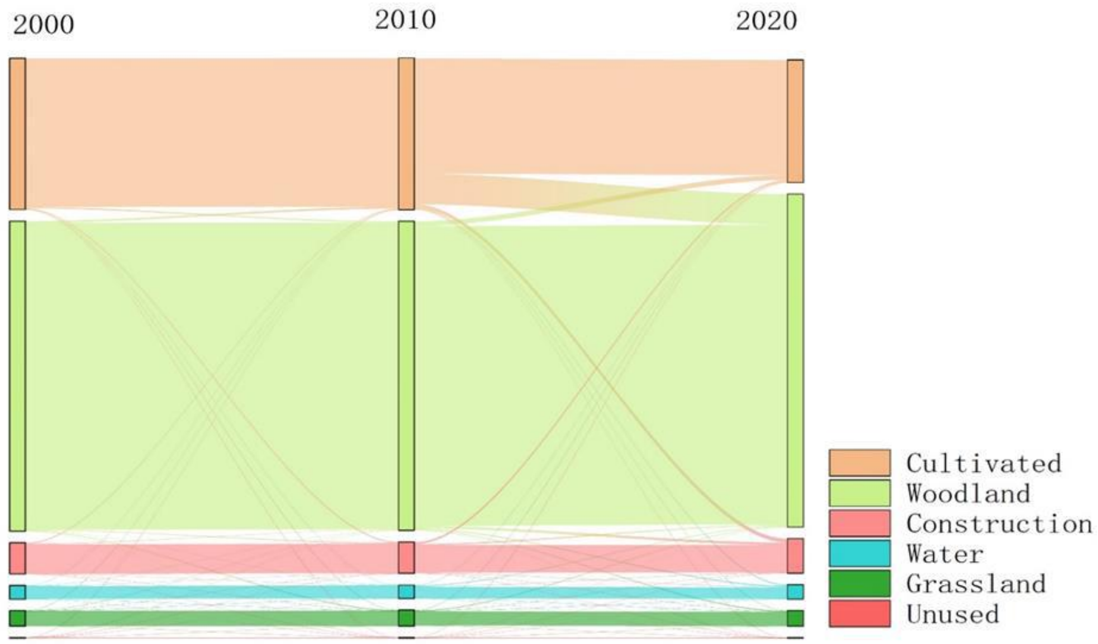

Fig.4 Trajectory of Land Use Changes from 2000 to 2020

The trend of cultivated land being converted to woodland and construction land is particularly evident from 2010 to 2020, indicating that as urbanization progresses, agricultural land is gradually decreasing, with more land likely being used for urban development and greening. While this transformation can help increase urban green coverage and improve ecological environment quality, it may also place pressure on food production and the balance and health of agricultural ecosystems.

The changes in woodland during 2010-2020 are also significant. Woodland has not only received a substantial amount of transferred cultivated land but has also been partially converted into construction land. This conversion can potentially enhance the region's carbon storage capacity, improve air quality, and regulate the local climate in Maoming. Meanwhile, as urbanization and industrialization accelerate, construction land continues to expand from both cultivated land and woodland. This expansion often accompanies the increase of impervious surfaces, which can exacerbate urban heat island effects, increase storm water runoff, and intensify urban flooding.

4.3 Analysis of Class-Level Landscape Pattern Indices

4.3.1 Density Indices

In landscape ecology, the NP and PD are critical indices for describing landscape patterns. NP provides an overall understanding of the number of landscape patches, while PD describes the spatial density and distribution of patches. A comprehensive analysis of these two indices can offer a deeper insight into the ecological characteristics of the landscape and its impact on the ecosystem. These indices are also valuable references for landscape management, biodiversity conservation, and ecological restoration planning.

The analysis shows that the number of cultivated land patches (NP) decreased in 2010 but slightly increased in 2020 (Table 4). The number of woodland patches peaked at 1513 in 2010 before significantly decreasing, likely due to the conversion of woodland into construction land or cultivated land. The number of grassland patches has shown a steady upward trend, indicating that grassland is gradually being fragmented or encroached upon by other land use types. The number of water body patches decreased in 2010 but increased again in 2020. The number of construction land patches has continuously increased, while the number of unused land patches decreased in 2020, indicating that unused land is gradually being converted to other land use types. This trend is likely a result of rapid urbanization and increased infrastructure development in Maoming.

Regarding PD, the density of cultivated land remained consistent in 2000 and 2020 but slightly decreased in 2010, indicating stabilization in cultivated land distribution. The patch density of water remained stable, showing little change in spatial distribution. The density of woodland decreased in 2020, possibly due to the replacement or consolidation of some wood areas. The density of construction land has continuously increased, reflecting the high-intensity of land use during urbanization. The density of unused land was zero in all three periods, indicating its very small proportion.

Table 4 Changes in Density Indices from 2000 to 2020 (Unit: count)

Index	Type	2000	2010	2020
Number of Patches (NP)	Cultivated	2505	2312	2479
	Woodland	1479	1513	1218
	Grassland	828	853	877
	Water	555	518	567
	Construction	3498	3518	3643
	Unused	45	45	38
Patch Density (PD)	Cultivated	0.22	0.20	0.22
	Woodland	0.13	0.13	0.11
	Grassland	0.07	0.08	0.08
	Water	0.05	0.05	0.05
	Construction	0.31	0.31	0.32
	Unused	0	0	0

4.3.2 Spatial Changes in NP and PD from 2000 to 2020

The NP and PD in Maoming experienced significant spatial changes from 2000 to 2020 (Figure 5). From 2000 to 2010, the southern part of Maoming had a higher number of patches compared to the central and northern parts. By 2020, the number of patches in the southern region had decreased rapidly, primarily concentrated in the eastern part of Huazhou City, the central part of Maonan

District, the southern part of Gaozhou City, and the western part of Dianbai District. Similarly, changes in PD can be observed. From 2000 to 2010, the spatial distribution of NP did not change significantly. However, from 2010 to 2020, the patch density in some areas showed a marked downward trend, possibly due to the development and integration of cultivated land, construction land, and woodland in Maoming over the past decade.

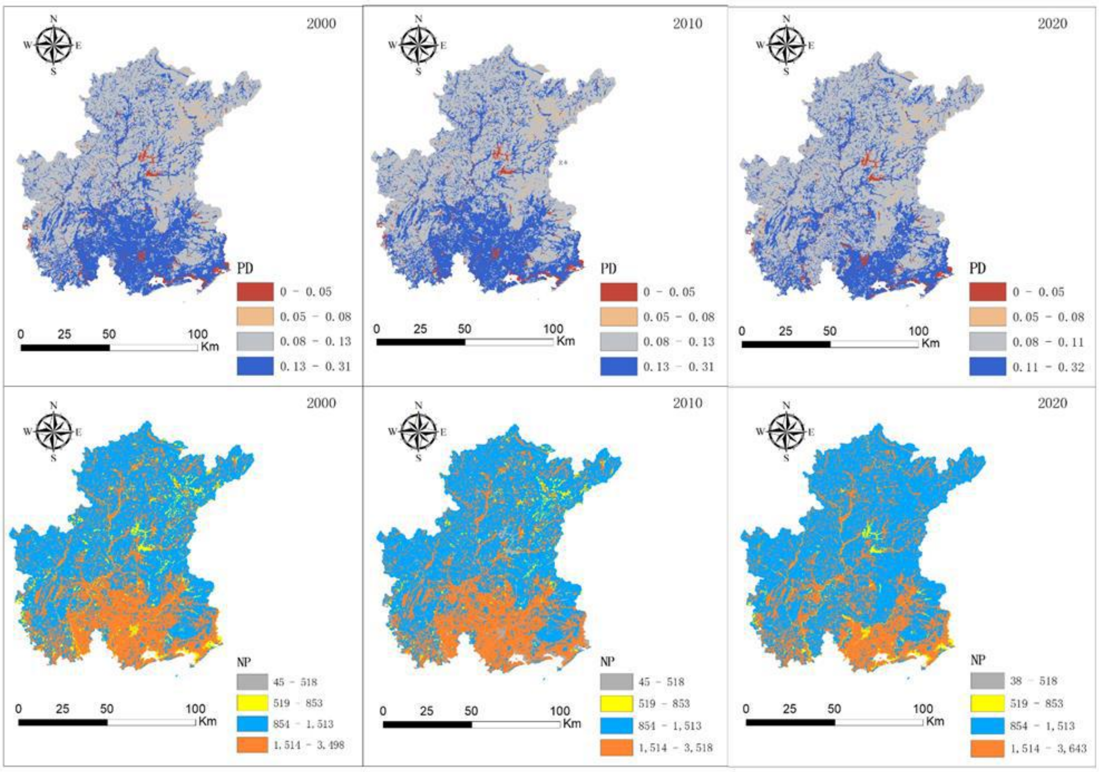

Fig.5 Spatiotemporal Distribution of NP and PD in Maoming from 2000 to 2020

4.3.3 Aggregation Indices

The IJI measures the spatial arrangement and relative position of different patch types in the landscape. Higher values indicate a more uniform spatial arrangement of landscape types. The AI reflects the degree of aggregation of a specific land use type within the landscape. Higher values indicate that the patches of that type are more aggregated.

The data in Table 5 show that from 2000 to 2020, the IJI for cultivated land in Maoming gradually decreased, indicating that the spatial arrangement of cultivated land patches became less uniform. The AI for cultivated land peaked in 2010 and then decreased, suggesting that the concentration of agricultural land and urbanization expansion indeed affected cultivated land. However, the degree of aggregation increased in 2020. The IJI for woodland increased to 59.88 in 2020, indicating that the spatial arrangement of woodland patches became more uniform. The AI value decreased in 2010 but then rebounded, likely due to afforestation and ecological restoration policies and projects in Maoming.

The IJI for construction land increased significantly, indicating that the spatial arrangement of construction land patches became more uniform and urban planning gradually improved. The AI for construction land remained relatively stable, suggesting a stable spatial pattern of urban construction land. The IJI for grassland slightly increased, indicating a trend toward a more uniform spatial arrangement, while the AI remained stable. The IJI for water also slightly increased, indicating a minimal change in spatial arrangement, while the AI slightly decreased. The IJI for unused land peaked at 93.51 in 2010 before declining, and the AI peaked at 93.51 in 2010 before declining as well.

Table 5 Changes in Aggregation Indices from 2000 to 2020

Index	Type	2000	2010	2020
Interspersion and Juxtaposition Index (IJI)	Cultivated	52.01	51.81	48.90
	Woodland	48.55	48.94	59.88
	Grassland	46.03	46.37	47.42
	Water	67.65	67.62	68.21
	Construction	43.07	44.08	57.35
	Unused	64.46	93.51	74.52
Aggregation Index (AI)	Cultivated	93.62	97.04	92.84
	Woodland	97.08	91.27	97.09
	Grassland	91.52	90.98	91.25
	Water	91.00	91.32	89.97
	Construction	91.63	91.35	91.58
	Unused	91.58	93.51	90.14

From Figure 6, the macroscopic spatial changes in IJI and AI values in Maoming between 2000 and 2020 can be observed. In 2000, the IJI values in the southern regions of Maonan District and Dianbai District were relatively high, while the central and northern regions, such as Gaozhou City and Xinyi City, had lower IJI values. This indicates that the land use types in the southern part were more uniformly arranged, whereas the central and northern parts were more irregular.

In 2010, the overall IJI values in Maoming changed significantly, concentrating between 47 and 52 and covering the entire area. Over the ten years, the IJI values decreased rapidly. By 2020, the IJI values had increased quickly, showing notable variability. These significant changes in IJI suggest that the land use types in Maoming shifted from uniform to disorder over these 20 years, possibly due to rapid urban development combined with ecological protection and restoration measures.

Regarding the AI, from 2000 to 2010, the AI values in the southern part were slightly lower than in the northern part, with little change, mostly concentrated in the range of 94-95. This indicates a higher degree of patch aggregation in the southern land use types, while the northern and eastern parts had denser patch distributions. In 2020, Figure 6 shows that AI values in most regions of Maoming decreased after 2010, falling within the range of 91-93, still maintaining a high level. Some areas, such as the northern part of Maonan District, the southern part of Gaozhou City, and the northwest of Dianbai District, showed a noticeable increase in AI values.

The possible reasons are that the rapid urbanization in the southern region led to more diverse land use types, with fragmented patch edges causing AI to rise. Meanwhile, in most regions, the implementation of ecological protection measures enhanced the integrity of patches, leading to a decrease in AI values.

4.4 Landscape-Level Index Analysis

The AWMSI and AWMPFD collectively reflect the complexity of patch shapes. Higher complexity may provide more habitat types and edge effects, thereby supporting higher biodiversity. The SHDI and SHEI reflect species diversity and distribution evenness within the landscape. High diversity and even distribution help maintain the stability and functionality of ecosystems. The combination of complex patch shapes (high AWMSI and AWMPFD) with high species diversity (high SHDI) and even distribution (high SHEI) usually indicates a healthy, stable landscape with high ecological functionality.

The AWMSI increased from 1.75 to 1.79, indicating an increase in the complexity of patch shapes within the landscape. This could be a result of the increased presence of irregularly shaped construction land and infrastructure development during urbanization, leading to decreased landscape connectivity and enhanced edge effects. The AWMPFD remained stable at 1.08, indicating that the spatial complexity of landscape patches did not significantly change, suggesting that urban planning and management measures have controlled changes in patch shapes to some extent.

The SHDI decreased from 1.05 to 1.01, and the SHEI remained relatively stable around 0.58, with only a slight decrease. This indicates that over the past 20 years, urbanization and agricultural intensification may have led to a simplification of land use types in Maoming, reducing the variety and richness of patches within the landscape. Although the distribution of different patch types within the landscape has not changed significantly, this minimal change may not be sufficient to counterbalance the loss of diversity.

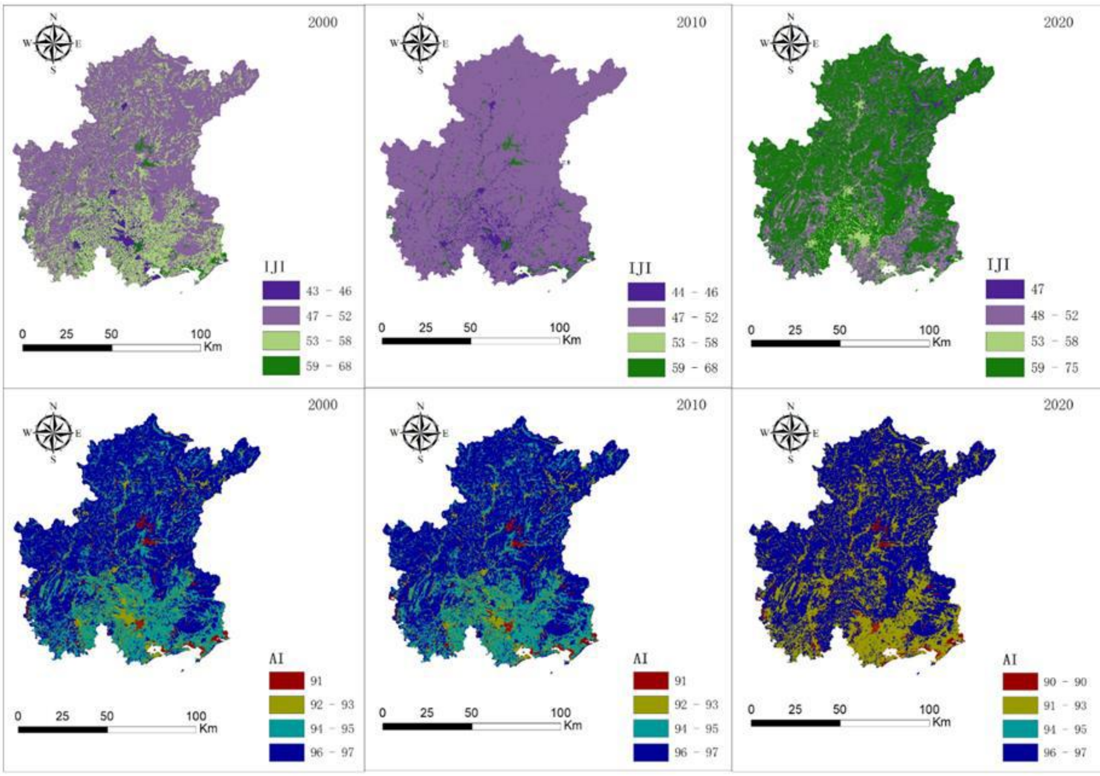

Fig.6 Spatiotemporal Distribution of IJI and AI in Maoming from 2000 to 2020

Table 6 Landscape-Level Pattern Indices from 2000 to 2020

Year	AWMSI	AWMPFD	SHDI	SHEI
2000	1.75	1.08	1.05	0.58
2010	1.78	1.08	1.04	0.58
2020	1.79	1.08	1.01	0.57

4.5 Temporal Differentiation Characteristics of LDI

4.5.1 Spatiotemporal Differentiation of LDI

Based on the analysis of landscape disturbance data from 2000, 2010, and 2020 (Figure 7), the LDI in Maoming has significantly increased over the past 20 years. In 2000, most areas had low landscape disturbance, with LDI values primarily concentrated between 0.2 and 0.5. High disturbance areas (LDI values close to or exceeding 1.69) were distributed in the city center and a few hotspot areas.

By 2010, the landscape disturbance had significantly increased, with a wider range of LDI values, and more areas had LDI values exceeding 1. The disturbance hotspots expanded, particularly around the urban periphery, where disturbances intensified. High-disturbance areas almost covered the entire city and its surroundings. In 2020, the LDI showed a decrease, with overall lower LDI values.

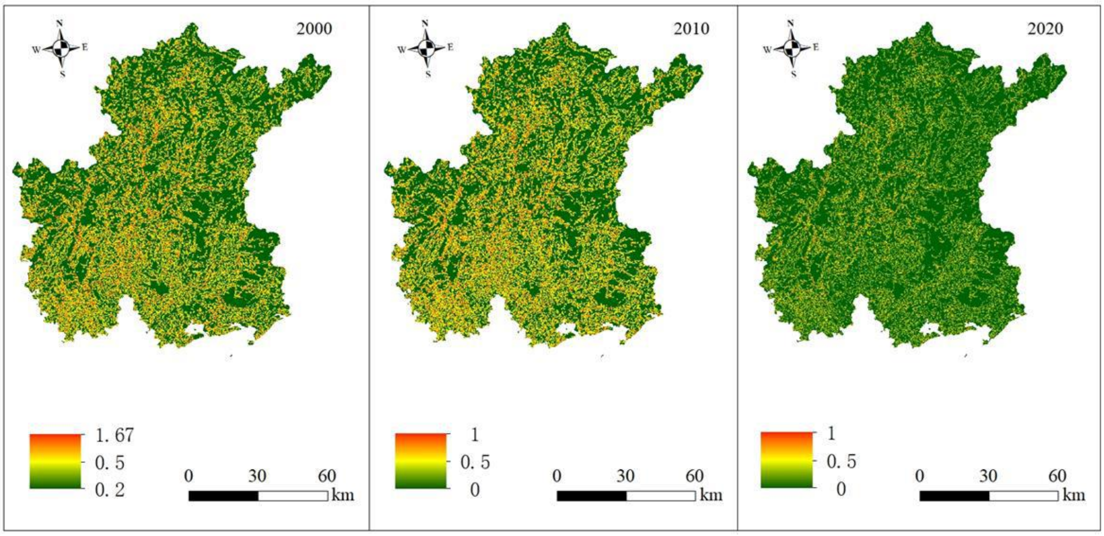

Fig.7 Spatiotemporal Distribution of LDI from 2000 to 2020

The expansion of high disturbance areas in 2010 likely led to habitat destruction, a decline in biodiversity, increased soil erosion, and degraded ecosystem functions in Maoming over the subsequent years. However, by 2020, the LDI had decreased and stabilized. This reduction is likely a result of effective ecological protection and comprehensive management strategies, such as the "Returning Farmland to Forest" policy, which have had a significant positive impact.

4.5.2 Analysis of Mean Landscape Disturbance Index (MLDI)

Based on the LDI calculations, the MLDI for Maoming at three time points (2000, 2010, and 2020) was computed using ArcGIS 10.7 [25]. The spatial distribution of the MLDI for these three time points is shown in Figure 8.

From 2000 to 2020, the MLDI in Maoming exhibited significant spatial changes and highlighted the impact of human activities on the landscape. In 2000, the MLDI values in the southern areas of Maonan District and Dianbai District ranged from 0.34 to 0.51, indicating higher disturbance levels. In contrast, the northern area, such as Xinyi City, had MLDI values between 0.20 and 0.27, dominated by agriculture and Woodland, indicating lower disturbance levels.

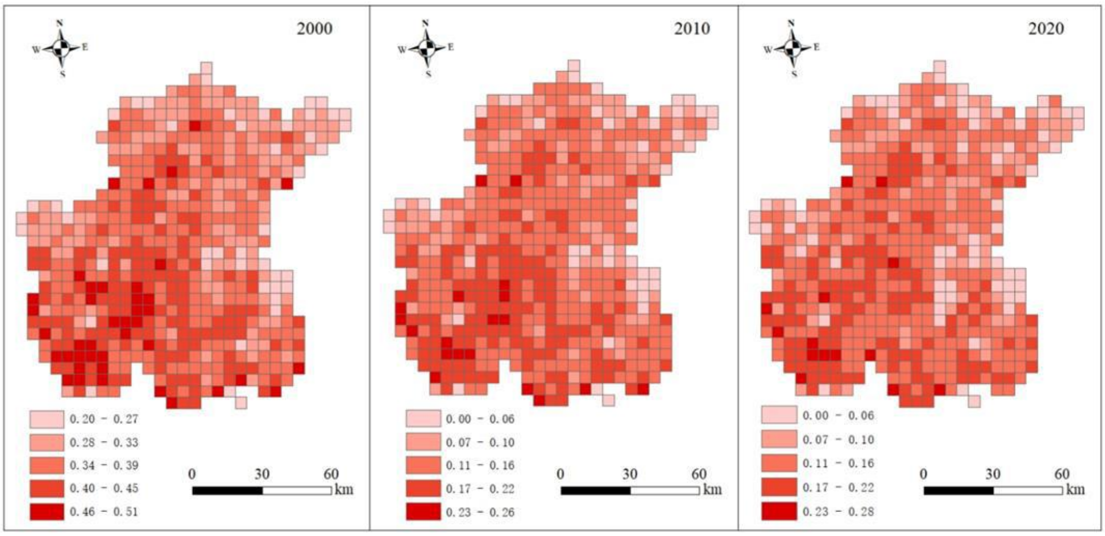

Fig.8 Spatial Distribution of MLDI from 2000 to 2020

By 2010, the MLDI values in the southern region increased to a range of 0.19 to 0.26, and the central regions, such as Gaozhou City, had MLDI values between 0.11 and 0.22. This increase in disturbance was likely influenced by agricultural intensification and infrastructure development. In 2020, the overall disturbance levels decreased, with MLDI values in the southern region concentrated between 0.17 and 0.28. The central and northern regions maintained relatively stable disturbance levels, but some local areas still showed higher disturbances.

To further analyze the changes in landscape disturbance, the average disturbance levels for the three periods were classified using the natural breaks method into five categories: very high, high, medium, low, and very low. The landscape area for each of these disturbance levels in Maoming was obtained (Figure 9). The landscape area with very high disturbance decreased from 1600 km² in 2000 to 675 km² in 2020. The area with high disturbances remained relatively stable. This suggests that urban planning and environmental protection measures have effectively reduced disturbance in some areas, but ongoing human activities continue to have a significant impact on the landscape.

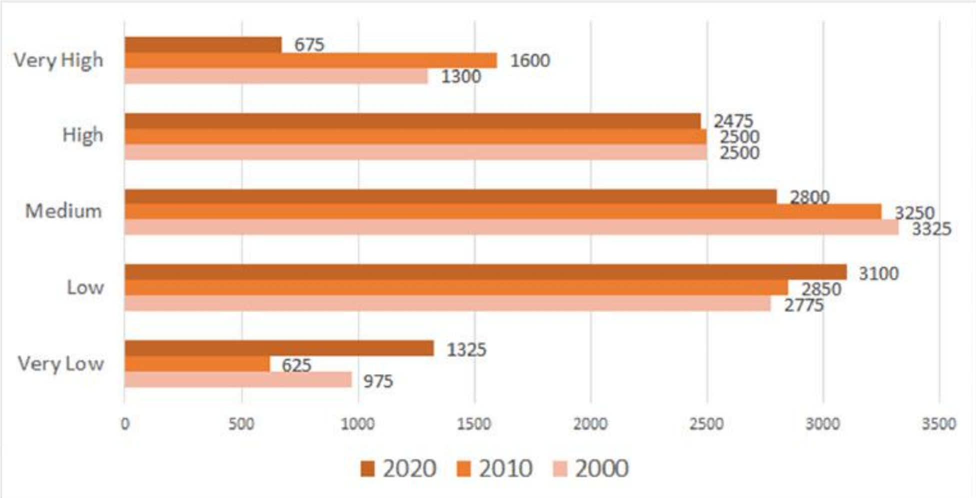

Fig.9 Changes in the Area of MLDI in Maoming from 2000 to 2020

The landscape area with medium disturbances decreased from 3325 km² to 2800 km². Meanwhile, the area with low disturbances also showed a decreasing trend. The landscape area with very low disturbance increased from 975 km² in 2000 to 1325 km² in 2010, but then decreased to 625 km² by 2020, indicating fluctuations over time. Overall, the landscape disturbance in Maoming has decreased, with areas of very high and high disturbance levels reducing. Although there has been a decrease in the area of medium and low disturbance levels, Maoming continues to experience ongoing pressure.

V. CONCLUSIONS

Through a detailed analysis of the spatiotemporal evolution of land use and landscape patterns in Maoming from 2000 to 2020, the following conclusions were drawn:

(1) Significant Land Use Changes

From 2000 to 2020, the cultivated land area in Maoming decreased by approximately 625.63 km², with a reduction of 11.68 km² between 2000 and 2010, and a significant reduction of 613.95 km² between 2010 and 2020.The construction land area increased by 64.67 km² from 2000 to 2020, with urbanization accelerating significantly after 2010, reflecting the notable trend of urban expansion and significant changes in land use in Maoming.

(2) Increasing Fragmentation of Landscape Patterns

The landscape pattern in Maoming is becoming increasingly fragmented, potentially making ecosystem restoration more difficult. The number of cultivated land patches decreased from 2505 to 2479, the IJI dropped from 52.01 to 48.9, and the AI also declined, indicating that the distribution of cultivated land patches became more uneven and less aggregated.

The number of woodland patches decreased by 261, but the IJI increased to 59.88 in 2020, and the AI rebounded to 97.09, indicating that wood protection and restoration measures have had some effect, albeit weaker compared to the rapid urbanization.

Overall, the distribution of IJI and AI indices from 2000 to 2020 showed fluctuations, with IJI significantly decreasing in 2010 and then recovering to a high state, while AI showed a notable decrease in 2020 in most areas. These fluctuations resulted in alternating patterns of uneven and highly dispersed landscape configurations, potentially leading to ecological issues.

(3) Ecosystem under Pressure

Urbanization likely exerts pressure on Maoming City's ecosystem, negatively impacting regional carbon storage and climate regulation. From 2010 to 2020, 84.23 km² of cultivated land and 52.34 km² of woodland were converted to construction land, while grassland also saw a slight decrease, potentially damaging the grassland ecosystem.

The increase in the AWMSI from 1.75 to 1.79 and the decrease in the SHDI from 1.05 to 1.01 suggest increased patch shape complexity but reduced landscape diversity, making the ecosystem more susceptible to disturbances and weakening its stability and resilience.

Despite the SHEI remaining relatively stable around 0.58, the lack of significant change in patch type distribution uniformity is insufficient to offset the negative impacts of reduced diversity, increasing overall ecosystem pressure.

(4) Significant Changes in Landscape Disturbance

The LDI in Maoming increased significantly from 2000 to 2020 but decreased in 2020. In 2000, most areas had low landscape disturbance, with LDI values mainly between 0.4 and 0.75. From 2000 to 2010, disturbance increased markedly, with more areas exceeding LDI values of 1. By 2020, disturbance levels had generally decreased. The MLDI was higher in the southern Maonan District and Dianbai District in 2000, reflecting high urbanization, population density, and active economic activities, while the northern Xinyi City had lower MLDI values due to lower urbanization and population density.

Based on the key conclusions from the systematic analysis of land use changes and landscape pattern evolution in Maoming from 2000 to 2020, the following recommendations are proposed:

(1) Promote Land Use Planning and Management

The study shows a significant reduction in cultivated land area over the past 20 years, particularly between 2010 and 2020. To protect limited cultivated land resources, it is recommended to reasonably control urban expansion and strictly limit the conversion of cultivated land to construction land, especially in southern areas like Maonan District and Dianbai District. Actively encourage efficient agriculture and intensive farming, and promote ecological agricultural models.

(2) Strengthen Cultivated Land Protection and Wood Restoration

The reduction in the number of cultivated land patches and the uneven changes in their distribution and aggregation indicate that urbanization and land development may lead to the fragmentation of cultivated land. It is recommended to restore and integrate cultivated land patches through land consolidation and efficient utilization measures to enhance the continuity and stability of agricultural production. Further strengthen wood protection and restoration efforts. Despite some success with wood protection measures, the number of woodland patches is still decreasing. Continue promoting reforestation and ecological restoration projects and strictly control the conversion of woodland to construction land. Improve wood connectivity and overall ecological function through scientific management and monitoring.

(3) Balance Urbanization and Ecological Protection

Considering the ecological pressures and changes in disturbance levels over the past 20 years, urban planning should incorporate more ecological construction elements, prioritize the protection of existing green spaces and natural landscapes, and avoid further damage to ecologically sensitive areas. Increase urban green spaces and wetland parks to regulate urban climate and carbon storage issues. In rapidly urbanizing areas like Maonan District and Gaozhou City, further improve the construction of grassland ecosystems and ecological corridors to reduce landscape damage and maintain ecosystem stability and orderliness. Establish long-term ecological monitoring and evaluation mechanisms, utilizing remote sensing technology and GIS to dynamically monitor landscape patterns and ecosystem health, promptly identifying and assessing the ecological impacts of urbanization.

REFERENCES

[1] Gao, P., Yue, Y., Yan, J., Wang, S., and Bie, Q. Spatio-temporal evolution and driving factors of land use and ecological risk in Gannan Tibetan Autonomous Prefecture. Arid Zone Research, https://link.cnki.net/urlid/65.1095.x.20240626.1418.003

[2] Huang, J.Y., Sun, Q., Huang, Y.G., Song, T.W., Hu, X.Y., and Zhang, Z.X. Landscape Pattern and Dynamic Change of Fractional Vegetation Cover in a Typical County in Arid Region. Environmental Science, https://doi.org/10.13227/j.hjkx.202402015.

[3] Huang, M., Li, Y., Ran, C., and Li, M. Dynamic changes and transformation of agricultural landscape pattern in mountainous areas: A case study in the hinterland of the Three Gorges Reservoir Area. Acta Geographica Sinica, 2021, 76(11): 2749-2764

[4] Chen, N., and Xu, G. Research on the Yangtze River Shoreline Changes in Jiangsu Province Using Transfer Matrix Model. Geospatial Information, 2024, (05):74-76+92.

[5] Cheng, S., and Pan, S. Land Use Change and Scenario Simulation Based on PLUS Model: A Case Study of Central Kaifen. Journal of Henan University (Natural Science), 2024, (03):303-313.

[6] Zhi, J., Han, C., Wang, X., Zhang, L., and Chu, C. Future construction land expansion under multiple simulation development scenarios and its impacts on landscape pattern evolution in China. GEOGRAPHICAL RESEARCH, 2024, 43(4): 843-860

[7] He, P., and Zhang, H. Study on Factor Analysis and Selection of Common Landscape Metrics. Wood Research, 2009,(04):470-474.

[8] Li, Z. Spatial Pattern Analysis and Dynamic Study of Wood Landscape in Niushou Mountain. Nanjing Forestry University, 2009(02).

[9] Han, Y. Landscape Pattern and Ecological Risk Assessment by Using Land Use Changes in Northern Shaanxi Province. Journal of Inner Mongolia Agricultural University (Natural Science Edition), 2023,(05):21-27.

[10] Cui, Y., Gao, X., Dong, B., and Wei, H. Landscape ecological risk assessment of county. Journal of Zhejiang A&F University, 2021, (03):541-551.

[11] Wang, Y., Dong, Y., He, Z., Wang, P., Zhao, H., and Zeng, W. Spatial-temporal variations of soil erosion intensity and landscape pattern analysis in Ehai Lkebasi. Environmental Pollution and Control, 2024, (05):626-630.

[12] Shen, Y.K., Zhang, Y., Wang, Z. Z., and Yang, Y. Dynamic Change Analysis of Landscape Pattern in Daqing River Basin. Haihe Water Resources, 2024, (05):14-17.

[13] Wei, Z., Li, J., Zou, Y., and Huang, Q. Characteristics of Landscape Pattern and Ecosystem Service Value Evolution in Southern Hilly Areas: A Case Study of Nanning. Agriculture and Technology, 2024, (08): 101-109.

[14] Gao, L., Zhao, Z., Song, D., Pei, and X. Spatial-temporal evolution of landscape ecological risk in Beijing Ecological Conservation Area and its response to natural and anthropogenic factors study from 1990 to 2020. China Environmental Science. Doi:10.15985/j.cnki.1001-3865.2024.05.003

[15] Liu, J., Jin, X., Xu, W., Wang, S., and Zhou, Y. Characteristic evolution and trend prediction of cultivated land landscape fragmentation in China from 1990 to 2020. Acta Geographica Sinica, 2023, 78(9): 2163-2185

[16] Wang, Z., Ju, S., and Wang, C. Temporal and spatial evolution of landscape pattern and its response to human disturbance in Jiangsu Province. Remote Sensing Technology and Application, 2023, 38(2): 264-273.

[17] Wu, J., and Qiu, N. Evaluation of Landscape Quality of Plant Communities in Park Green Spaces in Maoming City. Journal of Guangdong University of Petrochemical Technology, 2024, (01):121-126.

[18] Xiao, Y., Zhang, R., Li, C., and Li, H. Land Use Change and Its Impact on the Ecological Environment in Zunyi City. South-Central Agricultural Science and Technology, 2024, (05):109-115.

[19] Li, X. W., Zheng, L., Shen, X., Lin, X.B., and Zhou, Q.F. Research on the Characteristics and Driving Forces of Land Use Changes in Dali Prefecture in the Past 20 Years. Value Engineering, 2024,(18):152-155.

[20] Yin, Z., Wang, L., Liu, Y., Wang, L., and Wei, L. Visual Analysis of Water Intake Monitoring and Measurement in Harbin based on Sankey Diagram. Heilongjiang Hydraulic Science and Technology, 2023, (08):42-45.

[21] Lu, T., Zhao, S. T., and Zhou, C. Change of landscape pattern in Caizi Lake Basin from 1992 to 2022. Journal of Hubei University (Natural Science),

https://link.cnki.net/urlid/42.1212.N.20240508.1103.002

[22] Zhang, S., Hu, J., and Wang, M. Impact of land use change on ecosystem service value in Urumqi city. Environmental Protection Science, https://doi.org/10.16803/j.cnki.issn.1004-6216.2023120018

[23] Zhou, W., Wang, W., Luo, W., and Lin, Z. Study on the Evolution of Landscape Ecological Risk in Fujian Province Based on LUCC. Journal of Qinghai Normal University (Natural Science), 2023, (04):13-23.

[24] Lian, S., and Zhao, M. Study on the Correlation between Spatiotemporal Differentiation Characteristics of Urban Landscape Interference and Landscape Pattern Index. SHANDONG FORESTRY SCIENCE AND TECHNOLOGY, 2023, (06):1-9.

[25] Ying, X. Pengzhou City's spatiotemporal evolution and evaluation of landscape pattern and habitat quality, which is based on Fragstats and InVEST models. Sichuan Agricultural University, 2021.