OPTIMIZATION OF RURAL LANDSCAPE ECOLOGICAL NETWORK BASED ON LANDSCAPE ECOLOGICAL THEORY AND CA MARKOV MODEL

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Abstract. With the acceleration of urbanization construction, the contradiction between rural ecological construction and economic development is becoming increasingly prominent. To solve these problems the study takes Yanqian Town in Sanming City as the research object for empirical analysis. Using the landscape dynamic changes in landscape ecology theory, quantitative analysis was conducted on the data of Yanqi Town in China from 2011 to 2021 to study the changes in the use of six major land types. At the same time, the CA Markov model was used to simulate and predict the land use situation in the region in 2026. Finally, the minimum cumulative resistance model (MCR) and gravity model were used to extract and screen ecological corridors, in order to construct the landscape ecological network system of Yanqian Town, Sanming City. The CA Markov model predicts that the forest land in the region will further decrease to 83214.2 ha in 2026, and predicts that the contradiction between construction land, forest land, and grassland will further expand. To this end, the study calculated 4 important ecological corridors using the MCR model and gravity model, and planned a multi-level and multifunctional spatial ecological optimization network in Yanqian Town, Sanming City.
Keywords: *geographic environment, ecological network, ecological corridors, model, data geographic information systems, cellular unit*

Introduction

China's rural areas are currently in the comprehensive promotion of the rural revitalization strategy, which has brought new historical opportunities and challenges to the development of rural areas. However, with the development of rural urbanization and economy, the land use structure and ecological environment in rural areas have undergone significant changes, which have had a significant impact on the stability and species diversity of rural landscape ecosystems (Wang et al., 2022; Nye et al., 2020; Wu et al., 2023). Therefore, to optimize and protect the rural landscape ecological environment while ensuring economic development has become an urgent problem to be solved. Landscape ecology, as a discipline formed by the intersection of geography and ecology, provides strong theoretical support for the optimization of rural landscape ecological networks (Usman and Abdullah, 2023; Donnelly et al., 2021). Landscape ecology reveals the interaction mechanism between landscape pattern and ecological processes through systematic research on the structure, function, and dynamic changes of landscapes, providing scientific basis for landscape pattern planning and management. By studying the ecological effects and economic value of different land use methods, optimizing the land use structure, and promoting the development of low-carbon environmental

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protection industries such as green agriculture and ecotourism. In addition, with the increasing development intensity in rural areas, biodiversity is seriously threatened. Landscape ecology research can reveal the impact mechanism of landscape pattern changes on species diversity and ecological community structure, and propose strategies such as protecting key ecological nodes and constructing ecological corridors to maintain and enhance biodiversity in rural areas. Liu et al. established a landscape ecological security evaluation method based on grid partitioning based on landscape ecology theory. And this method was used to evaluate the ecological security of Zhengzhou City. The results show that this method can accurately predict the ecological security level of Zhengzhou City (Liu et al., 2021b). The CA Markov model, as a predictive model based on Cellular Automaton (CA) and Markov Chain, provides an effective tool for optimizing rural landscape ecological networks (Huang et al., 2020). The CA model can simulate the spatial dynamic changes of complex systems, while the Markov model can predict the future state of the system. The CA Markov model that combines the two can not only simulate and predict the dynamic changes in rural land use, but also provide decision support for landscape planning and management. Zhang et al. used the CA Markov prediction model with spatial and quantitative advantages to predict the landscape ecological security status in 2029 in response to the ecological security issues arising from the overlap between crop and coal production. The results show that the degree of landscape fragmentation in the region will decrease, connectivity will increase, landscape patch shapes will tend to be regular, and landscape heterogeneity will increase. The overall landscape ecological security situation will continue to improve (Zhang et al., 2023). Xing and Zhou proposed using geographic environment data from 2000, 2006, 2012, and 2018 to construct an ANN-CA Markov model for simulating and predicting the ecological space changes and future predictions in Wanzhou District in 2024, and evaluating the quality of ecological habitats. The results show that the model has high simulation accuracy, and the ecological space in Wanzhou District shows an increasing trend of fragmentation, differentiation, and area uniformity, with stability gradually decreasing and habitat quality declining year by year (Xing and Zhou, 2021). However, current research on the optimization of rural landscape ecological networks is relatively insufficient, especially in the context of rapid urbanization. There is still a lack of systematic research on how to optimize landscape ecological networks according to local conditions and maintain a balance between rural development and environmental protection (Khawaldah et al., 2020). This deficiency is mainly reflected in the following aspects: firstly, the lack of refined analysis targeting specific regional characteristics, resulting in a lack of targeted and operable optimization strategies; Secondly, the ability to predict long-term dynamic changes is insufficient, making it difficult to effectively cope with future uncertainties. Yanqian Town is located between Wuyi Mountains and Daiyun Mountains, with unique land landscape and rich natural resources. It has strong representativeness in terms of geography, climate, natural resources, and socio-economic conditions, and can better reflect the common characteristics of a certain type of rural area. Meanwhile, as a typical representative of Sanming City's implementation of policies and projects related to rural landscape ecological network construction, Yanqian Town's experience and practices have strong demonstrative and promotional value for other regions. With the development of rural urbanization and economy, the land use structure and ecological environment of Yanqian Town have undergone significant changes. These changes have had a significant impact on the stability and species diversity of rural landscape ecosystems. Therefore, optimizing the ecological network is crucial for

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maintaining a balance between rural development and environmental protection. In the process of optimizing the ecological network in Yanqian Town, although long-term planning is crucial, short-term forecasting is equally indispensable. The land use structure and ecological environment changes in rural areas are often influenced by multiple factors. These factors may have significant impacts in the short term, leading to rapid changes in land use patterns and ecological environment. Therefore, through short-term forecasting, it is possible to timely understand these changes and provide scientific basis and decision-making support for rural development. To this end, the study combines landscape ecological theory with the CA Markov model, and uses Yanqian Town as a case study for empirical analysis to deeply study the optimization process of rural landscape ecological networks. I look forward to providing new ideas for the optimization research of the current rural landscape ecological network.

Methods and materials

Data collection and organization

In the context of the national strategy of ecological civilization construction and rural revitalization, research on optimizing rural landscape ecological networks can help improve the ecological environment of rural areas, promote rural biodiversity and ecosystem stability. In order to optimize the rural landscape ecological network, it is necessary to collect and organize geographic and ecological data of the research area. The research is based on 10 land use data in the target area from 2011-2021. The basic land use remote sensing monitoring data is from the Institute of Geographic Sciences and Resources, Chinese Academy of Sciences (http://www.resdc.cn). The data for each period from 2011 to 2015 mainly used Landsat TM/ETM remote sensing image data, while the land use cover data for 2016-2021 mainly used Landsat 8 remote sensing image data (Casagli et al., 2023). After obtaining relevant data for the region, the data is processed, as shown in *Figure 1*.

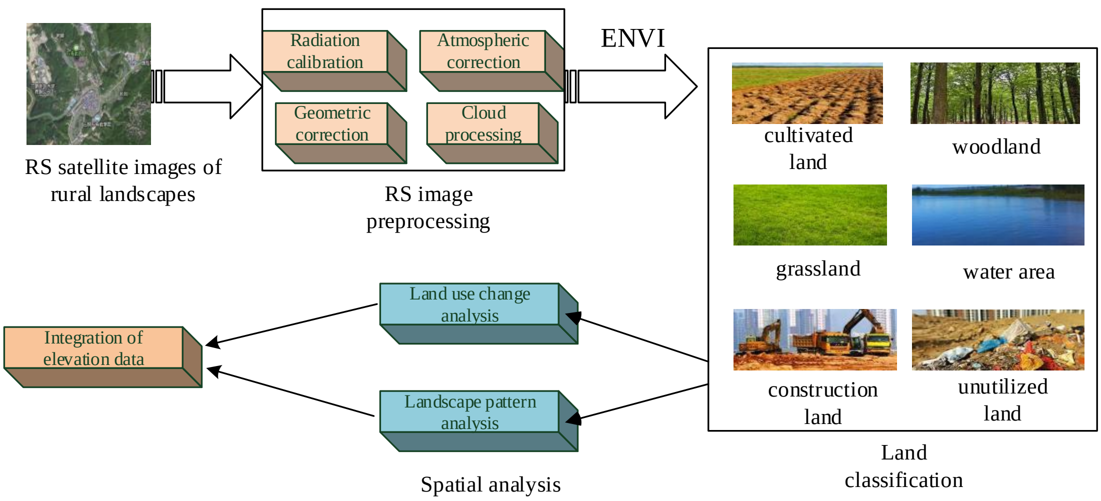

Figure 1. *Processing and analysis process of rural landscape satellite remote sensing data*

After obtaining the rural landscape remote sensing satellite image in *Figure 1*, ENVI (The Environment for Visualizing Images) software was used to correct, enhance, and

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classify the remote sensing image, and extract land use type information. Then convert the land information data into grid data types that can be recognized by geographic information systems. Afterwards, according to the regulations of the "Classification of Land Use Status" and the classification results of remote sensing images, the rural landscape area was divided into six types: cultivated land, water area, etc. (Fadlullah and Kato, 2021). Then, using geographic information system software, based on the classification results of land use types, create land use type maps for different years in the region. Statistically analyze the area of land use types in different years, calculate the proportion and change of each type of area. Construct a dynamic rural landscape change model to analyze the overall land use efficiency and landscape pattern evolution of the target area, providing data support for optimizing the rural landscape ecological network.

Construction of landscape dynamic change model

Constructing a landscape dynamic change model can better reflect the landscape pattern evolution of the target area. Taking cultivated land among the six major land types as an example, the landscape dynamic degree of cultivated land *k* represents the degree of change of cultivated land throughout the entire research period, as shown in *Equation 1* (Liu et al., 2021a).

$$k=\frac{U_b-U_a}{U_a}\times\frac{1}{T}\times 100\% \quad \text{(Eq.1)}$$

In *Equation 1*, U_a and U_b are the area sizes at the beginning and end of the farmland research, respectively, and *T* are the duration. The comprehensive landscape dynamics of the six major land types in the target area are *S* shown in *Equation 2* (Şenik and Kaya, 2022).

$$S=\sum_{i=1}^{n}\left(\frac{\Delta U_{i-j}}{U_i}\right)\times\frac{1}{i}\times 100\% \quad \text{(Eq.2)}$$

Equation 2 represents the differences in the change rates of all landscape types among the six major land types in the target area; *i* and *j* represent different types of landscapes; *U* area for different landscape types; *i* transform the area of the landscape into the absolute area *j* of the landscape. The evolution of different landscape land use types within the same time period is represented by a land use transfer matrix, as shown in *Equation 3*.

$$S_{ij}=\begin{bmatrix} S11 & S12 & ... & S1n \\ S21 & S22 & ... & S2n \\ ... & ... & ... & ... \\ Sn1 & Sn2 & ... & Snn \end{bmatrix} \quad \text{(Eq.3)}$$

In *Equation 3, S* represents the area of different landscape land use types; *n* number of types. For the overall land use type change in the target research area, it is represented by the transfer in and out rate, as shown in *Equation 4*.

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$$\begin{cases} q_i = \dfrac{\sum_{j=1}^{n-1} \Delta U_{ij}}{L_{t0}} \times 100\% \\ p_i = \dfrac{\sum_{j=1}^{n-1} \Delta G_{ij}}{L_{ik}} \times 100\% \end{cases} \tag{Eq.4}$$

In *Equation 4*, the *I* land use transfer rate of the type of land during the research period; The area *I* converted ΔU_{ij} from *j* type land to type land; The area of *I* land type at a certain moment; The *i* conversion rate of land use during the research period p_i for the type of land; The area *I* converted ΔG_{ij} from *j* type land to type land. Based on the dynamic changes of land in the target research area, the spatial layout of landscape elements can be optimized, the connectivity of the landscape can be increased, the fragmentation of the ecological environment can be reduced, the stability of the ecosystem can be improved, and the optimization of the rural landscape ecological network can be completed.

Construction of CA Markov model

The construction of the CA Markov model can better understand and predict the process of land use change in the target research area. The CA model in the CA Markov model uses cellular automata (CA) to represent the dynamic change trend of rural landscape land, as shown in *Equation 5*.

$$S_{t+1} = f\left(S_t, N\right) \tag{Eq.5}$$

In *Equation 5 S* is the set of cells; *N* for the cellular domain; *t* at the time point before the change; *t* + 1 at the time point after the change; *f* for conversion rules. The Markov model in the CA Markov model is based on the current state of rural landscape land to predict the future structural evolution process, as shown in *Equation 6*.

$$d_{(t+1)} = Z_{i,j}^{t}\left(P_t d_t\right) \tag{Eq.6}$$

In *Equation 6*, $Z_{i,j}^{t}$ is the overall conversion rate of landscape land use types; The spatial *t* structure type of landscape land at that time. Construct a CA Markov model to predict rural landscape land use, as shown in *Figure 2*.

As shown in *Figure 2*, during the learning and validation phase of the model, first use remote sensing images to obtain landscape land use status data of the target study area during the initial period; Then, use the Convention Tools function in ArcGis10.5 software to convert the obtained data into ASCII format, and then use IDRISI software to import ASCII format files and generate Rst files. Represent the corresponding landscape land use type using the cells in the CA model, and set the neighborhood of the cells to 6 × 6 using IDRISI Selva17.0 software. Neighborhood can directly act on a cell, causing its state to change. Next, input the starting and ending data of the target study area’s land into the Markov module of IDRISI Selva17.0 software to calculate the land use transfer matrix of the target study area during this time period. Finally, combined with the MCE module, generate transfer suitability images of various types of

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landscape land use, and display them in a visual atlas method. During the verification phase, Set the iteration number of the CA Markov model and repeat the above operation until the predicted land use error of the model meets the requirements with the actual land use error. Then, the model can be used to predict the future landscape land use status of the target study area. The Kappa coefficient was used to evaluate the accuracy of the CA Markov model in the study, as shown in *Equation 7*.

$$Kappa = \frac{P_a - P_r}{1 - P_r} \times d_{(t+1)} \quad \text{(Eq.7)}$$

Equation 7, P_r represents the theoretical simulation accuracy of the CA Markov model; P_a For overall simulation accuracy. By accurately predicting the land use status of each landscape, priority can be given to predicting the proportion of specific landscape types, optimizing the landscape pattern, and improving the continuity and integrity of the landscape.

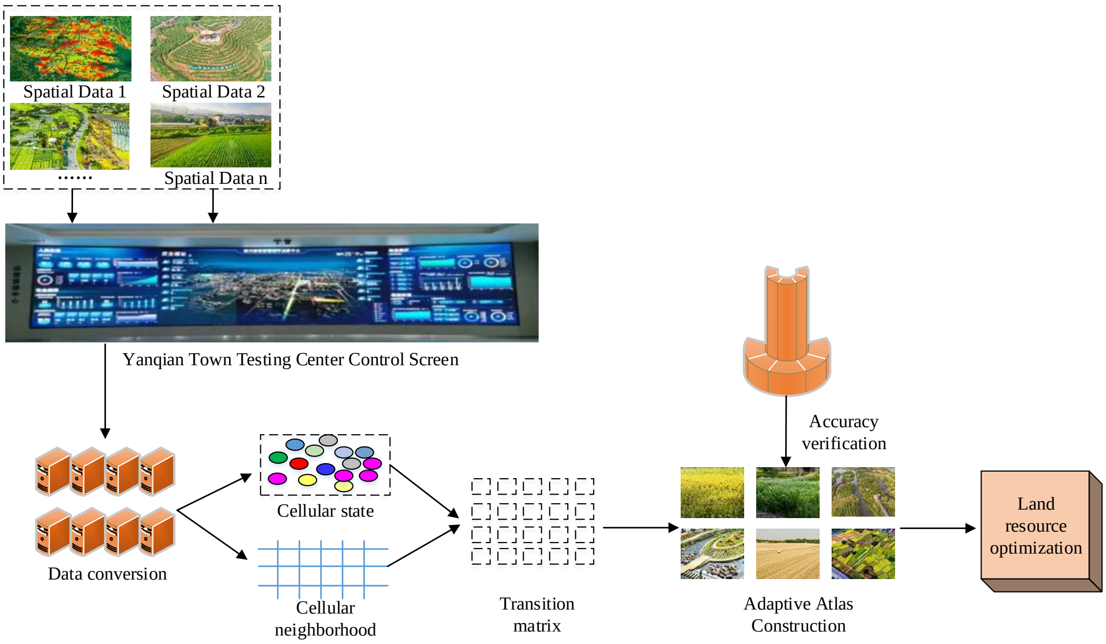

Figure 2. *Simulation and prediction process of rural landscape land use*

Optimization analysis of rural landscape ecological network

Through the above two models, we can understand the changes in the landscape land of the target study area. By combining the pattern changes of these landscape land with landscape ecology theory, we can construct an ecological network system of the target study area, thereby optimizing the landscape pattern of the target study area. The smooth flow of landscape information is crucial for the stability of the landscape ecosystem. Under various interfering factors, information flow is often hindered. The study utilizes the minimum cumulative resistance model to determine the optimal flow path, construct ecological corridors to reduce flow costs, enhance landscape connectivity, and maintain species and landscape diversity. The minimum cumulative resistance is *F* shown in *Equation 8* (Yao et al., 2022).

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$$F = \sum_{j=m}^{i=m} \left(H_{ij} \times \delta_i \right) \quad \text{(Eq.8)}$$

In *Equation 8*, the *j*distance between landscape information *I* flow from type land units to type land units; the *i* resistance coefficient of a type of land unit. When constructing the minimum cumulative resistance model, the construction of resistance factors and resistance surfaces needs to be selected based on the specific situation of the ecological source areas in the target research area (Wang et al., 2021). The study adopts an ecological sensitivity based method to select the ecological source areas of the target research area (ecological source areas refer to ecological environment patches that play a decisive role in regional ecological processes and functions, and have important significance or radiation functions for regional ecological security). At present, there is no unified standard for the definition of ecological sensitivity, which varies from time to time and from place to place. The study selected terrain factors (including elevation, slope, and aspect), water area factors (represented by the water area of the region), vegetation factors (represented by the normalized vegetation index), and land use factors (including six types of landscape land) as single landscape ecological sensitive factors for research (Wang et al., 2023; Shen and Wang, 2023; Han et al., 2022). The Delphi expert scoring method is used to score the four selected ecological sensitive factors. The specific steps are to invite 20 experts and scholars in environmental design, landscape design, and environmental engineering to score these four factors, and then establish a judgment matrix *W*, as shown in *Equation 9*.

$$W = \begin{bmatrix} W_{11} & W_{12} & ... & W_{1b} \\ W_{21} & W_{22} & ... & W_{2b} \\ ... & ... & ... & ... \\ W_{a1} & W_{a2} & ... & W_{ab} \end{bmatrix} \quad \text{(Eq.9)}$$

In *Equation 9*, W_b, the importance level of the W_a pair is determined according to the standards in the "scale value method". Calculate the weight values between each factor based on the judgment matrix. M_a The normalized vector weights are w_i shown in *Equation 10*.

$$w_a = \frac{\sqrt[n]{M_a}}{\sum_{a=1}^{l} \sqrt[n]{M_a}} \quad ,(a = 1, 2, ..., n) \quad \text{(Eq.10)}$$

Based on the normalized vector weights of each selected factor, the weights of the four ecological sensitive factors in the target area are superimposed to obtain the comprehensive ecological sensitivity index of the area SS_i, as shown in *Equation 11*.

$$SS_i = \sqrt[4]{w_a \bullet w_b \bullet w_c \bullet w_d} \quad \text{(Eq.11)}$$

In *Equation 11* w_b, w_a, and w_d, respectively, represent the weights of terrain factor, water area factor, vegetation factor, and land use factor. Identify the ecological source area of the target area using the comprehensive ecological sensitivity index and determine the

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direction of constructing the minimum cumulative resistance. After determining the ecological source area, establish an ecological corridor to reduce the resistance of the rural landscape ecological network and promote the flow of landscape information (He et al., 2021; Zhang et al., 2021). Ecological corridors optimize landscape structure and improve ecosystem connectivity by establishing connections between ecological source areas and ecological gathering points. Finally, preserve the nearest corridor between ecological source areas, remove overlapping excess corridors, and extract the most important and effective corridors from potential ecological corridors.

In addition, the establishment of ecological connectivity corridors aims to connect core protected areas, scenic spot clusters, and other important ecological regions, promoting species migration and material cycling and energy flow between ecosystems. The selection of ecological corridors should also consider the biodiversity of the target area and stakeholder inputs. For biodiversity, a comprehensive biodiversity survey of the target area is necessary, including species diversity (such as plant species, rare animal populations), genetic diversity, and ecosystem diversity. On the one hand, conduct on-site investigations in the target area to collect environmental data. Researchers go to the target area every six months to collect land use cover rate, elevation, river network distribution, urban resident distribution points, meteorological data, and ecological survey data. On the other hand, remote sensing technology and unmanned aerial vehicle equipment are used to collect data. The drone uses DJI Mavic 3 Pro Yu 3 triple camera drone, equipped with 4/3 CMOS sensor and Hasselblad camera, with 20 million effective pixels, which can complete the geographic information collection task of the target area. According to the survey results, important water conservation areas, rare plant communities, and habitats of endangered animals will be designated as core protected areas. When delineating the core protected area, consider the interests of multiple parties such as government departments, environmental organizations, and tourists in the target area. By means of public participation, policy incentives, and financial support, ensure that stakeholders have a positive attitude towards the delineation and management of protected areas.

Results

Empirical analysis of rural landscape ecological network optimization using Yanqian Town as an example

Analysis of land use area changes in Yanqian Town from 2011 to 2021

Select Yanqian Town, Sanyuan District, Sanming City, Fujian Province to conduct empirical analysis on the optimization model of rural landscape ecological network constructed for research. Because Yanqian Town has strong representativeness in terms of geography, climate, natural resources, socio-economic conditions, etc., it can better reflect the common characteristics of a type of rural area. Secondly, Sanming City has implemented a series of policies or projects related to the construction of rural landscape ecological networks in recent years. Yanqian Town, as a typical representative, has strong demonstrative and promotional value for other regions in terms of its experience and practices. Yanqian Town is located between Wuyi Mountains and Daiyun Mountains. There are cave like Paleolithic sites - Wanshouyan Ancient Human Site. The cave at the Wanshouyan Ancient Human Site preserves a wealth of ancient human fossils and cultural relics. Yanqian Town is a town with a unique land landscape, with a total area of

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274.43 km^2. Yanqian Town is located by the Changting River, with beautiful mountains and rivers and beautiful scenery. The area is mainly hilly, with higher elevations in the western, southern, and northeastern regions, interspersed with small patches of mountain flat land, generally at an altitude of 150-600 m. The highest peak is located in the Dahua Mountain in the northeast, with an altitude of 963.2 m. Yanqian Town mainly has streams such as Yutang Creek and Xiyuan Creek, as well as small tributaries such as Daji Creek, Huangshaban Creek, Xiaofutang Creek, and Dakeng Creek distributed in various villages. Among them, Yutang Creek is a major tributary of the Shaxi River basin, belonging to the Minjiang River system, with a main river length of 30.5 km within the area; The main river within Xiyuan Creek is 33 km long. The Global Mapper software was used to calculate the area changes of the six major land use types in Yanqian Town from 2011 to 2021, totaling 11 years. The results are shown in *Figure 3*.

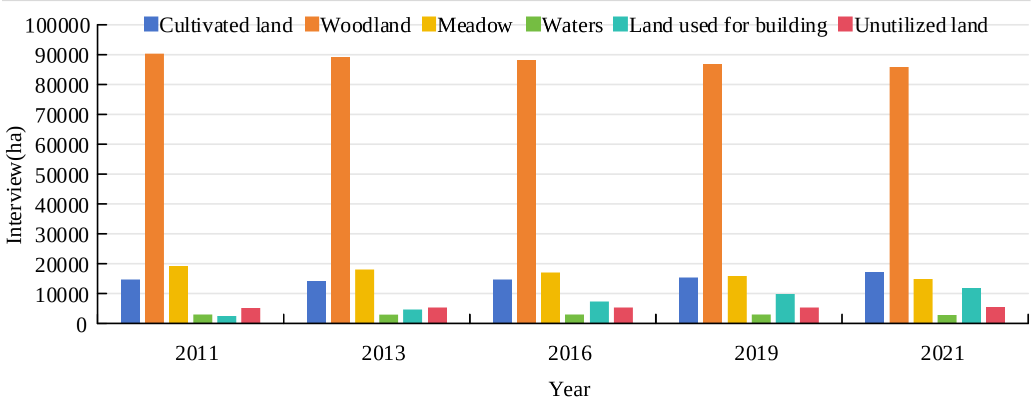

Figure 3. *Statistical results of six major land use types in Yanqian town from 2011 to 2021*

As shown in *Figure 3*, the total area of the six major land use types in Yanqian Town is approximately 134512.45 ha. The forest land area is the largest and is decreasing year by year, from 90352.12 ha in 2011 to 85632.1 ha in 2021. The construction land has been increasing year by year, with a significant increase, from 2363.23 ha in 2011 to 12335.23 ha in 2021. Grassland and water areas have also been decreasing, while arable land has increased first and then decreased. The specific changes in the area of the six major land use types in Yanqian Town from 2011 to 2021 are shown in *Table 1*.

Table 1. *Statistical results of area changes of six major land use types in Yanqian town from 2011 to 2021*

Six major types of land use	2011	2011-2013		2014-2016		2017-2019		From 2020 to 2021	
	Basic area (ha)	Area of change (ha)	Change ratio (%)	Area of change (ha)	Change ratio (%)	Area of change (ha)	Change ratio (%)	Area of change (ha)	Change ratio (%)
Cultivated land	14634.25	-426.35	-0.33	456.87	0.089	683	0.12	1765	0.15
Woodland	90352.12	-1163.2	-0.068	-984.82	-0.19	-1320	-0.23	-1120	-0.20
Meadow	19124.21	-1100.36	-0.10	-1000.23	0.006	-1123	-0.20	-1032	-0.19
Waters	2957.64	-42.36	-0.002	-32.6	0.51	-32.7	-0.006	-34.1	0.0007
Land used for building	2363.23	2280.32	0.28	2635.36	0.008	2456.3	0.43	2136.1	0.40
Unutilized land	5081.00	213.95	0.22	-42.3	0.09	65.3	0.01	78.9	0.02
Total absolute value	134512.45	4236.54	100	5152.18	100	5680.3	100	6166.1	100

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According to *Table 1*, the land change area from 2011 to 2013 was 4236.54 ha, accounting for 3.1% of the total area; The land change area from 2014 to 2016 was 5152.18 ha, accounting for 3.8% of the total area; The land change area from 2017 to 2019 was 5680.3 ha, accounting for 4.2% of the total area. The land change area from 2020 to 2021 was 6166.1 ha, accounting for 4.5% of the total area. During this period, the area of land change showed a rapid growth trend, which is because since 2011, Yanqian Town has been promoting comprehensive urbanization and rapid expansion development. Resulting in a significant reduction in forest and grassland areas, and a significant increase in the area of construction land.

Analysis of land use dynamics in Yanqian Town from 2011 to 2021

The dynamic degree of single land use reflects the magnitude of changes in a certain type of land over a certain period of time. Based on the statistical results of the changes in the area of the six major land use types in Yanqian Town from 2011 to 2021, the dynamic degree of each type of land use in Yanqian Town is calculated as shown in *Figure 4*.

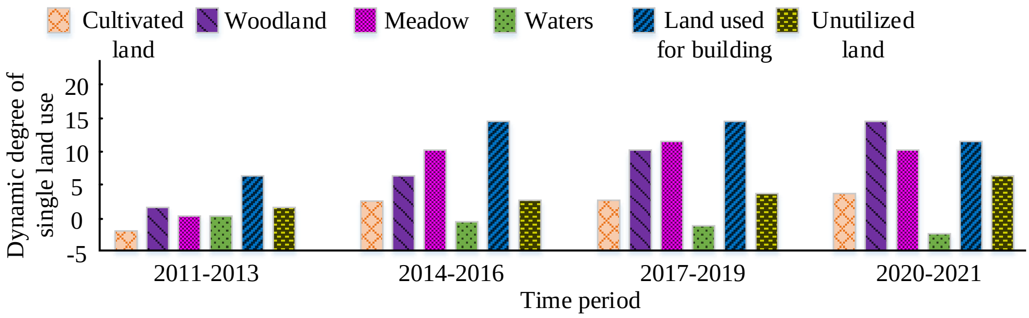

Figure 4. *Results of single land use dynamics in Yanqian town from 2011 to 2021*

As shown in *Figure 4*, the single land use dynamics of forest land, grassland, and construction land in Yanqian Town have relatively large changes from 2011 to 2021. The change rates of these three types of land are all positive, indicating an increasing trend in their area during this period. Specifically, from 2011 to 2013, the change rate of forest land was 2.01%, grassland was 1.23%, and construction land was 5.32%; Between 2014 and 2016, these rates of change increased to 5.21%, 8.45%, and 12.42%, respectively; Then, from 2017 to 2019, it further increased to 8.63%, 9.32%, and 13.61%. Finally, from 2020 to 2021, it further increased to 12.11%, 8.96%, and 11.21%. Compared to this, the area of cultivated land, water bodies, and unused land fluctuates less and shows a relatively stable trend. Select data from the past 5 years, the dynamic transfer of six types of land use in the target study area was analyzed using ArcGis10.5 software, and the results are shown in *Table 2*.

As shown in *Table 2*, the land use types of Yanqian Town have undergone significant changes in three different time periods (2017-2018, 2018-2019, 2019-2020, and 2020-2021). From the dynamic matrix analysis, it can be seen that the conversion between construction land, cultivated land, forest land, and unused land is particularly active, and there are differences in the direction and quantity of conversion during different time periods. The transfer of construction land has remained relatively stable in all four time periods, especially between 2020 and 2021.

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***Table 2.** Dynamic transfer matrix of land use cover in Yanqian town from 2017 to 2021*

	2017							
		Cultivated land	**Woodland**	**Meadow**	**Waters**	**Land used for building**	**Unutilized land**	**Transfer out quantity**
2018	24893.38	236.52	16.38	0.001	656.91	23.60	786.32	24893.38
	683.56	86952.2	65.32	9.65	56.39	78.96	596.21	683.56
	126.51	12.35	2236.35	0.35	24.63	14.65	135.60	126.51
	16.25	0.08	0.06	407.32	0.02	0.00	13.58	16.25
	0.96	0.56	0.96	0.07	2866.72	6.51	9.72	0.96
	9.65	19.65	10.65	0.002	156.23	185.13	63.23	9.65
	968.32	635.2	256.0	186.5	996.2	135.25	/	968.32
	2018							
		Cultivated land	**Woodland**	**Meadow**	**Waters**	**Land used for building**	**Unutilized land**	**Transfer out quantity**
2019	5012.02	563.26	103.56	0.001	2365.67	5.62	5012.02	563.26
	2352.12	99635.69	635.62	0.008	1268.33	1865.40	2352.12	99635.69
	1568.89	256.14	148.89	1.08	589.65	112.65	1568.89	256.14
	236.36	0.85	0.19	500.48	0.08	0.15	236.36	0.85
	19.63	0.35	4.12	5.63	5632.58	7.63	19.63	0.35
	561.63	225.96	78.63	0.05	796.32	122.32	561.63	225.96
	2644.14	2139.48	36.32	0.63	2636.23	2561.1223	2644.14	2139.48
	2019							
		Cultivated land	**Woodland**	**Meadow**	**Waters**	**Land used for building**	**Unutilized land**	Transfer out quantity
2020	Cultivated land	9652.56	58.96	25.32	0.00	2462.12	36.35	5682.14
	Woodland	3653.46	96323.35	86.75	0.08	224.65	254.56	4563.12
	Meadow	1384.12	125.35	261.21	0.04	125.14	263.35	245.36
	Waters	632.53	8.95	14.14	232.52	0.04	1.06	358.12
	Land used for building	163.25	1.35	7.12	0.08	4125.35	44.63	154.25
	Unutilized land	829.12	235.63	125.36	0.00	145.63	2563.25	1254.48
	Transfer out quantity	2596.12	365.14	561.36	0.3	2783.63	1254.36	/
	2020							
		Cultivated land	**Woodland**	**Meadow**	**Waters**	**Land used for building**	**Unutilized land**	**Transfer out quantity**
2021	Cultivated land	8652.45	158.96	125.23	0.00	1462.12	123.35	2562.24
	Woodland	4585.12	86378.45	486.56	0.08	324.65	457.56	2254.78
	Meadow	2384.12	256.12	261.21	0.04	254.14	456.35	1256.14
	Waters	2632.54	9.15	314.14	458.52	0.04	2.06	256.145
	Land used for building	2163.25	2.23	8.52	0.08	3115.45	568.41	1258.15
	Unutilized land	253.25	165.12	225.12	0.00	249.14	2564.12	2254.58
	Transfer out quantity	1524.25	456.25	461.23	0.3	3251.63	1548.12	/

Its total area has increased rapidly, mainly due to the conversion of arable land and forest land, which is an inevitable result of urbanization and rural construction. As the main type of land use, cultivated land is not only the main transferor (converted into construction land and forest land), but also the main transferor (mainly transferred from forest land),

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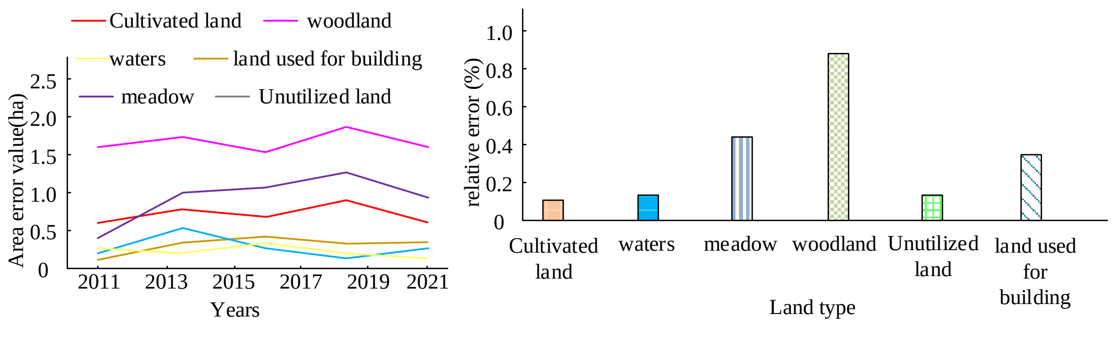
reflecting the dual trend of settlement style township structure expansion and cultivated land expansion towards forest land. Forest land shows a significant turnover, especially towards construction land and arable land, indicating the occupation of forest resources by development activities in the region. The conversion of unused land during two time periods is also relatively frequent, mainly converted into arable land and forest land, and there are also cases of some being converted back to construction land. In addition, the changes in water bodies are relatively stable, with only a small amount being converted into arable land. This change pattern reveals the diversity and complexity of land use in the development process of Yanqian Town, as well as the dynamic transformation between different land types. By analyzing these transformation processes and mechanisms, we can better understand the driving factors of land use change in Yanqian Town and provide scientific basis for future land use planning and management.

Accurate validation and predictive analysis of CA Markov models

Research and construct a CA Markov model, using the land data of Yanqian Town from 2000 to 2011 as the base for training, and then predict the land use structure of Yanqian Town from 2011 to 2021. The data is sourced from the Land and Resources Bureau and relevant departments of Yanqian Town, Wuping County, Longyan City, Fujian Province; Research on land image data obtained through remote sensing technology; Participated in the reference materials provided by the Land Use Research Institute of Yanqian Town. The results are shown in *Figure 5*.



(a) Prediction result difference (b) Relative error of prediction results

Figure 5. *CA Markov model prediction model results*

As shown in *Figure 5*, the CA Markov model used in the study can accurately predict the changes in land use area within the target area. Due to the significant changes in forest land, the accuracy of prediction is relatively low, with a prediction error value of about 1.60 ha and a relative error of about 0.86%. The prediction error value of other types of land is about 1.00 ha or less, and the relative error is less than 0.5%. In addition, the simulation accuracy of the results was once again verified using the IDRISI Selva17.0 software Crosstab function, and the results showed a Kappa coefficient of 0.95. The high value of Kappa coefficient once again indicates that the CA Markov model has good modeling performance. Then, based on the CA Markov model, using the land data of Yanqian Town from 2011 to 2021 as the basis, predict the land use situation of Yanqian Town from 2022 to 2026, laying the foundation for the optimization of the ecological network in the next stage of the region. The results are shown in *Table 3*.

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Table 3. *Land type prediction of Yanqian town from 2022 to 2026*

	Land type (ha)					
	Woodland	**Land used for building**	**Waters**	**Cultivated land**	**Meadow**	**Unutilized land**
2022	86352.12	17896.35	1325.12	1069.32	18963.21	964.36
2023	86125.32	17963.25	1320.23	1063.62	18864.23	965.45
2024	84541.32	18635.35	1321.14	1078.65	18365.14	964.32
2025	83651.21	18735.23	1319.35	1088.14	18158.68	964.61
2026	83214.20	18981.63	1318.41	1096.32	18014.24	965.52

According to *Figure 6,* the simulation prediction results of land use in Yanqian Town in 2026 show that the main landscape types in the area are forest land and grassland, which together occupy about 92.01% of the area, but both show a decreasing trend. The area of water and unused land remained basically unchanged during the simulation period, with water remaining stable at around 1320 ha and unused land remaining stable at around 965 ha. At the same time, the construction land area has significantly increased, from 17653.32 ha in 2021 to 18981.63 ha in 2026, and this growth trend is expected to continue with the further development of rural landscape construction.

Analysis of optimization results of rural landscape ecological network in Yanqian Town

The above results indicate that there are dynamic changes in the land use of Yanqian Town, with a decrease in forest and grassland while an increase in construction land. In order to optimize the rural landscape ecological network in the region reasonably, the study first calculated the weight of land sensitivity factors in the area, and the results are shown in *Table 3*.

According to the results in *Table 4,* the comprehensive weights of terrain factor, water area factor, vegetation factor, and land use factor in Yanqian Town are 0.21, 0.14, 0.24, and 0.41, respectively. Then, the ecological distribution of these four factors is weighted and overlaid to obtain the comprehensive ecological sensitivity evaluation index of Yanqian Town. Based on the comprehensive ecological sensitivity level classification, the distribution of sensitive areas in the region was further divided, as shown in *Figure 6.*

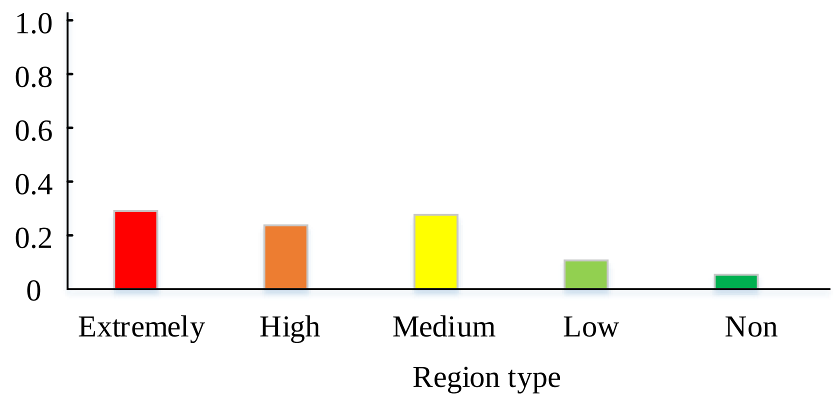

Figure 6. *Distribution and proportion of land sensitive areas in Yanqian Town*

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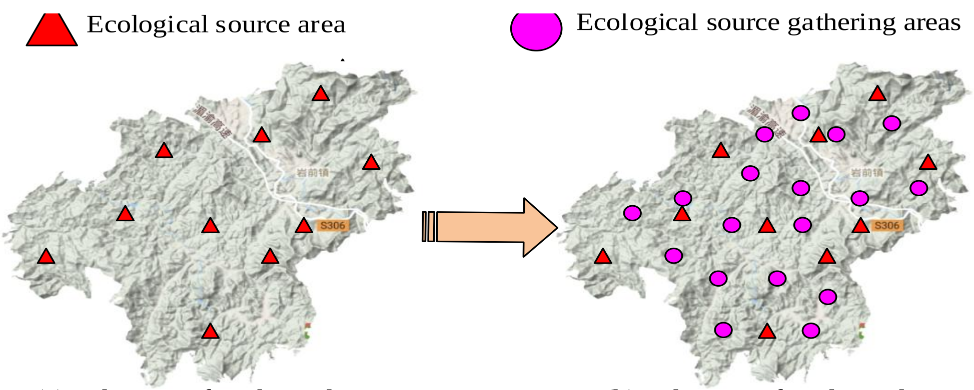
Table 4. *Land sensitivity factor judgment matrix and its weights in Yanqian town*

	Topographical factor	**Water factor**	**Vegetation factors**	**Land use factors**
Topographical factor	1	1/2	1/4	15
Water factor	2	1	1/2	1/3
Vegetation factors	3	2	1	
Land use factors	5	4	2	1
Comprehensive weight	0.21	0.14	0.24	0.41

From *Figure 6*, it can be seen that the highly sensitive areas in Yanqian Town are mainly distributed in forests and grasslands with weak ecological environments, accounting for about 30.10%; High sensitivity areas are mainly distributed at the edges of forests and grasslands, as well as in water bodies, accounting for approximately 21.84%; The medium sensitive areas are mainly distributed on the edges of cultivated land and construction land, accounting for about 27.65%; Low sensitive areas and non sensitive areas are mainly distributed on construction land, accounting for approximately 14.60%. According to the on-site investigation of the ecological environment and landscape construction status in Yanqian Town, it can be found that. he largest water system in Yanqian Town is Yutang Creek, which is a significant artificial vertical hardened river. At present, the overall ecological situation of Yanqian Town and its surrounding environment is not ideal, lacking the diversity and richness of natural ecology. Although Yutang Creek, as the main water system in the town, has certain landscape potential, the landscape value of the river has not been fully realized due to the lack of reasonable planning and design. The greening and landscape construction on both sides of the river are relatively lagging behind, lacking highlights that attract people to stop, admire, and relax. In addition, the public green space construction area in Yanqian Town is relatively small, making it difficult to meet the needs of residents for leisure, entertainment, and fitness activities. In order to more effectively manage and protect land resources, especially those environmentally sensitive areas, research is conducted based on the distribution of land sensitive areas in Yanqian Town, while also taking into account the ecological red line of Yanqian Town. Select a highly sensitive area with a relatively concentrated concentration as the ecological source of Yanqian Town, and the selection results are shown in *Figure 7a*.



(a) Selection of ecological source areas

(b) Selection of ecological source gathering areas

Figure 7. *Selection of ecological sources and aggregation areas in Yanqian town*

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As shown in *Figure 7,* the 10 ecological source areas selected for the study are mainly located around the Yanqian Town area, showing a trend of circular enclosure. Based on the trend of forest fragmentation in Yanqian Town and the active ecological environment characteristics of land use change, 18 ecological clusters were selected as important nodes in landscape information flow using the geographic information processing tool of ArcGis10.5 software, as shown in *Figure 7b*. These nodes are scattered and consistent with the local terrain, topography, and climate conditions of Yanqian Town, which can lay an information foundation for the construction of ecological corridors.

The study is based on the minimum cumulative resistance model to calculate the distance between ecological source areas and fragmented landscape patches. With the goal of minimizing cost, a total of 78 potential ecological corridors were calculated in Qingfeng Town. These ecological corridors mainly connect fragmented forest land and water, grassland and water. By utilizing the gravity model constructed through research, the interaction intensity between different ecological source areas in Yanqian Town was obtained, and based on this, 5 important ecological corridors were selected. Based on this, the ecological network optimization system of Yanqian Town constructed through research is shown in *Figure 8*.

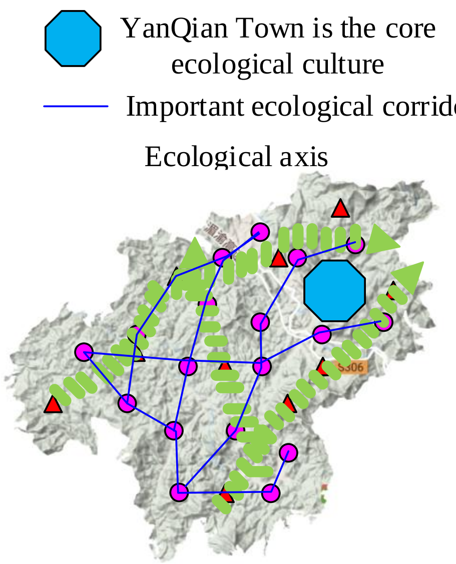

Figure 8. *Ecological network optimization system of Yanqian town*

As shown in *Figure 8,* the study aims to construct a multi-level and multifunctional spatial ecological network structure for the ecological network of Yanqian Town. The optimized structure presents a single center with multiple points, with Yanqian Town as the center, and three ecological belts running through the east, west, north, and south of the area, providing important ecological support for different landscape lands in the surrounding area. The four important ecological corridors selected have organically connected various regions together, promoting the sharing and utilization of ecological resources. The first one is the Wanshouyan Ecological Landscape Corridor, which starts from the Wanshouyan Scenic Area and extends to Bantou Village. Along the way, it integrates natural scenery and cultural landscapes, providing tourists with a rich ecological experience. The second article is the Yutangxi River Landscape Ecological Corridor, which is the largest water system in Yanqian Town. The management of its

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rivers and landscape construction are key to the construction of the ecological network. The research plan aims to build it into a multifunctional river channel that integrates flood control, ecology, and landscape through ecological restoration and landscape enhancement; The third article is the Xiyuan Creek Ecological Corridor, which aims to protect and restore the natural ecological environment of the Xiyuan Creek, enhance its ecological service function, and provide high-quality ecological resources for surrounding residents; The fourth article is the Small Watershed Ecological Corridor, which covers multiple small watersheds in Yanqian Town and is an important component of the ecological network. The research will improve the ecological environment quality within the watershed and enhance the efficiency of water resource utilization through the implementation of small watershed comprehensive management projects. In addition, multiple important ecological sources and nodes have become important components of the entire network, providing key support for the formation of ecological corridors.

In terms of maintaining ecological diversity, the establishment of ecological corridors helps to connect fragmented ecosystems and provide broader habitats and migration pathways for wildlife and plants. Promoting the spread and exchange of species can help increase species richness within the region. Taking the construction of the Tangtangxi River Landscape Ecological Corridor and Xiyuanxi Ecological Corridor in Yanqian Town as an example, these two ecological corridors will improve water quality and riverbank ecological environment, attracting more aquatic organisms and amphibians to inhabit and reproduce. According to preliminary observations, after the completion of the ecological corridor construction, various rare aquatic organisms represented by anti wave fish have emerged in the area, and the number of fish continues to increase. With the improvement of the riparian ecological environment, the habitats of amphibians have also been expanded. The number and distribution range of rare amphibians represented by salamanders have increased. The construction of the Xiyuxi Ecological Corridor provides abundant habitats and migration channels for birds, and the number of rare bird species such as billed gulls and white boned top chickens has increased after the ecological corridor was built. In addition to animals, the ecological corridor also protects various rare plants such as Fujian cypress, thorn tree fern, and pine fern. The establishment of ecological corridors can also reduce ecological fragmentation caused by human activities. Thus maintaining the balance and stability of the ecosystem, enhancing its resistance and resilience to external disturbances. Taking the ecological corridor of the small watershed in Yanqian Town as an example, this ecological corridor will improve the ecological environment quality within the watershed, reduce soil erosion and pollution emissions. In terms of stakeholder input, the construction of the ecological corridor will promote the transformation of the economic development model of Yanqian Town, from traditional resource dependent to eco-friendly. This will promote the development of green industries such as ecotourism and ecological agriculture, injecting new vitality into the local economy. Yanqian Town can rely on the natural landscape and cultural resources of the ecological corridor to develop the ecological tourism industry, attract tourists to come for sightseeing, leisure and vacation, and thus drive the development of related industries and economic growth.

Discussion and conclusion

Based on the theoretical framework of landscape ecology, this study empirically investigates the implementation methods of optimizing the village landscape ecological

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network in Yanqian Town. Firstly, study the construction of a landscape dynamic change model, based on the land data of Yanqian Town from 2011 to 2021. The results showed that during this period, construction land showed a significant and rapid growth trend, increasing from 17653.32 ha in 2021 to 18981.63 ha in 2026. This reflects the acceleration of urbanization and the strong momentum of economic development. At the same time, the decreasing trend of forest land is particularly evident, from 90352.12 ha in 2011 to 85632.1 ha in 2021. This reflects the drastic changes in the ecological environment. With the development of society and economy, humans have increased their efforts in land development in order to obtain more resources. Then, a CA Markov model was constructed to predict the future land use situation of Yanqian Town. The results showed that forest land and grassland will decrease in 2026, while construction land will continue to increase. This reflects a certain contradiction between economic development and ecological stability. To this end, we will study the construction of MCR models and gravity models, and optimize the rural landscape ecological network by establishing ecological corridors, in order to maintain the stability of the ecological network. The study selected 9 ecological source areas and 18 ecological aggregation areas to calculate 4 important ecological corridors and 3 ecological belts, and constructed a multi-level and multifunctional spatial ecological network optimization structure centered on Yanqian Town. Based on detailed land data, a landscape dynamic change model, CA Markov model, MCR model, and gravity model were constructed to scientifically predict the future land use situation of Yanqian Town, and based on this, an ecological network optimization plan was proposed. This method has higher accuracy and operability compared to traditional qualitative analysis or empirical judgment. As the core area of the ecosystem, ecological source areas have a complete ecological structure and strong ecological service functions, which are crucial for improving ecological quality. Therefore, strict ecological protection policies must be adopted to ensure the integrity and stability of key ecological sources such as forests and grasslands. By delineating ecological protection red lines, formulating targeted laws and regulations, curbing human activities from encroaching on ecological land, and establishing an ecological security monitoring system, ecological corridors play an important role in protecting biodiversity, maintaining the ecological environment, and enhancing the connectivity of landscape patches as bridges and channels connecting different ecological sources. For key ecological corridors, it is strictly prohibited to carry out development and construction activities that interfere with human activities within the corridor range, and separation zones should be set up and ecological buffer zones should be fully utilized to reduce interference and damage. However, the sensitivity factors selected in the study are subjective and there is currently no consensus. Further research will verify this.

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