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Ecological Suitability Evaluation of Construction Land Based on GIS: A Case Study of Yongzhou City

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Abstract: Ecological suitability evaluations of land use are often conducted as an important reference when formulating urban and rural planning and land use policies. This study selects five indicators—topography, hydrology, transportation, land use, and ecosystem The College of Forestryservices—and uses the Analytic Hierarchy Process (AHP) and GIS spatial analysis to evaluate the ecological suitability of construction land in Yongzhou City. The results show that the construction land in Yongzhou is mainly located in areas of moderate suitability, with the most suitable and moderately suitable areas together accounting for 51.55% of the total area, indicating good overall ecological suitability. The areas of basic suitability and unsuitability are mainly steep hill and mountain areas, which are prone to geological hazards. The unsuitable areas are primarily nature reserves and national forest parks, with high vegetation coverage and steep slopes, designated as restricted development zones. It is recommended that develop moderately in the Xintian-Ningyuan line and northern areas to achieve a coordinated development of urban growth and ecological conservation.

Keywords: Ecological suitability evaluation of construction land, Analytic Hierarchy Process (AHP), GIS spatial analysis, Yongzhou.

1. Introduction

By the end of 2023, China's urbanization rate reached 66.16%, marking the beginning of the "second phase" of urbanization. However, the "National New-Type Urbanization Plan (2014–2020)" highlighted issues such as the rapid pace of land urbanization outpacing population urbanization, inefficient land use, and mismatched urban spatial distribution and environmental capacity. The 19th National Congress report stressed the need for a spatial pattern that conserves resources and protects the environment, making coordination between urban development and ecological protection crucial in urban planning [1]. To address these challenges, ecological suitability evaluations are increasingly used as key references for urban and rural planning [2]. This approach, which integrates various disciplines, quantitatively assesses land suitability based on environmental and sustainability factors, providing a ranking of suitability levels [3]. The ecological suitability evaluation of construction land is vital, with GIS technology enhancing the accuracy of assessments by reducing subjectivity in traditionally used criteria like natural attributes and economic factors.

In recent years, an increasing number of scholars have focused on evaluating the suitability of urban construction land, conducting in-depth research on the subject. However, the evaluation systems, analytical methods, and research perspectives adopted by different studies vary. Some studies have conducted suitability evaluations of construction land at different scales. The Delphi method and Analytic Hierarchy Process (AHP) [4], least squares method and GIS spatial analysis [5], goodness evaluation method [6], weighted potential-restriction analysis method [7], Minimum Cumulative Resistance (MCR) model [8] and other methods are used to evaluate the ecological suitability of land use.

Construction land suitability evaluation identifies development potential and optimizes policy frameworks for sustainable urban growth. Yongzhou (southern Hunan), boasts abundant forest and mineral resources, including nearly 500,000 acres of mountainous land [9], faces challenges in balancing urban expansion with ecological conservation. Its low development intensity offers expansion potential. This study employs the Analytic Hierarchy Process (AHP) across five indicators—topography, hydrology, transportation, land use, and ecosystem services—to evaluate ecological suitability, aiming to guide sustainable planning and resource management strategies while mitigating land-use conflicts.

2. Overview of the study area

As shown in Figure 1, Yongzhou City (24°39′N–26°51′N, 111°06′E–112°21′E) is located on the southern edge of a horseshoe-shaped basin in southern Hunan. The terrain slopes from the southwest to the northeast in a terraced pattern, with hilly and mountainous landscapes dominating. The city governs 2 districts, 8 counties, and 1 county-level city, covering 22,400 km² with a population of 5.1437 million by the end of 2022.

As Hunan's second-largest city by land area (33.6425 million acres, 10.5% of the province), Yongzhou has high-quality land resources, including 5 million acres of arable land, 21 million acres of forest, 1.58 million acres of pastureland, and 5.63 million acres of undeveloped land.

The third national land survey [10] shows 1.9695 million acres of land used for urban, village, and industrial mining purposes, forming a "dual-core, multi-node" pattern, with 81.94% concentrated in Lingling, Lengshuitan, Qiyang, Dong'an, Daoxian, Ningyuan, and Jianghua.

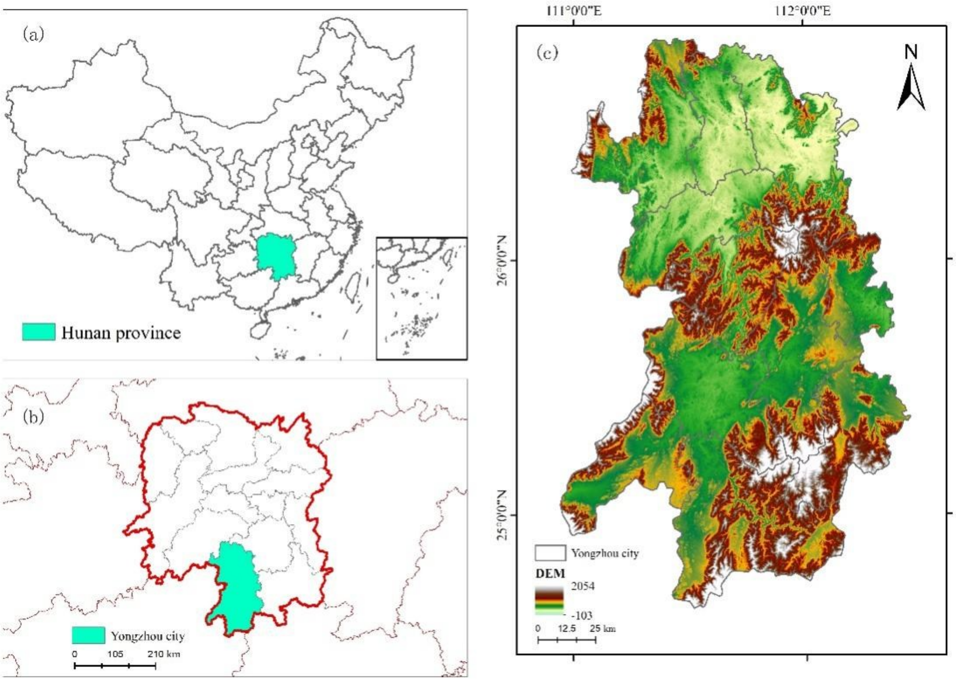

Figure 1: Location of the study area

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3. Data sources and methods

Based on GIS spatial analysis methods, this study comprehensively considers natural environment, ecological safety, and socio-economic factors. Seven factors—topography, slope, water systems, settlements, ecological protection areas, roads, and land use—are selected for the overall evaluation. Additionally, to better reflect real-world conditions, modifications are made by excluding water systems and ecological protection areas during the evaluation process. The collected data is shown in Table 1.

3.1. Data sources

Table 1: Data sources

Data	Year	Factor	Data Source
DEM Topography	2020	Elevation Slope	Geospatial Data Cloud
Basic Geographic Information	2020	Water Systems Roads Settlements Ecological Protection Areas	National Geographic Information Resource Directory System
Land Use Cover Data	2020	Current Land Use	Globeland30

3.2. Evaluation methods and model

3.2.1. Determination of the evaluation system

The evaluation of construction land suitability focuses on indicator selection, standardization, weight determination, and GIS integration [11-13]. Guided by McHarg's suitability evaluation theory [14] and principles of ecological priority, comprehensiveness, and local adaptation, this study categorizes influencing factors into natural environment, socio-economic, and ecological safety factors. Indicators include elevation, slope, and water systems (natural environment); land use, settlements, and roads (socio-economic); and proximity to ecological protection areas (ecological safety).

Based on the above evaluation principles and indicator analysis, this study establishes the construction land ecological suitability evaluation indicator system, with the evaluation goal (A) as the top layer, natural environment factors, socio-economic factors, and ecological safety factors as the criterion layer (B), and the next-level factors as the indicator layer (C). Figure 2 illustrates the evaluation system.

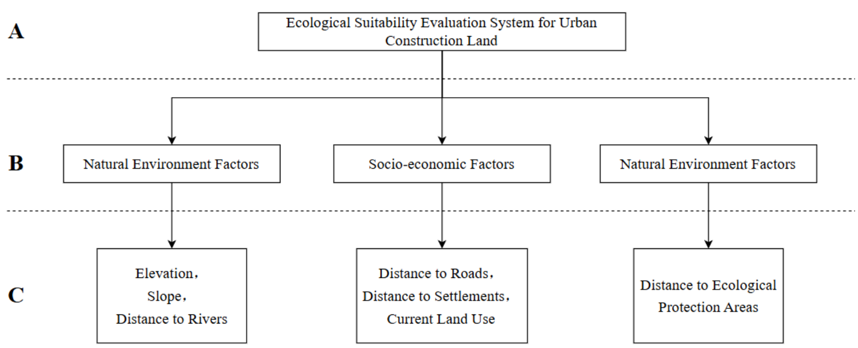

Figure 2: Ecological suitability evaluation system for urban construction land

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3.2.2. Evaluation levels and grading standards

After determining the evaluation factors, a comprehensive survey and repeated discussions on the natural environment and socio-economic conditions of the study area were carried out [15-17]. Based on the degree of impact of each evaluation factor on urban construction land, the factors are divided into five levels, with ecological suitability scores indicated by 5, 4, 3, 2, and 1, where a higher score represents higher ecological suitability for construction land (Table 2). Based on the quantified classification of each indicator, this study employed the spatial analysis tools of ArcGIS 10.8 to generate classification maps for each factor in the study area (Figure 3).

Table 2: Grading standards for ecological suitability evaluation factors

Influence Factors	Evaluation Indicators	Classification Conditions	Evaluation Scores
Natural Environment Factors B1	Elevation C1 (m)	>900	1
		700~900	2
		550~700	3
		450~550	4
		<450	5
	Slope C2 (°)	>25	1
		15~25	2
		8~15	3
		3~8	4
		<3°	5
	Distance to Rivers C3 (m)	<60	1
		60~100	2
		100~140	3
		140~200	4
		>200	5
Socio-economic Factors B2	Distance to Roads C4 (m)	500~1000	3
		200~500	4
		0~200	5
	Distance to Settlements C5 (m)	>800	1
		500~800	3
		200~500	4
		<200	5
	Current Land Use C6	Cropland、Water	1
		Forest	2
		Grassland	3
		Barren	4
		Impervious	5
Ecological Safety Factors B3	Distance to Ecological Protection Areas C7 (m)	<0	1
		0~200	2
		200~500	3
		>500	5

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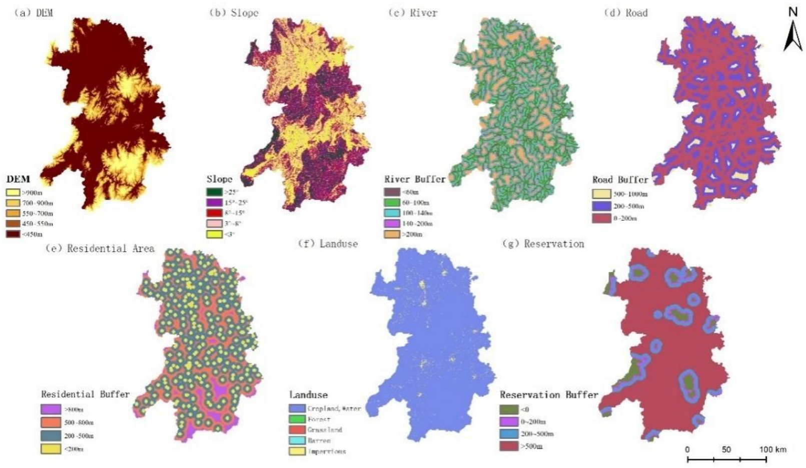

Figure 3: Grading diagram for each factor

3.2.3. Determination of indicator weights

To ensure the scientific accuracy and reliability of the evaluation factor weights, the Analytic Hierarchy Process (AHP) is applied to perform pairwise comparisons of the relative importance of each indicator at different levels. The consistency of the judgment matrix is verified through Formulas (1) and (2). When the consistency ratio (CR) is less than 0.10, the judgment matrix is considered to have satisfactory consistency. After calculating the weights for each indicator, the weights for the higher-level indicators are multiplied by the weights of the judgment matrix at the next level to calculate the composite indicators. Finally, the weight values for each indicator are obtained.

$$CR = \frac{CI}{RI} \tag{1}$$

$$CI = \frac{\lambda max - n}{n-1} \tag{2}$$

From Figure 2, let the judgment matrix for the target layer of urban construction land be denoted as A, the judgment matrices for the three criterion layers of natural environment, socio-economic, and ecological factors be denoted as B1, B2, and B3, and the indicators for the factors such as elevation (C1), slope (C2), water systems (C3), transportation (C4), settlements (C5), current land use (C6), and ecological protection areas (C7) be represented as C1 to C7. The constructed matrices are detailed in Table 3, Table 4, and Table 5.

Table 3: Target matrix

A	B1	B2	B3	Weight
B1	1	2	1/2	0.3108
B2	1/2	1	1/2	0.1958
B3	2	2	1	0.4934

Note: CR = 5.6%, λmax = 3.054, Weight = 1.000.

Table 4: Natural environment factor matrix

B1	C1	C2	C3	Weight
C1	1	1/2	1/4	0.1634
C2	2	1	1/2	0.2970
C3	4	2	1	0.5396

Note: CR = 1%, λmax = 3.009, Weight = 0.3108.

Table 5: Socio-economic factor matrix

B2	C4	C5	C6	Weight
C4	1	3	5	0.5584
C5	1/3	1	3	0.1220
C6	1/5	1/3	1	0.3196

Note: CR = 1.9%, λmax = 3.018, Weight = 0.1958.

Since only one indicator was selected for the ecological safety factor, no judgment matrix is constructed for it. After calculations, the final weights for the evaluation factors of the ecological suitability of construction land in Yongzhou are shown in Table 6.

Table 6: Weights of evaluation factors for ecological suitability of construction land in Yongzhou

First-Level Indicator	First-Level Indicator	First-Level Indicator
Natural Environment B1	Elevation C1	0.0508
	Slope C2	0.0923
	Water Systems C3	0.1677
Socio-Economic B2	Transportation C4	0.1093
	Settlements C5	0.0239
	Current Land Use C6	0.0626
Ecological Safety B3	Ecological Protection Area C7	0.4934

3.2.4. Construction of the evaluation model

Based on the Analytic Hierarchy Process and the spatial analysis functions of GIS, this study adopts a multi-factor comprehensive evaluation model to assess the overall suitability of each factor. The urban construction land ecological suitability evaluation model is expressed as:

$$S = \sum_{i=1}^{n} A_i W_i \tag{3}$$

Where: S is the composite ecological suitability evaluation index; Ai is the classification quantization value of the i-th evaluation indicator for the evaluation unit; Wi is the weight of the i-th evaluation indicator; n is the number of evaluation indicators [18].

4. Results and discussion

4.1. Overall evaluation results

Ultimately, the ecological suitability of construction land was classified into five levels: most suitable, moderately suitable, basically suitable, unsuitable, and unavailable [19]. The priority levels for urban land development were determined, and the final results are shown in Figure 4.

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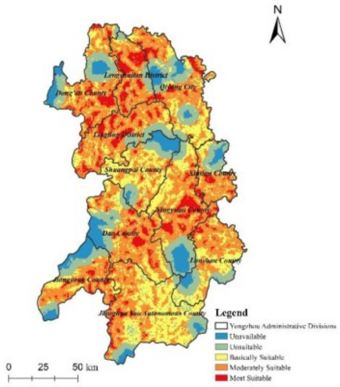

Figure 4: Ecological suitability level distribution map for construction land in Yongzhou

From Figure 4 and Table 7, it can be seen that the most suitable areas for construction account for approximately 8.98% of the total area. These areas are concentrated in the central region with a dense road network and clustered residential areas. This core functional zone supports high-intensity, high-density development.

Moderately suitable areas, the largest category at 42.57%, form a surrounding belt around the core. These areas offer favorable topography, accessibility, and infrastructure, facilitating industrial transfer and urban expansion. They are ideal for medium to large-scale development and play a crucial role in urban spatial planning.

Basically suitable areas account for 24.50%, covering suburban districts, county-level zones, and buffer areas along rivers and transportation corridors. These areas support controlled expansion, integrating ecological agriculture and tourism to balance development with ecological conservation.

Unsuitable areas make up 16.72%, primarily in ecologically sensitive zones like nature reserves and water source protection areas. Strict conservation measures are necessary due to their ecological constraints, limiting large-scale development.

Unavailable areas constitute 7.24%, including protected nature reserves and water bodies. These ecosystems are critical for biodiversity, climate regulation, and water management. Development is strictly prohibited to ensure ecological integrity.

Overall, Yongzhou's construction land is predominantly moderately suitable (40.75%), influenced by topography. The central region, with its flat terrain, is optimal for infrastructure, while the southern region's plains and gentle slopes support mid-scale development. Peripheral areas, benefiting from transportation and industrial collaboration, offer further development potential.

Table 7: Statistical distribution of ecological suitability levels for construction land in Yongzhou

Grade	Suitability Level	Number of pixels	Ratio/%
Most Suitable	4.60–5.00	3,896	8.98
Moderately Suitable	4.10–4.50	9,003	42.57
Basically Suitable	3.60–4.00	13,191	24.50
Unsuitable	2.10–3.50	22,924	16.72
Unavailable	1.00–2.00	4,835	7.24

4.2. Evaluation results at the county level

The distribution of ecological suitability for construction land in Yongzhou is uneven at the county level. The most suitable and moderately suitable areas, covering 51.55% of the total area, are primarily concentrated in the central, southern, and northern regions. Lengshuitan District, Lingling

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District, and Ningyuan County, with flat terrain, abundant water resources, and good transportation, are the most suitable, supporting urban expansion and infrastructure. As shown in Table 8, Lengshuitan District has the highest proportion of most suitable land at 25.49%.

Moderately suitable areas, including Daoxian, Xintian, and Dong'an Counties, also feature favorable conditions but face constraints like land slope and agricultural protection zones[20]. While these areas have high development potential due to flat terrain and dense populations, development must balance ecological protection with efficient land use. Qiyang County has the highest proportion of low-suitability land, at 23.27%.

Table 8: Statistical distribution of ecological suitability levels for construction land in Yongzhou (%)

County	Unavailable	Low Suitability	Basic Suitability	Moderately Suitable	Most Suitable
Jianghua Yao Autonomous County	3.13%	12.07%	43.00%	37.81%	3.99%
Dong'an County	11.27%	21.36%	14.48%	41.45%	11.44%
Daoxian County	8.48%	15.21%	20.05%	47.31%	8.95%
Shuangpai County	12.80%	17.40%	37.67%	30.65%	1.48%
Ningyuan County	8.66%	14.63%	20.83%	43.64%	12.23%
Jiangyong County	15.65%	19.66%	14.38%	42.61%	7.71%
Xintian County	7.26%	21.87%	17.59%	46.31%	6.97%
Lanshan County	4.45%	16.66%	33.98%	41.68%	3.23%
Lingling District	0.29%	12.45%	17.82%	54.16%	15.29%
Lengshuitan District	0.24%	12.51%	9.08%	52.69%	25.49%
Qiyang County	7.98%	23.27%	23.30%	37.41%	8.04%

4.3. Development space and recommendations

Future development in Yongzhou should focus on key areas based on ecological suitability. The central and southern regions, with a high proportion of moderately suitable land and concentrated construction areas, are ideal for urban expansion and functional upgrades. Lengshuitan and Lingling Districts, as core economic hubs, can optimize land use to support industry and population growth.

The northern region, particularly Ningyuan, Daoxian, and Dong'an Counties, has significant development potential due to its flat terrain and dense population. Infrastructure improvements can attract industrial clusters and drive regional economic growth.

Basic-suitability areas, mainly in ecological buffer zones, should avoid large-scale development, instead promoting low-intensity industries such as ecological agriculture and tourism to balance conservation with economic use.

Unsuitable and unavailable areas, including nature reserves and national forests, must remain strictly protected to preserve ecological integrity.

Overall, future land use planning should optimize spatial distribution, promote efficient development in suitable areas, and strengthen ecological protection in the mountainous southern and western regions to achieve balanced economic and environmental sustainability.

5. Conclusion

This study focuses on Yongzhou as research area and employs the Analytic Hierarchy Process (AHP) and spatial analysis technology to assess the ecological suitability of construction land. The most and moderately suitable areas cover 51.55%, indicating good overall suitability, while basic suitability and unsuitable areas are mainly in hilly regions with steep slopes, prone to geological hazards. Unavailable areas, such as nature reserves and national forests, are designated no-development zones.

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The northern and central areas are relatively flat, densely populated, and have higher suitability, offering significant development potential. The study recommends focusing on moderate development in the Xintian-Ningyuan line and northern regions, optimizing spatial layout, and balancing development with ecological protection.

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