Spatial Identification of Ecological Importance of Unused Land and Its Topographic Gradient Characteristics in Guyuan County*Post-print

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Abstract

As an important component of reserve land resources and ecosystems, unused land not only plays a significant role in alleviating the land supply-demand contradiction, but also provides strong support for ecosystem stability. Taking Guyuan County, Hebei Province, located in the agro-pastoral ecotone, as an example, this study constructs a spatial identification indicator system for the ecological importance of unused land in Guyuan County based on its ecological conditions, selecting indicators from three aspects: disaster prevention, habitat and water resource protection, and human disturbance. Combined with GIS spatial analysis functions, the ecological importance of unused land in Guyuan County is spatially identified and divided into four levels: extremely important, important, moderately important, and generally important. Furthermore, based on the topographic characteristics of Guyuan County, terrain gradients are divided into four elevation gradient zones and four slope gradient zones to analyze the terrain gradient distribution characteristics of unused land in Guyuan County. The results show that the areas of unused land with ecological importance levels of extremely important, important, moderately important, and generally important in Guyuan County are 11,082.78 hm², 11,209.05 hm², 11,450.25 hm², and 4,803.12 hm², respectively, accounting for 28.75%, 29.08%, 29.71%, and 12.46% of the total unused land area in the study area. Unused land with a generally important ecological importance level is relatively small. From the perspective of terrain gradient analysis, unused land in Guyuan County is mainly distributed in the 1,400–1,600 m elevation gradient zone and the two slope gradient zones of 0°–5° and 5°–15°; extremely important unused land is mainly distributed in the two elevation gradient zones of 1,400–1,600 m and 1,600–1,800 m, and the 5°–15° slope gradient zone. With the increase in elevation and slope, the proportion of unused land with extremely important ecological importance in each terrain gradient zone increases, rising from 11.31% and 13.86% to 97.95% and 93.64%, respectively. The research results can provide

data support and scientific basis for the development, utilization, and ecological protection of unused land in Guyuan County.

Full Text

Preamble

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Spatial Recognition of Ecological Importance and Analysis of Terrain Gradient Characteristics of Unused Lands in Guyuan County*

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Abstract

Unused land constitutes not only an important reserve land resource but also a vital component of the ecosystem, playing a significant role in alleviating land supply-demand contradictions while providing robust support for ecosystem stability. However, the ecological importance of unused lands has not received adequate attention in existing research, which has primarily focused on evaluating suitability for conversion to arable or construction land while neglecting ecological value. This study examines Guyuan County in Hebei Province—a typical ecologically fragile area in the agriculture-animal husbandry transition zone—to assess the ecological importance of unused lands for development and environmental protection. Based on local ecological conditions, we constructed a spatial identification index system from three perspectives: disaster protection, habitat and water resource protection, and human disturbance. Using GIS spatial analysis, we identified and classified the ecological importance of unused lands into four categories: very important, important, relatively important, and less important. Additionally, we divided the terrain into four elevation gradient zones and four slope gradient zones to analyze the distribution characteristics of unused lands across terrain gradients. The results show that unused lands classified as very important, important, relatively important, and less important cover 11,082.78 hm², 11,209.05 hm², 11,450.25 hm², and 4,803.12 hm², respectively, accounting for 28.75%, 29.08%, 29.71%, and 12.46% of the total unused land area. From a terrain gradient perspective, unused lands are mainly distributed in the 1,400–1,600 m elevation zone and the 0°–5° and 5°–15° slope zones. Ecologically very important unused lands are concentrated in the 1,400–

1,600 m and 1,600–1,800 m elevation zones and the 5°–15° slope zone. As elevation and slope increase, the proportion of very important unused lands in each terrain gradient zone rises significantly, from initial values of 11.31% and 13.86% to 97.95% and 93.64%, respectively. These findings provide data support and scientific basis for the development, utilization, and ecological protection of unused lands in Guyuan County.

Keywords: Agriculture-animal husbandry transition zone; Unused land; Ecological importance; Terrain gradient; GIS; Guyuan County

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1. Study Area Overview and Data Sources

1.1 Study Area Overview

Guyuan County is located in the Bashang region of northwestern Hebei Province, situated in the middle section of the northern agriculture-animal husbandry transition zone. Adjacent to the Beijing-Tianjin region in the south, it serves as a natural ecological barrier for these metropolitan areas. Geographically, it lies between 114°50 19 -116°04 34 E and 41°13 55 -41°56 54 N, covering a total area of 3,589.24 km². At the end of 2013, the county had a total population of 230,085, including 31,038 non-agricultural residents and 199,047 agricultural residents. The gross domestic product reached 3.846 billion yuan, with the primary, secondary, and tertiary industries contributing 1.744 billion, 1.103 billion, and 0.999 billion yuan, respectively.

The county has an average elevation of 1,475.18 m, ranging from a minimum of 1,263 m around the county seat to a maximum of 2,178 m in the southeastern part, resulting in substantial topographic relief. The remaining ranges of the Yinshan Mountains traverse the county from east to west, creating three distinct topographic regions: the southern Bashang marginal mid-low mountain area, the eastern low hilly area, and the central-northern undulating plateau area. Characterized by a cold temperate semi-arid continental monsoon climate, Guyuan County experiences severe cold and drought, with an average annual temperature of only 1.4°C, annual sunshine of 2,937.7 hours, and average precipitation of approximately 400 mm concentrated between June and September. With 50–70 windy days annually, the area frequently suffers from natural disasters including drought, hail, and frost, making it a typical ecologically fragile zone. As part of the Beijing-Tianjin ecological protection region, Guyuan County bears the crucial responsibility of serving as an ecological barrier, playing an important role in strengthening ecological protection and water source conservation functions in northern Hebei while alleviating environmental pressure on Beijing and Tianjin.

1.2 Data Sources

The foundational data for this study were obtained from multiple reliable sources: the 2013 land use status map of Guyuan County, digital elevation model (DEM) data, the 2013 Guyuan County Statistical Yearbook, Landsat 8 remote sensing imagery, the *Guyuan County Geological Disaster Planning* document, and field survey data.

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2. Research Methods

2.1 Research Framework

This study employed 30 m × 30 m raster cells as the evaluation unit. Based on the ecological conditions of Guyuan County, we selected indicators from three dimensions—disaster protection, habitat and water resource protection, and human disturbance—to construct a spatial identification index system for the ecological importance of unused lands. We first completed ecological importance identification based on individual factors, then performed spatial overlay analysis of these single-factor results to obtain comprehensive identification results from the three dimensions. Finally, we divided terrain gradients and analyzed spatial distribution characteristics based on these gradients. The ecological importance identification index system is presented in .

2.2 Index System

2.2.1 Disaster Protection Indicators Given the diverse landforms, substantial elevation differences, wide slope variations, and severe soil desertification and water erosion in Guyuan County, we selected four indicators for disaster protection assessment: degree of difficulty of geological disasters occurrence, water and soil loss intensity, terrain index, and topography degree. The geological disaster indicator was derived from the *Guyuan County Geological Disaster Planning* document, supplemented by field surveys and geological environmental conditions. Water and soil loss processes are complex, influenced by both natural and human factors. For unused lands, we determined water and soil loss intensity using five equally weighted indicators: slope, gully density, vegetation coverage, average annual rainfall, and unused land type. Classification standards for these indicators were based primarily on the *Technical Code for Water and Soil Conservation*, the *Standard for Classification and Gradation of Soil Erosion* (SL190—2007), and relevant research [12–14], with the natural breaks method used to classify intensity into four levels: mild, moderate, severe, and extremely severe. The terrain index and topography degree were derived from DEM data using ARCGIS spatial analysis tools and raster calculator. The terrain index was calculated as follows:

$$L = \frac{G}{\overline{G}} \times \frac{P}{\overline{P}}$$

where L is the terrain index, G represents the elevation value of a single grid cell, $\overline{G}$ is the average elevation of Guyuan County, P represents the slope of a single grid cell, and $\overline{P}$ is the average slope of the county [15].

2.2.2 Human Disturbance Indicators Human disturbance indicators reflect the intensity of human activities affecting ecological resources, which is inversely proportional to ecological importance. We selected three indicators for spatial identification: strength index of main traffic arteries, strength index of town construction land, and degree of population aggregation [7]. The traffic and construction land impact indices were implemented using buffer analysis in ARCGIS 9.3, as unused lands farther from these features maintain better natural ecological conditions with lower disturbance levels. Population aggregation reflects how population size affects the ecological environment—higher aggregation leads to greater impact and lower ecological importance. We characterized population aggregation using village-level population density (total population divided by total area) and classified it into four categories using the natural breaks method: commonly intensive, relatively intensive, intensive, and highly intensive.

2.2.3 Habitat and Water Resource Protection Indicators Despite superior natural landscapes, Guyuan County has experienced habitat destruction and severe water shortages due to urban expansion and ecological degradation, necessitating urgent protection of habitats and water resources. We selected four indicators: vegetation coverage, distance from river systems, aspect, and cover types of unused land. Vegetation coverage was obtained using ENVI 5.1 software. After radiometric calibration and atmospheric correction of August Landsat 8 imagery, we applied the NDVI function (Basic Tool→Transform→NDVI) and normalization processing. The calculation formula is:

$$F = \frac{\mathrm{NDVI} - \mathrm{NDVI}_{\min}}{\mathrm{NDVI}_{\max} - \mathrm{NDVI}_{\min}}$$

where F is vegetation coverage, and $\mathrm{NDVI}_{\max}$ and $\mathrm{NDVI}_{\min}$ represent the maximum and minimum normalized difference vegetation index values [16-17]. Distance from river systems was calculated using ARCGIS 9.3 buffer analysis. Cover types were determined based on the second land survey classification system, the 2013 land use status map, and field survey results. Aspect, which significantly influences sunshine duration and soil moisture redistribution, was derived from DEM data using ARCGIS aspect analysis and classified into four levels across nine aspect categories, as detailed in .

2.3 Comprehensive Evaluation

Based on the single-factor ecological importance assessment results, we used the raster calculator function in ARCGIS 9.3 to conduct equal-weight comprehensive analysis, obtaining an integrated ecological importance index covering disaster protection, human disturbance, and habitat and water resource protection. The natural breaks method was applied to classify the results into four grades, producing the comprehensive identification map of ecological importance for unused lands in Guyuan County.

The ecological importance index for each ecological problem was calculated as:

$$\mathrm{EISI}_j = \prod_{i=1}^{n} C_{ij}^{1/n}$$

where EISI_j represents the importance index of the jth ecological problem, C_{ij} is the importance grade index of the ith indicator for this ecological problem, and n is the number of indicators representing the ecological problem. Using this formula in ARCGIS, we assigned values to each indicator and calculated single-factor ecological importance indices, which were then clustered into four grades (very important, important, relatively important, and less important) using the natural breaks method.

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3. Results and Analysis

3.1 Spatial Identification of Ecological Importance of Unused Lands in Guyuan County

Using the methodology and index system described above in ARCGIS 9.3, we conducted both single-factor and comprehensive ecological importance identification for unused lands in Guyuan County. The results are presented in and [Figure 1: see original paper].

Regarding disaster protection, unused lands classified as very important and important cover 3,016.71 hm^2 and 6,521.19 hm^2, respectively, accounting for 7.83% and 16.89% of the total unused land area. As shown in [Figure 1: see original paper]a, these lands are mainly distributed in the southern part of the county, where slopes are generally steep (ranging from 5° to 62°) and elevation differences are substantial (from 1,320 m to 1,959 m). These conditions make the area prone to geological disasters and severe water erosion, representing a key disaster prevention zone where development should prioritize ecological benefits.

For human disturbance, unused lands classified as very important and important cover 21,685.59 hm^2 and 12,417.48 hm^2, respectively, representing 56.26%

and 32.22% of the total unused land area. Overall, most unused lands experience minimal human disturbance, primarily because they are located far from residential areas and major roads, receiving little impact from construction land and transportation infrastructure. Additionally, some unused lands are in areas with low population density, experiencing relatively minor impacts from human activities and maintaining good ecological conditions as important ecological conservation zones suitable for ecological construction.

Concerning habitat and water resource protection, unused lands classified as very important and important cover 2,439.45 hm² and 6,539.94 hm², respectively, accounting for only 6.33% and 16.97% of the total unused land area. This indicates that high-grade unused lands for habitat and water protection are relatively scarce, mainly because most unused lands are far from rivers and lakes, and the dominant unused land type is other grassland with average ecological condition. Some unused lands achieve higher importance grades due to relatively high vegetation coverage, south-facing aspects, or proximity to rivers, playing a more significant role in maintaining regional habitat and water security. These lands are primarily distributed in the southern part of the county and around rivers and lakes.

In the comprehensive assessment, unused lands classified as very important and important cover 11,082.78 hm² and 11,209.05 hm², respectively, exceeding 50% of the total unused land area at 28.75% and 29.08%. Spatial analysis using [Figure 1: see original paper]d reveals that very important unused lands are concentrated in four townships—Xiaohezi, Lianhuatan, Fengyuandian, and Changliang—which together account for 73.55% of all very important unused lands. These areas feature high elevations, steep slopes, high vegetation coverage, low population density, and minimal human disturbance, making them suitable for ecological land use development. Conversely, less important unused lands are mainly found in Jiuliancheng Town and Saibeiguanli District, where vegetation coverage is low, elevations are lower, slopes are gentler, topographic relief is moderate, and geological disasters and water erosion are less severe, allowing for appropriate economic development. The spatial distribution across townships is detailed in .

3.2 Analysis of Unused Land Distribution Based on Elevation Gradients

After comparative analysis and literature review [18–19], we found that using 100 m elevation intervals produced insufficient gradient differentiation, while larger intervals failed to adequately characterize distribution patterns. Therefore, we adopted 200 m intervals to divide the study area into four elevation gradient zones: 1,200–1,400 m, 1,400–1,600 m, 1,600–1,800 m, and above 1,800 m. Using ARCGIS 9.3 spatial analysis, we overlaid the comprehensive identification results with the elevation map to obtain the distribution of different importance grades across elevation zones, as shown in .

The results indicate that unused land distribution varies significantly across elevation gradients. The 1,400–1,600 m zone contains the most unused land (24,207.66 hm², 62.80% of the total), while the above 1,800 m zone has the least (188.19 hm², 0.49%). Very important unused lands are concentrated in the 1,400–1,600 m and 1,600–1,800 m zones, covering 6,123.69 hm² (55.25%) and 3,919.14 hm² (35.36%), respectively. Less important unused lands are mainly found in the 1,200–1,400 m and 1,400–1,600 m zones (1,337.22 hm² and 3,252.42 hm²), with none present above 1,800 m due to high elevations, substantial topographic variation, high geological disaster risk, and generally high vegetation coverage in this zone.

In summary, as elevation increases, the proportion of very important unused lands in each elevation gradient zone increases, while the proportions of relatively important and less important lands decrease. In the above 1,800 m zone, all unused lands exhibit high ecological importance, with no less important lands remaining, and very important lands dominate.

3.3 Analysis of Unused Land Distribution Based on Slope Gradients

Using Guyuan County' s DEM data and ARCGIS 9.3 spatial analysis, we generated a slope map. Since no clear standards exist for slope gradient classification [18–19], we divided the study area into four slope zones based on local characteristics: 0°–5°, 5°–15°, 15°–25°, and above 25°. Overlaying the slope map with the comprehensive ecological importance identification results and reclassifying yielded the relationship between ecological importance grades and slope, with statistical results presented in .

The analysis reveals that unused land distribution and ecological importance grades vary markedly with slope. Unused lands are predominantly located in the 0°–5° and 5°–15° slope zones (17,640.18 hm² and 17,497.98 hm², representing 45.76% and 45.40% of the total, respectively), while the above 25° zone contains the least (205.02 hm²). Very important unused lands are concentrated in the 5°–15° slope zone (5,960.88 hm², 53.79% of all very important lands), primarily because these lands are in the southern part of the county with high vegetation coverage, severe geological disasters and water erosion, and minimal human disturbance. Conversely, less important and relatively important unused lands are mainly found in the 0°–5° zone (3,638.34 hm² and 7,176.51 hm², representing 75.75% and 62.68% of their respective categories), as these areas in the northern part and around the county seat have lower elevations, weaker geological disasters and water erosion, higher population density, greater human and construction land disturbance, and lower vegetation coverage, making them more suitable for economic development.

In conclusion, as slope increases, the proportion of very important unused lands in each slope gradient zone increases, while the proportions of less important and relatively important lands decrease.

4. Conclusions and Discussion

As an important reserve land resource, unused land plays a crucial role in alleviating land supply-demand contradictions. While existing research has concentrated on suitability evaluation for arable and construction land development, unused lands also provide vital support for ecosystem stability as integral ecosystem components. Identifying unused lands with high ecological importance is therefore essential for regional ecological protection. Guyuan County, located in the ecologically fragile agriculture-animal husbandry transition zone with prominent ecological problems, requires careful ecological construction. Identifying the ecological importance of its unused lands can guide their development while providing a basis for ecological construction, achieving the dual goals of rational utilization and ecological enhancement.

Based on local ecological conditions, we selected indicators from disaster protection, human disturbance, and habitat and water resource protection dimensions to spatially identify the ecological importance of unused lands. The results show that very important and important unused lands cover 11,082.78 hm^2 and 11,209.05 hm^2, respectively, totaling 57.83% of the county' s unused land area. Spatially, very important unused lands are concentrated in the southern and southeastern parts of the county, particularly in Xiaohezi, Lianhuatan, Fengyuandian, and Changliang townships. These areas feature high vegetation coverage, substantial elevation differences, steep slopes, severe water erosion, and high geological disaster risk, combined with minimal human disturbance, making them important ecological conservation zones where development should emphasize ecological functions and potential. Less important unused lands are mainly distributed in Jiuliancheng Town and Saibeiguanli District, where lower vegetation coverage, gentler terrain, and fewer geological disasters result in relatively lower ecological importance, permitting appropriate economic development.

From a terrain gradient perspective, unused lands are primarily distributed in the 1,400–1,600 m elevation zone and the 0°–5° and 5°–15° slope zones. Ecologically very important unused lands are concentrated in the 1,400–1,600 m and 1,600–1,800 m elevation zones and the 5°–15° slope zone. As elevation and slope increase, the proportion of high-grade unused lands in corresponding terrain gradient zones increases. These findings demonstrate that some unused lands in Guyuan County possess significant ecological value, and their development should prioritize ecological benefits with directionally differentiated utilization based on their ecological importance grades.

This study investigates the ecological importance of unused lands and explores their relationship with terrain factors, representing an innovative approach compared to conventional arable or construction suitability studies. It highlights the ecological value of unused lands and expands the scope of unused land research, providing important implications for future development and ecological protection. However, this research represents preliminary findings with limited com-

prehensive analysis of terrain gradient characteristics and insufficient in-depth examination of relationships between terrain factors and unused lands. Future research will further explore these relationships, aiming to quantitatively express the connections between unused lands and terrain factors to provide more scientific guidance for regional land development and utilization.

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Note: Figure translations are in progress. See original paper for figures.