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Implementation of Ecological Product Value Zoning Based on Land Ecological Sensitivity Assessment: A Case Study of Altay City (Postprint)

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Abstract

A sound ecological environment constitutes the foundation for sustaining human survival and development, and serves as an important prerequisite for national ecological civilization construction. This study employs GIS technology to conduct an ecological sensitivity assessment of Altay City. The results indicate: (1) The influencing factors of ecological environment sensitivity in Altay City, ranked in descending order of impact magnitude, are: land use type > vegetation coverage > river buffer > road buffer > elevation > slope > aspect. (2) The overall ecological sensitivity of Altay City is relatively high, with areas classified as extremely sensitive and highly sensitive accounting for 42.45% of the total study area; these areas are distributed across the northern mountainous region, the central hilly region, and along both banks of the Irtysh River in the south. Conversely, areas classified as insensitive and low-sensitivity are predominantly located in the central hilly region and intermountain alluvial plains. (3) Based on the ecological sensitivity assessment results, Altay City is divided into three functional zones: ecological protection zone, ecological enhancement zone, and ecological protection and management zone. According to the characteristics of each zone, value realization pathways for ecological products are proposed, encompassing improvements to ecological compensation mechanisms, development of characteristic eco-tourism, promotion of ecological agriculture, and implementation of ecological restoration and management initiatives, thereby providing practical references for realizing the value of ecological products in Altay City.

Full Text

Implementation of Ecological Product Value Zoning Based on Land Ecological Sensitivity Assessment: Using Altay City as an Example

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Abstract

A healthy ecological environment is fundamental to human survival and development and constitutes an important prerequisite for national ecological civilization construction. This study employs GIS technology to evaluate the ecological sensitivity of Altay City in Xinjiang. The results indicate: (1) The degree of influence of various factors on ecological sensitivity in Altay City, ranked from highest to lowest, is: land use type > vegetation coverage > river buffer zone > road buffer zone > elevation > slope > aspect. (2) The overall ecological sensitivity of Altay City is relatively high, with areas classified as extremely sensitive and highly sensitive accounting for 42.45% of the total study area. These sensitive areas are primarily distributed in the northern mountainous region, central hilly area, and along both banks of the Ertix River in the south. Areas with low sensitivity are mainly located in the central hilly region and mountainous alluvial plains. (3) Based on the ecological sensitivity evaluation results, Altay City is divided into three primary zones: ecological protection zone, ecological enhancement zone, and ecological protection and governance zone. According to the characteristics of each zone, corresponding ecological product value realization models are proposed, including improving ecological compensation, developing distinctive ecological tourism, promoting ecological agriculture, and implementing ecological restoration and governance. These findings provide practical references for realizing ecological product value in Altay City.

Keywords: ecological sensitivity assessment; ecological products; ecological zoning; value realization mode; Altay City

Introduction

Ecological sensitivity refers to the responsiveness and vulnerability of ecosystems under human disturbance and natural environmental changes, indicating the difficulty with which ecological problems may arise in a region and their potential likelihood. Areas with higher sensitivity are more prone to various ecological issues. Ecological products are the final goods or services provided by ecosystems through the interaction of biological production and human activities that can enhance human well-being. The scope of ecological sensitivity research has

gradually expanded from large-scale areas such as national and provincial levels to smaller study areas like cities and scenic zones, with cross-regional studies also becoming a research hotspot. Domestic research on ecological sensitivity has developed rapidly, evolving from single-factor to comprehensive sensitivity assessments. However, there remains no unified standard for selecting evaluation factors or classifying sensitivity levels. In terms of factor selection, Li Zhenya et al. selected 11 sensitivity indicators including biodiversity and soil salinization to assess terrestrial ecological sensitivity in China. Li Hongqing et al. chose four indicators including elevation, vegetation coverage, and distance to water bodies and roads to evaluate the Yarlung Zangbo River Shannan Wide Valley Basin. Chen Yaoyao et al. selected six factors including elevation and land use type for ecological sensitivity analysis in Nanchang, Jiangxi Province. Regarding factor classification, Li Hongqing used 500 m intervals for elevation classification, while Chen Yao et al. limited elevation intervals to within 200 m, with the fundamental reason being that different study areas have varying altitude ranges, and other factor classifications also need to be determined based on local conditions.

Currently, domestic and international research on ecological sensitivity focuses primarily on analyzing or planning for regional sensitivity without in-depth exploration. Based on this, the present study takes Altay City as the research object, selects seven factors that appear most frequently in sensitivity evaluations—elevation, slope, aspect, vegetation coverage, river buffer zone, land use type, and road buffer zone—to construct an ecological sensitivity evaluation model, identifies areas of different sensitivity levels as references for ecological zoning, and proposes ecological product value realization models according to regional characteristics. This innovative combination of ecological sensitivity assessment and ecological product value realization research not only addresses the current lack of studies on ecological product value realization in western China but also provides valuable references for ecological product value realization in Altay City and even across Xinjiang, holding significant practical relevance for both ecological protection and economic development in Altay City.

As a key ecological function area, Altay City's primary task is to provide ecological products. However, due to its complex and diverse landform types, its ecosystem is inherently highly sensitive and fragile. Human activities such as intense interference, declining water conservation functions, and overexploitation of forest and grassland resources further disturb and damage the local ecological environment, increasing ecological sensitivity. Located in China's northwestern border region with relatively poor location conditions and limited transportation access, Altay City lacks efficient industrial foundations and rational industrial structures. Particularly in exploring the continuous supply and value realization of ecological products, the city remains in its initial stages, creating a gap with the people's growing needs for a better life. Therefore, balancing economic development and ecological protection has become an urgent issue for Altay City.

1 Study Area Overview

Altay City (86°53 –88°38 E, 47°27 –48°39 N) is located in the hinterland of the Asian continent, with a north-south length of 146 km and east-west width of 84 km. The city belongs to the temperate sub-arid and arid climate zones. With the Altai Mountains as a barrier to the north and the northern edge of the Junggar Basin to the south, climate conditions vary significantly between north and south: the northern mountainous area receives high precipitation with low evaporation, while the southern mountainous alluvial plains show the opposite pattern [Figure 1: see original paper]. Altay City is rich in water resources, known as Xinjiang’s “water tower,” and serves as a key water conservation ecological function area and a growing resource-based city, forming an important resource supply and reserve base for Xinjiang.

2 Data and Methods

2.1 Data Sources and Processing The zoning data were obtained from the National Geospatial Information Public Service Platform Standard Map Service website. Elevation data were sourced from the Geospatial Data Cloud (<http://www.gscloud.cn/>). Land use type data were derived from GLOBELAND30, a global geographic information public product (<http://www.globeland30.org/>). Landsat 8 OLI data were obtained from the Geospatial Data Cloud. Basic geographic information data came from the National Basic Geographic Information Center (<http://www.ngcc.cn/ngcc/>). All data were processed using ArcGIS 10.8 software, converted to the WGS_{{1984}}_{{UTM}}_{{ZONE}}_{{45N}} projected coordinate system, and resampled to a 30 m × 30 m pixel size to ensure data consistency.

2.2.1 Evaluation Factor Selection and Assignment Ecological sensitivity indicators form the foundation of ecological sensitivity assessment. Following principles of comprehensiveness, scientific rigor, and systematicity, this study comprehensively considered Altay City’s natural, social, and economic conditions. Seven indicators were selected from three criterion layers—topographic and geomorphological factors, ecological environmental factors, and human activity factors—to establish the ecological sensitivity evaluation index system for the study area. These indicators include elevation, slope, aspect, river buffer zone, vegetation coverage, land use type, and road buffer zone. Each single factor was classified into five sensitivity levels and assigned values accordingly .

2.2.2 Determination of Evaluation Factor Weights As research has advanced, weight determination methods have become increasingly diverse. Commonly used methods include the Analytic Hierarchy Process (AHP), principal

component analysis, neural networks, fuzzy comprehensive evaluation, and combined approaches. This study innovatively employs the AHP-CRITIC combination weighting method. The AHP method involves experts scoring each single factor to construct a judgment matrix, scientifically calculating subjective weights that pass consistency tests. The CRITIC method is an objective weighting approach that uses contrast intensity and conflict indicators to comprehensively measure objective weights while considering evaluation index differences and correlations. The combination of these two methods introduces Lagrange functions and Euclidean distance to establish an optimization decision model, enhancing the theoretical rationality and scientific validity of the evaluation results.

The combination weight calculation formula is as follows: $(\beta_i) = \frac{a\alpha_i + b\beta_i}{n}$, where n is the total number of evaluation factors, α_i is the sensitivity evaluation factor, α_i is the subjective weight of factor i , β_i is the objective weight of factor i , a is the subjective preference coefficient, and b is the objective preference coefficient. β_i represents the combined weight of factor i . Calculations yielded a subjective preference coefficient $a = 0.298$ and objective preference coefficient $b = 0.702$. Substituting these values into the formula produced the comprehensive weight values for each single factor.

2.2.3 GIS Spatial Analysis Methods Using ArcGIS surface analysis tools, slope and aspect data were extracted from elevation data and reclassified to obtain single-factor sensitivity distribution maps. Water system and transportation elements obtained from the National Basic Geographic Information Center were preprocessed through clipping, merging, and projection before using multi-ring buffer tools to analyze river and road ecological sensitivity in Altay City. After reclassification and assignment according to the evaluation index system, the weighted overlay function in ArcGIS was applied based on each factor's weight value to calculate the comprehensive ecological sensitivity index for each grid cell in Altay City. The natural breaks method was then used to reclassify the comprehensive evaluation index values into five levels from high to low, producing the comprehensive ecological sensitivity distribution map for Altay City.

2.2.4 Ecological Sensitivity Index The ecological sensitivity index for Altay City was calculated by applying the weight values from Table 2 using the ArcGIS weighted overlay function. The calculation formula is: $Z = \sum(\alpha_i \times L_i)$, where Z is the evaluation index sensitivity value, α_i is the comprehensive weight of indicator i , and L_i is the sensitivity level assignment of indicator i .

3 Results

3.1.1 Topographic and Geomorphological Factor Sensitivity Analysis Elevation is an important factor affecting the natural environment of the study

area—the higher the elevation, the stronger the ecological sensitivity. The northern mountainous area contains extensive alpine pastures that not only provide high-quality forage for animal husbandry development but also supply numerous public ecological products such as water conservation and soil retention. Altay City's overall elevation sensitivity is at low to moderate levels, with low-sensitivity areas covering the largest area of 3940.95 km² (36.52% of the total area), primarily distributed in the southeastern alluvial plains and southwestern regions. Highly sensitive and extremely sensitive areas are mainly located in the northern mountainous region.

Slope reflects the steepness of the terrain surface. Areas with higher slopes are less suitable for vegetation growth and human activities, significantly influencing the selection of ecological product value realization models. The southern part of the study area consists of insensitivity zones with slopes below 15°, covering approximately 5624.73 km² (52.20% of the total area). The central and northern parts of Altay City have more rugged terrain, with moderately sensitive and highly sensitive areas alternating and distributed relatively evenly, covering 1780.36 km² and 1208.12 km² respectively.

Aspect affects precipitation patterns and sunlight duration, thereby influencing ecological sensitivity. Generally, north-facing slopes receive the shortest sunlight duration, retain snow cover longer, and experience inhibited vegetation growth, resulting in unstable ecosystems with strong sensitivity that is difficult to restore once damaged. Aspect carries the lowest weight in Altay City's sensitivity evaluation because the city's topography is dominated by the Altai Mountains, with elevation decreasing from north to south and large areas of flat land and south-facing slopes. The aspect sensitivity levels in Altay City are predominantly low to moderate, with moderate-sensitivity areas covering the largest proportion at 5404.69 km² (50.03% of the total area), followed by low-sensitivity areas at 2866.67 km² (26.54%).

3.1.2 Ecological Environmental Factor Sensitivity Analysis Regarding river buffer factors, areas closer to water bodies have better plant survival conditions and higher ecological environmental quality, resulting in stronger ecological sensitivity. The distribution map shows that highly sensitive and extremely sensitive areas in Altay City's river buffer zones are primarily concentrated along the Ertix River and its tributary, the Kelan River, with sensitivity gradually decreasing outward from the river center.

Normalized Difference Vegetation Index (NDVI) reflects vegetation growth status and coverage. Higher NDVI values indicate greater supply of ecological products in the region, and this factor ranks second in weight among the seven factors. The distribution of vegetation coverage sensitivity levels in Altay City is relatively dispersed, with low, moderate, and high sensitivity areas concentrated primarily in the central and western parts of the city, accounting for 17.00%, 15.64%, and 16.67% of the total area respectively.

3.1.3 Human Activity Factor Sensitivity Analysis Land use type carries the highest weight and has the greatest impact on ecological sensitivity evaluation in Altay City because it directly determines the type and quality of ecological products produced. Overall, land use type sensitivity in Altay City is relatively high: extremely sensitive areas are mainly distributed in the two river basins and high-altitude mountainous areas in the north, while low-sensitivity areas are primarily located in the Ertix River and Kelan River basins where the terrain is flat and fertile, making them suitable for human habitation.

Road sensitivity impacts the ecological environment mainly through noise pollution and human accessibility. Areas closer to roads experience greater noise pollution and waste contamination, though human accessibility also affects ecological product value realization, particularly for material ecological products and production-oriented ecological products such as ecotourism. Overall road buffer sensitivity is not high, with insensitive areas accounting for 65.66% of Altay City's total area, and the proportions of various sensitivity levels are generally similar.

3.1.4 Comprehensive Ecological Sensitivity Analysis By applying weighted calculations to the seven factors, the comprehensive land ecological sensitivity index distribution map for the study area was obtained [Figure 3: see original paper]. Altay City's ecological sensitivity index ranges from 1.0 to 4.6, with overall sensitivity at moderate to high levels. Low-sensitivity areas are the smallest, covering 2347.20 km² (21.76% of the total area). Moderate to high sensitivity areas account for 52.29% of the total area, primarily distributed in the central low mountains and hills, river valleys in the northern mountainous area, and the Ertix River basin. Extremely sensitive areas are mainly distributed in the northern mountainous region [Figure 4: see original paper].

4 Ecological Zoning

4.1 Ecological Zoning Framework Ecological zoning involves dividing a study area into different ecological regions based on the spatial differentiation patterns of ecological characteristics, according to the heterogeneity and similarity of major ecological factors across different areas. This process provides an appropriate spatial reference for ecosystem research, evaluation, restoration, and management. The ecological sensitivity evaluation method comprehensively considers the impacts of topography, ecological resources, and human activities, using evaluation results as the foundation and basis for ecological zoning. Numerous domestic scholars have conducted research on this approach for many years, demonstrating its operability.

Based on the research results and following principles of scientificity, integrity, and hierarchical classification, the study area is divided into three primary

zones—ecological protection zone, ecological enhancement zone, and ecological protection and governance zone—which are further subdivided into six secondary zones [Figure 5: see original paper] .

4.2 Zoning Results and Characteristics

4.2.1 Ecological Protection Zone

The ecological protection zone features good ecological environments, abundant forest and grassland resources, and minimal human disturbance. Its primary purpose should be strengthening ecological protection to ensure continuous production of high-quality ecological products, covering approximately 4388.89 km² (40.66% of the total area). This zone is dominated by high and extreme sensitivity levels and includes the northern mountainous ecological protection zone (I-1) and the Ertix River basin ecological protection zone (I-2). The northern mountainous ecological protection zone, located in northern Altay City and covering about 35.41% of the total area, features high mountain canyons with relatively high elevations and abundant forest resources, making it one of Xinjiang's key forestry areas. The Ertix River basin ecological protection zone is situated at the confluence of the Ertix and Kelan Rivers, with rich water resources. It serves as the national aquatic germplasm resources protection area for endemic fish species in the Koksui section of the Ertix River and as the Xinjiang Altay Koksui Wetland National Nature Reserve, holding important ecological significance.

4.2.2 Ecological Enhancement Zone

The ecological enhancement zone experiences greater human activity interference and should focus on improving environmental quality to enable production of more high-quality ecological products by reducing human impacts. Covering approximately 4304.27 km² (39.89% of the total area), this zone is dominated by moderate comprehensive sensitivity levels and includes the central low mountain ecological enhancement zone (II-1) and the two rivers basin ecological enhancement zone (II-2). The central low mountain ecological enhancement zone has relatively flat terrain with low elevation and serves as a key urban agglomeration area and important grain production region for Altay City.

4.2.3 Ecological Protection and Governance Zone

The ecological protection and governance zone exhibits mostly low sensitivity levels but faces severe desertification due to mineral development, farmland reclamation, and grassland degradation. Covering approximately 2086.79 km² (19.34% of the total area), this zone includes the Ertix River alluvial plain ecological protection and governance zone (III-1) and the Junggar Basin edge ecological protection and governance zone (III-2). The Ertix River alluvial plain ecological protection and governance zone is located in central Altay City and consists mainly of desert and unused land. The Junggar Basin edge ecological protection and governance zone is situated in the southwestern corner of Altay City, at the northern edge of the Junggar geosynclinal fold system, near the desert.

5 Ecological Product Value Zoning Realization Models

President Xi Jinping proposed that “lucid waters and lush mountains are invaluable assets, and ice and snow also represent invaluable assets.” Under the guidance of this “Two Mountains” theory, China’s ecological civilization construction has advanced significantly, promoting positive interactions between ecological environments and socio-economic development. However, opening the transformation channel between these “Two Mountains” and exploring ecological product value realization remains challenging. Current domestic ecological product value realization models mainly include ecological compensation, carbon sink trading, green funds, and ecological industrialization, which have been widely implemented across many regions with good results, providing rich references for Altay City.

5.1 Ecological Protection Zone: Conduct GEP Accounting and Refine Ecological Compensation Drawing on practical experience from numerous provinces, clear natural resource property rights are prerequisites for ecological product value realization. Therefore, Altay City should accelerate natural resource ownership registration to solidify the foundation for value realization. Building upon central and local Gross Ecosystem Product (GEP) accounting guidelines and adapting to local conditions, the city should launch pilot GEP accounting projects and gradually improve accounting methods to establish local standards. GEP accounting results should be combined with ecological protection zone characteristics to refine and optimize ecological compensation funds, exploring the establishment of a “two-way” compensation mechanism that transforms ecological advantages into economic benefits.

5.2 Ecological Enhancement Zone: Rational Utilization of Ecological Resources to Promote Ecological Product Value Realization

5.2.1 Central Low Mountain Ecological Enhancement Zone: Utilize Ice and Snow Resources to Develop Distinctive Ecotourism

Altay City is renowned as “China’s Snow Capital.” Its central low mountain ecological enhancement zone features moderate elevation, diverse slope types, gentle and long slopes, abundant snowfall, long snow seasons, and excellent snow quality—top-tier resources for ski resort development with the potential to become an international ski industry cluster. By fully utilizing the ice and snow resources in the central low mountains, Altay can develop distinctive ice and snow tourism destinations, transforming “cold resources” into “hot industries” to achieve the comprehensive benefits of its ice and snow assets.

5.2.2 Two Rivers Basin Ecological Enhancement Zone: Rational Water Resource Utilization to Promote Ecological Industrial Development

Altay City is a water-rich region in Xinjiang, with three major water systems—the Ertix River, Kelan River, and Sumudayileke River—running through the city with an annual runoff of 4.3 billion m³. Although water resources are extremely abundant, utilization rates remain low. In the two rivers basin ecological enhancement zone, the city should leverage its water conservation ecological function area status to actively develop artificial aquaculture, cultivate technology for artificial breeding of endemic fish species, and create distinctive aquatic product brands. Good water breeds good fish and grows good crops. The city should establish quality certification systems for ecological fish and agricultural products, formulate management measures for ecological product quality certification, and actively promote “ecological labeling” certification. By attaching ecological product value to abundant fish and agricultural products and transforming them into high-quality ecological products directly tradable in the market, the city can enhance value conversion efficiency and increase added value through ecological brand appreciation.

5.3 Ecological Protection and Governance Zone: Strengthen Artificial Intervention and Implement Ecological Restoration The ecological protection and governance zone contains large areas of bare land and unused land with low precipitation and poor environmental quality. Without human intervention, ecological conditions will continue to deteriorate. Therefore, government departments should establish scientific policies and diversified models, strengthening artificial intervention to increase ecological product supply through ecological restoration and governance. Systematic measures including water and soil pollution control, biodiversity protection, and geological disaster prevention should be implemented. For example, artificial intervention can utilize meltwater from high mountain snow in the northern Altai Mountains to establish vegetation belts within river and road buffer zones, creating “ecological corridors” that gradually expand outward. In the Junggar Basin edge ecological protection and governance zone, ecological buffer zones should be established to prevent further environmental degradation.

6 Discussion and Conclusion

6.1 Discussion Altay City’s overall ecological sensitivity is relatively high, with sensitive areas concentrated primarily in the northern mountainous region with high elevations and abundant ecological resources. Compared with other county-level ecological sensitivity evaluations, highly sensitive areas are typically concentrated in regions with relatively high vegetation coverage and mountainous areas, consistent with this study’s findings. The six evaluation zones identified in this study align basically with the zoning scheme in the “Three Lines and One Permit” ecological environment zoning control plan for Altay City, demonstrating high rationality and credibility.

The seven evaluation factors selected are those most closely connected to Altay

City's ecological environment and economic development, capable of intuitively and simply reflecting the city's actual conditions and existing ecological environmental problems. However, the study has limitations, including insufficient comprehensiveness in indicator selection, certain subjectivity in determining evaluation factor levels, and lack of temporal and spatial change analysis for ecological sensitivity in Altay City. Future research could explore sensitivity center shifts in greater depth.

6.2 Conclusion

- (1) Among the seven selected evaluation factors, land use type has the greatest impact on ecological sensitivity assessment, accounting for 35.41% of the total weight.
- (2) The study area's overall comprehensive ecological sensitivity is relatively high, with moderate and above sensitivity levels accounting for over 60.00% of the region. Highly sensitive areas cover 2946.40 km² (27.34% of the total area), mainly distributed in central low mountains and hills, river valleys in the northern mountainous area, and the Ertix River basin.
- (3) Based on comprehensive sensitivity evaluation results, Altay City is divided into three primary zones (ecological protection zone, ecological enhancement zone, and ecological protection and governance zone) and six secondary zones (northern mountainous ecological protection zone, Ertix River basin ecological protection zone, central low mountain ecological enhancement zone, two rivers basin ecological enhancement zone, Ertix River alluvial plain ecological protection and governance zone, and Junggar Basin edge ecological protection and governance zone).
- (4) According to zoning results and regional characteristics, the study proposes ecological product value realization models including GEP accounting for improving ecological compensation, developing distinctive ecological tourism and agriculture, and promoting ecological restoration and governance. These models not only provide scientific basis for regional land ecological construction and protection but also offer valuable references for ecological product value realization in Altay City.

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