Postprint of Ecological Protection and Restoration Zoning in the Liupan Mountain Area Based on Ecological Importance and Sensitivity

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Abstract

Ecological protection and restoration zoning is the foundation for implementing differentiated ecological restoration and constructing the territorial ecological security pattern. Selecting the Liupan Mountain area of Ningxia, which holds important ecological status and barrier functions, this study constructs a comprehensive indicator system from a two-dimensional perspective of ecosystem "services-problems", and introduces quantitative zoning methods such as the InVEST model, spatial overlay mapping, and comprehensive indicator weighting to complete ecological protection and restoration zoning and clarify ecological restoration strategies. The results show that: (1) The highly important ecosystem area accounts for 33.4%, presenting an overall pattern of the "Liupan Mountain-Nanhuashan" corridor and the "Yuanzhou-Pengyang" region, which are the main ecological function supply areas and optimization-enhancement zones in the region. (2) The highly sensitive ecosystem area accounts for 32.0%, concentrated in the "Haiyuan-Xiji" region and the eastern Yuanzhou area, which are the main ecological function demand areas and conservation-restoration zones in the region. (3) The ecological protection zone accounts for 15.7%, promoting structural optimization and functional enhancement through strict ecological protection and monitoring management; the ecological restoration zone and conservation zone account for 17.7% and 26.1% respectively, oriented toward soil erosion control and land desertification prevention, comprehensively enhancing ecological benefits and controlling ecological degradation risks; the ecological regulation zone accounts for 40.5%, exploring the transformation path of "Two Mountains" theory to comprehensively optimize and coordinate the development and protection pattern of territorial space. The research results can provide spatial guidance for systematic and differentiated ecological protection and restoration of territorial space in the Liupan Mountain area.

Full Text

Zoning for Ecological Conservation and Restoration in Liupan Mountain Area Based on Ecological Importance and Sensitivity Evaluation

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Abstract: Ecological conservation and restoration zoning is fundamental for implementing differentiated ecological restoration and constructing an ecological security pattern for territorial space. Taking the Liupan Mountain area in Ningxia, which holds significant ecological status and serves as an ecological barrier, we construct a comprehensive indicator system from a two-dimensional perspective of ecosystem "services-problems." Using quantitative zoning methods such as the InVEST model, spatial overlay mapping, and comprehensive index weighting, we complete ecological conservation and restoration zoning and clarify ecological restoration strategies. The results show that: (1) Highly important ecosystem areas account for 33.4%, presenting an overall pattern of a "Liupan Mountain-Nanhua Mountain" corridor and a "Yuanzhou-Pengyang" region, serving as the main ecological function supply area and optimization zone in the region. (2) Highly sensitive ecosystem areas account for 32.0%, concentrated in the "Haiyuan-Xiji" region and the eastern part of Yuanzhou, representing the main ecological function demand area and conservation-restoration zone. (3) Ecological protection zones account for 15.7%, requiring strict ecological protection and monitoring management to promote structural optimization and functional enhancement. Ecological restoration zones and conservation zones account for 17.7% and 26.1% respectively, guided by soil erosion control and land desertification prevention to comprehensively improve ecological benefits and control ecological degradation risks. Ecological regulation zones account for 40.5%, exploring the transformation path of "two mountains" to comprehensively optimize and coordinate the development and protection pattern of territorial space. The research results can provide spatial guidance for systematic and differentiated ecological conservation and restoration of territorial space in the Liupan Mountain area.

Keywords: territorial space; ecological restoration; spatial distance index; InVEST model; Liupan Mountain

Introduction

Land use patterns and their spatial configurations continuously evolve alongside socio-economic development, such as urban expansion into agricultural spaces and agricultural encroachment on ecological spaces. These processes lead to overexploitation of natural resources, landscape fragmentation, and habitat area reduction, triggering a series of threats to regional ecological security and sustainable development, including declining ecosystem service capacity, increased ecological sensitivity and vulnerability, biodiversity loss, and climate change [1-4]. How to build a harmonious coexistence between humans and nature in territorial space, follow ecosystem succession and regional differentiation laws, carry out systematic, differentiated, and targeted ecological restoration, and establish a healthy, benign, and sustainable development path remains a critical issue for both government and academia [5-6].

Since the 21st century, high-quality territorial space construction has become an inherent requirement for advancing national ecological civilization [7-8]. Ecological restoration zoning is essential for optimizing territorial space development and protection patterns [9] and serves as an important prerequisite for implementing ecological restoration projects and differentiated spatial governance [10-11], attracting significant academic attention. Currently, ecological restoration zoning primarily focuses on traditional theoretical methods such as "pressure-state-response" [12-13], "ecosystem service supply-demand perspective" [14-15], and "ecosystem pattern-process multidimensional characteristics" [16-17], as well as new methods including circuit theory models and comprehensive index overlay mapping [18-19]. Based on this foundation, perspectives such as "ecological security pattern construction" [20-21], "ecological importance-ecological sensitivity" two-dimensional correlation matrix [22-23], and "potential-supply-restoration potential" adaptive cycle models [24] have become new research hotspots in this field. Overall, ecological conservation and restoration zoning has formed an indicator hierarchy combination and evaluation framework of "pattern-process-function-service-problem" [25-26]. Literature analysis shows that regardless of the ecological restoration zoning model or framework selected, multi-dimensional indicator system construction and quantitative accuracy remain key to measuring the rationality and reliability of ecological restoration zoning. However, current mainstream ecological restoration zoning frameworks and models have certain problems of single dimension, single indicator, or insufficient quantitative accuracy to some extent.

This study focuses on the natural site conditions and ecological environment background of the research area, aiming at comprehensive ecological function enhancement and key ecological problem restoration. We construct a "dual-objective" correlation matrix of "services (ecological importance) - problems (ecological sensitivity)" to refine, quantify, and target the indicator system. We introduce mainstream methods such as the InVEST model, spatial distance index, spatial overlay mapping, and comprehensive index weighting to carry out ecological restoration identification and zoning.

The Liupan Mountain area is currently an important strategic region for promoting "ecology-based region" and "three mountains and one river" construction in Ningxia, yet relevant supporting research lags behind. Only a few scholars have conducted relevant restoration zoning studies on Guyuan City's territorial space from the perspective of single ecological service dimension and supply-demand balance at the municipal scale and township unit [27-28]. Although these studies have certain spatial guidance significance at the macro scale and dominant service function enhancement level, they cannot meet the target requirements of systematic and differentiated ecological restoration zoning based on differentiation laws and multi-dimensional indicator system support. Consequently, ecological restoration in Ningxia still focuses on single elements such as rivers, wetlands, basins, and mines, without effectively forming an integrated protection, comprehensive management, and systematic restoration system for territorial space ecological conservation and restoration. This study quantifies the indicator system from a multi-dimensional perspective and constructs a "dual-objective" correlation matrix to carry out territorial space ecological conservation and restoration zoning in the Liupan Mountain area, providing spatial guidance for systematic and differentiated ecological restoration and project layout in this region.

1 Study Area Overview

The Loess Plateau rises in southern Ningxia, with elevations of 1500-2300 m. The terrain is fragmented, with crisscrossing gullies and severe soil erosion. The Liupan Mountains are located at the southern tip of Ningxia, extending northward in two parallel columns, forming the Xihua Mountain system and the Liupan Mountain-Yunwu Mountain system, with elevations of 2100-2900 m. The area belongs to a temperate semi-humid and semi-arid monsoon climate, with distinct wetter southern and drier northern characteristics, and annual precipitation of approximately 200-700 mm. The original vegetation constitutes the main body, with forests, shrubs, and grasses distributed along the mountains. It is the main water source conservation area for first- and second-level tributaries of the Jing River, with an average annual runoff of 7.28$\times10^{8}$ m^3, known as the "wet island" on the Loess Plateau. There are 2,900 species of wild vascular plants and 355 species of wild vertebrates, accounting for 76.8% of Ningxia's species and 4.6% of the national total, earning it the title of "germplasm resource gene bank" in Northwest China [29]. Industrial development in the Liupan Mountain area is primarily based on agriculture and light industry. According to the "Liupan Mountain Ecological Conservation and Restoration Special Plan (2022-2035)", the study area involves 13 counties and districts, with a total area of 18,680.2 km^2, accounting for 35.9% of Ningxia's total area.

[Figure 1: see original paper]

2 Data and Methods

2.1 Data Sources

The main data requirements for this study include ecological importance comprehensive evaluation and ecological sensitivity comprehensive evaluation. Specific data sources are as follows:

Landsat-8 OLI data were freely obtained from the Geospatial Data Cloud Platform (http://www.gscloud.cn). Land use/cover data were derived from the Ningxia thematic survey of the National Ecological Environment Remote Sensing Survey and Evaluation (2020), with a spatial resolution of 30 m. After verification, the overall accuracy of first-level classification samples was 85.61%, and the Kappa coefficient was 0.8855. Normalized Difference Vegetation Index (NDVI) data were extracted from Landsat-8 OLI remote sensing software with a spatial resolution of 30 m, used for grain supply service calculation. Precipitation data were obtained from the China Meteorological Data Network (http://data.cma.cn), used for water yield service simulation. Soil data were obtained from the National Forestry and Grassland Science Data Center (http://www.forestdata.cn), used for soil depth factor calculation in water yield service. Rainfall erosivity factor, soil erodibility factor, and potential evapotranspiration were obtained from the National Earth System Science Data Center (2018), used for soil conservation, water yield service simulation, and soil erosion sensitivity evaluation. Net Primary Productivity (NPP) data were calculated using the Carnegie-Ames-Stanford Approach (CASA) model, with spatial resolution data from 2015, used for carbon sequestration service simulation. Fault and earthquake data were derived from the 1:500,000 geological structure map published by the Geological Publishing House, used for geological disaster sensitivity evaluation. Basic geographic data were collected from local relevant units and processed through projection transformation and standardization, mainly used for various ecological sensitivity factor calculations.

2.2.1 Ecological Importance Evaluation

Identifying ecologically important areas aims to locate regions with stable ecosystem quality, reasonable structure, and sound function—critical natural ecological spaces that, once damaged, may disrupt the virtuous cycle and dynamic balance of ecosystems and even trigger systematic ecological risks [30]. Based on the ecological status of Liupan Mountain and its key role in ensuring regional ecological security, we selected water yield service, habitat maintenance, soil conservation, carbon sequestration service, and grain supply for importance evaluation. Carbon sequestration and habitat maintenance were estimated indirectly using the InVEST model, while soil conservation, water yield service, and grain supply were calculated using spatial overlay analysis [31,33]. We ultimately completed a comprehensive evaluation of ecological importance. The fuzzy membership function calculation method is as follows:

$$X = (c_i - c_{\min})/(c_{\max} - c_{\min})$$

where X is the normalized value, dimensionless between 0-1; $c_{\max}$ and $c_{\min}$ are the actual maximum and minimum values of each evaluation factor; and c_i is the actual value of each evaluation factor [32].

The Analytic Hierarchy Process (AHP) is a practical multi-objective decision-making method combining qualitative and quantitative approaches, completed through establishing a hierarchical structure, constructing judgment matrices, and conducting consistency tests [34]. The consistency test method is as follows:

$CI = (\lambda_{\max} - n)/(n-1), CR = CI/RI$

where CI is the consistency index; $\lambda_{\max}$ is the maximum eigenvalue of the matrix; n is the number of indicators; RI is the average random consistency index; and CR is the consistency ratio. When $CR < 0.1$, the judgment matrix has satisfactory consistency. The calculated ecological service factor weights were $\lambda_{\max} = 5.156$, $CI = 0.039$, $RI = 1.120$, and $CR = 0.035 < 0.1$, passing the consistency test.

2.2.2 Ecological Sensitivity Evaluation

Ecological sensitivity identification diagnoses areas vulnerable to environmental changes and human activity disturbances that may cause ecological environmental problems and trigger ecological degradation [35]. Considering the natural environmental characteristics and main ecological environmental problems in the Liupan Mountain area, we selected five ecological sensitivity factors: geological disasters, soil erosion, land desertification, habitat degradation, and climate characteristics. Geological disasters were calculated using the comprehensive index method [31,33], selecting four categories of factors: geological structure, topography, meteorology and hydrology, and human activities. The fault disaster-causing coefficient in geological structure varies according to distance from faults, energy concentration, and tectonic activity strength, with associated deep gullies and steep slopes having different hazard levels. We assigned coefficients through scoring [31,33]. Kernel density analysis calculates the density of unknown points in the neighborhood of features in probability theory. Using earthquake point data above magnitude 4.0 in the study area since 1900, we calculated it using ArcGIS kernel density analysis tools [31,33]. Other geological disaster-related factors were obtained through spatial analysis in ArcGIS. Habitat quality and water yield services were calculated using InVEST models. Grain supply factors were obtained through spatial interpolation of county crop yields from statistical yearbooks [31,33]. All factor evaluation parameters are shown in Figure 2.

This study uses the fuzzy membership function for data standardization, focusing on the ecological benefits of each ecological service function factor in Ningxia and its role in maintaining ecological security and welfare. Considering differences in pattern, area, and functional types based on natural protected areas, ecological protection red lines, and main functional zone divisions, we constructed the Analytic Hierarchy Process (AHP) through literature review and expert scoring [34], completing the comprehensive evaluation of ecological importance through weight analysis and data overlay analysis [31,33].

[Figure 2: see original paper]

Table 1 Methods for evaluating the importance of ecosystems

Ecosystem Service	Model	Basic Principles and Calculation Formula
Habitat Quality	InVEST Habitat Quality model	Q_{xj}: habitat quality of grid x in land use type j; D_{xj}: threat level; k: half-saturation constant; H_j: habitat suitability; z: normalization constant [30]
Water Yield	InVEST Water Yield model	Y_{jx}: annual water yield; AET_{xj}: actual evapotranspiration; P_x: precipitation; R_{xj}: dryness index; ω_x: plant-available water ratio; k: vegetation coefficient [29]
Soil Conservation	InVEST Sediment Delivery Ratio model	SR_x: soil retention; SE_y: sediment from upslope; R_x, K_x, LS_x, C_x, P_x: RUSLE factors [28]
Carbon Sequestration	CASA model	$NPP_{x,t}$: net primary productivity; $APAR_{x,t}$: absorbed photosynthetically active radiation; ξ: light use efficiency [27]
Grain Supply	NDVI correlation	$Crop_{mn}$: grain supply; $NDVI_{mn}$: NDVI value; $Crop_n$: county grain yield [27]

2.2.3 Territorial Space Zoning Identification

According to the quantile classification method used in the "National Ecological Protection Red Line Delimitation Technical Guidelines (Trial)", ecological importance evaluation results were divided into five levels: extremely important, highly important, moderately important, relatively important, and generally important. Ecological sensitivity evaluation results were divided into five types: extremely sensitive, highly sensitive, moderately sensitive, relatively sensitive, and generally sensitive. Following the high-low sequence and "short-board effect" principle [36], we used highly important areas (extremely and highly important levels), moderately important areas, and low importance areas (relatively and generally important levels) as the horizontal axis, and highly sensitive areas (extremely and highly sensitive levels), moderately sensitive areas, and low sensitivity areas (relatively and generally sensitive levels) as the vertical axis.

From the perspectives of comprehensive ecological function enhancement and key ecological problem restoration, we constructed a two-dimensional correlation judgment matrix of "ecological importance-ecological sensitivity" (Table 3) to complete ecological conservation and restoration zoning. Protection zones have extremely important ecological functions with optimal ecosystem structure, function, and quality, playing an irreplaceable and critical role. Restoration zones have highly important ecological functions while key areas, watersheds, and nodes show prominent ecological problems, representing important restoration and enhancement areas. Conservation zones have important ecological functions but fragile ecological foundations, vulnerable to human activities and natural disasters, representing important conservation control areas. Regulation zones have important or general ecological functions, high development intensity, acute human-land conflicts, and rapid ecological space loss, representing important sustainable development coordination areas.

3 Results and Analysis

3.1 Ecological Importance Evaluation and Pattern Characteristics

The habitat quality pattern in the Liupan Mountain area forms a medium-high importance zone along the central mountains and eastern "Yuanzhou-Pengyang" region. From the perspective of composition, areas above moderate importance account for 59.7%, with extremely important areas accounting for 19.4%, mainly distributed along the mountains. These are regulated by spatial controls such as natural protected areas and ecological protection red lines, maintaining stable and healthy regional biodiversity and habitats. Meanwhile, the "Xiji-Haiyuan" region and "along the Qingshui River" corridor show obvious habitat degradation due to high-intensity agricultural and socio-economic activities.

Water yield services show north-south differentiation characteristics influenced by climate. Areas of high importance and above account for 38.5%, concentrated in the southern "Jingyuan-Pengyang" region of the Liupan Mountain core area. The high forest-shrub-grass vegetation cover and abundant precipitation create a significant "wet island" effect for water conservation. In contrast, the "Xiji-Haiyuan" and "Yuanzhou" regions north of the Liupan Mountains have significantly reduced precipitation, sparse vegetation showing desertification characteristics, and markedly decreased water yield importance, becoming a major constraint on environmental carrying capacity.

Soil conservation areas of high importance and above account for 32.3%, distributed along the "Liupan Mountain-Nanhua Mountain" mountain belt and the "Yuanzhou-Pengyang" region. Due to large terrain relief, steep slopes, and the influence of northeast-southwest trending faults and seismic belts, these areas are prone to geological disasters. Continuous implementation of ecosystem protection, vegetation optimization, large-scale terraced field construction, and returning farmland to forest and grassland projects have formed the current spatial pattern of highly important soil conservation areas.

Grain supply is dominated by dryland farming in Xiji and the Qingshui River Yellow River irrigation area. Currently, grain supply in Xiji County is supported by excessive land reclamation, urgently requiring coordination of human-land conflicts and restoration of damaged ecological functions.

The comprehensive ecological importance evaluation results for the study area show: (1) Areas of high importance and above account for 39.8%, presenting an overall pattern of a "Liupan Mountain-Nanhua Mountain" corridor and a "Yuanzhou-Pengyang" region, serving as the main ecological function supply area and optimization zone. (2) Areas of moderate importance and below account for 60.2%, showing an overall pattern of a "along Qingshui River" development axis and a "Xiji-Haiyuan" region, representing the main ecological function demand area and damaged function restoration zone.

[Figure 3: see original paper]

Table 4 Area composition of ecological importance

Ecological Importance Evaluation Factor	Area (km^2)	Percentage (%)
Water Yield Service	7,234.6	38.7
Habitat Quality	6,238.7	33.4
Soil Conservation	6,038.2	32.3
Carbon Sequestration	7,291.5	39.0
Grain Supply	5,980.4	32.0

3.2 Ecological Sensitivity Evaluation and Pattern Characteristics

Areas with soil erosion sensitivity below moderate level account for 81.1%, indicating relatively light overall soil erosion. However, 18.9% of areas with high sensitivity and above are concentrated in the northeastern part of Haiyuan County, central-eastern Pengyang County, and local ecological degradation areas in central-southern Xiji County. Additionally, local areas in Pengyang County and northern desert mountains show point, patch, and belt-shaped high sensitivity characteristics due to mining activities, gravel-mulched field reclamation, and various unreasonable development and construction activities. The geological structure along the Qingshui River corridor is stable with gentle terrain, showing general geological disaster sensitivity.

Influenced by climate differentiation patterns, land desertification areas with high sensitivity and above account for 40.3%, mainly distributed in the arid "semi-arid" region north of Haiyuan County. In recent years, comprehensive factors such as gravel-mulched field reclamation, inadequate grazing bans, continued cultivation of returned farmland, and insufficient ecological monitoring have led to reduced local ecological resilience and self-recovery capacity, showing vegetation degradation and intensified desertification trends. In contrast, the "semi-humid to semi-arid" region south of Haiyuan County has stronger ecological resilience and self-recovery capacity, with land desertification below moderate level or generally sensitive.

Habitat quality degradation areas with high degree and above account for 39.7%, concentrated in the "Xiji-Haiyuan" region under high-intensity agricultural activity stress and the "along Qingshui River" development corridor under comprehensive stress from agricultural and socio-economic activities. The "Liupan Mountain-Nanhua Mountain" mountain belt maintains high habitat quality under comprehensive control by protected areas, ecological protection red lines, and prohibited development zones.

Climate sensitivity in the study area is consistent with the overall pattern of "semi-humid to arid" from south to north.

The comprehensive ecological sensitivity evaluation results for the study area show: (1) Areas with high sensitivity and above account for 39.6%, concentrated in the "Haiyuan-Xiji" region and eastern Yuanzhou region, representing the main ecological function demand area and restoration-conservation zone. The primary driving factors are fragile ecological foundations, high geological disaster risk, high-intensity agricultural activities, and large terrain relief. (2) Areas with moderate sensitivity and below account for 60.4%, concentrated in the "Liupan Mountain-Nanhua Mountain" mountain belt and the "along Qingshui River" corridor. The mountain belt is regulated by protected areas and prohibited development zones with strong ecological resilience and self-recovery capacity, while the "along Qingshui River" corridor is dominated by artificial and semi-artificial ecosystems with high human intervention and regulation.

[Figure 4: see original paper]

Table 5 Area composition of ecological sensitivity

Ecological Sensitivity Evaluation Factor	Area (km^2)	Percentage (%)
Geological Disasters	5,970.7	32.0
Soil Erosion	3,532.4	18.9
Land Desertification	7,529.7	40.3
Habitat Degradation	7,418.6	39.7
Climate Sensitivity	4,876.2	26.1

3.3 Territorial Space Ecological Protection and Restoration Zoning and Management

By constructing a two-dimensional correlation matrix, we identified territorial space ecological protection and restoration zones. The results show ecological protection zones account for 15.7%, concentrated in the "Liupan Mountain-Nanhua Mountain" mountain belt, showing "high importance-low sensitivity" characteristics. These zones are oriented toward comprehensive ecological function enhancement, aiming to optimize ecosystem quality, structure, and function. Main measures include: (1) Advancing the construction of natural protected area system projects, strengthening boundary demarcation and optimization of nature reserves and ecological protection red lines, and promoting quality upgrading through integrated ecological management, monitoring, and protection to exert ecological radiation and barrier effects. (2) Implementing forest quality improvement projects in the main Liupan Mountain area through comprehensive measures such as young forest tending, stand structure improvement, "skylight" replanting, and pest control. In the "Moon Mountain-Nanhua Mountain" extension zone, adopt shrub replanting and grassland conservation restoration measures to optimize vegetation structure and increase vegetation coverage. (3) Constructing biodiversity protection network systems, precisely implementing damaged ecological corridor restoration and key habitat reconstruction, and promoting integrated protection and management.

Ecological restoration zones account for 17.7%, mainly concentrated in the "Pengyang-Yuanzhou" region and the transition zone between "Liupan Mountain-Nanhua Mountain," showing "high importance-moderate sensitivity" characteristics. Oriented toward soil conservation function enhancement, these zones aim to identify key ecological problems and implement differentiated ecological restoration. Main measures include: (1) Strengthening ecological construction effectiveness monitoring, adopting combined vegetation restoration and engineering measures to carry out refined soil erosion control in key watersheds, regions, and nodes. (2) Enhancing mine ecological restoration and geological disaster monitoring, focusing on integrated comprehensive management, ecological restoration, and green mine construction in damaged mining sites in northern Pengyang County and eastern Yuanzhou District, and scientifically establishing mine and river sand mining exit-repair mechanisms. (3) Scientifically implementing returning farmland to forest and ecological migration according to key ecological elements such as watersheds, units, and corridors, building soil conservation forests, constructing typical grasslands, and restoring river and lake ecosystems to construct a regional ecological security pattern.

Ecological conservation zones account for 26.1%, concentrated in the arid belt of "Haiyuan-Zhongning," showing "moderate importance-high sensitivity" characteristics. Oriented toward desertification prevention, these zones aim to consolidate existing ecological construction achievements and suppress ecological degradation risks. Main measures include: (1) Exploring ecological transfer payment fund allocation linked to desertification prevention effectiveness, tapping rural ecological industry development potential and multi-channel farmer income increase pathways, and promoting new "forage planting-subsidy incentive" breeding models to reduce ecological carrying load and consolidate achievements of enclosure conservation and returning farmland to forest. (2) Upgrading grassland ecological conservation and restoration efforts, driving regional grassland protection quality improvement through the construction of Xihua Mountain and Xiangshan Temple National Grassland Nature Parks, adopting comprehensive measures such as aerial seeding, shrub replanting, rodent control, and degraded grassland restoration to improve grassland ecosystem quality. (3) Integrating grassland construction with desertification prevention, combining terraced field transformation, gravel-mulched field exit, mine ecological restoration, and "four-wasteland" management to improve surface vegetation cover and water conservation capacity, reducing human activity interference and systematic ecological degradation risks.

Ecological regulation zones account for as high as 40.5%, concentrated in the Xiji County region and along the Qingshui River corridor, showing "low importance-high sensitivity" and "low importance-low sensitivity" characteristics. Oriented toward enhancing regional sustainable development capacity, these zones aim to comprehensively coordinate human-land relationships. Main measures include: (1) Continuously conducting cultivated land assessment and research on ecological exit mechanisms for sloping and dry farmland, strengthening farmland protection and restoration, agricultural non-point source pollution control, and high-standard farmland construction, developing modern agriculture and grass-livestock industries to improve land production efficiency. (2) Promoting integrated rural-urban complex construction, advancing comprehensive improvement of human settlements, river and lake wetland ecological restoration, and "urban-suburban" green space system construction to build urban ecological security patterns. (3) Strengthening scientific delimitation of territorial space planning and three-zones-three-lines, promoting construction land reduction, ecological space optimization, modernization of agricultural space, improving land conservation and intensive use levels, and actively exploring the transformation path of "two mountains" and "collaborative" development of ecological services.

[Figure 5: see original paper]

Table 6 Area composition of ecological conservation and restoration zones

Ecological Restoration Zone	Ecological Importance	Ecological Sensitivity	Area (km^2)	Percentage (%)
Ecological Protection Zone	High	Low	2,934.8	15.7
Ecological Restoration Zone	High	Moderate	3,307.4	17.7
Ecological Conservation Zone	Moderate	High	4,876.2	26.1
Ecological Regulation Zone	Low	High/Low	7,561.8	40.5

Table 7 Composition of land use types in ecological conservation and restoration zones

Land Use Type	Ecological Protection Zone (%)	Ecological Restoration Zone (%)	Ecological Conservation Zone (%)	Ecological Regulation Zone (%)
Broadleaf, coniferous, mixed forests, sparse forest	12.3	8.7	4.2	3.1
Broadleaf shrubland, sparse shrubland	21.3	18.4	9.8	7.2
Meadow, grassland, herbaceous community, sparse grassland	56.9	48.3	82.1	51.4
Swamp, lake, river, reservoir	0.5	0.4	0.3	0.8
Cropland, orchard	6.8	17.1	2.4	28.6
Residential, urban green space, industrial/mining/transportation	1.8	4.2	0.6	7.8
Bare land, desert	1.4	2.9	0.6	1.1

4 Discussion

Systematic restoration of the life community of mountains, rivers, forests, farmland, lakes, grass, and sand across entire regions, all elements, and whole processes is an important pathway to establishing benign, healthy, and high-quality territorial space [12,15-16]. Currently, Ningxia's ecological restoration planning lacks strong macro-scale territorial space ecological restoration zoning guidance and theoretical method guidance, relying more on the experience and practical judgment of ecological restoration special planning or scheme compilers. Although some scholars have conducted ecological restoration zoning exploration from the "ecological service supply-demand" perspective at the municipal scale [27-28], the overly single scale, indicators, and dimensions have certain guidance at the administrative unit level but cannot support the current requirements of Ningxia's "three mountains and one river" and the Yellow River Basin ecological protection and high-quality development pilot zone from the perspective of large ecology, large systems, and large patterns [6]. The Liupan Mountain area, due to its important ecological status, urgently needs systematic, multi-dimensional assessment from the perspective of "pattern-process-function-service-problem" [25-26] to carry out comprehensive territorial space ecological restoration zoning research, providing spatial guidance for holistic, differentiated, and targeted ecological restoration projects.

This study constructs a comprehensive two-dimensional correlation indicator system oriented by "function-problem," focusing on identifying restoration zones from the perspective of territorial space ecological function damage and ecosystem degradation. The results are consistent with Yue Wenze et al. [27] from the "ecological service supply-demand" perspective, while optimizing deficiencies in dimensions, scales, and indicators and increasing the reliability of ecological restoration zoning.

From the zoning results, the central "Liupan Mountain-Nanhua Mountain" mountain system core area serves as an ecological protection zone, an important high-supply area of ecological services in the region. Most areas are designated as protected areas, prohibited development zones, and ecological protection red lines, playing a strategic ecological role in Ningxia's current "three mountains and one river" ecological construction. The vegetation structure has a high forest-shrub-grass ratio of 90.5%, but forests account for only 12.3%, indicating that ecosystem quality, quantity, structure, and function still have optimization space. The eastern "Pengyang-Yuanzhou" ecological restoration zone is a soil erosion, desertification, and geological disaster-prone area. Based on the single-factor evaluation results of "function-problem," further refined zoning can support national ecological function county-level ecological construction special planning, strengthen systematic project management of watersheds and regions, and upgrade the current status, optimizing the transformation from the single grassland advantage (82.1%) to comprehensive forest-shrub-grass improvement (Table 7). The western and northern ecological conservation zones have sensitive and fragile ecological foundations. From the problem-oriented and refined zoning perspective, we should coordinate artificial intervention with enclosure conservation, maximize the exit of cultivated land in vulnerable areas (below the current 17.1%) and strengthen grassland quality improvement (above the current 82.1%) to alleviate ecological pressure and restore damaged functions. The "along Qingshui River" ecological regulation zone is an important industrial development belt, belonging to the "low supply-high demand" area of ecological services, showing a spatial land use characteristic of agricultural towns (28.6%) and cropland (51.4%). Improving land use efficiency, optimizing three-zones-three-lines, controlling ecological land loss, and increasing greenway, park, and wetland ecological network construction can guide policy formulation through spatial guidance, regulate spatial development through policy, strengthen internal planning and policy coordination in regulation zones, and build a Qingshui River human-land harmonious ecological security corridor.

This study carries out restoration zoning based on natural boundaries at the grid scale, which can support ecological management and policy formulation at the macro scale, and support differentiated ecological restoration project layout at medium and small scales such as counties, watersheds, and units through overlay analysis, overcoming the deficiency of traditional methods such as "ecological service supply-demand" and "pressure-state-response" that use administrative units as scales and cannot provide spatial guidance at smaller scales. Due to data acquisition limitations, this study lacks comprehensive analysis from the "pattern-process-function-service-problem" perspective and multi-period dynamic evolution of ecosystems, especially without introducing social and economic indicators, making the comprehensiveness, systematicity, and process-orientation of ecological restoration zoning slightly insufficient. However, at the macro scale, it conforms to regional actual conditions and can provide spatial guidance for strengthening ecological management, policy formulation, and systematic restoration projects in the Liupan Mountain area.

5 Conclusions

From the perspective of systematic and differentiated ecological restoration, this study constructs a comprehensive indicator system from the two-dimensional level of ecosystem "services-problems." Using mainstream methods such as the InVEST model, spatial overlay mapping, and comprehensive index weighting, we conduct quantitative evaluation of ecological importance and sensitivity at the grid unit scale. Overcoming previous research limitations of single dimensions and indicators, mechanical administrative unit boundaries, and insufficient quantitative diagnosis of ecological functions and problems, we complete ecological conservation and restoration zoning. The main conclusions are as follows:

(1) The area of highly important ecosystem regions is 6,238.7 km^2, accounting for 33.4%, presenting an overall pattern of a "Liupan Mountain-Nanhua Mountain" corridor and a "Yuanzhou-Pengyang" region, serving as the main ecological function supply area and optimization zone.

(2) The area of highly sensitive ecosystem regions is 5,970.7 km^2, accounting for 32.0%, concentrated in the "Haiyuan-Xiji" region and eastern Yuanzhou region, representing the main ecological function demand area and conservation-restoration zone.

(3) The proportions of ecological protection zones, restoration zones, conservation zones, and regulation zones are 15.7%, 17.7%, 26.1%, and 40.5%, respectively. Ecological protection zones are oriented toward comprehensive ecological function enhancement, aiming to optimize ecosystem quality, structure, and function through integrated ecological management, monitoring, and protection quality upgrading to exert ecological radiation and barrier effects. Ecological restoration zones are oriented toward soil conservation function enhancement, aiming to identify key ecological problems and implement differentiated ecological restoration through refined soil erosion control and ecological security pattern construction. Ecological conservation zones are oriented toward desertification prevention, aiming to consolidate existing ecological construction achievements and suppress ecological degradation risks through coordinated grassland construction and desertification governance. Ecological regulation zones are oriented toward enhancing regional sustainable development capacity, aiming to comprehensively coordinate human-land relationships by exploring the "two mountains" transformation path, optimizing "production-living-ecological" space, and scientifically delimiting three-zones-three-lines to improve land production efficiency and conservation-intensive use levels.

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