Journal of Sustainable Build Environment

https://doi.org/10.70731/nae54285

Ecological Spatial Restoration in Gannan Prefecture Based on the Coupling of Ecological Security Pattern and Ecological Problems

Xuelian Yang [a,*]

[a] School of Architecture and Urban Planning, Lanzhou Jiaotong University,Gansu,Lanzhou,730070,China

KEYWORDS

Ecological Network, Ecological Security Pattern, Ecological Problem Identification, Ecological Space Restoration

ABSTRACT

Ecological fragmentation, resource depletion, and soil erosion significantly impact ecosystems, making ecological restoration crucial for maintaining and enhancing ecosystem services. This study explores strategies for ecological spatial restoration in Gannan Tibetan Autonomous Prefecture by integrating ecological security patterns and ecological problems. Using ecological remote sensing indices and morphological spatial pattern analysis, we identified ecological sources, resistance surfaces, and corridors to construct an ecological security pattern. Simultaneously, ecological problem areas were identified through an ecological problem index (EPI) based on the “mountain, water, forest, farmland, lake, grass, and sand” framework. By coupling the ecological security pattern with problem regions through spatial and regional coordination, a multi-level restoration strategy is proposed, emphasizing ecological source protection, corridor construction, and problem area restoration. These strategies aim to promote sustainable ecological development in Gannan Prefecture.

1. Introduction

Gannan Tibetan Autonomous Prefecture has a unique plateau ecosystem and rich biodiversity. In recent years, the region has faced a series of ecological problems such as grassland degradation, soil erosion, and biodiversity decline (Lv, et al., 2023), which not only threaten the livelihoods of local residents, but also pose challenges to the ecological security pattern of the entire region (Lin, et al., 2021). In the context of ecological civilization construction in the new era, China's concept of "mountain, water, forest, field, lake, grass and sand are a community of life" came into being (Gao, et al., 2022), and the close connection and mutual influence among various ecological elements can make the ecosystem an organic whole (Dong, et al., 2020). How to comprehensively build an ecological security pattern, how to scientifically apply the concept of mountain, water, forest, field, lake, grass and sand life community to ecological space restoration, and how to coordinate all natural elements to achieve "unified protection and uni-

* Corresponding author. E-mail address: 1837141577@qq.com

Received 24 December 2024; Received in revised form 12 January 2025; Accepted 12 January 2025; Available online 31 January 2025;.

fied restoration" have become hot issues that need to be solved urgently in ecological protection and restoration.

At present, the construction of ecological security pattern has aroused wide attention in the world, and scholars with different professional backgrounds have constructed ecological security pattern from different directions.The international research on ecological security pattern mainly includes five aspects and directions. The first is to adopt the framework of "ecological source - ecological resistance surface - ecological corridor", and strengthen the relevant technology and content within the framework.In the direction of ecological source recognition, some scholars adopt different scenario recognition methods of “structure-pattern-function" (Hou, et al., 2024) and “pattern-function-stability" (Qiao, et al., 2024); Other scholars have integrated multi-factor identification of ecological sources (Cao, et al., 2024; Wang, et al., 2024); Some scholars also considered the innovation of ecological source and resistance surface, combined with landscape index to optimize ecological resources, and considered the spatial differentiation of ecological resistance from the microscopic perspective of landslide sensitivity assessment (Li, et al., 2024).In addition to innovation and research within the framework, some scholars also add innovation points on the basis of the framework; Some scholars draw on the basic theory of "source-resistance-corridor" and comprehensively consider the ecosystem service zoning and supply and demand relationship (Liu, et al., 2024; Wu, et al., 2024); Some construct a "water-energy-food" framework, and identify and optimize the ecological security pattern from the perspective of ecosystem services related to the three (Ding, et al., 2024).The second is to write from different perspectives on the construction of ecological security pattern. For example, from the perspective of ecological resilience assessment of ecosystem resistance-ecosystem adaptive-ecosystem resilience framework (Jie, et al., 2024); Landscape ecological risk assessment from the perspective of potential-connection-resilience framework (Bai, et al., 2023); From a regional and interregional perspective (Liu, et al., 2024); With the technological innovation, some use the XGBoost (limit gradient lift) -MCR (minimum cumulative resistance) algorithm (Sun, et al., 2024) and introduce the ordered weighted average (OWA) model and the quantitative perspective of the ant colony algorithm model (Pan, et al., 2023).The third is to break the traditional ecological security pattern construction and introduce new aspects of ecological security pattern construction with the help of traditional paradigm.For example, Hui He and other scholars evaluated the suitable habitat for the ecological restoration of giant panda habitat and optimized the ecological security pattern (He, et al., 2024) ;Zeng et al. (2024) studied the ecological security pattern in the alpine wetland grassland region; Zilong Chen et al. have studied the dynamic changes in the pattern of wading ecological security in the area over the past 20 years (Chen, et al., 2023), Contribute to regional ecological planning and sustainable water management.The fourth is to construct the ecological security pattern from different time dimensions, study its changes at different times, summarize the current situation, and guide and predict the future planning and management.For example, most of the scholars are studying the regional status characteristics and spatio-temporal data characteristics from 2000 to 2020. The ecological security pattern of "grid-county-basin" at different scales (Chen, et al., 2023) or "point-line-surface" at different angles (Zhang, et al., 2024) was analyzed;The further prediction for the future is to analyze the change and driving mechanism of ecological carrying capacity in the study area from 1990 to 2040 (Zhang, et al., 2023), The idea of "history-present-future" to construct ecological security pattern is proposed, and the time scale of the study is longer, and the future is also predicted.Fifth, a lot of research has been done on the application of ecological security pattern after construction. For example, the most direct and widespread application is the demarcation of ecological control areas to determine the priority areas for ecological protection and restoration (Gao, et al., 2022; Wang, et al., 2024; Ran, et al., 2022);Some scholars build multi-strength ESP and put forward differentiated management strategies (Jiang, et al., 2024); The advantages and economic countermeasures of ecological carbon sink under the ecological security pattern are also explored (Wang, et al., 2024).

At present, many international scholars' ecological space restoration identification is based on the condition of ecological security pattern (Lan, et al., 2024; Yang, et al., 2024), However, there are also other perspectives to realize the identification of ecological space restoration areas and points.For example, based on the concept of ecological environment restoration, the optimization strategy of green settlement landscape is studied (Liu, et al., 2023); From the Angle of human-land relationship and structuralism (Chen, et al., 2022), The evaluation scheme of ecological space based on ecosystem services and the planning control of land planning based on ecological protection and restoration were constructed; Some have also built five ecological performance systems with earth boundary and ecological pressure as indicators (Zhao, et al., 2024), As a basis for prioritizing ecological restoration areas and implementing zoning control;Kun Yu et al. proposed an assessment framework for the comprehensive effect of ecological restoration that included public satisfaction (Yu, et al., 2024), The performance before and after ecological restoration was analyzed from 2015 to 2021;Yuyang Wang and other scholars put forward targeted ecological restoration suggestions from the perspectives of habitat, ecology and life from both theoretical and practical perspectives (Wang, et al., 2024). Some scholars also comprehensively assess the present ecological situation and put forward corresponding measures for ecological restoration regionalization based on the past ecosystem health level (Chen, et al., 2024).

Most of the above scholars use a single factor to identify the ecological restoration space, and the current research on the identification under the comprehensive multi-factor condition is relatively scarce,Bo Han and other scholars have broken the disadvantages of studying ecological problems on a single ecosystem or a single scale (Han, et al., 2021), A multi-scale evaluation framework for land and air ecological restoration planning strategy based on PSR perspective and landscape, ecology and GIS methods was proposed; Some scholars have considered the estimation of the recovery capacity of the muddy coast and the selection of two conceptual models of the common technical measures for the ecological restoration of the muddy coast (Wu, et al., 2023), Determine the ecological restoration path of the study area;A comprehensive approach coupling ecological benefits and restoration costs has been proposed (Dong, et al., 2024), giving priority to the restoration of abandoned mines.In terms of the selection of research areas, many scholars choose the southern region with better ecological environment than the northern region, and there are few studies on some special environmental regions, such as the ecological restoration region of dryland in China (Han, et al., 2023) and the northwestern region of Qinghai-Tibet Plateau (Tang, et al., 2024).

Therefore, the construction of ecological security pattern has formed the research paradigm of "ecological source - ecological resistance surface - ecological corridor” (Duan, et al., 2022), but the research on the refinement and improvement of the three links is also extensive. Firstly, the multi-factor synthesis method is still lacking in the identification of ecological sources, and the improvement in this aspect is still a hot spot. Secondly, the selection of ecological resistance surface factors is basically started from the three aspects of terrain, landscape and human factors, and there are more and more factors. Finally, the identification of ecological corridors has made a big leap since the introduction of linkage mapper. In addition, with the concept of the community of "mountains, rivers, forests, fields, lakes, grass and sand" proposed, some scholars also use it as a targeted indicator to identify ecological problems, and then identify the space for ecological restoration. However, this method is still too lacking, and a comprehensive multi-factor should be considered to identify the ecological restoration space. Therefore, the research of ecological spatial restoration is moving towards a more comprehensive and systematic direction, and the future trend will focus on the in-depth coupling and synergistic development of multiple factors, the quantitative identification of ecological restoration space and the proposal of optimization strategies, especially in the face of global challenges such as climate change, resource management and socio-economic changes.

Considering the special position of Gannan prefecture at the junction of three provinces and the current situation of unbalanced development of ecosystem, this study aims to explore how to realize the ecological spatial restoration strategy according to local conditions in Gannan Prefecture. Therefore, based on the dual factors of ecological security pattern and ecological problems, this study identified ecological spatial restoration strategies, and established a multi-directional restoration strategy of "point-line-plane". Firstly, ecological security pattern and ecological pattern zoning are constructed through the paradigm of "ecological source - ecological resistance surface - ecological corridor - ecological key point". Then, comprehensive indicators for ecological problem identification are established to identify ecological problem regions in Gannan Prefecture based on the concept of "mountains, rivers, forests, fields, lakes, grasses and sand" community. Finally, the key areas for ecological restoration and protection in the future are determined by coupling ecological pattern and ecological problem zones, and corresponding strate-

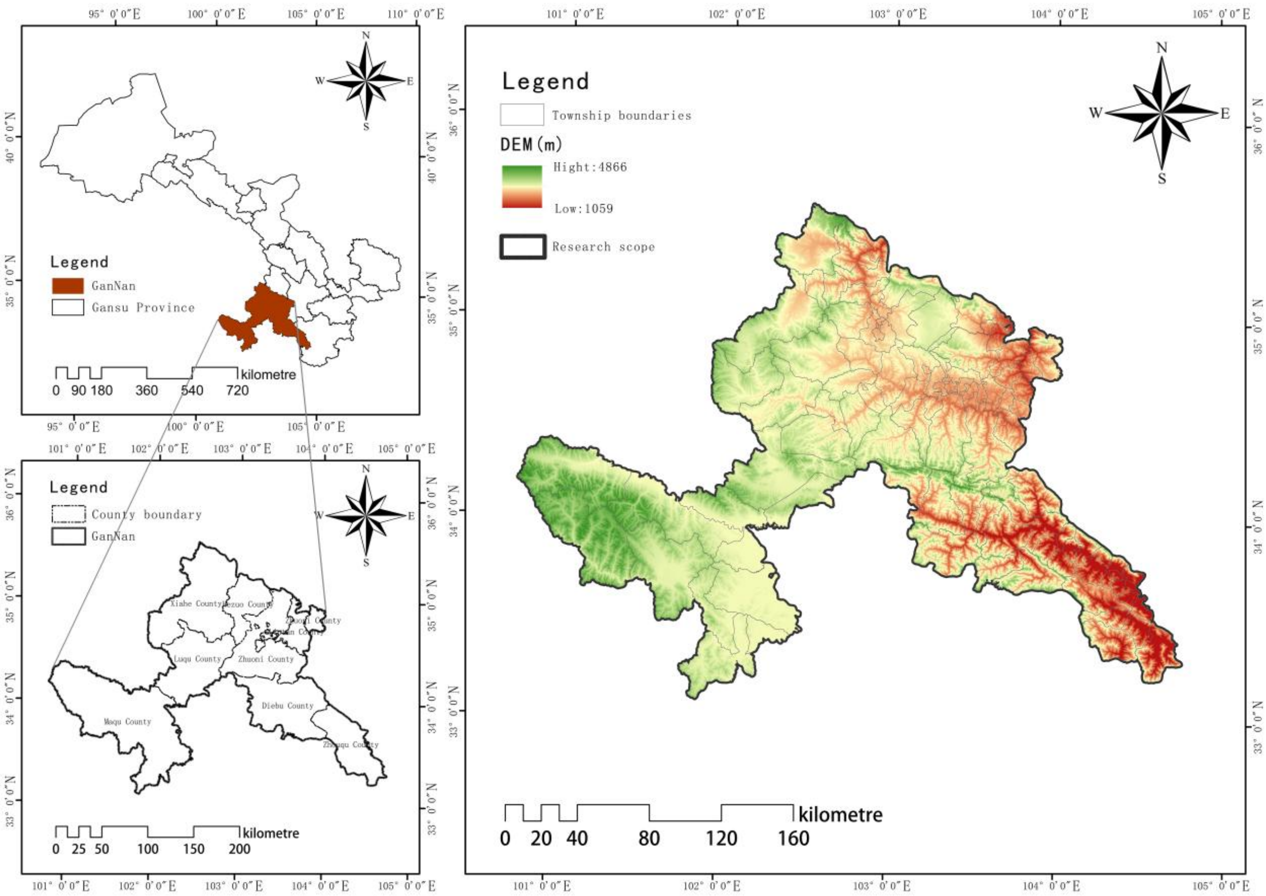

Figure 1 I Location map of Gannan Prefecture

gies and measures are formulated to achieve sustainable ecological development and the construction of ecological civilization. Based on this, this paper aims to solve the following problems: 1) How to establish a more accurate and comprehensive ecological source and ecological source point? 2) How to identify ecological problems according to local conditions? 3) How to systematically and quantitatively identify ecological restoration space? 4) How to formulate ecological restoration strategies based on the special geographical environment of Gannan Prefecture? As a beneficial supplement, this study will provide scientific and accurate ecological restoration programs for Gannan Prefecture and similar northwest regions, promote the construction of ecological civilization, and provide references for ecological planning and territorial spatial planning to achieve regional ecological sustainable development.

2. Materials and Data

2.1. Overview of the Study Area

Gannan Tibetan Autonomous Prefecture is located in the southwest of Gansu Province (Zou, et al., 2022). It has jurisdiction over seven counties and one city, namely Lintan, Zhuoni, Dibe, Zhouqu, Xiahe, Maqu and Luqu, and Hezuo City (Figure. 1). It is 360.7 kilometers long from east to west and 270.9 kilometers wide from north to south, with a total area of 45,000 square kilometers. The average elevation of the state is between 3,000 and 4,000 meters, with the lowest point at Guazigou Estuary in Zhouqu County at 1,172 meters above sea level and the highest at 4,920 meters. The south is Diemin mountains, the east is hilly mountains, the west is flat grassland, the terrain is high in the northwest, low in the southeast, and tilted from northwest to southeast. Gannan Prefecture has unique features such as special geographical location, multi-cultural gathering and frequent natural disasters, so it is typical and exemplary to study its ecological space restoration.

Table 1 | Data sources

Data Types	Data Source	Content	Specification
Landsat8 OLI remote sensing image data	Geospatial data cloud （https://www.gscloud.cn/search）	Remote sensing image data of Gannan Prefecture	July - August, 2021-2022; Spatial resolution is 30M; Image cloud cover is less than 5%
DEM data		ASTER GDEM 30M resolution digital elevation data	2022; Spatial resolution is 30M
LUCC data	Resource and Environmental Science Data Center（https://www.resdc.cn/Default.aspx）	Raster data of land use remote sensing monitoring	2022; Spatial resolution is 30M
GDP data		GDP spatial distribution kilometer grid dataset	2022; The spatial resolution is 1KM
Township data of Gannan Prefecture	Statistics Bureau of Gannan Tibetan Autonomous Prefecture（http://tjj.gnzrmzf.gov.cn/index.htm）	Population data; Crop data; Livestock inventory data, etc	2022
POI data	Amap platform（https://www.amap.com/）	Scenic spots, commercial service facilities, transportation facilities, tourist attractions POI data	2022
Road data	Open Street Map(https://www.openstreetmap.org)	Gannan road vector data	2022
Drainage data		Gannan water system vector data	2022

2.2. Data Sources

All the data in this paper come from official websites, including geospatial data Cloud website, Resources and Environmental Science Data Center, Statistics Bureau of Gannan Tibetan Autonomous Prefecture, National Earth System Science Data Center platform, Amap Platform and Open Street Map data platform, etc. (Table 1).

2.3. Research Framework

This paper identifies areas for ecological protection and restoration based on the superposition of ecological security pattern and ecological problem identification. On this basis, a multi-directional strategy of "point-line-surface" is proposed, and reasonable planning and management is proposed at last (Figure 2).

3. Methods

3.1. Ecological Source Identification

3.1.1. Ecological Remote Sensing Index

Ecological Remote Sensing Index (RSEI) is a method to evaluate ecological environment quality by remote sensing technology. It is usually based on satellite remote sensing images and reflects various attributes of ecological environment by analyzing spectral characteristics of the surface. In this study, four ecological remote sensing indexes, namely vegetation index (NDVI), humidity index (WET), surface temperature (LST) and building index (NDBSI), are selected as ecological remote sensing indexes, which can comprehensively reflect the ecological status of a region. The formula is as follows:

$$NDVI = \frac{b_5 - b_4}{b_5 + b_4} \quad (1)$$

$$WET = 0.151 \times b_2 + 0.1973 \times b_3 + 0.3283 \times b_4 + 0.3407 \times b_5 - 0.7117 \times b_6 - 0.4559 \times b_7 \quad (2)$$

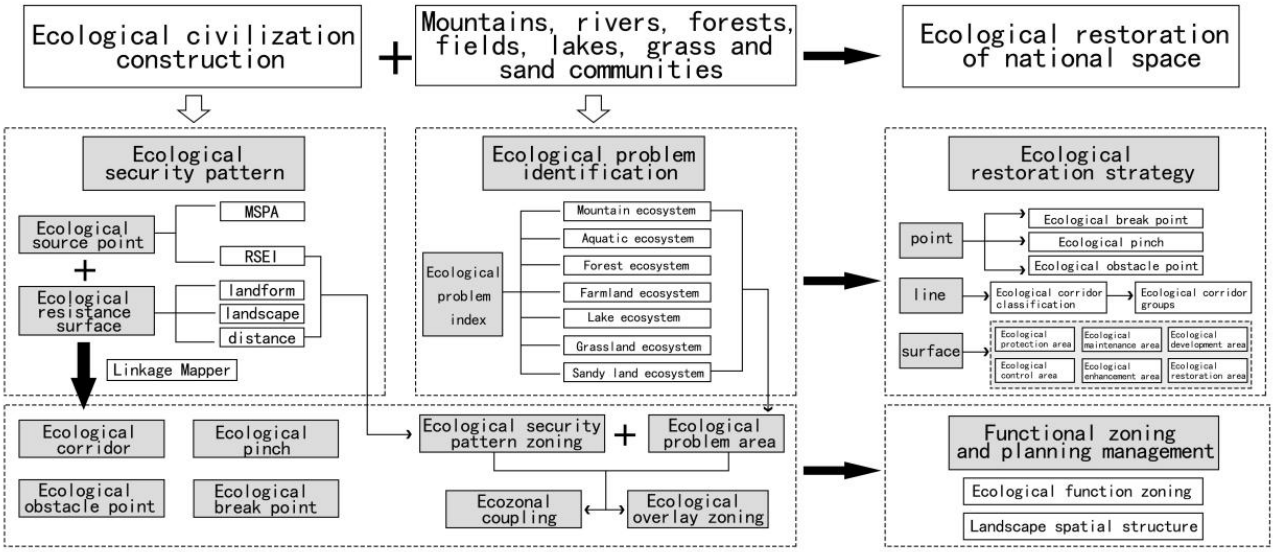

Figure 2 | Research framework

$$LST = \frac{1321.08}{alog(\frac{774.89}{b_1} + 1)} - 273 \quad (3)$$

$$SI = \frac{(b_4 + b_6) - (b_2 + b_5)}{(b_6 + b_4) + (b_2 + b_5)} \quad (4)$$

$$IBI = \frac{\frac{2 \times b_5}{b_5 + b_4} - \frac{b_4}{b_4 + b_3} + \frac{b_2}{b_2 + b_5}}{\frac{2 \times b_5}{b_5 + b_4} + \frac{b_4}{b_4 + b_3} + \frac{b_2}{b_2 + b_5}} \quad (5)$$

$$NDBSI = \frac{IBI + SI}{2} \quad (6)$$

Where, b1, b2, b3, b4, b5, b6 and b7 are respectively coastal band, blue band, green band, red band, near infrared band, shortwave infrared 1 and shortwave infrared 2.

The ecological remote sensing index was synthesized by principal component analysis (PCA). Before synthesizing the ecological remote sensing index, it is

$$NI = \frac{I + I_{min}}{I_{max} - I_{min}} \quad (7)$$

necessary to conduct standardized dimensional-1 processing on related indicators, and the standardization formula of each indicator is as follows:

Where, NI is the index after standardization; Imin and Imax are the minimum and maximum values.

Principal component analysis was carried out on the normalized new indicators, and principal component (PCA) containing the main features of the four indicators was selected, and then PCA was subtracted from 1 as the initial ecological index RSEI. The formula was as follows:

3.1.2. Morphological Spatial Pattern Analysis

$$RSEL = 1 - PCA(NDVI, WET, LST, NDBSI) \quad (8)$$

Morphological Spatial Pattern Analysis (MSPA) is an image processing method based on the principle of mathematical morphology, which is used to analyze and recognize landscape spatial patterns. MSPA is combined with ArcGIS10.6 to pre-process land use data, convert it into binary data (foreground and background), and then use the specific analysis tool Guidos software for MSPA analysis. MSPA can identify important habitat patches and corridors in the study area from the pixel level, such as core area, bridge area, ring area, branch area, edge area, pore and island patch.

3.2. Ecological Resistance Surface

Landscape Resistance refers to the degree of obstacles encountered by individual organisms or material flows in a landscape. It is used to describe the resistance of living things to migration, diffusion or energy flow in a landscape. In this study, seven resistance factors including DEM, slope, slope direction, LUCC, NDVI, distance from road and distance from water system were selected based on previous research results and regional characteristics of Gannan Prefecture, and a comprehensive resistance surface was constructed by grid weighted superposition of ArcGIS10.6 software. The specific resistance values and weights of each factor were shown in Table 2.

3.3. Ecological Network Construction

Linkage Mapper in ArcGIS 10.6 software was used in this study to construct ecological corridor, ecological sandwich point and ecological barrier point in Gannan Prefecture.

Linkage Mapper is an open source toolset designed for ArcGIS that uses integrated circuit theory to model potential movement paths of species across complex landscapes and prioritizes these movement paths based on ecological cost and connectivity assessments.

Linkage Pathways Tool in Linkage Mapper is a circuit theory-based tool that identifies ecological corridors by simulating the flow of electricity through a network. This approach takes into account landscape connectivity, species dispersal potential, and ecological processes to determine the best path for species to move through the landscape.

Eco pinch points run in the Pinchpoint Mapper tool. It requires the invocation of the Circuitscape program, which is used to identify key ecological pinpoints within the established ecological corridor network. By analyzing the minimum cost path and combining with circuit theory, the important alternative path and pinch area are identified.

The ecological Barrier point is realized by using Barrier Mapper tool. The circuit theory is applied to calculate and quantify the potential of connectivity improvement through analysis on the resistance surface data, and the important barrier affecting the quality of the channel can be detected, namely, the ecological barrier point.

3.4. Ecological Problem Identification

$$EPI = \sum_{i=1}^{u} K_i \times W_j \tag{9}$$

The identification of territorial ecological problems is based on the life community concept of "mountains, rivers, forests, fields, lakes, grass and sand". The Ecological Problems Index (EPI) of Gannan Prefecture was constructed from seven factors, namely mountain ecosystem, water ecosystem, forest ecosystem, farmland ecosystem, lake ecosystem, grassland ecosystem and sandy ecosystem, weighted by superposition of prominent ecological problems in Gannan Prefecture. The calculation formula is as follows:

Where ,EPI is the ecological problem index; Ki is the standardized ecological problem index value; u is the number of ecological problem indicators; Wj is the weight of each ecological problem index. When the

Table 2 | Resistance factor assignment index

Resistance factors		Weight	Assign				
			1	2	3	4	5
landform	DEM/（m）	0.1307	＜2400	2400-2800	2800-3200	3200-3600	＞3600
	slope/（°）	0.0997	＜10	10-20	20-30	30-40	＞40
	aspect/（m）	0.1142	-1	0-45	45-135	135-315	＞315
landscape	LUCC	0.2546	Artificial surface	Forest/shrub	Water body/ bare land	Cultivated land/ Wetland	meadow
	NDVI	0.1497	0.8-1	0.6-0.8	0.3-0.6	0.1-0.3	0-0.1
distance	Distance from road/（m）	0.1419	＞2000	1500-2000	1000-1500	500-1000	＜500
	Distance from water/（m）	0.1092	＞2000	1500-2000	1000-1500	500-1000	＜500

EPI value is larger, it means that the ecological problems in the key area to be repaired are more prominent, and vice versa.

$$C = \frac{1}{n}\left(\prod_{i=1}^{n} \frac{U_i}{U_i + \lambda}\right) \quad (10)$$

$$T = \sum_{i=1}^{n} \beta_i U_i \quad (11)$$

$$D = \sqrt{C \times T} \quad (12)$$

3.5. Coupling Coordination Degree

The coupling coordination degree model is a method used to analyze and evaluate the level of coordination development between two or more systems. It is mainly used to assess the degree of interaction, interdependence and interdependence between different systems, and the impact of these interactions on the overall coordinated development. The core concepts of the coupling coordination degree model include coupling degree (C value) and coordination degree (D value), and the formula is:

Where, U_i represents a certain index value of each subsystem, n is the number of subsystems; λ is an adjustment factor greater than 0, which is used to adjust the sensitivity of the coupling degree. Is the weight of the I-th subsystem; Is the standardized subsystem index value; D is coupling coordination degree; C is for coupling degree; T is the coordination index.

The classification of coupling coordination degree depends on the interval of coordination degree D value, as shown in Table 3.

4. Results

4.1. Ecological Source Point Selection

4.1.1. Ecological Remote Sensing Index

The Landsat 8 LI TIRS data of Gannan Prefecture were preprocessed, corrected, merged and clipped on ENVI software to obtain a pre-data. The four indices of ecological remote sensing, namely NDVI, WET, LST and NDBSI, were calculated through the above formula, as shown in Figure 3 below. Gannan Prefecture has high vegetation coverage and humidity, but low overall humidity and uneven distribution of surface temperature.

4.1.2. MSPA and RSEI

In this study, by using the 2022 LUCC data of Gannan Prefecture, important patches in the study area were identified, such as core area, bridge area,

Table 3 l Classification standard of coupling coordination degree

Coupling coordination degree D value size interval	Coupling coordination level	Degree of coupling coordination
[0,0.1)	1	Extremely dysfunctional recession class
[0.1,0.2)	2	Severe dysfunctions recession class
[0.2,0.3)	3	Moderate dysfunction decline category
[0.3,0.4)	4	Mild disorder decline class
[0.4,0.5)	5	On the verge of dysfunctions
[0.5,0.6)	6	Barely coordinated development class
[0.6,0.7)	7	Primary coordinated development category
[0.7,0.8)	8	Intermediate coordinated development category
[0.8,0.9)	9	Well coordinated development class
[0.9,1]	10	Quality coordinated development category

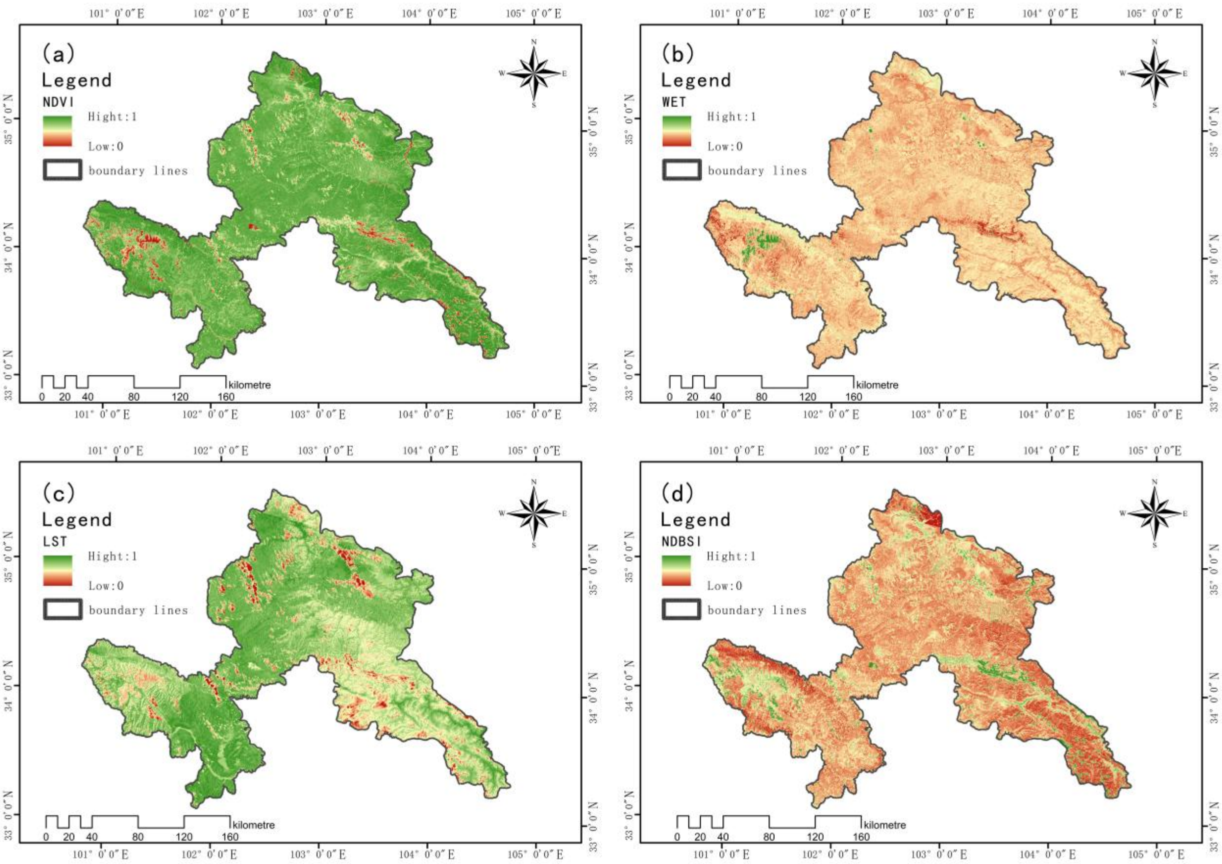

Figure 3 | (a) NDVI index (b) WET index (c) LST index (d) NDBSI index

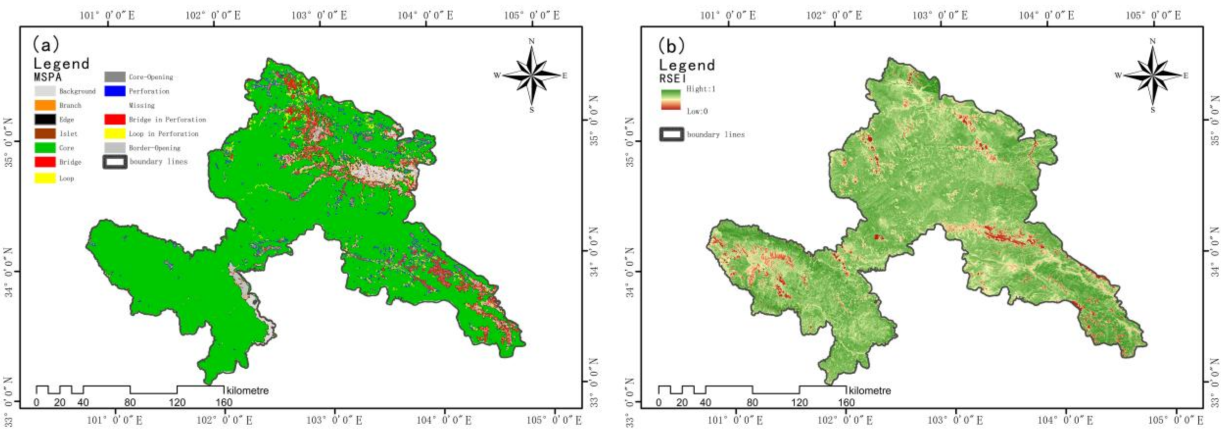

Figure 4 | (a) MSPA analysis (b) RSEI analysis

ring road area, feeder area, edge area, pore and island patch, etc., as shown in Figure 4 (a). In this study, the ecological remote sensing index was generated according to the weight of $NDVI \times 0.6923 + WET \times 0.2655 + LST \times 0.0374 + NDBSI \times 0.0048$, as shown in Figure 4 (b).

As can be seen from Figure 4, the overall ecological situation of Gannan Prefecture is relatively good, except that the ecology of northeast and southeast regions is worse than that of western regions, which is the reason for human activities and development.

4.1.3. Comprehensive Source and Comprehensive Source Point

The obtained MSPA data and RSEI data were reclassified in GIS respectively, and the reclassified data were calculated in the raster calculator with the weight of 0.5 each to obtain the comprehensive data, as shown in FIG.5 (a) below. The obtained compre-

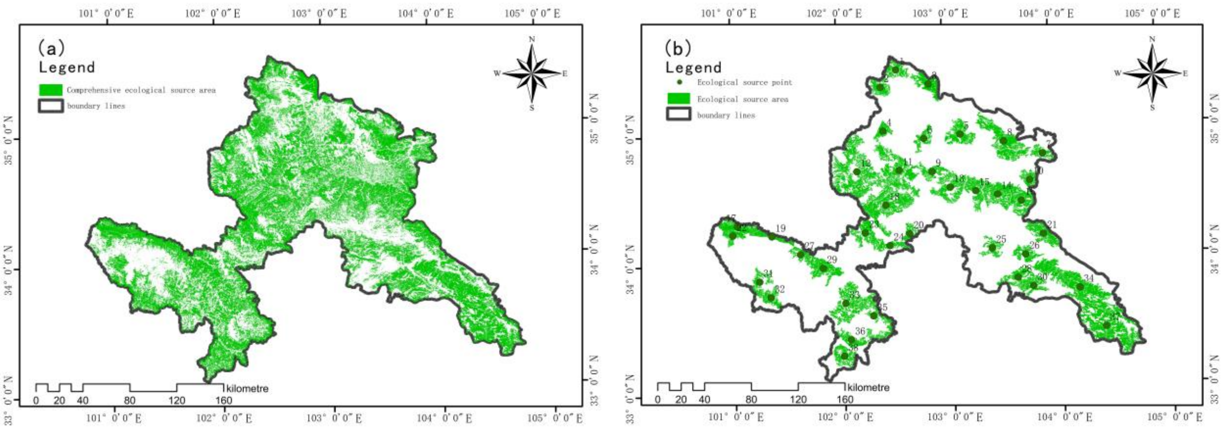

Figure 4 | (a) comprehensive source analysis (b) comprehensive source analysis

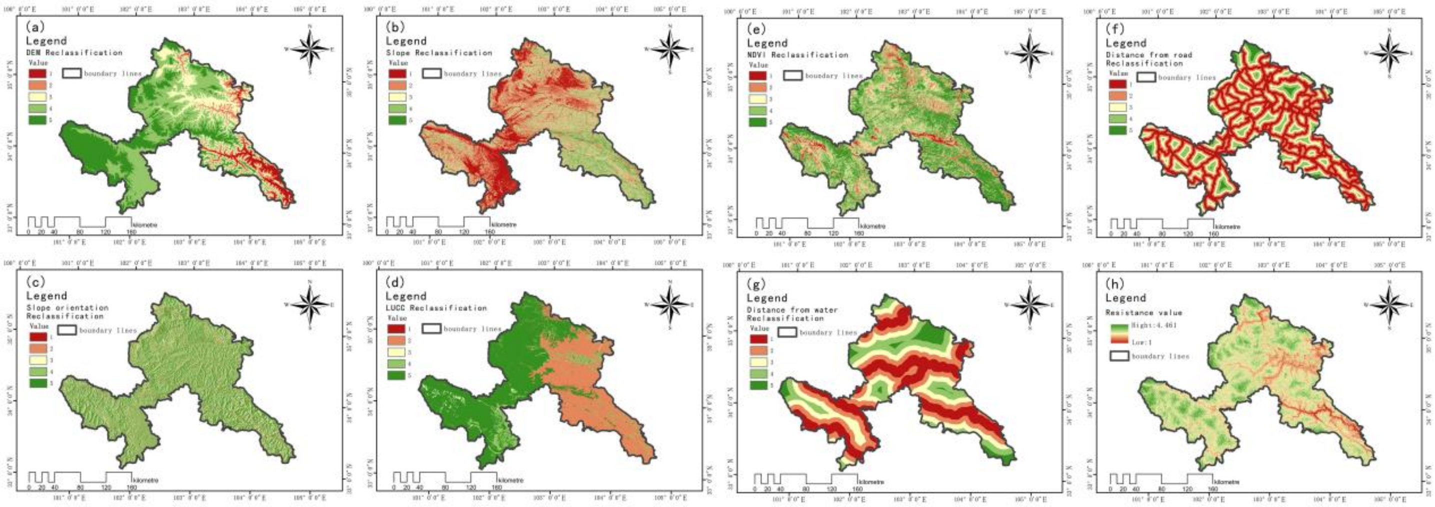

Figure 6 | (a) elevation resistance value (b) slope resistance value (c) slope resistance value (d) LUCC resistance value (e) NDVI resistance value (f) Distance from road resistance value (g) distance from water body resistance value (h) comprehensive resistance value

hensive data was raster first. On the one hand, the patches were sorted in descending order; on the other hand, patch connectivity analysis was carried out with the Conefor plug-in, and patches with an area larger than 100Km2 and strong connectivity were selected as the integrated ecological source. The centroid of each source was selected as the ecological source point and numbered. A total of 38 ecological source points were selected, as shown in Figure 5 (b).

4.2. Construction of Ecological Resistance Surface

The seven resistance surface single factors mentioned in the research method are first cut to the same range size, resampling resolution is 30M, then unified reclassification is carried out, and finally the comprehensive resistance surface is obtained by superposition according to the weights, as shown in Figure 6.

As can be seen from Figure 6, the high-resistance area is mainly distributed in the east of the study area, which is greatly affected by the traffic network and other construction land. In addition, the area with high elevation and slope has rough terrain, which will increase the difficulty of species migration and ecosystem service flow. Low resistance in the western region, due to high vegetation cover and better ecological connectivity, is less resistance to the flow of species and ecosystem services.

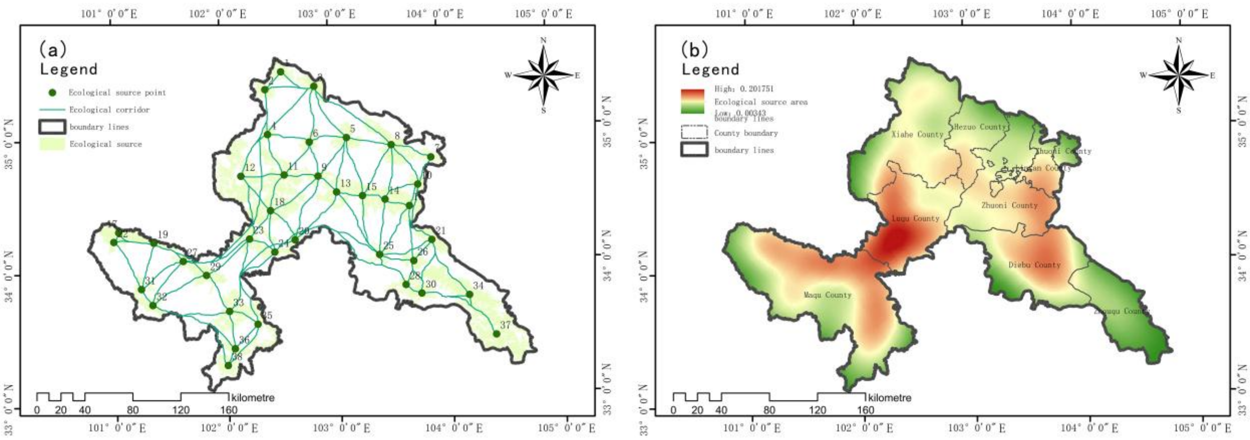

Figure 7 | (a) Ecological corridor analysis diagram (b) kernel density analysis diagram of ecological elements

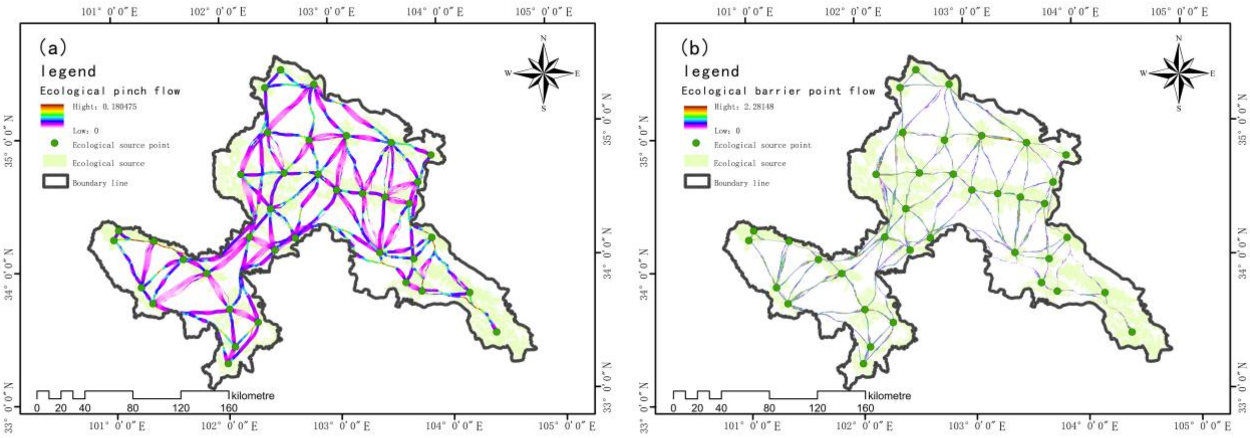

Figure 8 | (a) Ecological pinch point analysis diagram (b) ecological barrier point analysis diagram

4.3. Ecological Corridor and Key Point Identification

4.3.1. Ecological Corridor Identification

Linkage Mapper was used to identify and draw the lowest-cost route between ecological source points. As shown in Figure 7 (a), the ecological flow path mapped 96 ecological corridors, connecting the whole Gannan. The length of the ecological corridor is between 9.66 and 257.68km, and the total length is 5221.39km. The ecological corridors in Gannan are mainly distributed in the central and western regions, and the ecological source patch density in these regions is relatively high. These corridors realize the connectivity of the ecological source areas of the whole city, successfully ensuring that each source area has at least one corridor connection, and forming a network loop. On the whole, the ecological corridor is relatively evenly distributed in the whole city.

The kernel density analysis of ecological source points and ecological corridors was carried out respectively, and then the two were assigned a weight of 0.5 respectively for superposition to obtain the kernel density analysis diagram of ecological elements, as shown in Figure 7 (b) below. In this way, the kernel density of different counties in the urban ecological source points was different, which was the ecological basis for the future development of different types of counties.

4.3.2. Ecological Pinch Identification

Ecological "Pinch point" is based on the "all to one" model of Pinch point Mapper tool, and 20km is selected as the weighted distance of corridor cost to obtain the value of corridor distribution current density, as shown in FIG. 8 (a) below. The identification of "pinch points" in the minimum-cost channels can often serve as a "stepping stone" role in the ecological network to prioritize the protection of these areas that are important for the connectivity of the study area and deserve to be protected.

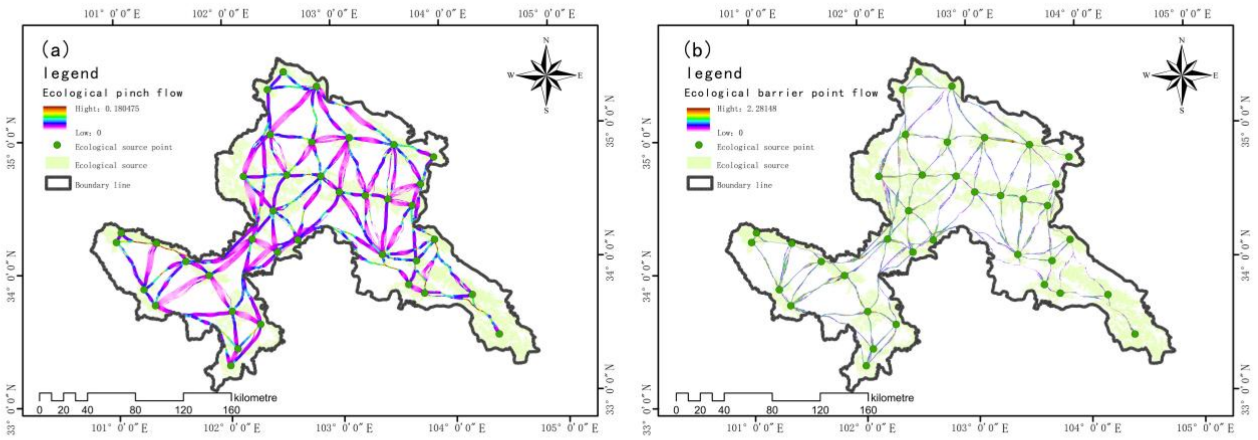

Figure 8 | (a) Ecological pinch point analysis diagram (b) ecological barrier point analysis diagram

4.3.3. Ecological Barrier Point Identification

The Barrier Mapper function of Linkage Mapper was used to identify the obstacle point, and the detection radius of 50-500m and step length of 50m were combined with the actual result to select 200m gradient as the most reasonable generation radius in this study, as shown in FIG. 8 (b) below.

4.3.4. Ecological Break Point Identification

In this study, the overlapping points of national highways, expressways and ecological corridors are identified as ecological "breaking points". As an important transportation infrastructure, the construction and operation of expressways have a significant impact on the surrounding environment, including not only the destruction of ecological environment, the reduction of biodiversity, and the fragmentation of landscape, but also the impact on ecosystem functions. Such as the blocking of animal migration path, loss of ecological niche and so on. The function of the ecological corridor is to promote the communication between species and the health of the ecosystem, and to ensure the integrity of the ecosystem. However, the existence of highways often becomes a "breaking point" in the ecological corridor, which hinders the movement of wildlife and the progress of ecological processes.

4.4. Ecological Security Pattern Identification

4.4.1. Ecological Corridor Classification

The method of quantitative analysis of ecological corridor classification in this study is based on the ratio of cost-weighted distance to the minimum cost path, which can help researchers evaluate and compare the quality and function of different ecological corridors. An index reflecting the connectivity of ecological corridors can be obtained. The smaller the ratio, the smaller the gap between the actual moving distance and the minimum-cost path, indicating that the stronger the connectivity of the ecological corridor, the fewer barriers for species to migrate within it. Among them, the ratio between 1-1.06 is the key ecological corridor, the ratio between 1.06-1.1 is the important ecological corridor, and the ratio greater than 1.1 is the general ecological corridor. The specific results are shown in FIG. 9 (a) below. Among them, there are 10 important ecological corridors, 61 key ecological corridors and 25 general ecological corridors. In the future, the protection and restoration strategies for ecological corridors are different. The general corridors with the least connectivity should be repaired with emphasis, while the important ecological corridors with the strongest connectivity should be protected and maintained. It can be seen from the figure that important ecological corridors are located in areas with relatively high resistance values, such as Diib County and Xiahe County, which have relatively flat terrain and mild climate conditions, providing important migration channels. General ecological corridors are located in areas with high resistance values such as Maqu County, where the terrain is different and the connectivity is weak. In addition, it is worth noting that there are many general ecological corridors in Zhouqu County, but the resistance value in Zhouqu County is small, which is related to the reason why natural disasters are distributed most in Zhouqu County.

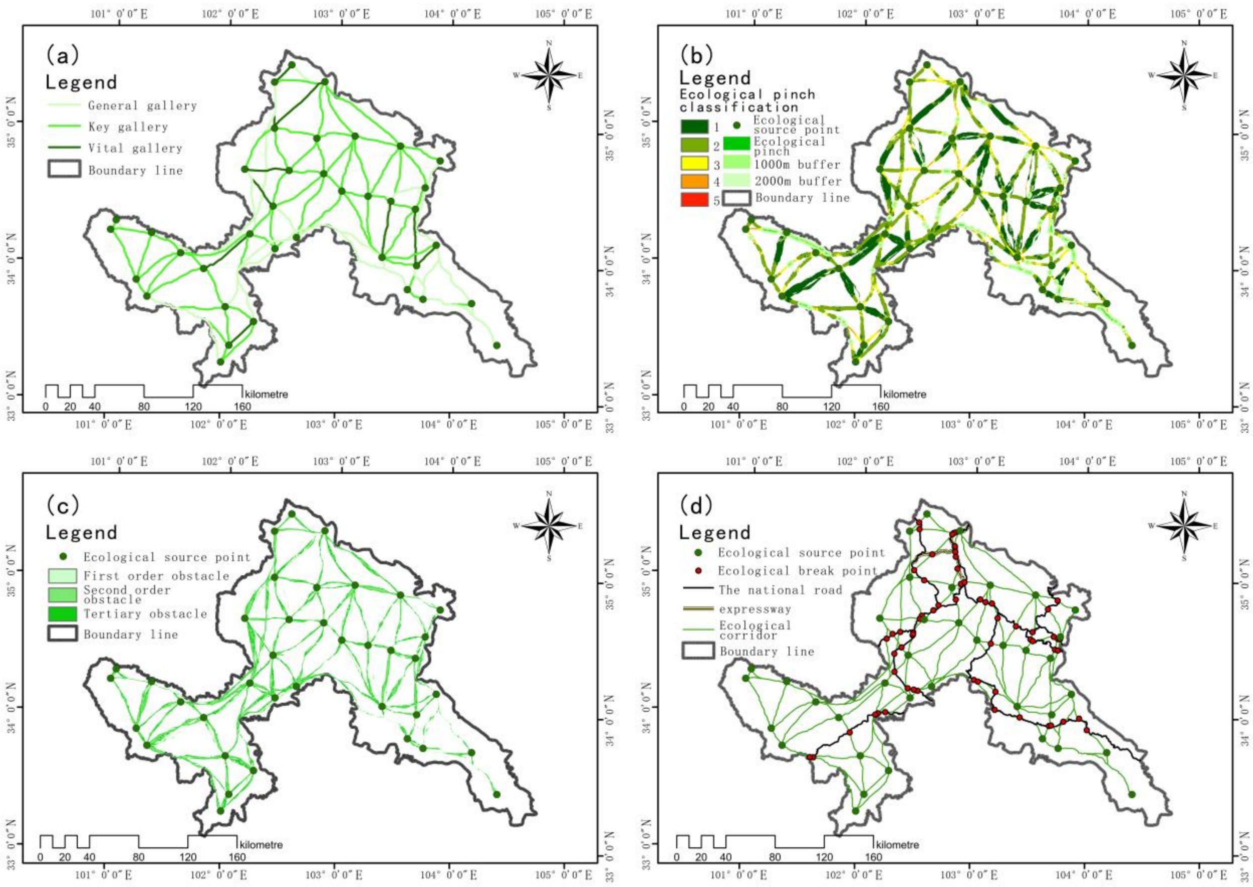

Figure 8 | (a) classification of ecological corridor (b) extraction of ecological pinch points (c) extraction of ecological barrier points (d) extraction of ecological break points

4.4.2. Ecological Key Point Extraction

The ecological key points mentioned here refer to the ecological break points of ecological pinch points and ecological obstacle points.

Firstly, the ecological pinch points were divided into five categories by the natural fracture method to extract the current value. The area with the highest value of the fifth category was taken as the ecological pinch points. The consensus was 908 spots with a total area of 47.82km2, the largest ecological pinch point area was 6.350502km2, and the minimum ecological pinch point area was 0.000576km2. Ecological pinch points were obtained on the basis of an analysis within a buffer zone of 1000 and 2000 m, as shown in Figure 9 (b) below.

Secondly, for ecological obstacle points, the generated obstacle areas are divided into three levels using the natural breakpoint method, including first-level obstacle points, second-level obstacle points and third-level obstacle points, as shown in FIG. 9 (c) below. The cumulative current recovery value was divided into 698 first-order obstacle points, 550 second-order obstacle points and 550 third-order obstacle points, with a total area of 6105.36km2, accounting for 13.57% of the study area. The obstacle points are mainly distributed in Maqu County, Luqu County, Zhuoni County and Lintan County in Gannan Prefecture. The number of Grade I obstacle points in Luozhilu, Gahai Lake and Guomeng Wetland reserve is large and the area is large. Therefore, ecological restoration should be strengthened in the surrounding areas. Secondary and tertiary obstacle points are the supplement of primary obstacle points, which mainly appear near the source area and inside the ecological corridor. The spatial structure is distributed in groups, and the restoration is difficult and the effect is relatively slow. Long-term improvement and optimization plans need to be formulated.

Thirdly, for ecological "break points", the consensus identifies 66 ecological "break points", of which 8 intersect with highways and 58 intersect with national highways, as shown in Figure 9 (d) below. Xiahe County and Hehe City have a large number of "break points" formed by cutting expressways. Overall, there are 19 "break points" in Xiahe County, 12 "break points" in Luqu County, 9 "break points" in Zhuoni

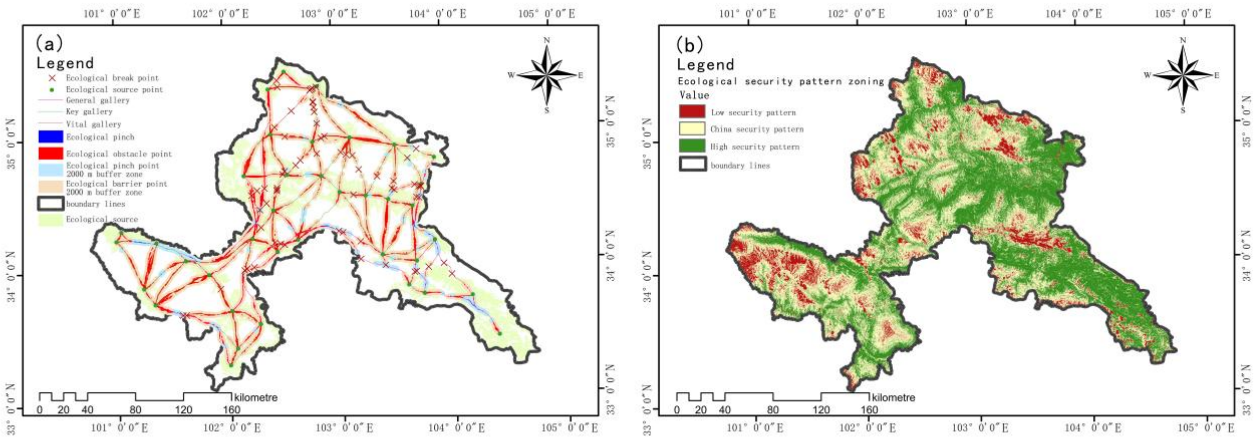

Figure 10 | (a) Ecological security pattern of Gannan Prefecture (b) ecological security zoning

County and Diebe County, 8 in Lintan County, 6 in Maqu County, 2 in Hehe City and 1 in Zhouqu County. The "break point" has a great impact on ecological transmission, and most of the traffic arteries and ecological corridors are vertically distributed, so it is difficult to find other alternative points near the corridors, which seriously hindering the ecological flow. Xiahe County, Luqu County, Zhuoni County and Dibu County have a large number of fracture points, among which Xiahe County has 19 "fracture points". Xiahe County is in the north of Gannan Prefecture, and has close material exchanges with peripheral cities, and the traffic quantity is developed, which increases the number of ecological fracture points.

4.4.3. Construction of Ecological Security Pattern

The ecological security pattern is constructed by combining the ecological corridors classified by ecological pinch points, ecological barrier points and ecological break points analyzed above, as shown in Figure 10 (a).

Combined resistance surface data and ecological remote sensing index were used to partition the ecological security pattern. The ecological resistance surface reflects the impeding effect of different landscapes on ecological processes, while the ecological remote sensing index provides a rapid assessment of regional ecological environment quality. By combining these two methods, the regions of low security, medium security and high security can be more accurately divided, as shown in Figure 10 (b). There are three types of ecological security pattern, in which the low security pattern refers to the area with poor ecological status and serious obstruction of ecological process, including the area with high ecological resistance and low RSEI value. In the middle security pattern, the region requires certain ecological restoration and management measures, and the ecological resistance and RSEI value are at a medium level. The high security pattern area refers to the area with good ecological status, smooth ecological process, low ecological resistance and high RSEI value.

4.5. Ecological Problem Identification

4.5.1. Building an Ecological Issues Index (EPI)

The concept of "mountains, rivers, forests, fields, lakes, grass and sand are a community of life" emphasizes the interdependence and integrity of these natural elements, and requires us to adopt a systematic governance approach when carrying out ecological protection and restoration, taking into account the relationship between various elements as a whole, and achieving the goal of harmonious coexistence between man and nature.

In the construction of China's ecological civilization, each word "mountains, rivers, forests, fields, lakes, grass and sand" represents a specific natural element or ecosystem. Based on the practical needs of practicing green mountains and mountains as gold and silver mountains and preventing and resolving ecological risks, this paper starts from the concept of "mountains, rivers, forests, fields, lakes, grass and sand are a community of life", and constructs the diagnostic indicators of ecological problems of "mountain - water - forest - field - lake - grass - sand", as shown in Table 4.

For the mountain ecosystem in the index system of "mountain - water - forest - field - lake - grass - sand", vegetation coverage and natural disaster distribution kernel density were selected, and the kernel density of natural disaster mainly included landslide,

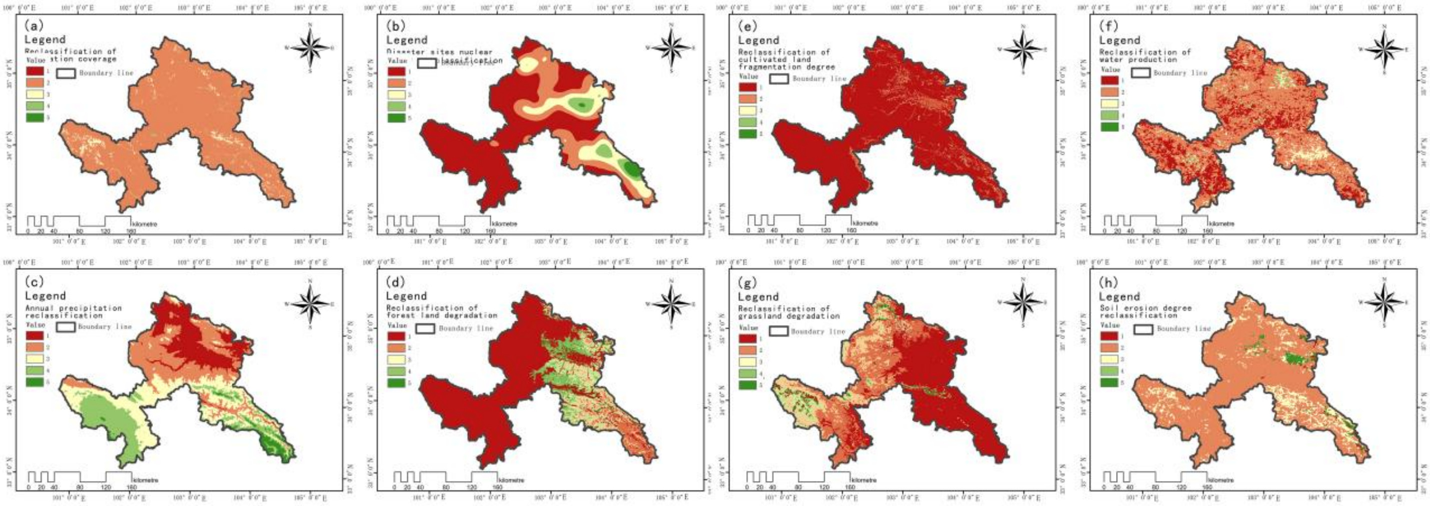

Figure 11 | (a) Reclassification of vegetation coverage (b) Reclassification of core density of disaster sites (c) reclassification of annual precipitation (d) reclassification of woodland degradation (e) reclassification of cultivated land fragmentation (f) reclassification of water yield (g) reclassification of grassland degradation (h) reclassification of soil erosion

Table 4 | Diagnostic index system of ecological problems of "mountain-water-forest-field-lake-grass-sand"

Repair object	Ecosystem	Ecological problem	Index name	Weight	Data processing	Nature	Assign				
							1	2	3	4	5
mountain	Mountain ecosystem	Vegetation thinning	Vegetation coverage	0.17	NDVI	-	0.8-1	0.6-0.8	0.3-0.6	0.1-0.3	0-0.1
		Geological disaster	Disaster distribution map		Nuclear density analysis of disaster site distribution map	+	0-0.01	0.01-0.03	0.03-0.06	0.06-1	＞1
water	Aquatic ecosystem	Extreme precipitation	Annual precipitation distribution	0.14	Annual precipitation distribution map	+	＜550	550-580	580-620	620-660	＞660
forest	Forest ecosystem	Forest degradation	Forest degradation degree	0.15	Woodland NPP data + woodland fragmentation	+	＞0.7	0.6-0.7	0.5-0.6	0.4-0.5	＜0.4
field	Farmland ecosystem	Farmland fragmentation	Cultivated land fragmentation	0.15	Cultivated land distribution data	+	＜0.006	0.006-0.015	0.015-0.03	0.03-0.09	＞0.09
lake	Lake ecosystem	Water shortage	Water conservation capacity	0.13	Yield data	-	＞2000	1900-2000	1800-1900	1700-1800	＜1700
grass	Grassland ecosystem	Grassland degradation	Grassland degradation degree	0.15	Grassland NPP data + grassland fragmentation	+	＞0.4	0.35-0.4	0.3-0.35	0.25-0.3	＜0.25
sand	Sandy land ecosystem	The land has been severely eroded	Soil erosion degree	0.11	Soil erosion degree	+	No obvious erosion	Slight erosion	Mild erosion	Moderate erosion	Intense erosion

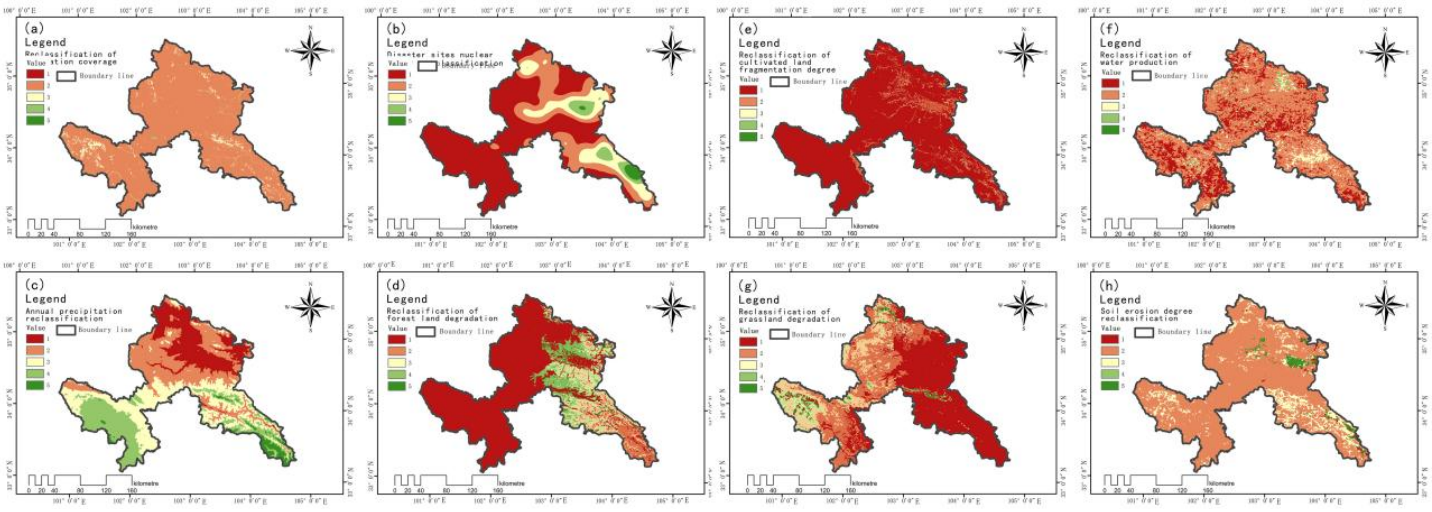

Figure 11 | (a) Reclassification of vegetation coverage (b) Reclassification of core density of disaster sites (c) reclassification of annual precipitation (d) reclassification of woodland degradation (e) reclassification of cultivated land fragmentation (f) reclassification of water yield (g) reclassification of grassland degradation (h) reclassification of soil erosion

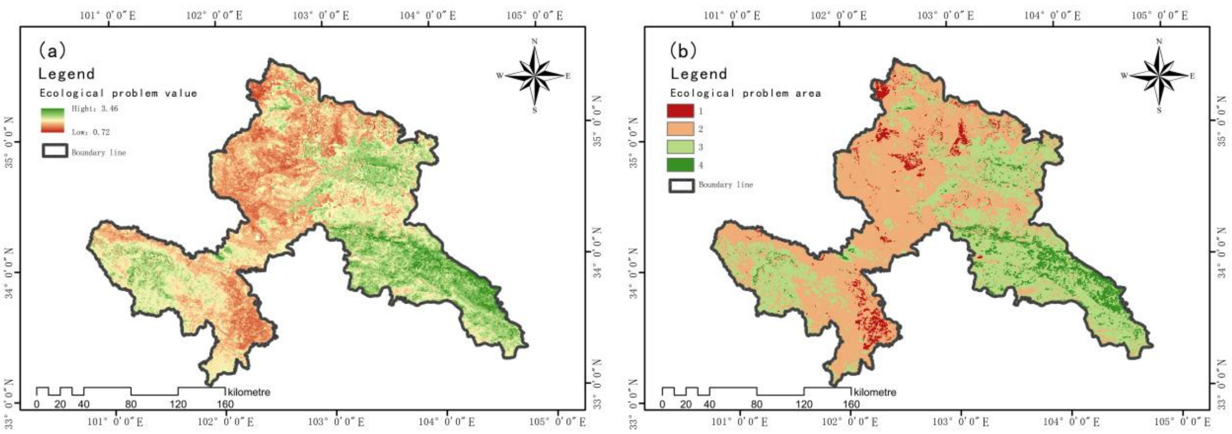

Figure 12 | (a) Integrated ecological issues (b) Ecological issues regionalization

debris flow, collapse, slope and other disasters related to the mountain. In the water ecosystem, the distribution of annual precipitation is selected. The northerly slope of Gannan aggravates the decline of precipitation from south to north. Therefore, the annual precipitation in southern Gannan can reach more than 600 mm, while that in central and northern Gansu is less than 200 mm. For forest ecosystem and grassland ecosystem, the net primary productivity of forest land and the primary productivity of grassland were selected respectively. Farmland ecosystem is an index of cultivated land fragmentation. The boundary density index represents cultivated land fragmentation, and the ratio of cultivated land patch circumference to cultivated land area is used. The greater the ratio of the two, the higher the degree of cultivated land is divided by boundary. The lake ecosystem was represented by the water conservation of Gannan Prefecture. The ecosystem of sandy land was represented by soil erosion index.

According to the eight indicators in the above table, all of them are first cut to the same range size, the resampling resolution is 30M, and then uniformly reclassified into five categories. For the three factors such as forest land degradation degree, grassland degradation degree and cultivated land fragmentation degree, the empty value is assigned as 1, in order to facilitate the subsequent calculation of comprehensive ecological problem data with the Ecological problem index (EPI) formula. Among them, the reclassification of eight indicator factors is shown in Figure 11 below.

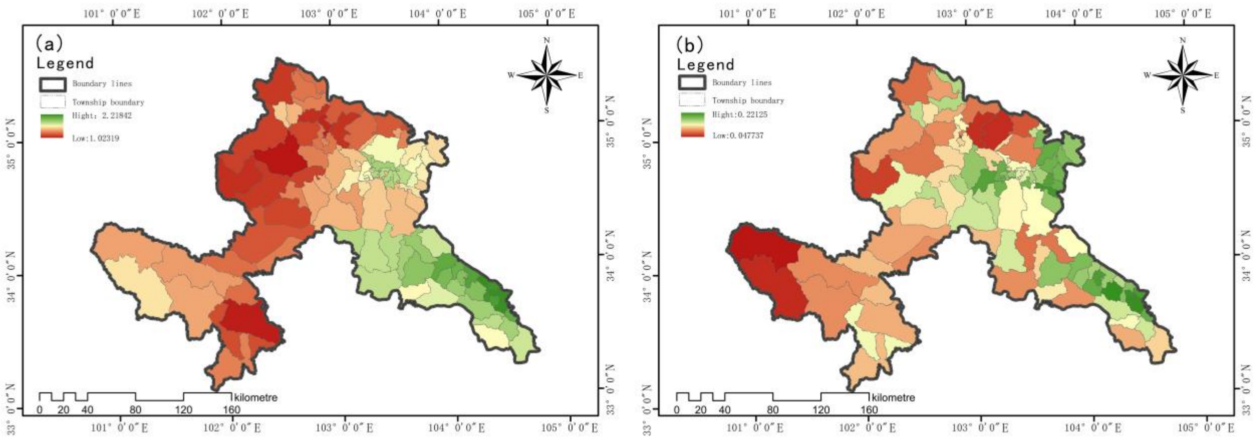

Figure 13 | (a) Regional statistics of ecological problems (b) regional statistics of ecological security pattern

4.5.2. Territorial Ecological Problems Identification Zone

According to the Ecological Problem Index (EPI) formula, combined with the weights of eight index factors, the comprehensive ecological problem data was calculated, as shown in Figure 12 (a). Then, the obtained comprehensive data are reclassified into four categories, as shown in Figure 12 (b). The larger the regional value of ecological problems, the more prominent the ecological problems. When 0.72≤EPI<1, it is classified as 1, which belongs to the critical maintenance area. When 1≤EPI<1.5, it is classified as 2 and belongs to the critical control area. When 1.5≤EPI<2, it is classified as 3 and belongs to the key lifting area. When 2≤EPI<3.46, it is classified as 4 and belongs to the key repair area. It can be seen from the figure that the most ecological restoration areas are in Zhouqu County, Diib County and Maqu County.

First of all, Zhouqu County, as an area with frequent natural disasters, the wide distribution of its ecological restoration area is closely related to the topography and climate conditions of the area. Zhouqu County's complex terrain, mountainous and steep, coupled with the changeable climate, these factors together lead to frequent geological disasters, such as landslides, debris flows and so on. These disasters not only destroy the local ecological environment, but also pose a threat to the life and safety of residents. Therefore, ecological restoration efforts focus on stabilizing the terrain, restoring vegetation, reducing soil erosion, and improving the resilience of ecosystems to natural disasters.

Secondly, the ecological restoration area in Dibe County is related to its specific geographical location and ecological environment. Dibe County is located in the transition zone between plateau and mountain, where the ecosystem is relatively fragile and vulnerable to climate change and human activities. Ecological restoration efforts focus on restoring and protecting local forest ecosystems, as well as improving soil and water conservation. In addition, Dibe County needs to take measures to reduce the negative impact of agricultural activities on the ecosystem, such as overgrazing and land degradation, so as to maintain the ecological balance and biodiversity.

Third, although the geographical location of Maqu County is relatively high, the ecological resistance value is relatively low, but this does not mean that the ecological restoration work is not important. The ecological environment of Maqu County is good, which provides a good basis for ecological restoration. The distribution of restoration areas is more focused on improving ecosystem services, such as water conservation capacity and biodiversity conservation.

4.6. Ecological Coupling Result

The data of ecological problems and the data of ecological security pattern were analyzed in different regions, and the average value of each data was distributed to 99 townships in Gannan Prefecture, as shown in Figure 13.

It can be seen from the figure that the regions with high ecological problem value in Gannan are mainly distributed in Diabe County, Zhouqu County and Lintan County. The pattern of high ecological security is distributed in four regions: Zhouqu County, Zhuoni County, Lintan County and Hehe City. The paradox is that Zhouqu County and Lintan County have high ecological problem value and high ecological security

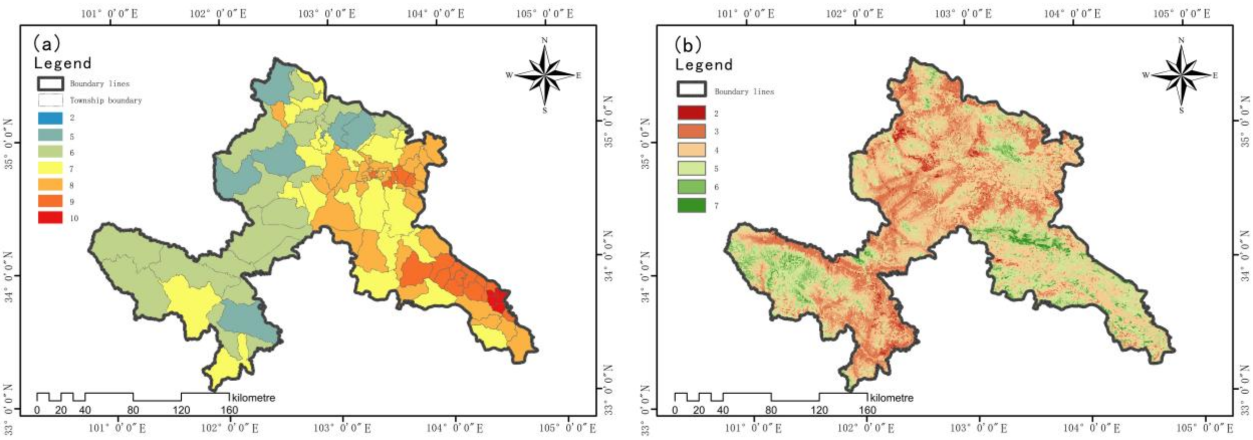

Figure 14 | (a) ecological coupling level (b) ecological coupling zone

pattern. Because these areas have a high ecological sensitivity, easy to be affected by natural factors (Zhouqu debris flow) and human activities, leading to more prominent ecological problems. At the same time, it is precisely because of historical ecological events in these regions that the ecological protection awareness of local governments and residents has been enhanced, prompting them to invest more resources and efforts in ecological protection and restoration, thus forming a high ecological security pattern.

In order to further study the interaction relationship between ecological problems and ecological security pattern, the two are coupled, as shown in Figure 14. Two coupling methods are adopted in this paper. The first is the coupling coordination model, which identifies the coordination degree of ecological problems and ecological security pattern in each township and identifies the synchronization before them. The second is spatial coupling superposition, which superimposes ecological problems and ecological security pattern.

In combination with Figure 14 (a) and Table 5, it can be found that only 8 townships in Gannan are within the scope of imbalance, while the others are within the scope of coordination, indicating that the identification of ecological problems in Gannan is largely consistent with the identification of ecological security pattern. But Thongchin street is seriously dysfunctional, and Ganga Town and Kecai Town are

Table 5 | Coupling coordination degree of towns and villages in Gannan Prefecture

Coupling coordination level	Degree of coupling coordination	Number of townships	Specific township
2	Severe disorder	1	Tongchin street
5	Borderline disorder	7	Ganga Town, Kocai Town, Amugohu Town, Manzhima Town, Janmukir Street, Sogaimanma Town, Sogaidoma Township
6	Forced coordination	19	Kangduo Township, Madang Town, Tanggaang Township, Jicang Township, etc
7	Primary coordination	22	Wanmao town, scoop wa Tu Township, Kailchin town, Chagai Township, etc
8	Intermediate coordination	29	Narang Town, Niba Town, Azitan Town, Zagulu town, etc
9	Good coordination	16	Liulin Town, Lijie town, Hanban town, Basang town, Fengdiai town, etc
10	Quality coordination	5	Guoye Town, Dongshan Town, Jiangpan Town, Nanyu Township, Dachuan town

Table 6 | Superimposed data table of ecological problems and ecological security pattern in Gannan Prefecture

Superimposed result	Area (km2)	Sectional implication	Partition name
2	790.75	High - maintenance area	Ecological protection area
3	10623.57	Medium - maintenance area, high - control area	Ecological maintenance area
4	19871.56	Medium - control area, high - lifting area, low - maintenance area	Ecological development area
5	8510.18	Medium - lift area, low - control area	Ecological control area
6	2797.62	Low-lift area, medium-repair area	Ecological enhancement area
7	598.25	Low - repair area	Ecological restoration area

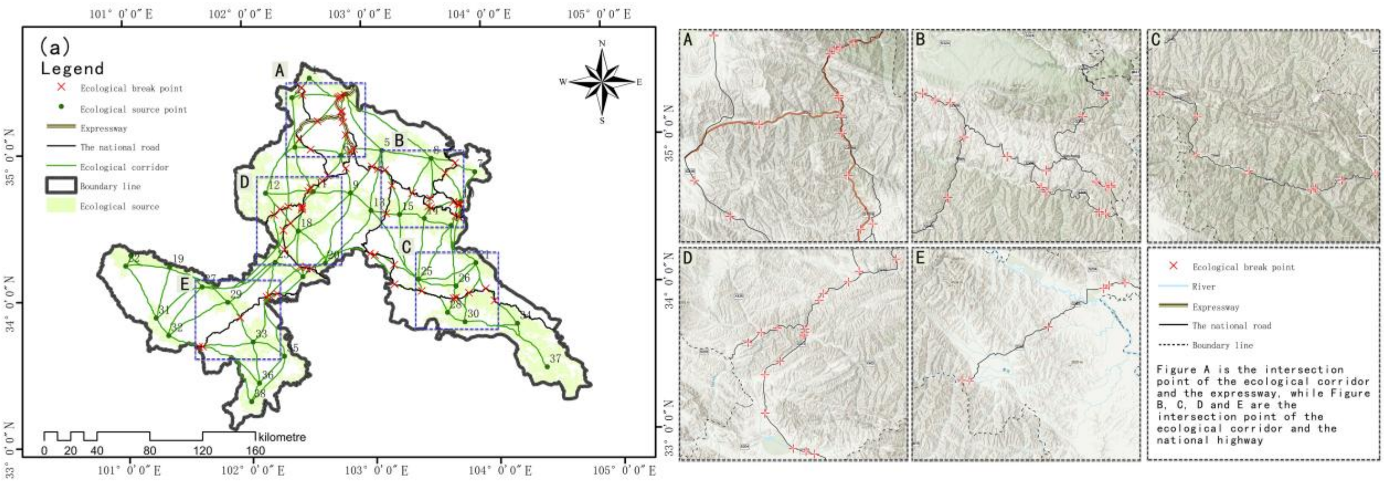

Figure 15 | Ecological break point strategy

among the seven towns on the verge of dysfunctional towns that need different strategies and measures.

There are six types of spatial superposition results, the values are 2, 3, 4, 5, 6 and 7 respectively, as shown in Table 6.

5. Discussions

5.1. Ecological Space Restoration Strategy Proposed

5.1.1. Ecological Point Strategy Is Proposed

a. Ecological break point

In this study, the break points are divided into highway break points and national highway break points, so targeted strategies are proposed. First, for the ecological break points of the highways, the restoration strategy focuses on the design and implementation of dedicated wildlife passageways, such as overpasses or underpasses, and the planting of native vegetation on both sides of the highways to form natural ecological corridors. In addition, the effectiveness of the ecological corridor is ensured through the installation of isolation facilities and regular monitoring management. These measures aim to reduce animal-vehicle conflict while improving ecological connectivity and protecting and promoting biodiversity. Secondly, for the ecological break points of national highways, the strategy focuses more on reducing the speed limit and optimizing the road design to reduce the impact on the ecologically sensitive areas. Implementing ecological compensation measures, such as afforestation near affected areas, to balance ecological losses. In addition, through traffic control and community participation, the construction and maintenance of ecological corridors are

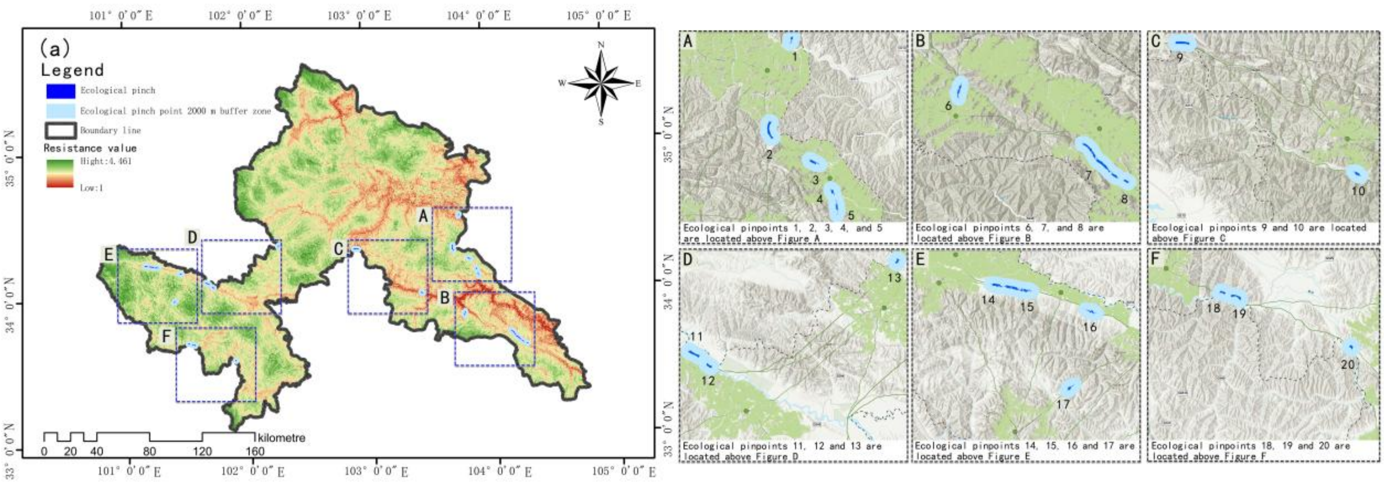

Figure 16 l Ecological pinch strategy

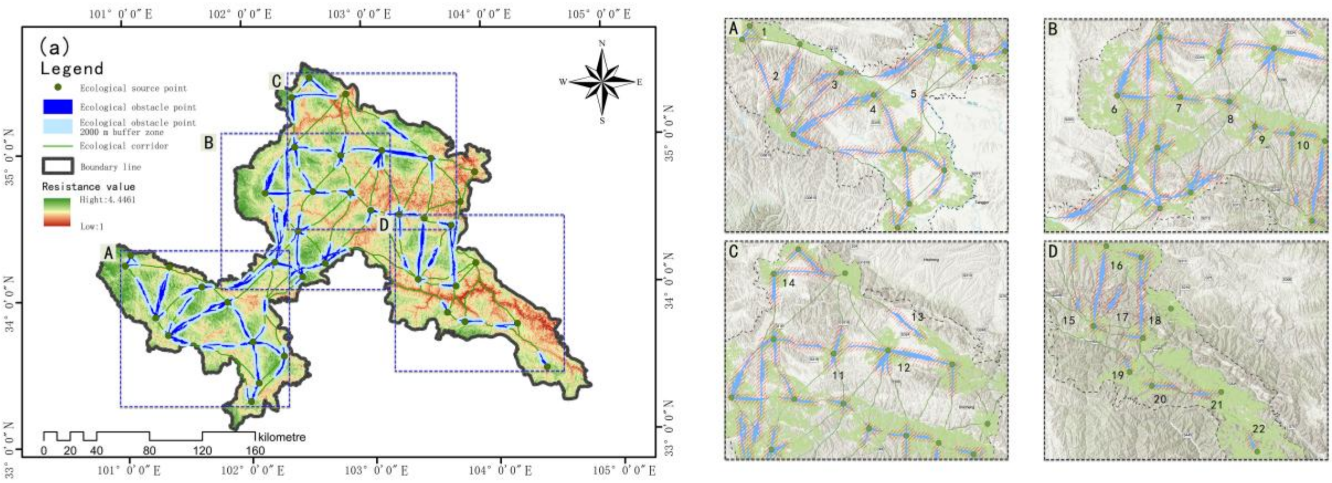

Figure 17 l Ecological barrier point strategy

strengthened. At the same time, multi-functional green Spaces and intersectoral cooperation mechanisms, as well as continuous monitoring and evaluation, will be established to ensure the long-term benefits of ecological corridors in conserving biodiversity and providing ecosystem services.

b. Ecological pinch

When the ecological pinch points are superimposed with the integrated resistance surface, the ecological pinch points are located with less resistance and easy to migrate species, so it is necessary to focus on protection and management of these areas. Superimposed with land use classification and remote sensing images, the land types located in the pinch points are mainly woodland, grassland and water bodies. Some pinch points have high vegetation coverage, and these areas are extremely sensitive when subjected to certain external interference activities. These areas need to be protected and managed to prevent natural disasters such as soil erosion.

The ecological pinch area larger than 0.5km2 was selected as the key protection area, and a buffer area of 2000 meters was set around it. A total of 20 spots were numbered, as shown in Figure 16. Among them, 13 sites are located in the ecological source area (2, 3, 4, 5, 6, 7, 8, 11, 12, 13, 14, 15, 16), and 7 sites are not located in the ecological source area (1, 9, 10, 17, 18, 19, 20).

For ecological pinch points located in ecological source areas, conservation strategies should focus on ecological monitoring and restoration, establishing conservation buffer zones to reduce human disturbance, maintaining ecological connectivity to ensure species migration, protecting water sources, using areas for scientific research and education, and encouraging community participation and sharing in ecological conservation benefits. These measures help to maintain the natural state and ecological function of the ecological pinch, while promoting harmonious symbiosis with the surrounding ecosystem. For ecological pinpoints that are not located in ecological sources, conservation strategies need to include environmental impact assessments to prevent potential damage, ecological risk management and compensation to mitigate the impact of development activities, ecological restoration works to restore damaged areas, rational land use planning to avoid improper development, stronger enforcement of laws and regulations to curb vandalism, and public awareness to increase social participation. Promoting cross-regional cooperation to achieve broader ecological protection. These strategies are designed to ensure that these key ecological areas receive appropriate attention and protection, even if they are not directly located within the ecological source area.

c. Ecological obstacle point

According to the superposition analysis of ecological barrier points and comprehensive resistance surface, the barrier points are mostly distributed in the positions with higher resistance values, which is not conducive to the connectivity of landscape pattern. Superimposed with land use classification and remote sensing images, the obstacle points are mainly located on construction land, forest land, grassland and cultivated land, and the first-order obstacle points are mostly distributed on construction land, which has great interference from human activities and obstructs material exchange.

In this study, a total of 48 patches with ecological obstacle points larger than 10km2 were selected. A buffer zone of 2000 meters was made around them, and the buffer zones were connected into pieces to number the remediation areas, with a total of 22 numbered areas, as shown in Figure 17. Strategies are classified according to the number of ecological source points in the region shown in the figure. There are 4 sites without source points: 5, 13, 15 and 17; 10 sites with 1 source point: 7, 8, 9, 10, 11, 12, 19, 20, 21 and 22; and 6 sites with 2 source points: 1, 2, 3, 14, 16 and 18. The ones with 3 or more are 4 and 6.

In the face of non-ecological source points in Gannan (No. 5, 13, 15, 17), the strategy should focus on ecological reconstruction and vegetation restoration. Specific measures include the selection of cold-tolerant and drought-tolerant native plants for large-scale planting, as well as the establishment of long-term ecological monitoring sites to regularly assess the restoration effect, and ensure that the ecosystem gradually recovers and ADAPTS to the local alpine environment. For obstacle sites with a single ecological source point (numbers 7, 8, 9, 10, 11, 12, 19, 20, 21, 22), the strategy should strengthen source point protection and expand ecological restoration. By establishing ecological buffer zones around obstacle points, limiting possible disturbance activities, while building ecological corridors, enhancing biodiversity and ecological connectivity, and promoting safe species migration and gene flow. In the face of obstacle points with two ecological source points (numbers 1, 2, 3, 14, 16, 18), the strategy needs to optimize the ecological network structure. Through vegetation restoration and ecological engineering, the two source points are connected through an ecological corridor to form a more stable ecological network, while improving the ecological service functions of the obstacle points and their surrounding areas, such as enhancing carbon sink capacity and water conserva-

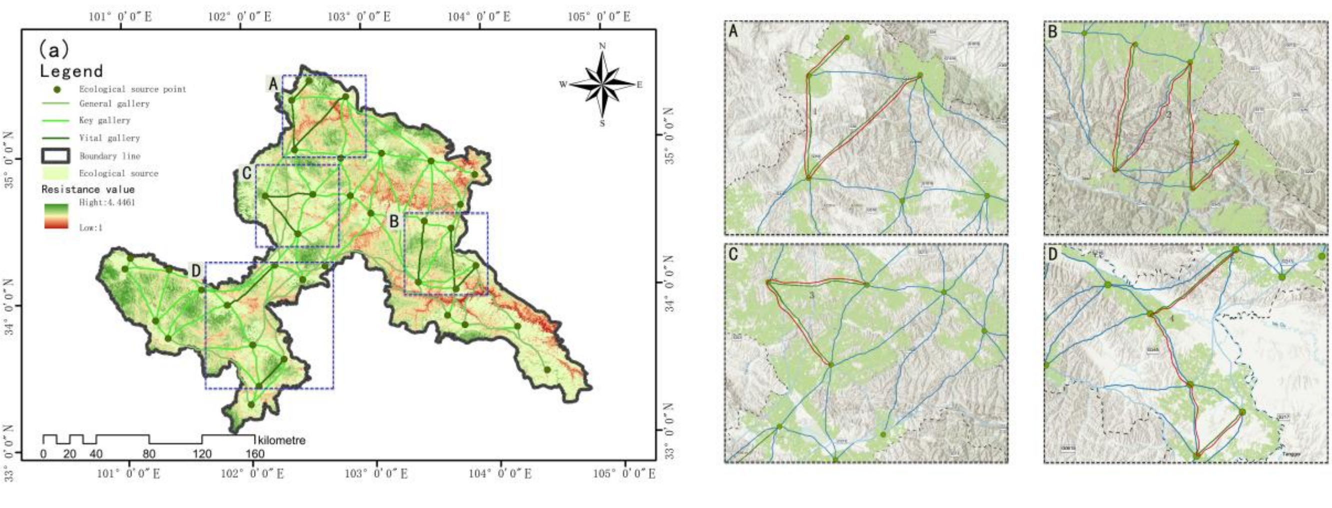

Figure 18 | Ecological corridor strategy

tion. For obstacle sites with three or more ecological source sites (numbers 4 and 6), integrated ecological planning is required. According to the ecological functions and geographical distribution of the source points, different ecological functional areas are divided, differentiated protection and management measures are implemented, priority is given to restoring the more vulnerable areas with high ecological value, and ecological protection complexes are built to achieve the optimization and sustainable development of the entire ecosystem.

5.1.2. Ecological Line Strategy Proposed

In this study, 10 important ecological corridors were selected, but the 10 ecological corridors were widely distributed. Therefore, in order to further stabilize the role of ecological corridors, 10 corridors are formed into 4 ecological corridor groups, as shown in Figure 18. Among them, corridor group No. 1 and corridor Group No. 3 are connected by important corridors, corridor group No. 2 is a corridor group combined by adding a key corridor, and corridor group No. 4 is a corridor group combined by adding two key corridors, as shown in Figure 18.

According to the information of each corridor shown in Table 7 above, different strategies are given respectively. The No. 1 Ganga Town-Sangke Town-Quao Town ecological corridor group, given that it spans many roads and is dominated by grassland, the strategy should include limiting construction activities within a certain range on both sides of the road to reduce light and noise pollution; Add ecological signs and speed bumps to remind drivers of wildlife; At the same time, seasonal grazing bans are implemented to promote the natural recovery of grasslands, and grassland health conditions are regularly monitored. The No. 2 Muler Town-Dianga Town-Narang Town-Wangzang Town-Lazikou town-ecological corridor group, since it passes through many towns and mainly forests, the strategy should include formulating ecological connectivity planning among townships and increasing the biodiversity hotspots at the forest edge; Implement long-term forest ecosystem monitoring projects to assess ecological service functions; And promote sustainable forest management practices, such as selective logging and forest renewal. No. 3 Sangke Town - Kecai Town - Amuohu Town ecological corridor group, land use is mainly grassland and transverse across the river, the strategy should focus on the maintenance of river ecological flow, to ensure the health of river ecosystem; Implement the construction of riverbank vegetation buffer zone to reduce agricultural non-point source pollution; And carry out grassland ecological monitoring, rational planning of grassland utilization, avoid overgrazing. No. 4 Gahai Town-Eula Town-Manzhima Town-Zezhima ecological corridor group, the land use is wetland and grassland, across the Yellow River and the national highway, the strategy should include the establishment of wetland protection areas, limiting activities that may affect water quality; Set up ecological isolation zones and sound barriers along the national highway to reduce the disturbance to the wetland ecosystem; The value assessment of wetland ecosystem services should be carried out to raise public awareness of the importance of wetland protection.

5.1.3. Ecological Surface Strategy Is Proposed

According to the six regions divided into ecological problems and ecological security patterns, protection and restoration strategies are proposed for each re-

Table 7 | Ecological corridor group information table

name	Number of towns crossed	Land use type	Roads (Main roads)	Rivers (main stream)
1. Ganga-sanko-treau Corridor Group	3	grassland	7	4
2. Muer - Dianga - Narang - Wangzang - Lazikou corridor Group	5	forest, grassland	0	1
3. Sangke - Kecai - Amu go Hu corridor Group	3	grassland	2	3
4. Gahai-eula-manzhima - Tsezhima Corridor Group	4	wetland, grassland	2	3

Table 8 | Ecological zoning strategies

Ecoregional types	Strategic perspectives	Specific strategies and measures
Ecological protection area	Protection and monitoring	Develop a visitor management plan, including visitor restrictions and education; Community involvement in conservation activities, such as ranger training; Establish ecological education centers to raise public awareness.
Ecological maintenance area	Conservation and sustainable use	Promote ecological agriculture to increase farmers' income and reduce the pressure on the natural environment; Establish a community co-management mechanism and encourage residents to participate in ecological protection.
Ecological development area	Control development and ecological compensation	Develop guidelines for environmentally friendly development and limit high-polluting projects; Provide preferential policies for industries with low ecological impact.
Ecological control area	Ecological restoration and risk management	Strengthen the enforcement of environmental laws and regulations and punish violations; Establish environmental monitoring stations to monitor environmental quality in real time.
Ecological enhancement area	Improved ecosystem services	Supporting local communities to develop ecotourism and environmental education programs; Encourage residents to participate in ecological restoration work and provide relevant skills training.
Ecological restoration area	Emergency repair and community involvement	Provide technical and financial support to help local communities participate in ecological restoration projects; Strengthen the late management and maintenance of ecological restoration areas.

gion from a strategic perspective and specific strategic measures, and customized according to the characteristics of its ecological security pattern and ecological problems faced, so as to ensure that ecological protection and restoration work is scientific, reasonable and practical. To achieve the health of the ecosystem, the enrichment of biodiversity and the enhancement of ecological services.

According to the ecological problem identification and the ecological security pattern of the coupling of the seven districts, also for the township gives different strategies. For the seriously disordered area of Tongqin street, a comprehensive ecological restoration project should be started immediately, including pollution control and ecological reconstruction. At the same time, environmental supervision will be strengthened to ensure that all activities comply with ecological protection standards, and key ecological issues will be identified and prioritized through ecological risk assessment.

For areas on the brink of dysregulation, such as Ganga and Kecai towns, it is key to strengthen ecological monitoring in order to detect and respond to early signs of ecological degradation. Develop ecological conservation plans that focus on soil and water conservation and biodiversity conservation, while promoting ecological agriculture and sustainable resource management, reducing pressure on ecosystems, and strengthening enforcement of environmental regulations.

Narrowly coordinated areas such as Kondo Township need to promote ecological restoration projects, such as revegetation of degraded land and water purification. Optimize land use planning, balance ecological protection and economic development needs, and support community participation and local autonomy to improve the initiative and effectiveness of ecological protection.

Primary coordination areas such as Wanmao Town should promote eco-friendly agricultural practices, such as organic farming and crop rotation. Strengthen ecological education and training to enhance the ecological protection capacity of local residents, and establish ecological reserves to protect key ecosystems and biodiversity.

Intermediate coordination areas such as Narang Town should continue to promote ecological protection projects, such as forest protection and wetland restoration. Promote ecotourism and environmental education, raise public awareness of ecological val-

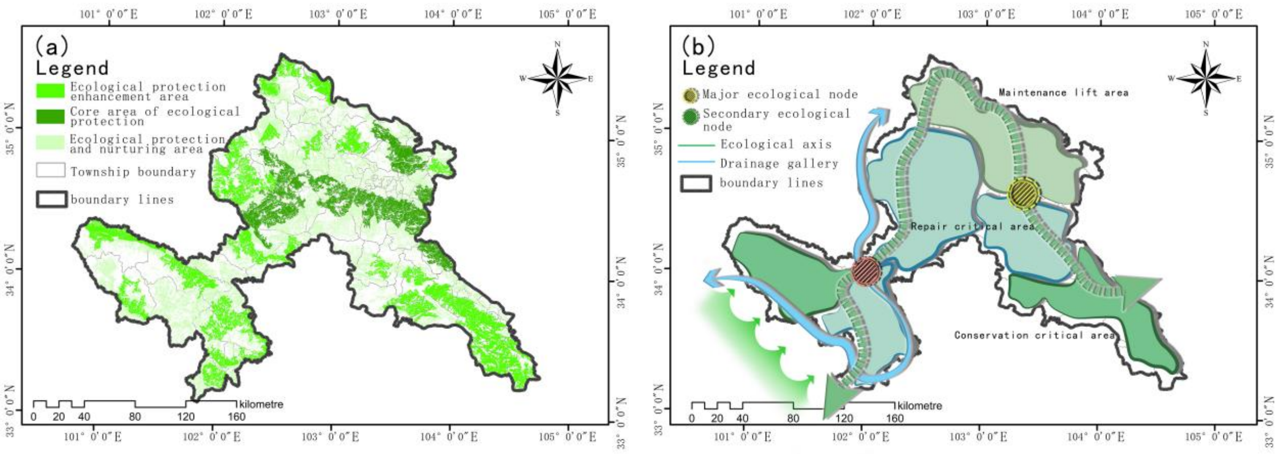

Figure 19 | (a) Ecological function zoning of Gannan Prefecture (b) Spatial landscape pattern planning of Gannan Prefecture

ues, and strengthen ecological infrastructure, such as ecological corridors and green transportation systems.

Well-coordinated areas such as Liulin Town should maintain and strengthen existing ecological protection measures to ensure the long-term stability of the ecosystem. Promote ecological innovation, such as the application of green technologies and sustainable materials, and establish ecological monitoring and evaluation systems to continuously track ecological conditions.

High-quality coordination areas such as Goye Town serve as models of ecological protection, demonstrating advanced ecological management and protection practices. Explore and implement eco-economic models, such as eco-agriculture and clean energy, and strengthen exchanges and cooperation with other regions to share successful experiences and technologies.

5.2. Ecological Function Zoning and Planning Management

The territorial spatial planning of Gansu Province aims to rationally divide various spatial functional areas, optimize spatial structure, improve the utilization efficiency of land and resources, protect the ecological environment, and promote sustainable economic and social development.

Combined with the previous studies in this study, the ecological function zoning and spatial pattern planning of Gannan Prefecture were proposed, as shown in Figure 19. 1) Regarding ecological function zoning, Gannan Prefecture is divided into three zones: core area of ecological protection, improved area of ecological protection and important area of ecological protection. The core area of ecological protection is the key area of environmental protection in Gannan Prefecture, and the strictest protection measures are implemented to ensure the integrity of the ecosystem and biodiversity; The ecological protection and improvement zone aims to improve the quality of ecological environment and promote regional sustainable development through scientific management and rational utilization; The important areas of ecological protection focus on protecting key ecological functions and important natural resources, maintaining ecological balance, and ensuring regional ecological security. 2) Gannan Prefecture formed an overall pattern of "two cores - two axes - three regions". The two cores are the main ecological development cores and the secondary ecological development cores in the key areas of ecological protection and ecological construction. The two axes are the green ecological protection axis and the Yellow River charm corridor axis; The three areas are the important protection area, the key restoration area and the maintenance and improvement area.

Ecological function zoning and landscape spatial pattern planning, through scientific division and effective management of territorial space, ensure key ecological functions, improve environmental quality, and promote the coordinated development of economy, society and ecological environment, is an important means to achieve sustainable development and build a harmonious coexistence between man and nature. These plans not only improve the modernization of ecological and environmental governance, but also support balanced development among regions, safeguard ecological security, provide strong support for comprehensive decision-making, and play a core role in high-quality development, ecological urbanization and ecological civilization construction.

6. Conclusions

This study adopts the comprehensive source points of Gannan according to local conditions to construct the ecological security pattern, and well combines the theory of "mountains, rivers, forests, fields, lakes, grasses and sand" to identify ecological problems, and then combines these two approaches to propose ecological restoration strategies for Gannan. This method breaks the traditional "ecological security pattern", which is a single identification space for ecological restoration, and innovates the all-dimensional ecosystem of "ecological security pattern - ecological problem identification", which is more suitable for Gannan Prefecture and increases the richness of the whole article. This study also put forward a comprehensive "point-line-surface" restoration strategy suitable for Gannan Prefecture. Therefore, theoretically speaking, this study enriches the theoretical methods of ecological space restoration; It also provides a more detailed and comprehensive perspective for ecological problem identification. Realistically, the evaluation system and ecological spatial restoration strategy of this study are helpful for Gannan Prefecture to formulate a more scientific and reasonable regional ecological development plan, promote the coordination and unification of ecological environment protection and restoration.

In addition, it is important to acknowledge the limitations of the study. 1) Data source and quality. Studies may be limited by the quality and coverage of available data. If data collection is incomplete or biased, the results of network analysis may not be accurate enough. 2) Subjectivity of index selection. Although the multi-index evaluation system is adopted, the selection of indicators may still be subjective. Different indicators may identify areas of different ecological problems, and which indicators to choose and how to weigh their importance may require further validation and discussion. 3) Long-term effects and dynamic changes. Studies may not adequately consider long-term dynamic effects and the dynamics of ecological restoration over time in order to predict future ecological spatial restoration so that it can be prevented in advance.

Declaration of Competing Interest

The authors declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

References

1. Lv J, Zhou W, 2023.Ecological Environmental Quality in China: Spatial and Temporal Characteristics, Regional Differences, and Internal Transmission Mechanisms.J. Sustainability.15(2071-1050), 3716.10.3390/su15043716
2. Lin J, Lin M, Chen W, Zhang A, Qi X, Hou H, 2021.Ecological risks of geological disasters and the patterns of the urban agglomeration in the Fujian Delta region.J. Ecological Indicators.125(1470-160X), 107475.10.1016/j.ecolind.2021.107475
3. Gao M, Hu Y, Bai Y, 2022.Construction of ecological security pattern in national land space from the perspective of the community of life in mountain, water, forest, field, lake and grass: A case study in Guangxi Hechi, China.J. Ecological Indicators.139(1470-160X), 108867.10.1016/j.ecolind.2022.108867
4. Dong J, Peng J, Liu Y, Qiu S, Han Y, 2020.Integrating spatial continuous wavelet transform and kernel density estimation to identify ecological corridors in megacities.J. Landscape and Urban Planning.199(0169-2046), 103815.10.1016/j.landurbplan.2020.103815
5. Hou Y, Liu Y, Wu Z, Zeng H, 2024.Construction of regional multi-scenario spatially balanced ecological security pattern based on self-organizing feature map: A case study of Guangzhou, China.J. Ecological Informatics.82, 102690.https://doi.org/10.1016/j.ecoinf.2024.102690
6. Qiao E, Reheman R, Zhou Z, Tao S, 2024.Evaluation of landscape ecological security pattern via the “pattern-function-stability” framework in the Guanzhong Plain Urban Agglomeration of China.J. Ecological Indicators.166, 112325.https://doi.org/10.1016/j.ecolind.2024.112325
7. Cao W, Li X, Lyu X, Dang D, Wang K, Li M, Liu S, 2024.To explore the effectiveness of various ecological security pattern construction methods in many growth situations in the future: A case study of the West Liaohe River Basin in Inner Mongolia.J. Science of The Total Environment.948, 174607.https://doi.org/10.1016/j.scitotenv.2024.174607
8. Wang B, Fu S, Hao Z, Zhen Z, 2024.Ecological security pattern based on remote sensing ecological index and circuit theory in the Shanxi section of the Yellow River Basin.J. Ecological Indicators.166, 112382.https://doi.org/10.1016/j.ecolind.2024.112382

9. Li B, Han L, Li L, 2024.Construction of ecological security pattern in combination with landslide sensitivity: A case study of Yan'an City, China.J. Journal of Environmental Management.366, 121765.https://doi.org/10.1016/j.jenvman.2024.121765
10. Liu X, Han Y, Li Y, Li L, Liu Y, 2024.Construction of ecological network in Daihai Basin based on ecological security pattern and ecological service accessibility.J. Ecological Frontiers.https://doi.org/10.1016/j.ecofro.2024.07.004
11. Wu S, Zhao C, Yang L, Huang D, Wu Y, Xiao P, 2024.Spatial and temporal evolution analysis of ecological security pattern in Hubei Province based on ecosystem service supply and demand analysis.J. Ecological Indicators.162, 112051.https://doi.org/10.1016/j.ecolind.2024.112051
12. Ding T, Chen J, Fang L, Ji J, 2024.Identifying and optimizing ecological security patterns from the perspective of the water-energy-food nexus.J. Journal of Hydrology.632, 130912.https://doi.org/10.1016/j.jhydrol.2024.130912
13. Jie Y, Shiying W, Jie Z, Jing Z, Wenliu Z, 2024.Optimisation of ecological security patterns in ecologically transition areas under the perspective of ecological resilience – a case of Taohe River.J. Ecological Indicators.166, 112315.https://doi.org/10.1016/j.ecolind.2024.112315
14. Bai H, Weng L, 2023.Ecological security pattern construction and zoning along the China-Laos Railway based on the potential-connectedness-resilience framework.J. Ecological Indicators.146, 109773.https://doi.org/10.1016/j.ecolind.2022.109773
15. Liu M, Peng J, Dong J, Jiang H, Xu D, Meersmans J, 2024.Trade-offs of landscape connectivity between regional and interregional ecological security patterns in a junction area of Beijing-Tianjin-Hebei region.J. Applied Geography.167, 103272.https://doi.org/10.1016/j.apgeog.2024.103272
16. Sun D, Wu X, Wen H, Ma X, Zhang F, Ji Q, Zhang J, 2024.Ecological Security Pattern based on XGBoost-MCR model: A case study of the Three Gorges Reservoir Region.J. Journal of Cleaner Production.470, 143252.https://doi.org/10.1016/j.jclepro.2024.143252
17. Pan J, Liang J, Zhao C, 2023.Identification and optimization of ecological security pattern in arid inland basin based on ordered weighted average and ant colony algorithm: A case study of Shule River basin, NW China.J. Ecological Indicators.154, 110588.https://doi.org/10.1016/j.ecolind.2023.110588
18. He H, Yu X, Yu H, Ma Z, Luo Y, Liu T, Rong Z, Xu J, Chen D, Li P, Yuan F, Zhao Y, 2024.Suitable habitat evaluation and ecological security pattern optimization for the ecological restoration of Giant Panda habitat based on nonstationary factors and MCR model.J. Ecological Modelling.494, 110760.https://doi.org/10.1016/j.ecolmodel.2024.110760
19. Zeng W, He Z, Bai W, He L, Chen X, Chen J, 2024.Identification of ecological security patterns of alpine wetland grasslands based on landscape ecological risks: A study in Zoigê County.J. Science of The Total Environment.928, 172302.https://doi.org/10.1016/j.scitotenv.2024.172302
20. Chen Z, Lin J, Huang J, 2023.Linking ecosystem service flow to water-related ecological security pattern: A methodological approach applied to a coastal province of China.J. Journal of Environmental Management.345, 118725.https://doi.org/10.1016/j.jenvman.2023.118725
21. Chen D, Guo K, Zeng W, Wang F, Li L, Jin X, 2023.Study on the spatial–temporal patterns and evolution characteristics of ecological security based on dynamic evaluation in the Three Gorges Reservoir Area.J. Ecological Indicators.151, 110297.https://doi.org/10.1016/j.ecolind.2023.110297
22. Zhang Y, Yang R, Sun M, Lu Y, Zhang L, Yin Y, Li X, 2024.Identification of spatial protection and restoration priorities for ecological security pattern in a rapidly urbanized region: A case study in the Chengdu–Chongqing economic Circle, China.J. Journal of Environmental Management.366, 121789.https://doi.org/10.1016/j.jenvman.2024.121789
23. Zhang Z, Hu B, Jiang W, Qiu H, 2023.Construction of ecological security pattern based on ecological carrying capacity assessment 1990–2040: A case study of the Southwest Guangxi Karst - Beibu Gulf.J. Ecological Modelling.479, 110322.https://doi.org/10.1016/j.ecolmodel.2023.110322
24. Gao M, Hu Y, Bai Y, 2022.Construction of ecological security pattern in national land space from the perspective of the community of life in mountain, water, forest, field, lake and grass: A case study in Guangxi Hechi, China.J. Ecological Indicators.139, 108867.https://doi.org/10.1016/j.ecolind.2022.108867
25. Wang J, Bai Y, Huang Z, Ashraf A, Ali M, Fang Z, Lu X, 2024.Identifying ecological security patterns to prioritize conservation and restoration：A case study in Xishuangbanna tropical region, China.J. Journal of Cleaner Production.444, 141222.https://doi.org/10.1016/j.jclepro.2024.141222
26. Ran Y, Lei D, Li J, Gao L, Mo J, Liu X, 2022.Identification of crucial areas of territorial ecological restoration based on ecological security pattern: A case study of the central Yunnan urban agglomeration, China.J. Ecological Indicators.143, 109318.https://doi.org/10.1016/j.ecolind.2022.109318
27. Jiang H, Peng J, Xu D, Tang H, 2024.Constructing ecological security patterns with differentiated management intensity based on multifunctional landscape identification and multi-criteria decision-making.J. Global Ecology and Conservation.50, e2862.https://doi.org/10.1016/j.gecco.2024.e02862
28. Wang L, Zhao J, Lin Y, Chen G, 2024.Exploring ecological carbon sequestration advantage and economic responses in an ecological security pattern: A nature-based solutions perspective.J. Ecological Modelling.488, 110597.https://doi.org/10.1016/j.ecolmodel.2023.110597
29. Lan Y, Wang J, Liu Q, Liu F, Liu L, Li J, Luo M, 2024.Identification of critical ecological restoration and early warning regions in the five-lakes basin of central

Yunnan.J. Ecological Indicators.158, 111337.https://doi.org/10.1016/j.ecolind.2023.111337
30.Yang M, Wang Z, Zhang Z, Chen P, Zhao D, Cheng E, Wang C, Yan Y, 2024.Pathways for ecological restoration of territorial space based on ecosystem integrity: A case study of approach to protecting and restoring mountains, rivers, forests, farmlands, lakes, and grasslands in Beijing, China.J. Ecological Frontiers.https://doi.org/10.1016/j.ecofro.2024.07.003
31.Liu F, Lin B, Meng K, 2023.Green space settlement landscape optimization strategy under the concept of ecological environment restoration.J. Journal of King Saud University - Science.35(3), 102539.https://doi.org/10.1016/j.jksus.2023.102539
32.Chen Y, Xu F, 2022.The optimization of ecological service function and planning control of territorial space planning for ecological protection and restoration.J. Sustainable Computing: Informatics and Systems.35, 100748.https://doi.org/10.1016/j.suscom.2022.100748
33.Zhao Y, Liu S, Liu H, Wang F, Dong Y, Wu G, Li Y, Wang W, Phan Tran L, Li W, 2024.Multi-objective ecological restoration priority in China: Cost-benefit optimization in different ecological performance regimes based on planetary boundaries.J. Journal of Environmental Management.356, 120701.https://doi.org/10.1016/j.jenvman.2024.120701
34.Yu K, Duan C, Chen B, Song D, Su R, Yang X, 2024.Ecological restoration effectiveness assessment based on social media analytics: A case study of Yongding River, China.J. Journal of Cleaner Production.448, 141604.https://doi.org/10.1016/j.jclepro.2024.141604
35.Wang Y, Ge J, Zhang Y, Lu J, Zhang Y, Ma F, 2024.Health assessment of the current situation of rivers and discussion on ecological restoration strategies: A case study of the Gansu province section of the Bailong river.J. Ecological Indicators.163, 112038.https://doi.org/10.1016/j.ecolind.2024.112038
36.Chen W, Gu T, Xiang J, Luo T, Zeng J, Yuan Y, 2024.Ecological restoration zoning of territorial space in China: An ecosystem health perspective.J. Journal of Environmental Management.364, 121371.https://doi.org/10.1016/j.jenvman.2024.121371
37.Han B, Jin X, Xiang X, Rui S, Zhang X, Jin Z, Zhou Y, 2021.An integrated evaluation framework for Land-Space ecological restoration planning strategy making in rapidly developing area.J. Ecological Indicators.124, 107374.https://doi.org/10.1016/j.ecolind.2021.107374
38.Wu L, Ouyang Y, Cai L, Dai J, Wu Y, 2023.Ecological restoration approaches for degraded muddy coasts: Recommendations and practice.J. Ecological Indicators.149, 110182.https://doi.org/10.1016/j.ecolind.2023.110182
39.Dong Z, Bian Z, Jin W, Guo X, Zhang Y, Liu X, Wang C, Guan D, 2024.An integrated approach to prioritizing ecological restoration of abandoned mine lands based on cost-benefit analysis.J. Science of The Total Environment.924, 171579.https://doi.org/10.1016/j.scitotenv.2024.171579
40.Han Y, Zhao W, Zhou A, Pereira P, 2023.Water and wind erosion response to ecological restoration measures in China's drylands.J. Geoderma.435, 116514.https://doi.org/10.1016/j.geoderma.2023.116514
41.Tang B, Wang H, Liu J, Zhang W, Zhao W, Cheng D, Zhang L, Jiao L, 2024.Identification of ecological restoration priority areas integrating ecological security and feasibility of restoration.J. Ecological Indicators.158, 111557.https://doi.org/10.1016/j.ecolind.2024.111557
42.Duan J, Fang X, Long C, Liang Y, Cao Y E, Liu Y, Zhou C, 2022.Identification of Key Areas for Ecosystem Restoration Based on Ecological Security Pattern.J. Sustainability.14(2071-1050), 15499.10.3390/su142315499
43.Zou S, Qian J, Xu B, Tu Z, Zhang W, Ma X, Liang Y, 2022.Spatiotemporal changes of ecosystem health and their driving mechanisms in alpine regions on the northeastern Tibetan Plateau.J. Ecological Indicators.143(1470-160X), 109396.10.1016/j.ecolind.2022.109396