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Ecological Security of Desert–Oasis Areas in the Yellow River Basin, China

Yuanyuan Liu [1], Caihong Ma [1,*], Zhonghua Yang [1] and Xin Fan [2,3]

[1] School of Geography and Planning, Ningxia University, Yinchuan 750021, China; 12022130985@stu.nxu.edu.cn (Y.L.); yzhzxrs@163.com (Z.Y.)
[2] School of Public Administration, China University of Geosciences, Wuhan 430074, China; fanfx8@cug.edu.cn
[3] Center for Turkmenistan Studies, China University of Geosciences, Wuhan 430074, China
* Correspondence: mchyanni@nxu.edu.cn

Abstract: The desert–oasis interaction zone plays a crucial role in safeguarding oasis ecological security and maintaining stability within oases. This paper proposed a framework of EN-DSS, based on long-term remote sensing data and fundamental data, adopted morphological spatial pattern analysis (MSPA) and Linkage Mapper among other methods, and it took Lingwu City in the Ningxia Hui Autonomous Region, which is located in the desert–oasis interaction zone in the upper reaches of the Yellow River, as a case study. The results indicate the following: since 1995, this desert–oasis system has exhibited the characteristics whereby the oasis is expanding eastward and the desert is significantly receding. The vegetation coverage has improved overall, forming an ecological security pattern characterized predominantly by shrub forests, which is referred to as the "one core, two corridors, three zones, and multiple clusters" pattern. This pattern has significantly reduced the risk of wind and sand erosion in the agricultural irrigation areas along the Yellow River. However, the construction of this ecological security pattern still faces challenges, including high construction and maintenance costs and the need to enhance the network's quality. In the future, it will be necessary to strengthen the integrated ecological network construction of ecological areas, agricultural areas, and urban areas to enhance the stability of this regional ecological network system.

Keywords: morphological spatial pattern analysis (MSPA); circuit theory; ecological security; desert oasis zone

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1. Introduction

The sustainable development of human–land relations in oasis–desert interaction areas is a dilemma in the world. How should the balance between disturbance and construction in these desert–oasis areas be dealt with? In recent years, we have made tremendous progress in enhancing desert–oasis interactions. For example, Sun et al. [1] simulated the history of desert–oasis ecozone change; Liu et al. [2] and Li et al. [3] studied the evolutionary mechanism of oasis–desert interactions; Ji et al. [4] conducted research on the identification of the width of the transition zone between desert and oasis; An et al. [5] conducted research on the quantification of the stability of desert–oasis systems in ecological zones; and Raffaele et al. [6] examined the ways in which climate change and human activities can transform desert landscapes into oases. As an important natural barrier, the desert–oasis interaction area plays an important role in ensuring the ecological security of an oasis, maintaining the stability of agricultural production in an oasis, and protecting the safety of an oasis habitat. An ecological network refers to a model that describes the interactions and connections between species in an ecosystem [7]. Due to the important value of ecological networks in ecological construction, the study of regional ecological security patterns from the perspective of ecological networks has attracted academic attention [8,9]. At present, the research paradigm of "identification of ecological source—construction of resistance surface—extraction of ecological corridor" has been basically proposed. In terms of ecological source identification, the method of combining MSPA with the ecological protection red line [10] and the method of directly using nature reserves as ecological sources [11] are mainly used. In terms of ecological corridors, methods such as minimum cumulative resistance (MCR) [12] and Linkage Mapper [13] have been used to identify species' migration paths, and on this basis, a gravity model [14], the atlas theory [15], and other methods have been used to analyze the importance of corridors, to form ecological networks, and to propose optimization and improvement schemes [16]. However, there are few studies on the ecological security pattern of desert–oasis interaction areas based on the ecological network perspective.

There are four types of human–land relationships in desert–oasis interaction areas: green line into sand line, sand line into green line, tug of war, and relatively stable boundary. Lingwu City belongs to a desert–oasis area. It has experienced events ranging from oasis construction to desertification control, showing a comprehensive development pattern for agricultural areas, ecological areas, and energy areas. This paper aims to reply to two questions: what kind of situation is the desert–oasis ecosystem in Lingwu City under complex land consolidation and development activities? What are the challenges to the healthy and sustainable development of this desert–oasis ecosystem? The contents of this paper are arranged as follows: (1) a description of the evolutionary characteristics of Lingwu's territorial space development pattern; (2) a description of the temporal and spatial characteristics of habitat quality change in Lingwu City; and (3) a description of the construction of the ecological network security pattern in Lingwu City. The objective of this study is to explore the ecological network security construction in this desert–oasis interaction area to provide a reference for its territorial space governance.

2. Methods and Data

2.1. Study Area

Lingwu City is located between 106°11′~106°52′ E and 37°35′~38°21′ N, with a total area of 3846 km^2 (Figure 1).

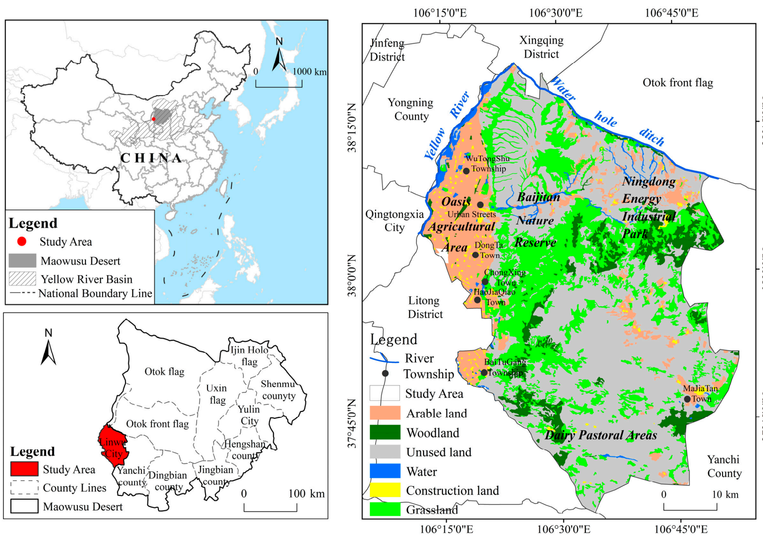


Figure 1. Scope of the study area (produced based on the base map of a standard map with the reference number GS(2023)2763), which was download from the standard map service website of the Ministry of Natural Resources of the People's Republic of China (http://bzdt.ch.mnr.gov.cn/ (accessed on 28 September 2023)). No modifications were made to the base map, the same below.

Lingwu City is located on the eastern side of the Yellow River and on the western side of the Mu Us Desert. It has a temperate continental monsoon climate that is characterized by dryness, limited rainfall, and high evaporation rates, making its ecological foundation fragile. The western part of Lingwu City is a traditional oasis agricultural area. In the past, the Mu Us desert expanded at a speed of 5 to 7 m per year to the west, and the Yellow

River annually transported 100 million tons of yellow sand, which was equivalent to the load of seven 20-ton trucks per minute. Since the 1960s, the region has vigorously explored the mode of desert forest preservation and control. In 1995, there was a large amount of desertified land on the edge of this oasis agricultural area. To combat the adverse effects of the Mu Us Desert on the agricultural region, the Baiji Beach Nature Reserve was established on the eastern edge of the agricultural area. Lingwu City is rich in coal resources. In 2008, the development of an energy industrial zone commenced in the eastern part of the city. With adjustments in the agricultural industry structure, starting from 2020, a dairy industry zone has been initiated in the southern part of the city.

2.2. Methodology

2.2.1. Design of EN-DSS Framework in Ecological Security

For the desert–oasis area, how to coordinate the development of land resources and ecological protection is an important problem that must be solved by decision makers. Based on the concept of DSS, the framework of a land ecological security decision support system based on an ecological network was constructed to provide an auxiliary decision for the optimal allocation of land resources and ecological security construction in ecologically fragile areas [17]. The decision system consists of three modules: data acquisition, ecological network model operation, and auxiliary decision making. Among them, the data acquisition module can increase the required data options according to the actual situation in different regions. According to the theory of "patch-corridor-matrix" in landscape ecology, the ecological network operation module is composed of three sub-modules: ecological network components, an ecological network model, and ecological network evaluation. In the decision module, there are three auxiliary decision sub-modules, namely, elements, structure, and function, which can be selected according to the research needs (Figure 2).

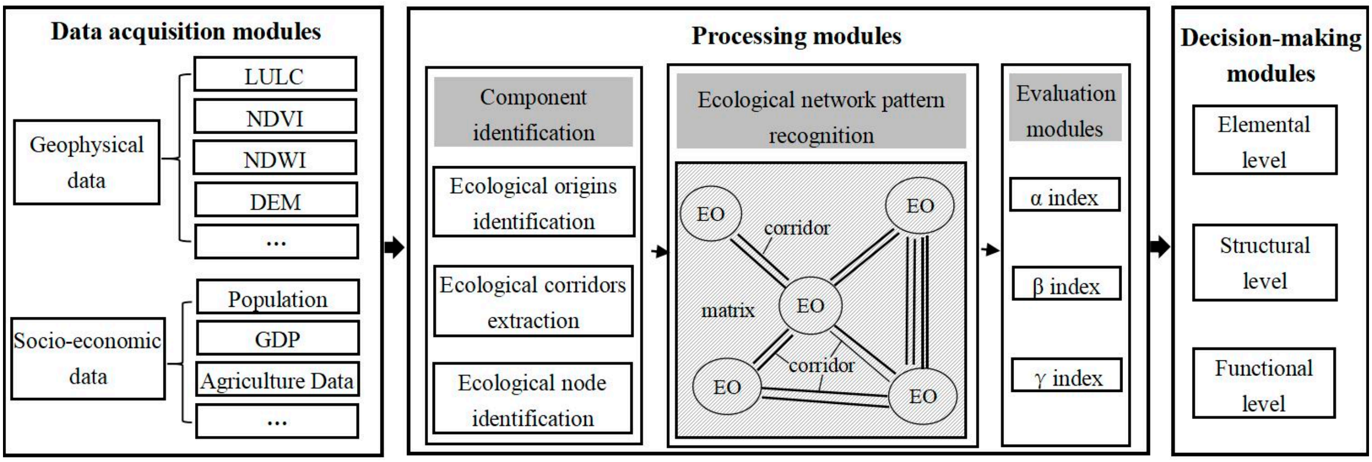


Figure 2. The framework of EN-DSS based on the ecological network. (EO: Ecological origins).

2.2.2. Ecological Network Analysis Method

1. Source site identification includes steps such as habitat quality assessment, MSPA core area recognition, energy factor calculation, and so on.

a. InVEST Model for Habitat Quality Assessment

The habitat quality module of the InVEST model primarily quantitatively assesses the habitat quality within a study area based on land-use data and stressor factors [18]. The analysis principles and formulas are as follows [19]:

$$Q_{xj} = H_j \times \frac{D_{xj}^z}{D_{xj}^z + k^z} \tag{1}$$

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{W_r}{\sum_{r=1}^{R} W_r} \right) \times r_y i_{rxy} \beta_x S_{jr} \tag{2}$$

In the formula, Q_{xj}, H_j, D_{xj}^z, and D_{xj} represent the habitat quality of ground class J at spatial raster cell x, habitat suitability, habitat stress level, and habitat degradation, respectively; k is the semi-saturation coefficient, whose typical value is one half of D_{xj}; r is the stress factor; R, W_r, and Y_r represent the number of stress factors, the proportion of stress factors, and the number of stress factor rasters, respectively; i_{rxy}, r_y, S_{jr}, and β_x represent the influence of the stress factors on habitat quality, the intensity of the stress factors, the sensitivity of ground type J to stress factor R, and the influence of policy and law, respectively. The relevant literature [20,21] was consulted, and field surveys were conducted according to the InVEST model's user manual to obtain weighted average scores from experts in various fields, such as ecology and mineral development. These scores were used to determine the model's impact distance, habitat suitability, and threat source sensitivity. Throughout the analysis process, multiple adjustments were made in consideration of the actual conditions. The habitat quality was categorized into five levels for each year: low (0, 0.005], relatively low (0.005, 0.41], moderate (0.1, 0.6], relatively high (0.6, 0.8], and high (0.8, 0.1], as described in the consulted references.

b. Morphological spatial pattern analysis (MSPA)

Cultivated land and construction land are the types of land uses characterized by intensive impacts of human activities, which are not conducive to species migration. In general, woodland, grassland, and water are used as alternative types of ecological sources. According to reference [22], the ecosystem service value of cultivated land, forest land, water bodies, and grassland in Lingwu City is 1537.35 yuan/hm^2, 1311.30 yuan/hm^2, and 584.94 yuan/hm^2, respectively. Obviously, the ecological service value per unit area of grassland is very low, mainly because the main type of grassland in this region is desert grassland; thus, grassland was not taken as an alternative type of ecological source. Forest land and water bodies were selected as the foreground data and assigned a value of 2, while the value of other land ecological services was lower and was assigned a value of 1, with their data being used as the background data [23]. For more information, readers are referred to the Guidelines for Using the Guidos Toolbox [24–26]. After multiple simulations, the settings were determined as follows: edge width was set to 1, transition was set to 1, intext was set to 0, and foreground connectivity was set to 4. These settings were used to calculate the distribution of various landscape types in the city of Lingwu. The meanings and thresholds of each landscape type, as well as the area and percentage of each landscape type within the study area, can be found in the table below (Table 1).

c. Method for Ecological Source Site Classification

Different ecological source sites correspond to different ecological energy levels. Depending on the ecological energy level, the normalized difference vegetation index (NDVI) and normalized difference water index (NDWI) are used to describe the characteristics of different ecological source sites. The formula is as follows [10]:

$$P_i = A_i N_{ir} \tag{3}$$

In the formula, A_i represents the patch area of the ecological source land and N_{ir} represents the r-th normalization index of the i-th ecological source land patch, with r taking the value of 1 or 2. N_{i1} represents the vegetation index of the i-th patch, while N_{i2} represents the water index of the i-th plaque. The larger the value of P_i, the greater the ecological energy.

Table 1. MSPA landscape types and meanings.

Type of Landscape	Meanings	Threshold	Area/hm^2	Percentage of the Study Area/%
Core	Large habitat patches can provide substantial habitats for species and serve as ecological source sites.	17/117	186.37	4.85
Perforation	The transition zone between the core zone and the non-green landscape patch, i.e., the inner patch edge, has an edge effect.	5/105	7.24	0.19
Islet	The degree of connection is low, the internal matter and energy are less likely to communicate and transfer, and the isolated and broken small patches are not connected.	9/109	19.98	0.52
Edge	Transition areas between the core areas and the predominantly non-green landscape areas.	3/103	87.11	2.26
Loop	The corridors connecting the unified core area are small in scale and have low connectivity to the surrounding natural patches.	65/165	1.28	0.03
Bridge	The narrow and long area connecting the core area is of great significance for biological migration and landscape connection.	33/133	3.79	0.10
Branch	Only one end is connected to other landscape types.	11/101	0.15	0.00004

2. Ecological Corridor Extraction Method

a. Circuit Theory Model. According to the characteristics of electrons randomly wandering in circuits, the Circuit Theory Model can simulate the process of species and biotic flow migration in heterogeneous landscapes [27]. Based on the research conducted in similar ecological environment areas [28,29], the resistance factor index system was adopted, and the mean value method was used to assign factor weights (Table 2).

Table 2. Ecological resistance index system in Lingwu City.

Drag Factor	Index	Drag Coefficient	Weight	Drag Factor	Index	Drag Coefficient	Weight
NDVI	<0.03	80	0.25	Type of land use	Construction land	110	0.25
	[0.03, 0.11)	70			Arable land and unused land	70	
	[0.11, 0.16)	60					
	[0.16, 0.23)	50			Grassland	30	
	[0.23, 0.34)	40			Water	20	
	[0.34, 0.45]	30			Woodland	10	
	>0.45	20		MSPA landscape type	Core	10	0.25
Distance from the road (m)	<800	240	0.25		Bridge	20	
	[800, 2100)	220			Loop	30	
	[2100, 3600)	180			Branch	40	
	[3600, 5100)	140			Islet	50	
	[5100, 6900)	100			Edge	70	
	[6900, 8900]	60			Perforation	90	
	>8900	30			Background	100	

b. Modified gravity model. The importance of ecological corridors is determined by employing an improved gravity model [29]. In academic research, calculations are often based on the area of the source patches [11]. The energy factor is used to calculate the magnitude of gravitational attraction in the source area. The modified formula is as follows [10]:

$$F = \frac{\frac{P_i}{P_{\max}} \times \frac{P_j}{P_{\max}}}{\left(\frac{L_{ij}}{L_{\max}}\right)^2} \tag{4}$$

In the formula, F represents the interaction force between patches i and j; P_i and P_j are the energy factors of ecological source patches i and j, respectively; $P_{\max}$ represents the maximum energy factor in the ecological source patches; L_{ij} represents the cumulative resistance value between patches I and j; and $L_{\max}$ represents the maximum cumulative resistance value among all corridors between the patches in the study area.

3. Identification of Ecological Nodes and Ecological Breakpoints

Ecological nodes play an auxiliary role in optimizing the ecological network structure in the study area. The number and the area of these nodes influence the length of the biological migration cycle within the ecological corridors. The distribution pattern of these nodes affects the stability and circulation of the ecological network structure, making them crucial elements for ecological network optimization. The Linkage Mapper model was employed to extract potential ecological corridors, and hydrological analysis was conducted to extract ridge lines. By intersecting the main transportation corridors with potential ecological corridors, this study identifies ecological breakpoints, which can provide a reference for transportation road planning and the establishment of ecological corridors within the study area [30].

2.2.3. Evaluation of Ecological Network Connectivity

The patch connectivity of the ecological network was evaluated by using the index of ecological network closure (α), the degree of connectivity of the ecological network (β), and the connectivity rate of the ecological network (γ). The formula is as follows [31]:

$$\alpha = (L - V + 1)/(2V - 5) \tag{5}$$

$$\beta = L/V \tag{6}$$

$$\gamma = L/3(V - 2) \tag{7}$$

In the formula, L is the number of corridors; V is the number of nodes; α ranges from 0 to 1, with a higher value indicating more alternative paths; β is between 0 and 3, and the higher the value, the higher the network complexity; γ is between 0 and 1, and the larger the value, the better the connection between a node and a corridor.

2.3. Data Source

The data sources used in this study included Landsat 8 OLI remote sensing imagery data, the data of a digital elevation model (DEM), and the data on road networks and water systems (Table 3). Some vector data were obtained based on literature vectorization. The access time of the different types of data was 31 July 2020. The space reference was WGS_1984_UTM_Zone_48N.

Table 3. Information on the different types of data used in this study.

Data Name	Source	Resolution
Digital elevation model data	http://www.gscloud.cn/ (accessed on 4 May 2023)	30 m
Road and water system data	https://www.webmap.cn/ (accessed on 26 June 2023)	1:250,000
Land-use raster data for 1995 and 2020	http://www.resdc.cn/ (accessed on 1 May 2023)	30 m
Normalized difference water index	Obtained by remote sensing image data calculation	-
Normalized difference vegetation index	https://www.nesdc.org.cn (accessed on 25 July 2023)	30 m
Administrative division vector data	https://www.webmap.cn/ (accessed on 1 May 2023)	1:250,000

3. Results

3.1. Temporal and Spatial Changes of Land Use

Between 1995 and 2020, there were significant changes in land-use types in Lingwu City (Table 4). The most notable change was the conversion of grassland to arable land, with a total area of 69.67 km^2, accounting for 4.82% of the total grassland area. Upon examination, this change was most pronounced in the central and western regions of Baiji Beach. After years of governance, ecologically used land has been effectively utilized for agricultural development. This indicates that the management of ecologically used land not only promotes ecological development but also stimulates the development of agricultural land. The second significant change was the conversion of construction land to arable land, with a transferred area of 30.09 km^2. This change was mainly observed in the oasis agricultural areas, where some fragmented pieces of construction land were developed into arable land through governance. This transformation has led to the formation of a typical agricultural area in the northwest along the Yellow River in Lingwu City. The areas converted from the water body, forest land, and unused land to arable land were relatively small but still noteworthy. Additionally, there was an area of 3.33 km^2 where arable land was converted to construction land. This was primarily due to the construction of natural reserves and the development of the Ningdong Energy Base, leading to further contraction of scattered dryland in the eastern region. This shift has caused the focus of agricultural development to tilt further toward the western area along the Yellow River irrigation district.

Table 4. Land-use-type transfer matrix from 1995 to 2020 in Lingwu City.

Land Use Type	Arable Land	Woodland	Construction Land	Water	Grassland	Unused Land	1995
Arable land	305.04	1.51	30.09	3.51	69.67	0.43	410.25
Woodland	1.15	152.01	15.40	3.29	4.86	21.18	197.89
Construction land	3.33	0.08	38.66	0.12	0.38	0.05	42.62
Water	7.72	0.04	2.75	29.62	4.08	5.78	49.99
Grassland	57.38	10.80	38.01	7.04	75.23	517.97	706.43
Unused land	58.67	50.99	116.98	14.49	1289.68	43.27	1574.08
2020	433.29	215.43	241.89	58.07	1443.9	588.68	2981.26

Unit: km^2.

In 1995, the western part was an oasis agricultural zone, with scattered dryland in the central and eastern areas, along with significant expanses of grassland and unused land. With the vigorous implementation of policies such as urban–rural integration and rural revitalization, rapid industrialization and urbanization led to the rapid expansion of residential land, primarily in the form of urban and industrial land, with the main expansion areas being the urban area of Lingwu City and the Ningdong Energy and Industrial Zone. By 2020, a basic pattern had formed with the western region as an oasis eastern zone, the central area as a nature reserve, the eastern part as an energy industrial zone, and the southern part as a dairy production pastoral zone. This represented a significant optimization of land spatial functional zoning (Figure 3).

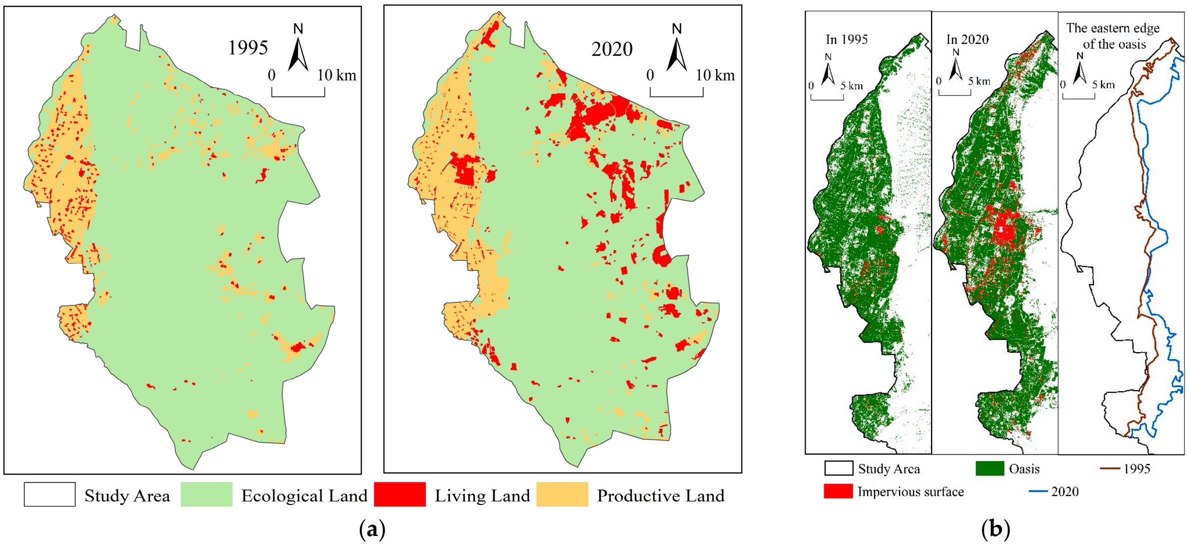


Figure 3. Map of land-use pattern and oasis line change: (**a**) land-use pattern; (**b**) oasis line change.

Over the study period, there was an overall expansion of production land. Among the areas converted into production land, the dynamic analysis of the oasis boundary, which is composed mainly of irrigated land, shows that from 1995 to 2020, the oasis had obvious eastward expansion, and the expansion was most obvious in the northeast and southeast. This result reflects that the desertification of nature reserves has been greatly improved through ecological construction and development, and the interactive boundary between the eastern edge of the oasis and the desert shows an eastward expansion trend. The expansion of the northeast and southeast sections of the oasis is more significant. The extent of sandy land has shrunk significantly. By examining the 1995 land-use-type map, it can be observed that the converted area was previously sandy terrain, and its current state is the result of several years of ecological environmental conservation and protection efforts.

3.2. Spatial–Temporal Variation Characteristics of Habitat Quality in Land and Space

From 1995 to 2020, the habitat quality in Lingwu City improved significantly, but there were obvious spatial differentiation characteristics (Figure 4).

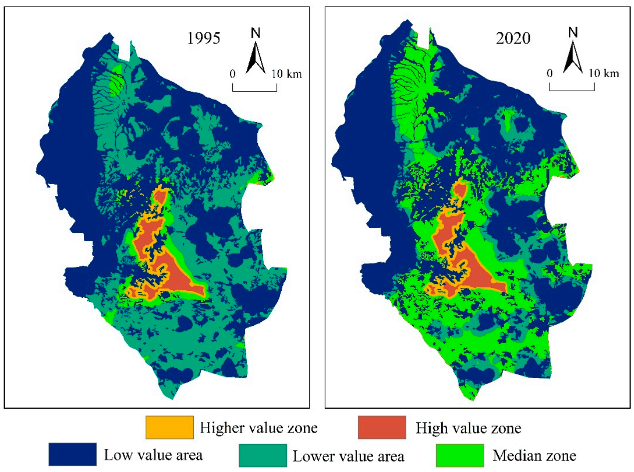
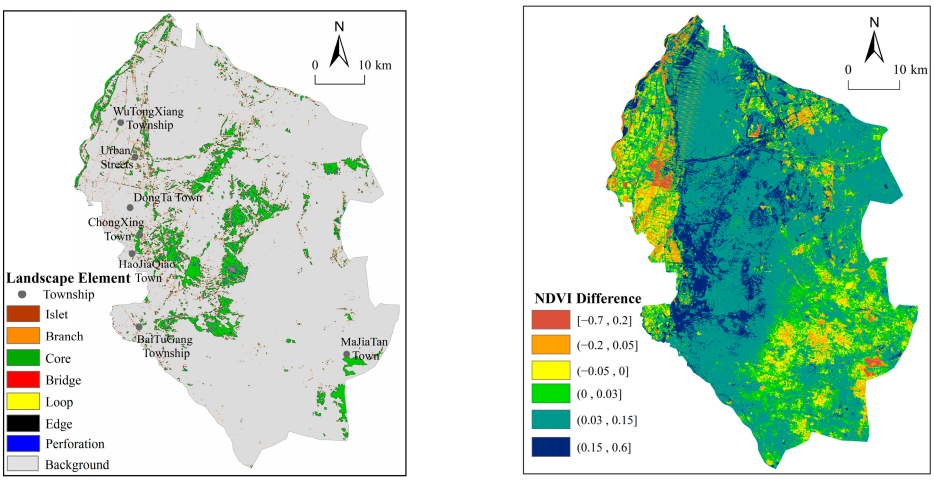


Figure 4. Spatial distribution map of habitat quality grades in different years in Lingwu City.

The overall ecological quality in the study area remained relatively stable, displaying a gradual decrease from the center outward. Areas with a high-value ecological quality were predominantly found in the central part of Lingwu City and were characterized by limited human activities and a prevalence of grassland and forested land-use types. These areas exhibited a significantly higher ecological quality compared to other regions. Areas with moderately high ecological quality were mainly situated around the high-value ecological zones, while areas with intermediate ecological quality had a broader distribution, primarily within the Baiji Tan Nature Reserve. Areas with a low-value ecological quality were primarily located in the western region of Lingwu City, including the oasis agricultural area and in the eastern energy industrial zone. These areas featured a substantial concentration of residential lands, urban lands, and industrial lands, accompanied by frequent human activities, leading to a generally lower ecological quality throughout the region. In general, from 1995 to 2020, the ecological quality of the central region improved significantly, effectively curbing the ecological threat of the Mu Us Desert to agricultural areas.

3.3. Characteristics of Ecological Network Security Pattern

According to the NDVI interpolation from 1995 to 2020, the places with a high vegetation coverage in Lingwu City in 2020 had a higher agreement with the ecological patches obtained using MSPA. The size of the ecological patches was sorted according to the capacity factors, and a total of 297 patches with a cumulative contribution rate greater than 85% were calculated, in which the ecological patches with an energy factor threshold greater than 1 [32] were formed into 30 clusters as the ecological sources. These ecological sources were mainly composed of shrub lands or lakes. According to the energy factors of the ecological sources [28], 6 first-grade sources, 9 second-grade sources, and 15 third-grade sources were obtained. The ecological corridors were composed of river ecological corridors and the corridors were extracted using the circuit theory model. Except for the river ecological corridor, the other ecological corridors mainly took the desert steppe base as the main body and had a low ecological quality. Considering the importance of rivers in ecological security, the Yellow River and Shuidonggou were taken as the first-level ecological corridors, the other 55 important corridors with a cumulative contribution rate of more than 80% were taken as the second-level corridors, and the remaining 9 ecological corridors [33] were taken as the third-level corridors. These ecological sources were concentrated in the nature reserve and had an obvious crossover with the oasis and the energy area. The study found that there were many ecological nodes and ecological break points. Among them, there were 36 ecological nodes and 62 ecological fracture points (Figure 5).



(**a**) (**b**)

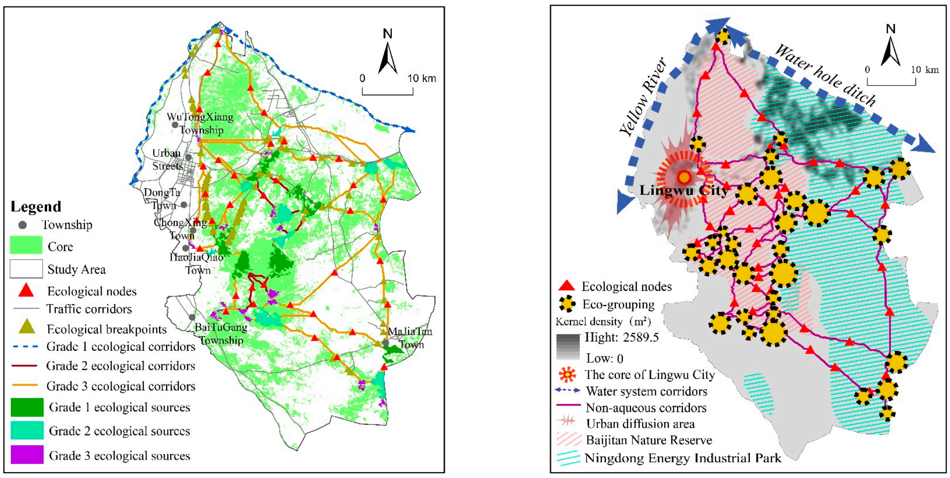
Figure 5. MSPA landscape index analysis results and NDVI difference: (**a**) MSPA landscape pattern, and (**b**) NDVI difference during the years 1995–2020.

The ecological break points were avoided by setting overpasses and underpasses [34], and the ecological network was optimized by laying ecological stepping stones [35] at the ecological nodes. After optimization, the α, β, and γ index values of the ecological network all increased significantly (Table 5).

Table 5. Comparison of ecological network connectivity indicators before and after optimization.

Index	1st Ecological Network		2nd Ecological Network		3rd Ecological Network	
	Before Optimization	**After Optimization**	**Before Optimization**	**After Optimization**	**Before Optimization**	**After Optimization**
α index	0.50	0.71	0.67	0.71	0.74	0.80
β index	1.50	1.67	2.00	2.08	2.25	2.35
γ index	0.75	0.83	0.79	0.82	0.83	0.87

Through decades of ecological construction, Lingwu City has formed the following ecological network pattern (Figure 6a).



(**a**) (**b**)

Figure 6. Distribution map of ecological network and ecological security pattern of Lingwu City in 2020: (**a**) ecological network and (**b**) ecological security pattern.

Under the principle of mutualism and coordinated development [36] and in accordance with the idea of "overall layout and key protection", an ecological security pattern of "one core, two corridors, three districts and multiple groups" is proposed (Figure 6b): the central urban area of Lingwu City is the "one core", and the Yellow River corridor and Shuidonggou corridor are the main water corridors. The agricultural area, energy area, and nature reserve are the "three areas", while shrub lands and water bodies are the high-quality sources that form "multiple ecological clusters".

4. Discussion and Conclusions

4.1. Discussion

1. Evolution situation of desert–oasis interaction zone

The harmonious development of human–land relationships in oasis–desert interaction areas is a worldwide problem. An oasis line refers to the boundary line of an oasis, which is one of the important indicators of the evolution of a desert–oasis ecosystem. It has four prominent types: green line into sand line, sand line into green line, tug of war, and relatively stable border. This study found that during the study period, Lingwu City was in a state where the green line was advancing, whereas the sand line was retreating. Since the 1990s, mainly through afforestation and grass grid sand fixation, 680,000 mu of windbreak and sand-fixing shrubs were built, and nearly one million mu of quicksand area was controlled, which significantly inhibited the southward movement and westward expansion of the Mu Us Desert. As a result, the oasis line continued to advance toward the desert direction, which was more prominent in the northeast and southern sections of the oasis, and the advancing distance of the southern section was 5–6 km. In addition, the vegetation coverage improved significantly, especially in the central nature reserve, which reduced the risk of the oasis ecosystem being assaulted by wind and sand. The sandy land shrunk, and the distance between the desert and the Yellow River retreated by nearly 20 km. This has effectively prevented the desertification process of the land and protected the development of the oasis agricultural area.

2. Challenges of ecological network security construction in desert–oasis area

How to construct ecological networks to coordinate the development of desert–oasis areas is an urgent issue. Under the framework of EN-DSS, an ecological security pattern is constructed to form an ecological network system with shrubland as the main body in Lingwu city. It shows that the framework of the land-use decision support system is feasible. However, the stability of the developed ecological network in Lingwu City is sensitive, and the construction and maintenance costs of ecological security still face many challenges. Zhao et al. [37] have pointed out that the costs are high for ecological restoration projects. The ecological source area in Lingwu City is mainly distributed in the central shrub forest area, and the spatial pattern of the ecological network is unbalanced and unstable, with many ecological nodes and ecological break points. How to effectively associate shrubland in nature reserves with the farmland forest network in oasis areas and the green space system in urban areas to form a comprehensive ecological network system covering ecological areas, agricultural areas, and cities so as to further improve the stability of the ecological network is an important challenge for ecological security construction in similar areas in the future.

3. Future prospects

It is necessary to enhance the stability of the ecological network system developed in this study in terms of structure and function. Considering the sensitive and fragile natural ecological environment in the desert–oasis area, and the high costs of ecological network construction and maintenance, subsequent studies will focus on the development of ecological break points and carry out targeted maintenance and restoration, which can further reduce the costs of ecological construction. In addition, the default values of Guidos Toolbox were used for a parameter setting in this study. A study of the parameter setting will be carried out in the future.

4.2. Conclusions

Using long-series remote sensing data and basic data support, this study took Lingwu City, Ningxia, which is a typical county with a desert–oasis interaction zone located in the middle and upper reaches of the Yellow River, as an example and studied the ecological network structure of the desert–oasis interaction zone with a framework of EN-DSS. The main conclusions are as follows:

1. The whole desert–oasis system shows the characteristics of oasis expansion and desert retreat, and the spatial pattern of land is clearly divided into functional divisions. From 1995 to 2020, the boundary between the eastern edge of the oasis and the desert showed an eastward expansion trend, and the expansion amplitude was more significant in the northeast and southeast sections of the oasis. The extent of sandy land shrunk significantly.
2. The vegetation coverage of the desert–oasis system has improved generally, but the improvement in the nature reserves is the most prominent, which reduces the risk of the oasis suffering from wind and sand. In the Baijitan Nature Reserve, clumps of shrub land were found. The vegetation coverage in the eastern energy area has become worse overall but has improved locally.
3. An ecological network system with shrubland as the main body has been formed, but the quality of the network needs to be improved. The ecological network of Lingwu

City presents the ecological security pattern of "one core, two corridors, three districts and multiple groups", but there is still a small number of ecological sources with small areas and unbalanced spatial distribution. The ecological corridors are mainly based on the desert steppe base, with a low ecological quality, many ecological nodes and fracture points, and poor ecological network stability.

4. The challenge that must be solved in the construction of ecological security in a desert–oasis area is how to include ecological areas, agricultural areas, and urban areas into a comprehensive ecological network. It is necessary to strengthen the construction of stepping stones and the restoration of ecological break points. In terms of ecological corridors, it is necessary to organically associate the farmland forest network and urban and rural green space corridor systems to further enhance the stability of the developed ecological network system in terms of structure and function.

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