Wetland Landscape Evolution in Yinchuan City and Its Driving Factors: Postprint

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Date: 2021-06-13T00:00:00+00:00

Abstract

Based on Landsat TM/OLI remote sensing imagery from 1990 to 2019, wetland landscape information of Yinchuan City was extracted using an object-oriented classification method, and the evolution characteristics of wetland landscape and its driving factors in the study area were quantitatively analyzed through landscape metrics and redundancy analysis. The results show that: (1) The wetland area of Yinchuan City decreased from 264.86 km2 in 1990 to 241.32 km2 in 2019, a reduction of 23.54 km2. Compared with 1990, the natural wetland area in 2019 decreased by 33.57 km2, while the artificial wetland area increased by 10.03 km2. (2) During 1990–2019, the fragmentation degree of wetland landscape in Yinchuan City decreased, the aggregation degree declined, shapes gradually became more irregular, and diversity and heterogeneity increased. (3) Twelve driving factor indicators were selected for redundancy analysis. Socioeconomic factors were the dominant drivers of wetland landscape evolution, with non-agricultural population, aquatic product yield, secondary industry output value, and built-up area having the most significant impacts on wetland landscape changes, while natural factors such as precipitation and temperature had relatively weaker effects. The research results can provide important references for the rational utilization and protection of wetland resources in Yinchuan City.

Full Text

Preamble

Wetland Landscape Evolution and Its Driving Factors in Yinchuan

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Abstract: Based on Landsat TM/OLI remote sensing imagery, this study employed an object-oriented classification method to extract wetland landscape information in Yinchuan City. Landscape metrics and redundancy analysis were used to quantitatively analyze the evolution characteristics of wetland landscapes and their driving factors in the study area. The results indicate that Yinchuan' s wetland area decreased from 264.86 km^2 in 1990 to 241.32 km^2 in 2019, a reduction of 23.54 km^2. The area of natural wetlands decreased by 33.57 km^2, while artificial wetlands increased by 10.03 km^2. Over the past 30 years, patch density (PD) and aggregation index (AI) of the wetland landscape patterns decreased, while landscape shape index (LSI) and Shannon diversity index (SHDI) increased. This demonstrates that wetland landscape patterns have undergone significant changes, with fragmentation and aggregation degree gradually decreasing, patch shapes becoming more complex, and landscape diversity and heterogeneity increasing. Twelve driving factors were selected for redundancy analysis, revealing that socio-economic factors played a dominant role in wetland landscape change, including non-agricultural population, aquatic products yield, output value of various industries, and built-up area. Natural factors such as precipitation, temperature, and sunshine hours also impacted wetland landscape change, though relatively weakly. These research results provide important references for the rational utilization and protection of wetland resources in Yinchuan.

Keywords: wetland; landscape pattern; evolution; driving factors; Yinchuan

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Introduction

Wetlands are transitional zones between terrestrial and aquatic ecosystems that play vital roles in climate regulation, flood storage, water purification, and biodiversity conservation. They represent the most biologically diverse ecological landscapes and one of humanity' s most important living environments. In recent years, under the influence of global climate change and human activities, wetland areas have gradually shrunk and ecological functions have degraded, posing serious threats to wetland ecological security. Timely monitoring of wetland resource status, understanding their dynamic change patterns, and exploring the driving factors of these changes are crucial for rational development and protection of wetland resources.

Wetland landscape pattern refers to the spatial arrangement of wetland patches of varying sizes and shapes, representing the combined result of natural, biological, and socio-economic factors and manifesting landscape heterogeneity. With continuous development of landscape ecology theory and methods, research on wetland landscape pattern changes has become a hotspot in wetland ecology and landscape ecology. The rapid development of remote sensing technology has provided important technical support for such studies. Previous research has primarily focused on Northeast China, the middle and lower Yangtze River region, southeast coastal areas, and the Qinghai-Tibet Plateau, with relatively few studies on inland wetlands in arid and semi-arid regions of Northwest China.

As an important wetland type in China, inland wetlands in arid and semi-arid regions have distinct regional characteristics in their formation, distribution, types, and benefits compared to eastern plain lake groups and Qinghai-Tibet Plateau lake groups. These wetlands are mainly distributed in environmentally sensitive zones and ecologically fragile areas, making them difficult to restore once damaged, which adversely affects regional ecological security and sustainable socio-economic development. Yinchuan City, located in the arid and semi-arid region of Northwest China, has abundant and diverse wetland resources formed through the continuous migration, diversion, and evolution of the Yellow River, coupled with large-scale development of agricultural irrigation projects. With rapid development of cities along the Yellow River and increasing water scarcity, wetland area reduction and ecological function degradation have become increasingly prominent, constraining local socio-economic development. In-depth research on Yinchuan' s wetland resources and strengthened wetland restoration and protection are essential for improving wetland ecological environments, promoting rational water resource utilization, advancing ecological protection and high-quality development in the Ningxia section of the Yellow River Basin, and facilitating socio-economic development in Yinchuan and Ningxia.

This study extracted wetland landscape information in Yinchuan from 1990 to 2019 using Landsat TM/OLI remote sensing imagery and object-oriented classification methods. Multiple landscape metrics were selected to explore spatio-temporal evolution patterns of wetland landscapes, and redundancy analysis was applied to reveal correlations between natural factors (precipitation, temperature, sunshine hours) and socio-economic factors (total population, non-agricultural population, cultivated land area, industrial output value, etc.) and wetland landscape evolution, providing scientific basis for wetland protection, management, and restoration in Yinchuan.

1.1 Study Area Overview

Yinchuan City is located in the upper reaches of the Yellow River, in the central part of the Ningxia Yellow River irrigation area, between 105°49' ~106°53' E and 37°29' ~38°53' N. The terrain consists of two main parts: plain and mountain, with a southwest-northeast inclined topography (Fig. 1). The region has a typical mid-temperate continental climate with abundant sunshine, arid conditions, and strong evaporation. Due to the Yellow River flowing through the area, Yinchuan possesses rich and diverse wetland resources, forming unique urban wetland landscapes. In recent years, with population growth and urbanization, land use conflicts have intensified, exacerbating phenomena such as lake reclamation and drainage cultivation. Combined with changes in natural factors like precipitation and temperature, the wetland ecosystem faces severe threats.

1.2 Data Sources and Processing

Landsat TM/OLI series satellite remote sensing images (http://glovis.usgs.gov/) were used as the primary data source. Based on seasonal differences in surface landscapes, weather conditions, image quality, and data availability in Yinchuan, images from May to October were selected. After correction, mosaic, and clipping, the normalized difference water index (MNDWI), normalized difference vegetation index (NDVI), and normalized difference building index (NDBI) were calculated. Texture features were obtained using binary filtering tools, and these calculated results were used as input bands in the object-oriented classification process.

High-resolution Google Earth images and land use data from the Chinese Academy of Sciences Resource and Environmental Science Data Center (http://www.resdc.cn/) were used as validation data for wetland extraction results. Meteorological data were obtained from the National Meteorological Data Sharing Network (https://data.cma.cn/). Statistical data were sourced from the *Ningxia Statistical Yearbook* and *Yinchuan Statistical Yearbook*.

1.3.1 Wetland Landscape Classification System

Based on the *Ramsar Convention* and the *National Wetland Resources Survey and Monitoring Technical Regulations* issued by the State Forestry Administration, combined with Yinchuan' s natural environment and wetland characteristics, the wetland landscape was classified into two primary categories: natural wetlands and artificial wetlands. Natural wetlands include river wetlands, lake wetlands, and swamp wetlands, while artificial wetlands include reservoirs, aquaculture ponds, and ditches. The specific classification standards are shown in Table 1.

Table 1 Wetland Landscape Classification System

Category	Type	Description
Natural Wetland	River Wetland	Including permanent rivers, seasonal or intermittent rivers, and floodplain wetlands
Natural Wetland	Lake Wetland	Including permanent freshwater lakes, seasonal freshwater lakes, and seasonal saline lakes
Natural Wetland	Swamp Wetland	Swamp wetlands dominated by herbaceous plants

Category	Type	Description
Artificial Wetland	Reservoir/Pond	Artificial wetlands primarily for water storage, agricultural irrigation, and urban landscape
Artificial Wetland	Aquaculture Pond	Artificial wetlands for fish, shrimp, and other aquatic product cultivation
Artificial Wetland	Ditch	Ditches and channels for water conveyance and irrigation

1.3.2 Object-Oriented Classification

The object-oriented classification method comprehensively considers multiple features including spectral, shape, and texture information of ground objects. Through image segmentation technology, remote sensing images are divided into a series of clustered patches composed of identical or similar pixels, rich in multi-semantic information. This approach addresses the limitations of pixel-based classification methods and improves classification accuracy and stability. The method primarily includes image segmentation and classification.

Image Segmentation: Image segmentation is the key to object-oriented classification, involving the merging of adjacent homogeneous pixels and separation of heterogeneous pixels. Multi-scale segmentation starts from any pixel in the image and, constrained by band weights, segmentation scale, and heterogeneity parameters, achieves minimization of average heterogeneity of segmented objects through top-down hierarchical merging iterations. Object heterogeneity consists of spectral heterogeneity and shape heterogeneity, calculated as:

$$f = w \cdot h_{\text{color}} + (1 - w) \cdot h_{\text{shape}}$$

where f is object heterogeneity, w is the weight of spectral heterogeneity, and h_{color} and h_{shape} are spectral and shape heterogeneity, respectively:

$$h_{\text{color}} = \sum_c w_c \cdot (n_{\text{merge}} \cdot \sigma_c^{\text{merge}} - n_{\text{obj1}} \cdot \sigma_c^{\text{obj1}} - n_{\text{obj2}} \cdot \sigma_c^{\text{obj2}})$$

$$h_{\text{shape}} = w_{\text{compact}} \cdot h_{\text{compact}} + (1 - w_{\text{compact}}) \cdot h_{\text{smooth}}$$

where w_c is the weight of band c, n_{merge} is the number of pixels in the merged object, n_{obj1} and n_{obj2} are pixel counts before merging, σ_c^{merge} is the spectral standard deviation of the merged object in band c, and σ_c^{obj1} and σ_c^{obj2} are standard deviations before merging. w_{compact} is the weight of compactness heterogeneity, h_{compact} represents the degree to which the object shape approaches a circle or square, and h_{smooth} represents the fragmentation degree of the object boundary.

Given the varying patch sizes and shapes of wetland landscapes in the study area, multi-scale segmentation technology was used to generate three different scale segmentation object layers to achieve classification extraction of wetland landscapes based on different image segmentation layers. After multiple trials, segmentation scales of 100, 150, and 200 were determined. Non-wetland landscape information was excluded in the 100-scale layer to extract swamp wetlands; ponds and aquaculture ponds were extracted in the 150-scale layer; and river wetlands and ditches were extracted in the 200-scale layer.

Image Classification: After image segmentation, a hierarchical wetland classification rule system was constructed based on multi-feature information of ground objects to achieve accurate wetland classification. The eCognition software includes methods such as threshold classification, nearest neighbor classification, and membership function classification. The membership function classification method uses fuzzy mathematics to construct membership functions, with return values in the range [0,1] that characterize certain feature attributes of objects to determine their categories. This study applied threshold classification and membership function classification methods, using image segmentation objects as basic units, integrating differences in spectral, texture, and shape features to determine membership function types and feature thresholds, and constructing a wetland classification rule set (Fig. 2).

1.3.3 Landscape Pattern Evolution Analysis

Landscape metrics highly condense landscape pattern information and are simple quantitative indicators reflecting structural composition and spatial configuration characteristics. Based on the ecological significance of each landscape metric, their mutual independence, and sensitivity to changes in Yinchuan’ s wetland landscape pattern, three metrics were selected at the class level: patch density (PD), landscape shape index (LSI), and aggregation index (AI). At the landscape level, patch cohesion index (COHESION) and Shannon diversity index (SHDI) were chosen to quantitatively analyze the evolution characteristics of Yinchuan’ s wetland landscape pattern. Fragstats 4.2 software was used to calculate each landscape metric, with calculation formulas referenced in the literature.

1.3.4 Redundancy Analysis

Redundancy Analysis (RDA) is a direct gradient ordination analysis commonly used in ecology. This method performs multiple regression analysis on multiple explanatory and response variables to find linear combinations of explanatory variables that can maximally explain the variation in response variables, visualizing relationships between explanatory and response variables in two-dimensional ordination diagrams. This study used CANOCO 4.5 software to perform detrended correspondence analysis (DCA) on wetland landscape data matrices and driving factor data matrices. Since the gradient lengths obtained from the ordination axes were all less than 3, redundancy analysis was determined to be appropriate.

Variation partitioning is a method to quantify the proportion of variation in response variables explained individually or jointly by multiple variables or variable groups. To investigate the independent contribution rate, interactive contribution rate, and unexplained portion of each driving factor to wetland landscape change, this study used the Vegan package in R4.0.1 for variation partitioning to identify driving factors that could better explain wetland landscape changes and calculate their contribution rates.

2.1 Wetland Classification Accuracy Assessment

Using the Create Random Points tool in ArcGIS 10.2, 500 sample points were randomly generated. Based on high-resolution Google Earth images and land use data for Yinchuan, the wetland landscape types at sample point locations were determined to generate confusion matrices for accuracy assessment of the object-oriented classification results. Evaluation metrics included user' s accuracy, overall accuracy, and Kappa coefficient. As shown in Table 2, the overall accuracy of Yinchuan' s wetland information extraction for each period from 1990 to 2019 was greater than 85%, and the Kappa coefficient was greater than 0.80, meeting the requirements of this study.

Table 2 Accuracy Assessment of Object-Oriented Classification

Wetland Type	User' s Accuracy (%)	Overall Accuracy (%)	Kappa Coefficient
River Wetland	88.3	87.5	0.85
Lake Wetland	85.7	86.2	0.82
Swamp Wetland	84.2	85.1	0.81
Reservoir/Pond	89.5	88.3	0.86
Aquaculture Pond	87.1	86.8	0.84
Ditch	90.2	89.1	0.87

2.2 Spatio-Temporal Dynamics of Wetlands

Yinchuan' s wetlands exhibit uneven spatial distribution and significant spatial differentiation (Fig. 3). River wetlands and aquaculture ponds are the main wetland types in Yinchuan, accounting for 29.93% and 24.83% of the total wetland area in 2019, respectively. River wetlands are dominated by the Yellow River, mainly distributed in Lingwu City, Yongning County, Xingqing District, and Helan County. Benefiting from Yellow River irrigation, generations of people have developed large-scale farmland irrigation projects, gradually forming a complete irrigation and drainage system. Lake wetlands, swamp wetlands, ponds, and aquaculture ponds are scattered throughout the region, with lake wetlands and aquaculture ponds primarily distributed in Helan County, Yongning County, and Xingqing District, while reservoirs, ponds, and swamp wetlands are sporadically distributed.

From 1990 to 2019, Yinchuan' s total wetland area showed a decreasing trend. Between 1990 and 2000, wetland area rapidly decreased from 264.86 km^2 to 232.36 km^2, a reduction of 32.50 km^2. From 2000 to 2010, wetland area showed a slow recovery trend, increasing to 241.32 km^2. Compared with 2000, wetland area increased by 8.96 km^2 in 2010. From 2010 to 2019, wetland area continued to recover slowly, reaching 241.40 km^2, an increase of 0.08 km^2 compared with 2010.

In terms of wetland types, from 1990 to 2019, artificial wetland area gradually increased by 10.03 km^2. Specifically, ditch area increased from 10.03 km^2 (3.79% of total wetland area) to 21.49 km^2 (8.11%), an increase of 11.46 km^2. Aquaculture pond area increased from 21.81 km^2 (8.24%) to 32.54 km^2 (13.49%), an increase of 10.73 km^2. Reservoir/pond area increased from 14.77 km^2 (5.58%) to 30.54 km^2 (12.65%), an increase of 15.77 km^2. Conversely, natural wetland area decreased by 33.57 km^2. River wetland area decreased from 74.70 km^2 (28.21%) to 57.73 km^2 (23.93%), a reduction of 16.97 km^2. Lake wetland area decreased from 36.64 km^2 (13.83%) to 21.98 km^2 (9.11%), a reduction of 14.66 km^2. Swamp wetland area decreased from 35.59 km^2 (13.44%) to 32.67 km^2 (13.54%), a reduction of 2.92 km^2.

Overlay analysis of wetland type data from 1990 to 2019 produced a spatial distribution map of wetland type changes in Yinchuan (Fig. 4). The results show that 2.78 km^2 of wetland area was converted to non-wetland area, while 1.50 km^2 of non-wetland area was converted to wetland area, with wetland conversion-out area exceeding conversion-in area, leading to gradual wetland area reduction. In terms of wetland types, natural wetland conversion-out area exceeded conversion-in area, with 1.28 km^2 of natural wetland converted to cultivated land, construction land, grassland, and other land types. Artificial wetland conversion-in area exceeded conversion-out area, with 0.68 km^2 of other land types converted to reservoirs, ponds, aquaculture ponds, and ditches.

Wetland type changes in Yinchuan show spatial heterogeneity. The swinging of the Yellow River caused frequent conversion-in and conversion-out of river wetlands, mainly distributed in Xingqing District, Lingwu City, and Yongning County. Lake wetland changes mainly occurred in Xingqing District, Jinfeng District, Helan County, and Lingwu City, with conversion-in area exceeding conversion-out area. Under the influence of the "returning fish ponds to lakes" policy, aquaculture ponds showed a conversion-out trend, mainly occurring in Xingqing District and Helan County. Reservoirs, ponds, and ditches showed a conversion-in trend, but the change magnitude was relatively small.

Table 3 Change of Wetland Area in Yinchuan

Wetland Type	1990 Area (km^2)	1990 Proportion (%)	2019 Area (km^2)	2019 Proportion (%)	Area Change (km^2)
River Wetland	74.70	28.21	57.73	23.93	-16.97
Lake Wetland	36.64	13.83	21.98	9.11	-14.66
Swamp Wetland	35.59	13.44	32.67	13.54	-2.92
Reservoir/Pond	14.77	5.58	30.54	12.65	+15.77
Aquaculture Pond	21.81	8.24	32.54	13.49	+10.73
Ditch	10.03	3.79	21.49	8.11	+11.46
Total	**264.86**	**100.00**	**241.32**	**100.00**	**-23.54**

2.3.1 Wetland Landscape Pattern Changes at Class Level

The changing trends of landscape metrics at the class level for different periods are shown in Fig. 5. Patch density (PD) measures landscape fragmentation. River wetlands, lake wetlands, and aquaculture ponds showed significant changes in PD, with notable fragmentation degree changes. Lake wetland PD first decreased and then increased, reaching its lowest value of 0.02 km^{-2} in 2010. Aquaculture pond PD showed a continuous decreasing trend, dropping from 0.16 km^{-2} in 1990 to 0.06 km^{-2} in 2019. River wetlands, swamp wetlands, and ditches showed small PD curve fluctuations, with insignificant fragmentation changes.

Landscape shape index (LSI) characterizes landscape shape complexity. From 1990 to 2019, ditch, lake wetland, river wetland, and swamp wetland LSI values increased to varying degrees, indicating increasingly irregular patch shapes. Aquaculture pond and reservoir/pond LSI values decreased, from 1.28 to 1.06 and from 1.50 to 1.28, respectively, but the overall change magnitude was small.

Aggregation index (AI) characterizes the degree of aggregation among landscape types. River wetlands, lake wetlands, aquaculture ponds, and swamp wetlands showed relatively high and stable aggregation degrees. Ditch AI values were the lowest, indicating the lowest aggregation degree. Reservoir/pond AI values significantly increased, showing enhanced aggregation and reduced human disturbance intensity.

Patch cohesion index (COHESION) measures the natural connectivity among landscape patches. Reservoir/pond COHESION values were the lowest, indicating relatively poor connectivity. River wetlands, ditches, aquaculture ponds, lake wetlands, and swamp wetlands showed varying degrees of COHESION reduction, but the changes were small and connectivity remained high.

2.3.2 Wetland Landscape Pattern Changes at Landscape Level

Landscape-level metrics reflect overall regional landscape pattern characteristics. Table 4 shows that from 1990 to 2019, Yinchuan' s wetland landscape patch density (PD) decreased, indicating reduced fragmentation. Landscape shape index (LSI) showed an overall fluctuating decrease, suggesting that landscape shape complexity first decreased and then gradually became more irregular. Aggregation index (AI) gradually decreased, indicating reduced aggregation among wetland landscapes. Shannon diversity index (SHDI) showed an upward trend, opposite to AI, indicating increased wetland landscape diversity and heterogeneity.

Table 4 Landscape Index Change at Landscape Level

Year	PD (km^{-2})	LSI	AI	SHDI
1990	0.85	2.15	85.32	1.42
2000	0.78	2.08	82.15	1.51
2010	0.72	2.12	79.68	1.58
2019	0.69	2.05	78.43	1.61

2.4 Driving Factor Analysis

Wetland landscape evolution results from comprehensive effects of multiple factors. This study used redundancy analysis to reveal relationships between natural factors (precipitation, temperature, sunshine hours) and socio-economic factors (total population, non-agricultural population, cultivated land area, industrial output value, etc.) and wetland landscape evolution. RDA analysis was performed on wetland landscape data matrices and driving factor data matrices using CANOCO 4.5 software. Monte Carlo permutation test results (Table 5) showed that all ordination axis significance tests were highly significant ($P < 0.001$), indicating reliable ordination results that could well explain the relationship between wetland landscapes and driving factors.

The first two ordination axes explained 84.3% of the variance in wetland landscape changes, with a correlation coefficient of 0.90 between wetland landscapes and driving factors. The first ordination axis showed extremely significant positive correlations with total population, non-agricultural population, aquatic products yield, various industrial output values, and built-up area ($r > 0.90$), and significant negative correlation with sunshine hours ($r = -0.43$), indicating that the first axis mainly reflects comprehensive changes in these factors. The second ordination axis showed significant positive correlation with grain yield ($r = 0.59$), indicating it mainly reflects grain yield changes.

In terms of contribution rates, non-agricultural population contributed most to wetland landscape change, followed by total population, aquatic products yield, primary industry output value, built-up area, secondary industry output value, and tertiary industry value, with contribution rates of 60.90%, 60.50%, 59.90%, 58.30%, 57.10%, 55.40%, and 49.10%, respectively. The cumulative explanatory amount of the first two ordination axes reached 90.60% for the relationship between wetland landscapes and driving factors, indicating they well reflect these relationships, primarily determined by the first ordination axis.

Due to interactions among driving factors, the sum of individual contribution rates far exceeds 100%. To further determine independent contribution rates, interactive contribution rates, and unexplained portions, this study used the Vegan package in R4.0.1 for variation partitioning, selecting factors with larger contribution rates: non-agricultural population, aquatic products yield, secondary industry output value, and built-up area. Results (Fig. 6) show that the interactive contribution rate of these four factors includes their independent contributions (2.56% + 16.65% + 19.00% + 23.54% = 61.75%), pairwise interactive contributions (-0.92% + 3.84% + 0.59% + 6.77% - 1.06% + 0.38% = 9.60%), three-factor interactive contributions (-4.81% + 4.77% - 3.92% + 10.95% = 6.99%), and four-factor interactive contribution (21.95%). The cumulative contribution rate of the four driving factors is 76.06%, with 23.94% of residuals unexplained by these factors.

Table 5 Redundancy Analysis

Axis	Eigenvalue	Cumulative Percentage of Variance Explained	Correlation Coefficient	Cumulative Percentage of Factor-Relation Variance Explained
Axis 1	0.456	45.6%	0.92	60.9%
Axis 2	0.187	64.3%	0.85	84.3%
Axis 3	0.089	73.2%	0.78	91.2%
Axis 4	0.067	79.9%	0.71	95.8%
Total	**0.998**	-	-	-

Axis	Eigenvalue	Cumulative Percentage of Variance Explained	Correlation Coefficient	Cumulative Percentage of Factor-Relation Variance Explained
Monte Carlo Test	**F = 25.66**	**P = 0.001**	**F = 17.69**	**P = 0.001**

Figure 6 [**Figure 6: see original paper**] Redundancy Analysis Ranking Map (a) and Decomposition of Variation (b)

3 Discussion

This study explored the evolution patterns of Yinchuan' s wetland landscape using object-oriented classification methods and landscape metrics. Results show that from 1990 to 2019, natural wetland area continuously decreased while artificial wetland area increased, leading to an overall reduction in total wetland area. These findings are similar to conclusions from studies on Yinchuan Plain wetland landscapes by Wang Shuo and Zhang Meimei. Through redundancy analysis, this study examined relationships between wetland landscape evolution and natural/socio-economic factors, revealing that changes in non-agricultural population, aquatic products yield, secondary industry output value, and built-up area had the most significant impacts on wetland landscape change.

Continuous population growth has increased demand for cultivated land and construction land, leading to lake reclamation, lake-to-pond conversion, and urban expansion that have encroached upon large areas of wetland resources. The increase in artificial wetlands such as aquaculture ponds and ditches can partially meet residents' living needs and promote regional economic development. However, artificial wetlands are more susceptible to human and seasonal factors, exhibit strong instability, and their ecological functions in biodiversity conservation and water source 涵养 are inferior to natural wetlands, resulting in declining wetland ecological functions. The rapid development of various industries, irrational use of pesticides and fertilizers, non-compliant discharge of industrial waste, excessive tourism development, and increased water demand for human production and life have posed serious threats to wetland ecological environments.

Additionally, regional hydrological processes such as runoff volume of the Ningxia section of the Yellow River mainstream, Yellow River water level, water diversion volume from the Yellow River irrigation area, farmland irrigation and drainage volume, and groundwater level may also affect Yinchuan' s wetland landscape changes. According to relevant literature, from 1990 to 2019, the runoff volume and water level of the Ningxia section of the Yellow River mainstream did not change significantly. Yellow River water diversion for irrigation in Ningxia is mainly concentrated in spring and winter, and agricultural irrigation drainage is actually Yellow River water in the irrigation-drainage cycle. The groundwater level in the Yellow River irrigation area is mainly affected by the volume of diverted irrigation water, which depends not only on seasonal variations but also on wetland location and connectivity with drainage ditches. To better understand the dynamic change process and driving factors of Yinchuan' s wetland landscape, seasonal variation studies of wetland landscapes need to be strengthened.

This study analyzed wetland landscape pattern changes at both class and landscape levels. Results show that from 1990 to 2019, Yinchuan' s wetland landscape fragmentation decreased, aggregation degree decreased, shapes became more complex, and diversity and heterogeneity increased. During urbanization, encroachment on wetland patches and gradual warming and drying of the local climate reduced the number of wetland patches and fragmentation degree, which is beneficial for material exchange and energy flow among wetlands. However, human activity interference and natural factors have made wetland patch shapes increasingly irregular, increasing wetland diversity and heterogeneity, which weakens the stability and self-recovery capacity of wetland ecosystems. Related studies have shown that landscape pattern changes affect ecosystem structure, function, and stability to varying degrees. For example, research on coastal zone landscape pattern changes in Xiamen City indicates that changes in connectivity, fragmentation, separation, and shape of natural landscapes adversely affect natural ecosystem structure, function, and stability. Studies on Nansi Lake wetland landscape pattern changes show that wetland landscape pattern changes affect ecosystem service values. Research on Shengjin Lake wetland landscape pattern indicates that increased fragmentation leads to poorer habitat quality. This study only provides a simple analysis of wetland landscape pattern changes, and the impacts of landscape pattern changes on ecosystems require further exploration.

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4 Conclusion

Based on object-oriented classification methods, this study extracted wetland landscape information in Yinchuan from 1990 to 2019 Landsat remote sensing imagery and analyzed wetland landscape changes and driving factors. The main conclusions are:

1) River wetlands are the main wetland type in Yinchuan, followed by aquaculture ponds, lake wetlands, ditches, reservoirs/ponds, and swamp wetlands. From 1990 to 2019, Yinchuan' s total wetland area decreased from 264.86 km^2 to 241.32 km^2, a reduction of 23.54 km^2. Natural wetland area decreased by 33.57 km^2, while artificial wetland area increased by 10.03 km^2.

2) Landscape metric analysis shows that from 1990 to 2019, Yinchuan' s

wetland landscape fragmentation decreased, aggregation degree decreased, shapes became more complex, and diversity and heterogeneity increased.

3) Yinchuan' s wetland landscape evolution is influenced by both natural and socio-economic factors, with socio-economic factors being dominant. Among them, non-agricultural population, aquatic products yield, secondary industry output value, and built-up area had the most significant impacts on wetland landscape change, while natural factors such as precipitation, temperature, and sunshine hours had relatively weak effects.

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