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Wetland Functional Area Division Method: A Correlation Analysis of Water Quality and Landscape Structure

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Abstract: The purpose of this study is to provide a clearer idea for the optimization of wetland functional areas and a new method for the identification and analysis of wetland functional areas under the background of the latest Wetland Protection Law in China. This study selected Pan'an Lake Wetland, the first national wetland park built in coal mining subsidence land in China, as the research object. By constructing a "Water-water-landscape-function" (WLF) model, combined with landscape pattern index and Nemerov pollution index method (NPI), the differences in water quality and landscape structure of different functional areas were analyzed. Then, Pearson's Correlation Analysis and Redundancy Analysis are combined to quantitatively analyze the correlation between water quality environment and landscape structure. Finally, Inverse Distance Weighting (IDW) was introduced to help study the spatial difference in water quality in different functional areas. This study lasted for one year. Twelve water quality sampling points were set up, and 216 effective samples were collected monthly for one year. The results showed that: (1) the ratio of built-up land and cultivated land area had a high impact on water quality indicators in each water period, especially the increase in cultivated land patch density would increase the risk of TN and TP losing to surrounding water bodies; (2) the lakes and rivers in the wetland park have good ecological effects and should be widely used in various functional areas; (3) the degree of landscape fragmentation was negatively correlated with the overall water quality, while the degree of landscape agglomeration and landscape diversity were positively correlated with the overall water quality; (4) ecological corridors should be established between WCA and WRA, artificial corridors should be established between MEA and LEA, and ecological interception should be set between MEA and WRA; and (5) the "Water-quality-landscape-function" (WLF) model is an effective tool for the analysis and optimization of wetland functional areas, which provides a reference for the new round of wetland planning in China.

Keywords: wetland; water quality; landscape structure; correlation analysis; functional area division; water-landscape-function model

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1. Introduction

As the transitional zone of land and water ecosystem, wetland is an important habitat for wild animals and plants, playing an important role in water conservation and groundwater recharge. In recent years, about 50% of wetlands in the world have experienced landscape fragmentation and ecological function degradation [1,2], and the water quality of wetlands in the Yellow River delta in China is also facing habitat degradation [3]. The Chinese government has decided to implement the Wetland Protection Law of the People's Republic of China from 1 June 2022, which means that a new round of master plans for national wetland parks will soon be prepared. The division of functional areas is an important feature in compiling the new version of wetland planning, which has many problems such as heavy workload and complex "natural–human" influencing factors. Therefore, based on fully considering the existing planning and current wetland habitat problems, this study proposes a functional area optimization scheme based on the combination of "water quality and landscape structure", which provides a solution to reduce the work burden caused by planning revision and avoid repeated work. At the same time, to enhance the resilience and anti-risk strength of constructed wetland ecosystems and alleviate their natural degradation, it is particularly important in today's global advocacy of green, low-carbon and energy saving.

Water area is an important part of wetland, and water quality can objectively reflect the ecological health status of wetland [4]. As people pay more attention to the quality of the water environment, the methods of water quality assessment are increasing gradually. At present, the commonly used water quality evaluation methods mainly include fuzzy comprehensive evaluation method [5], single factor index method [6], comprehensive pollution index method [7], analytic hierarchy process [8], Nemerov pollution index method, etc. [9]. In this study, Nemerov pollution index method is selected as the water quality assessment method, which is one of the most used methods for the calculation of comprehensive pollution index in the world.

Landscape structure is a key factor affecting wetland hydrological process and quality [10], and functional zoning is closely related to landscape structure [11]. Previous studies have shown that unreasonable landscape structure is the key to water quality deterioration [12,13]. Therefore, many scholars have studied the relationship between landscape structure and water quality from different spatial scales [10,14–16]; they have also analyzed the impact of landscape structure evolution on water quality from time scale [17–20]. However, some studies have shown that there are differences in landscape structure and water quality in different functional areas [21,22], but few studies have explored the relationship between landscape structure and water quality at the level of functional zoning, and how water quality environment and landscape structure guide the optimization of functional areas. To better reveal the complex relationship between wetland functional areas and water quality, this study seeks to improve this research field.

The optimization of wetland functional area is different from the research on the division of functional area. It is an in-depth study on the ecological environment quality of wetland based on the existing wetland protection planning. At present, the main method of wetland functional area optimization is to construct an evaluation model, but there are some differences in the evaluation content. McKenna et al. [23] studied the impacts of climate and land use change on wetland sustainability. Chen et al. [24] evaluated coastal wetlands from the perspective of energy ecological footprint. Das et al. [25] evaluated the wetlands in Murshidabad based on PSR model and analytic hierarchy process, and mainly studied the impact of urbanization process on wetlands. Tian et al. [26] used the Cellular Automation (CA-Markov) model to construct the ecological risk assessment (ERS) index model and reveal the ecological risk changes in Yancheng coastal wetland. In addition, this kind of research often does not highlight the main role of water in wetland, by ignoring the interpretation of water quality environment caused by the difference in landscape structure between different functional areas. At the same time, it is not easy to obtain index data, and it is difficult to popularize and apply the method. Considering the convenience of implementation and the availability of data, this study constructed the "Water Quality, Landscape and Function" (WLF) model. The data were collected from 12 monitoring points, 6 water quality indicators were collected from each monitoring point, and 216 water samples were collected monthly for 12 months. Landscape pattern index and Nemerov pollution index were used to study the differences in water quality and landscape structure in different functional areas. Pearson's Correlation Analysis and Redundancy Analysis were used to quantitatively analyze the correlation between water quality environment and landscape structure. Finally, Inverse Distance Weighting (IDW) was introduced to help study the spatial difference in water quality in different functional areas.

The primary objective of this paper is to study the construction status and ecological problems of wetland water quality, landscape structure and functional layout from three spatial scales of "macroscopic–meso–micro" by ENVI, ArcGIS and Fragstats, respectively. Based on this, SPSS and Canoco were used to quantitatively analyze the mechanism and influence between the spatial structure of "water quality, landscape and function" and its ecological efficiency. This was to engage the existing wetland functional zoning in the new round of planning timely layout and adjustment, so as to promote wetland water ecological restoration and sustainable development. This study selected Pan'an Lake as the research object, which is the earliest state-level wetland park restored in coal mining subsidence areas in China. It is typical and representative of the constructed wetlands in Huang-Huai-Hai plain area of China. The research aims to solve the following questions: (1) What is the relationship between Water Quality and Landscape Structure? (2) How to guide the optimization of wetland functional areas in the new round of wetland planning?

2. Materials and Methods

2.1. Study Area

Pan'an Lake (34°21′33.45″–34°22′34.10″ N, 117°21′5.52″–117°23′21.07″ E) is located in the Huang-Huai-Hai plain, an area with water shortage and high water level in China. The study area is located in mid-latitudes, belongs to the north subtropical and warm temperate zone transition region, is in the humid to semi-humid monsoon climate zone, has the hottest month of the year in July with the average temperature of 26.8 °C, the coldest in January, has an annual average temperature of 0.4 °C, annual average rainfall of 869 milliliters, and solar-thermal resources; the heat condition is good, there is moderate rainfall, with rain heat over the same period. Its climatic characteristics and ecological location are very typical in the Huang-Huai-Hai plain of China. After 50 years of coal mining, Quantai, Qishan and other places experienced a coal mining depression. Pan'an lake wetland is the first national 4A level ecological wetland park for restoration and construction in coal mining subsidence areas in our country, with a total construction area of 52.89 km^2. Compared with natural wetlands, the constructed wetlands in coal mining subsidence areas are characterized by fragile ecological function, high ecological sensitivity, poor ecological integrity and weak ecological carrying capacity. As a typical plain wetland in the Huang-Huai-Hai region, it is an important node for water quality assurance and biodiversity protection of the wetlands in the Huang-Huai-Hai plain. It is extremely important for the protection of the wetland ecosystem in the region (Figure 1).

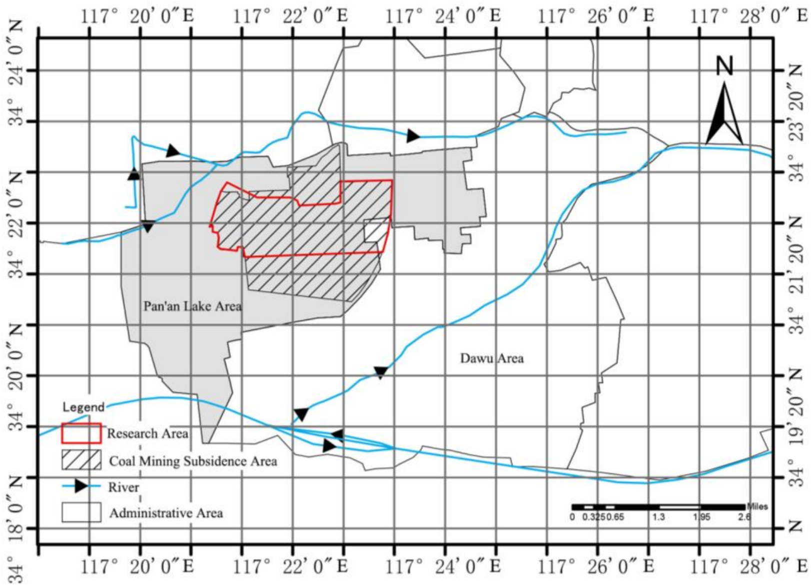

Figure 1. Location map of Pan'an Lake National Wetland Park.

2.2. Functional Zoning and Characteristics of Pan'an Lake Wetland

The wetland park in Pan'an Lake coal mining subsidence area of Jiawang has undergone a series of land reclamation and restoration projects [27], such as topography remodeling, soil reconstruction, vegetation reconstruction, landscape reproduction, biodiversity reorganization and protection, etc., and its habitat environment and landscape structure have undergone great changes. At present, Pan'an Lake Wetland Park still uses the planning zoning at the beginning of ecological restoration. Due to the differences in functional orientation and planning and construction objectives, the landscape structure and animal and plant community characteristics of different functional areas have emerged with similarities and differences.

2.2.1. Function Partitions

According to the Construction Code of National Wetland Park [28], the Master Plan of Pan'an Lake National Wetland Park in Xuzhou, Jiangsu Province [29] and the status quo of surrounding construction land, Pan'an Lake National Wetland Park is divided into a wetland planning area and wetland edge area (Figure 2). The wetland planning area includes Wetland Conservation Area (WCA), Wetland Restoration Area (WRA), Missions Exhibition Area (MEA), Management Service Area (MSA) and Leisure Experience Area (LEA). According to land use construction and planning, the wetland edge area is divided into a health resort area, smart manufacturing area and modern agriculture area. The text focuses on the wetland planning area, and it is necessary to consider the disturbance of the wetland edge area to the functional zoning of the planning area (Figure 3). Different functional areas in the wetland have different functional positioning. The wetland conservation area is based on the restoration of wetland ecosystem and protection of biodiversity. The purpose of the wetland restoration area is to improve and enrich habitat types and improve the structure of biological community. The publicity and education exhibition area is the center for ecological restoration, providing convenience for tourists to popularize wetland culture; the leisure experience area focuses on creating characteristic waterfront space and leisure experience projects; the management service area mainly undertakes management services, science popularization and education, scientific research monitoring and other functions [30].

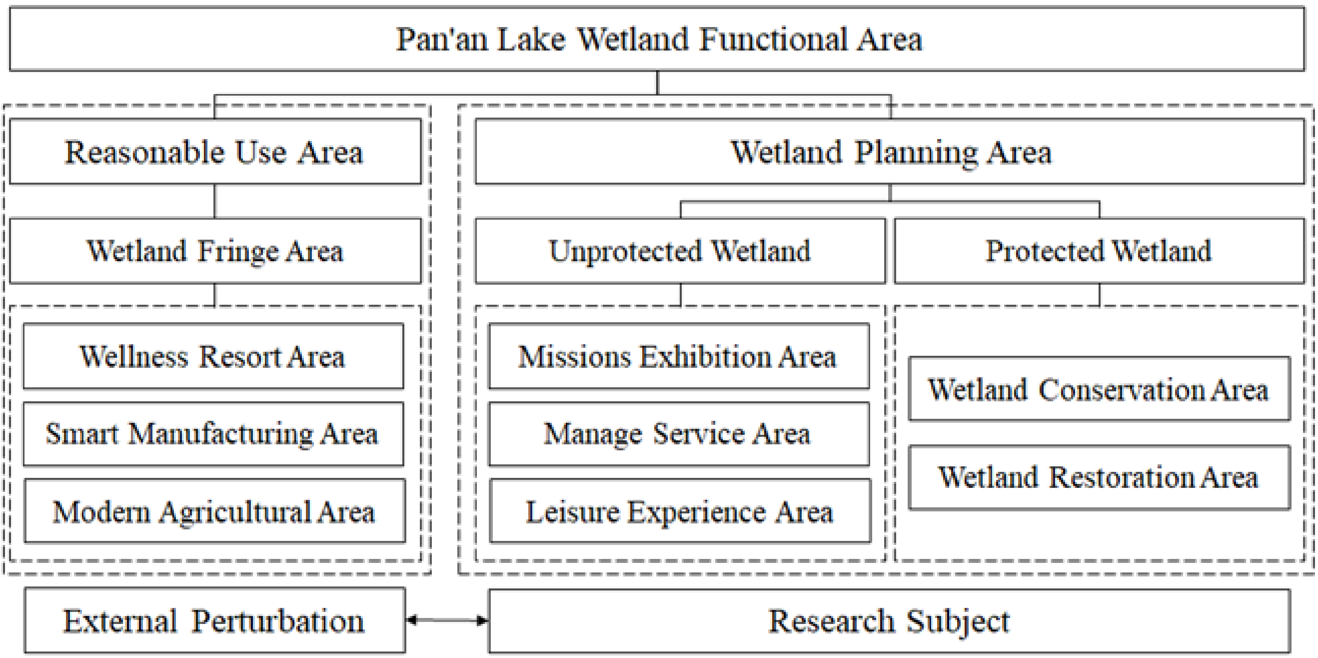

Figure 2. Structural diagram of functional partition.

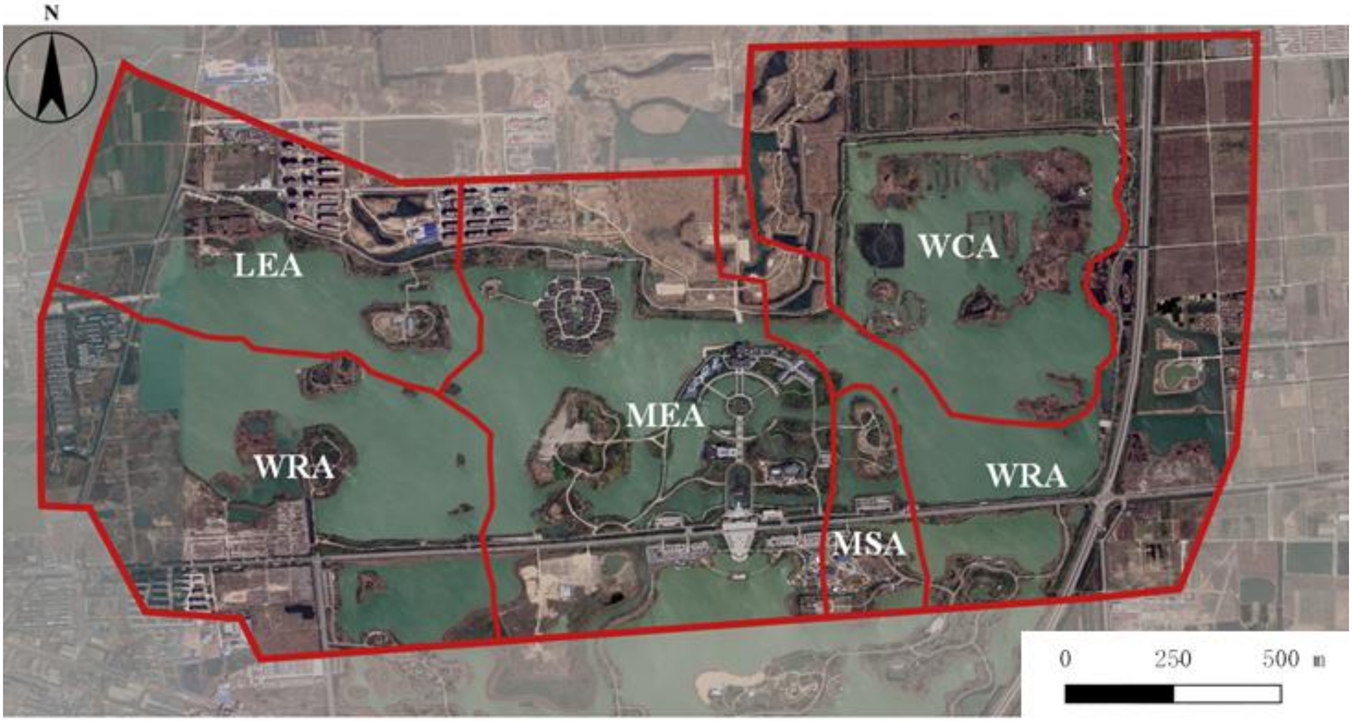

Figure 3. Functional zoning of Pan'an Lake Wetland.

2.2.2. Landscape Structure and Function Characteristics

Water ecological function is affected by landscape structure, and landscape evenness and fragmentation are inversely proportional to water quality [11]. In terms of landscape composition, WCA and WRA landscape elements had high similarity, with natural ecology and native flora and fauna as the main elements. MEA and LEA are artificial and natural complex ecological spaces, with various landscape elements interspersed and arranged. MSA is located at the entrance of the Wetland Park and is dominated by artificial "patch-corridor" [31]. In terms of landscape connectivity, LEA and MSA were affected by economic value, the connectivity of human landscape was better, and the landscape elements were connected in a ring or grid shape. The MEA landscape path is single and linearly arranged, and all elements interact to form an orderly landscape network. The natural landscape elements of WRA and WCA have good connectivity. Most of the landscape elements of MSA have regular geometric characteristics. MEA and LEA are in between, and the morphological rules and disorder of landscape elements coexist.

Each functional area of Pan'an Lake wetland is relatively independent, but also supports each other. WCA is the core area of the wetland park, and WRA and the ecological transition area are closely related to it. The outer part of WRA is the rational utilization area, including MEA, MSA, LEA, DJQ and NYQ. Among them, the areas not protected by nature wetlands in the planning area have more disturbance surfaces and greater interference intensity to WRA and WCA. The disturbance surface of ZZQ and DJQ in the wetland edge area is less, and the disturbance intensity is relatively less (Figure 4).

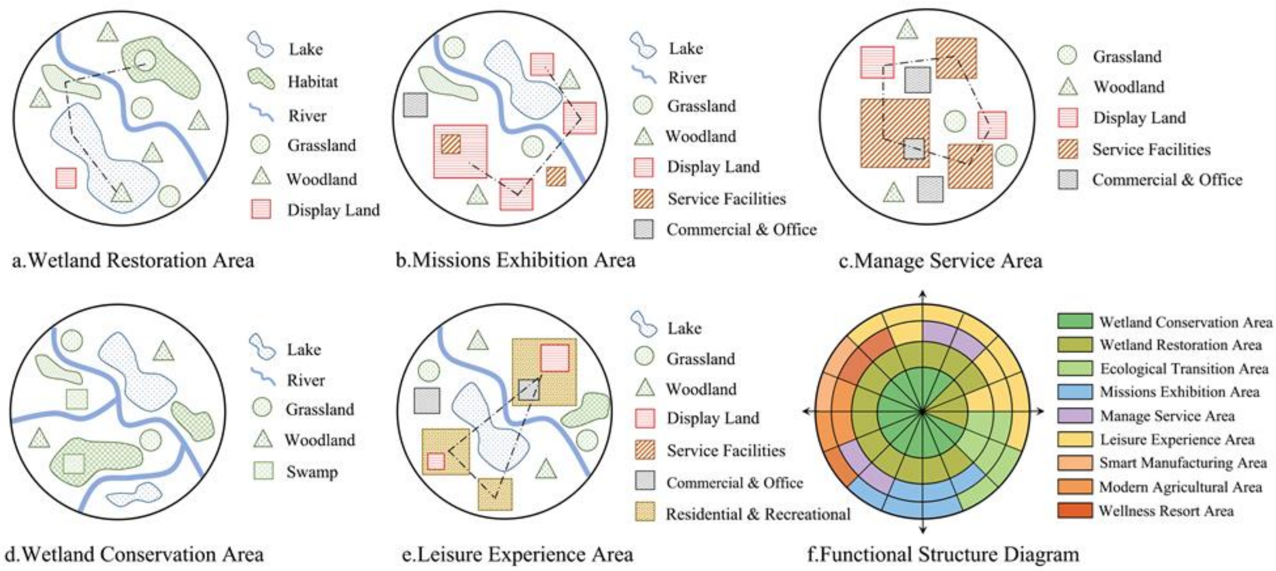

Figure 4. Landscape and functional structure of Pan'an Lake constructed wetland.

2.2.3. Characteristics and Distribution of Plant and Animal Communities

After reviewing relevant literature, there were 311 species of wildlife in Pan'an Lake wetland, including 28 species of invertebrates, 44 species of fish in 7 orders, 208 species of birds in 18 orders, 6 species of amphibians in 1 order, 13 species of reptiles in 3 orders, and 12 species of mammals in 3 orders. Plant resources are also relatively rich, including 65 families of 205 species of woody plants, more than 1000 species of flower seedlings, 160,000 restored trees, 1 million square meters of shrub cover, and 980,000 square meters of aquatic plants (Figures 5 and 6). The wetland conservation area for the rare and endangered birds' habitats holds local birds from northern and central China, flying birds' habitats, the egret, swan, mandarin duck and national protected animals. The northeast wetland gives priority to the sancho type of plant community, also has the bird island, as well as more than 300 kinds of lotus, plants and animals in very rich resources, with good habitat conditions. The wetland restoration area covers a total area of 206.9 hectares. There are red fox, weasel, hedgehog, badger, pig badger and other provincial-level protected animals. The lake island is dominated by wetland trees and shrubs, and the lake surface is dominated by emergent plants, forming a rich and colorful river, lake, island, forest and wetland landscape system. The publicity and education exhibition area, leisure experience area and management service area are mainly artificial and natural complex ecological space, where local plants such as crape myrta, hibiscus, pomegranate and red maple are planted. The main route is publicity and education display and tourism appreciation (Table 1).

Table 1. Biological types and impacts on aquatic ecological environment in Pan'an Lake.

Typical Biological	Type	Main Distribution	Positive Feedback	Negative Feedback
Reed, cattails, aquatic canna etc.	Emergent aquatic plants	Water depth <0.3 m	To provide habitat for birds, at the same time play the role of water convection, the first into the upper and lower water circulation	Its own transition reproduction, decay after the pH value decreases, DO concentration decreases
Spatterdock, Lotus flower, duckweed etc.	Floating plants	Water depth 0.3 m~0.9 m	Purify water, can effectively degrade TP, TN, etc. [32]	Overbreeding thus obscuring sunlight and affecting photosynthesis in submerged plants

Table 1. *Cont.*

Typical Biological	Type	Main Distribution	Positive Feedback	Negative Feedback
Water caltrop, tape grass etc.	Submerged plants	Water depth 0.9 m~2.5 m	N, P removal effect is good, zinc enrichment, arsenic and other metal ions have a strong purification ability [33]	It is easy to cause eutrophication of water after decay
Wheat, rice etc.	Economic crops	Land at the edge of the planning area	To enrich the species diversity index, and at the same time to provide security for local economic society and food security	Agriculture had a negative effect on TN, TP and COD [34]
Silver carp, crucian carp etc.	Aquatic animals	Each functional area	Effectively inhibit the production of planktonic algae, effectively reduce the concentration of suspended matter, improve the transparency of water	Crucian carp positively increased TN, TP, planktonic biomass and TSS, but negatively improved shallow water ecosystem [35]

Figure 5. Plant community distribution map of Pan'an Lake wetland.

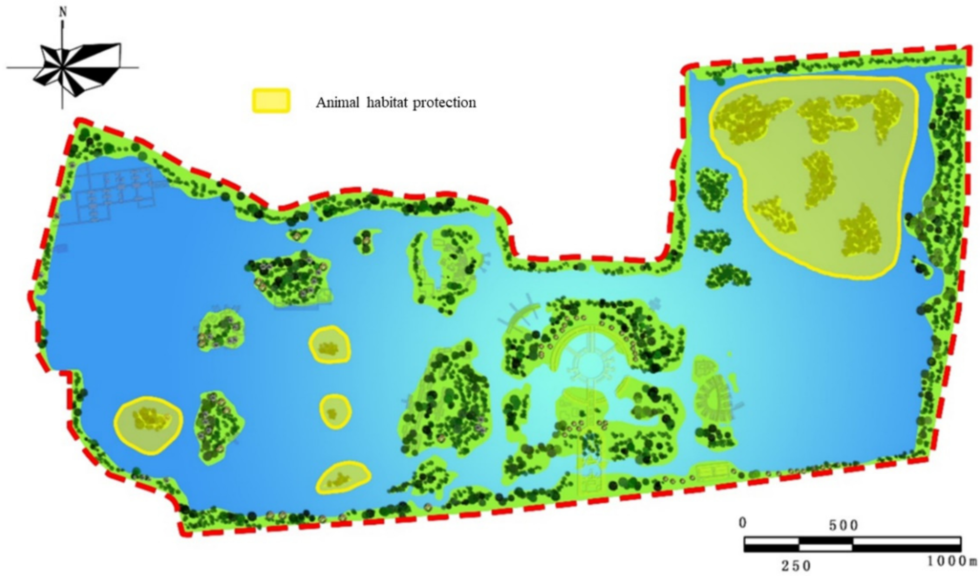

Figure 6. Distribution map of the animal community in Pan'an Lake wetland.

2.3. Research Methods

The main steps of this study are shown in the figure and are explained in the following chapters: (1) firstly, we determined the land use composition of each functional area and the location of water quality monitoring points; (2) secondly, the Spatial Analyst Tool was used in ArcGIS10.5 software to calculate the area and proportion of landscape elements in each functional area, and the landscape pattern index of each functional area was analyzed in Fragstats4.2 software; (3) then the Nemerov index method was used to evaluate the six water quality indicators in each functional area; (4) after that, Pearson's Correlation Analysis of landscape structure and water quality was carried out by SPSS23.0 software, and RDA analysis of landscape structure and water quality was calculated by Canoco4.5 software; and (5) Inverse Distance Weighting Analysis and Geostatistical Analysis are finally completed in ArcGIS10.5 software (Figure 7).

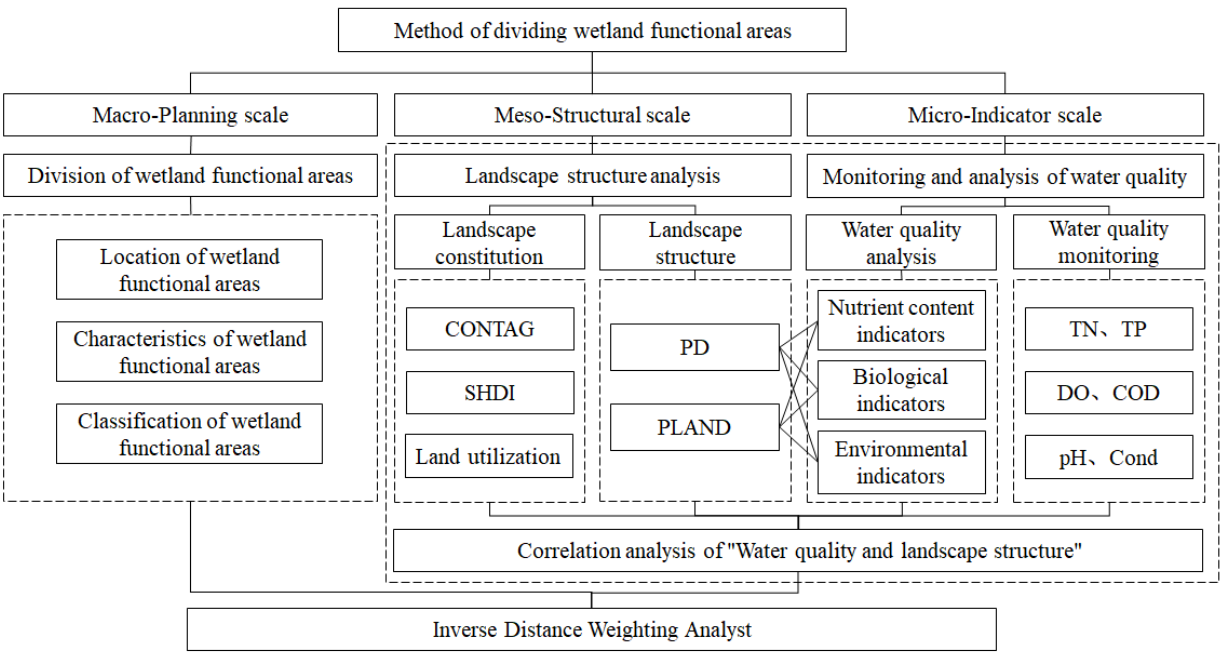

Figure 7. Technology roadmap.

2.3.1. Stage 1: Determine the Land Use Composition of Each Functional Area and the Location of Monitoring Points

The remote sensing impact data are from the 2020 TM/OLI image data downloaded from the geospatial data cloud platform. ENVI 5.1 and ArcGIS 10.5 software are used to determine the land use types of each functional area. Considering the terrigenous impact of the marginal area on wetland water quality, studies have shown that the land use in the 500 m buffer zone has the highest resolution on wetland water quality [36]. Thus, since Pan'an Lake wetland park planning set up a boundary buffer (500 m) to delimit the scope of data collection, and the TM image data/OLI radiation processing means scaling and atmospheric correction, so as to obtain range image data in the study area; then, using the multi-spectral superposition with visual interpretation methods to distinguish the different land types, to ensure that the confusion matrix classification provides results accuracy. Finally, the land use status map of Pan'an Lake wetland was obtained. Based on field research and relevant data, the classification results were revised and divided into five categories: farmland, forest, water body, grassland and construction land.

To accurately represent the environmental quality and conditions of sampling sites, follow the principle of representativeness and uniformity of sampling sites, avoid setting in stagnant water areas, and at the same time take into account the accessibility of sampling sites. A total of 12 conventional monitoring sites are set up, among which WRA has D1, D2, D3, D4 monitoring sites, MEA has D5, D6, D7 monitoring sites, and MSA has D8 monitoring sites. WCA is equipped with D9 and D10 monitoring points, while LEA is equipped with D11 and D12 monitoring points. The geographic coordinate information of GPS collection points is used for monitoring (Figure 8). Since the water depth of Pan'an Lake is less than 5 m, the sampling points are uniformly arranged at 0.5 m below the water surface.

Figure 8. Water quality monitoring point map of Pan'an Lake.

2.3.2. Stage 2: Quantitative Research on Landscape Structure of Functional Areas

This study introduced the landscape pattern index to evaluate the wetland area landscape structure, and selected four significantly higher weight and relatively independent ecological meanings of landscape pattern index that were used to quantify the structure of the functional area landscape research [22]. The landscape pattern analysis software Fragstats4.2 environment already selected indicators in the landscape pattern index calculations, and the landscape pattern index of the functional area was statistically analyzed. The specific calculation formula selected is as follows:

1. Patches Density (PD)

This index can effectively characterize the landscape fragmentation degree of each functional area. The greater the fragmentation degree, the lower the landscape security degree and the higher the risk of runoff pollution. The formula is as follows:

$$PD = \frac{n_i}{A} \times 10^6 \quad (1)$$

where n_i is the number of plaques; A is the total area of the landscape or patch.

2. Contagion (CONTAG)

The CONTAG index describes the degree of agglomeration or extension trend of different patch types in the landscape. Generally speaking, a high spread value indicates that a dominant patch type in the landscape has formed good connectivity. On the contrary, it indicates that the landscape is a dense pattern with multiple elements and the degree of fragmentation is relatively high. The formula is:

$$CONTAG = \left\{ 1 + \frac{\sum_{i=1}^{m} \sum_{k=1}^{m} \left[p_i \left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}} \right) \right] \cdot \left[\ln p_i \left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}} \right) \right]}{2 \ln(m)} \right\} \times 100 \quad (2)$$

where p_i is the proportion between patch type i and the total patch area of the study area, g_{ik} is the number of nodes between patch type i and patch type k based on the doubling method. M represents the number of patch types, including patch types in the landscape boundary. The CONTAG value ranges from 0 to 100. A small CONTAG value indicates that most of the landscape is small patches, while a large CONTAG value indicates that there are major patches with higher connectivity in the landscape.

3. Percentage of Landscape (PLAND)

It refers to the relationship between the landscape shape and area of a patch and its composition, reflecting the complexity of landscape patches and landscape patterns at a certain observation scale. The higher the PLAND value, the less human interference and the lower the risk of runoff pollution. The formula is:

$$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A} \times 100 \quad (3)$$

where a_{ij} represents the area (m^2) of the j patch in class i landscape type. A is the total area of the landscape (hm^2). When the patch area percentage value is close to zero, it indicates that the patch type in the landscape decreases. When the ratio is equal to 100, it means that the whole landscape is composed of only one type of patches.

4. Shannon's Diversity Index (SHDI)

SHDI is an index to judge the overall heterogeneity of landscape in ecological space. The higher the index is, the more complex the ecological space type of the region is. Incense diversity is closely related to species diversity in ecology, and it is one of the common indicators to measure species diversity from the side. The larger the SHDI value, the richer the land use types in the study range, and the higher the degree of landscape fragmentation. The formula is:

$$SHDI = -\sum_{i=1}^{m} (p_i \times \ln p_i) \quad (4)$$

where p_i is the proportion of landscape patch type i in the total patch area, m is the number of patch types in the study area, SHDI = 0 indicates that the landscape type in the study area is single, and the larger SHDI indicates that the richness of landscape type is higher, or all landscape patch types are evenly distributed in the middle range of the system.

2.3.3. Stage 3: Water Quality Sampling and Water Quality Assessment at Monitoring Points

1. Water quality sampling.

Based on the field investigation of Pan'an Lake National Wetland Park, referring to the national "Surface Water Environmental Quality Standard" (GB3838-2002) and combining with the actual pollutants in the project area [18,37], the water quality monitoring content of Pan'an Lake wetland was determined, including: 1. Nutrient index: TN and TP; 2. Biological indicators: DO and COD; 3. Environmental indicators: pH and Cond, 6 items in total. According to the Technical Specifications for Surface Water and Sewage Monitoring (HJ/T91-2002) [38,39], the six indicators were monitored three times a month from January to December 2020. Polyethylene bottles were used to collect 50 cm water from the surface of the lake, A total of 216 valid water samples were collected, including 36 samples in the Leisure Experience Area of the study area; 36 samples were collected from Wetland Conservation Area; Management Service Area a total of 22 samples; a total of 68 valid samples were collected for the Wetland Restoration Area. Missions Exhibition Area 54 samples were collected, pH, DO and Cond were measured in the field, and the remaining samples were sent to Changshu Institute of Ecological Environment (Tables 2 and 3). According to the hydrological and climatic characteristics of Xuzhou, the whole year from January to December 2020 is divided into three periods, namely, the wet season (May to August), the dry season (November to February), and the normal season (March to April, September to October). Considering the possibility of data error in the actual measurement, we use the average value to better reflect the average level of water quality over a period of time.

Table 2. Water quality monitoring methods and reference standards.

Monitoring Project	Determination Method	Measuring Range	Resolution	Accuracy	Reference Standard	Note
pH	Glass electrode method	0–14	±0.01 PH	±0.02 PH	GB6920—86	In situ determination
DO	Fluorescence	0–20 mg/L	0.01 mg/L	±5%Fs	HACH	In situ determination
TN	Persulfate oxidation method	0–25 mg/L	0.01 mg/L	<5%	HACH	Laboratory analysis
TP	Ascorbic acid method	0–1.5 mg/L	0.01 mg/L	<5%	HACH	Laboratory analysis
COD	Colorimetric method	3–150 mg/L	0.01 mg/L	<1%	USEPA	Laboratory analysis
Cond	Metal electrode method	0–200 ms/cm	0.01 ms/cm	<1%	USEPA	In situ determination

Table 3. Number and distribution of water quality monitoring samples.

Functional Division	Characteristic	Proportion of Area	Monitoring Stations	Monitored Items (N)	Monthly Samples (N)	Annual Samples (N)
WRA	Seminatural ecosystem	44.3%	D1, D2, D3, D4	6	68	816
MEA	Natural ecosystem	22.5%	D5, D6, D7	6	54	648
MSA	Artificial ecosystem	1.6%	D8	6	22	264
WCA	Complex ecosystem	22.7%	D9, D10	6	36	432
LWA	Complex ecosystem	8.9%	D11, D12	6	36	432

2. Nemerov index method was used for water quality assessment.

Compared with the single factor evaluation method, Nemerov index can evaluate both the main impact factors and the comprehensive impact factors, which is one of the main methods for the comprehensive evaluation of water quality. By comparing the measured value of water environmental quality with the standard of Surface Water Environmental Quality (GB3838-2002) [40], the mean value (P) and maximum value (P_{imax}) of the single factor index can be obtained. Thus, the comprehensive pollution index (P_i) can be calculated to evaluate the pollution degree of nutritional and biological indicators. Range (R), standard deviation (σ) and dispersion index (V_s) were used to evaluate environmental indicators. The smaller the annual mean and dispersion index, the better the water quality was.

The calculation formula of Nemerov index is:

$$P = \sqrt{\frac{\left(\frac{C_i}{C_{oi}}\right)^2_{max} + \frac{1}{n}\left(\frac{C_i}{C_{oi}}\right)^2}{2}} \quad (5)$$

C_i—The measured concentration of pollutants (mg/L); C_{oi}—Evaluation criteria for pollutants (mg/L).

2.3.4. Stage 4: Correlation Analysis between Landscape Structure and Water Quality in Functional Area

Correlation analysis was used to study the relationship between landscape pattern and water quality environment in wetland functional areas, and correlation analysis and redundancy analysis were used to study the coupling mechanism between landscape structure and water environment quality [41,42].

1. Pearson's Correlation Analysis

Pearson's Correlation Analysis was carried out with SPSS23.0 software. As an effective method to study the "one-to-one" relationship, Pearson's could conduct bivariate analysis on landscape index and water quality index, which was convenient to explore the correlation between landscape pattern index and water quality index in each functional area of Pan'an Lake wetland. In this paper, the significance between landscape index and water quality index is tested by unilateral test method, and the index with significant correlation coefficient ($r < 0.05$) is selected for analysis. The calculation formula of correlation coefficient is as follows:

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum f(x - \bar{x})^2}\sqrt{\sum f(y - \bar{x})^2}} \quad (6)$$

2. Redundancy Analysis (RDA)

This method can not only obtain the variance contribution rate of a single landscape variable to the variation in wetland water environment quality, although it can also intuitively reflect the comprehensive relationship between landscape variables and water quality variables, which is a good method to analyze the "many-to-many" relationship. The water quality index of each functional area was selected as the response variable, and the landscape pattern index was selected as the explanatory variable. Canodraw for Windows 5.0 software was used to conduct Detrended Correspondence Analysis (DCA) on water quality indexes in different functional areas. The results showed that the gradient value was less than 4, so this model could be used in this study [43].

2.3.5. Stage 5: Analysis of Spatial Distribution Characteristics of Water Quality

Inverse Distance Weighting (IDW) [44] was used in ArcGIS10.5 based on the results of water quality evaluation, which means that in the same area, the closer the distance between two testing points is, the more similar the determination parameters are, and conversely, the farther the distance is, the less similar the measurement parameters are. It takes the distance weight between the interpolation point and the sample point to carry out the weighted average, and the sample point closer to the interpolation point gives more weight. The formula is:

$$Z^*(x_0) = \sum_{i=1}^{N} \lambda_i Z(x_i) \quad (7)$$

where $Z^*(x_0)$ is the predicted value at x_0; N is the number of surrounding sample points used for interpolation; $Z(x_i)$ is the measured value at x_i of the sample point; and λ_i is the weight of the i sample point to the predicted point, which is calculated by Equation (7).

$$\lambda_i = \frac{d_0 - p}{\sum_{i=1}^{N} d_{i0} - p}, \sum_{i=1}^{N} \lambda_i = 1 \quad (8)$$

where d_{i0} is the distance between prediction point x_0 and various points; p is the power of distance, that is, with the increase in distance between sample points and predicted points, the influence of sample points on the weight of predicted points decreases exponentially. The sum of the weights is 1.

3. Results

3.1. Landscape Structure Analysis of Pan'an Lake Wetland Functional Area

By analyzing the area and proportion of landscape elements in different functional areas (Table 4), it can be seen that the cultivated land area around LEA and WRA was larger, with a ratio of 20.09% and 15.87%, respectively. The sum of forestland and grassland area accounted for 45–55% of each space, and the ratio of forestland area to regional area was the smallest in MSA. Except MSA, the water area of each functional area accounted for 30–40% of the total area, and the ratio of water area to regional area of WCA was the largest, with a value of 39.81%. The ratio of MSA building area to regional area was the largest, with a value of 9.21%.

Table 4. Area and proportion of landscape elements in different functional areas.

Functional Division	Agriculture Area (ha)	Percentage %	Forest Area (ha)	Percentage %	Grassland Area (ha)	Percentage %	Water Area (ha)	Percentage %	Built-Up Land (ha)	Percentage %
WRA	59.76	15.87	84.87	22.54	95.94	25.48	133.83	35.54	2.16	0.57
MEA	31.68	14.11	42.93	19.12	72.63	32.34	75.6	33.67	1.71	0.76
MSA	2.73	9.52	5.4	18.83	10.35	36.09	7.56	26.36	2.64	9.21
WCA	12.6	6.96	48.33	26.69	47.97	26.49	72.09	39.81	0.09	0.05
LEA	24.84	20.09	24.48	19.79	33.57	27.15	38.7	31.29	2.07	1.67
Total	131.61	14.08	206.01	22.04	260.46	27.87	327.78	35.07	8.67	0.93

The wetland restoration area has a low degree of landscape fragmentation (Figure 9 and Table 5), a high degree of landscape agglomeration, obvious landscape advantages, and the highest landscape diversity, indicating that it has good ecological stability and sustainability. The wetland display area had a general degree of landscape fragmentation, a general degree of landscape agglomeration, a low landscape advantage and a high landscape diversity, indicating that it had been disturbed by human activities. The wetland service area had the highest degree of landscape fragmentation, the lowest degree of landscape aggregation, the lower landscape dominance, and the higher landscape diversity, indicating that its ecological environment was greatly influenced by human beings. The wetland conservation area had the lowest degree of landscape fragmentation, the highest degree of landscape agglomeration, the most obvious landscape advantages than other functional areas, and the lowest landscape diversity, indicating that it was dominated by natural ecological landscape and weakly disturbed by human activities. The wetland experience area has a high degree of landscape fragmentation, low degree of landscape agglomeration, general landscape advantages and general landscape diversity, indicating that the natural landscape and human activities are more balanced.

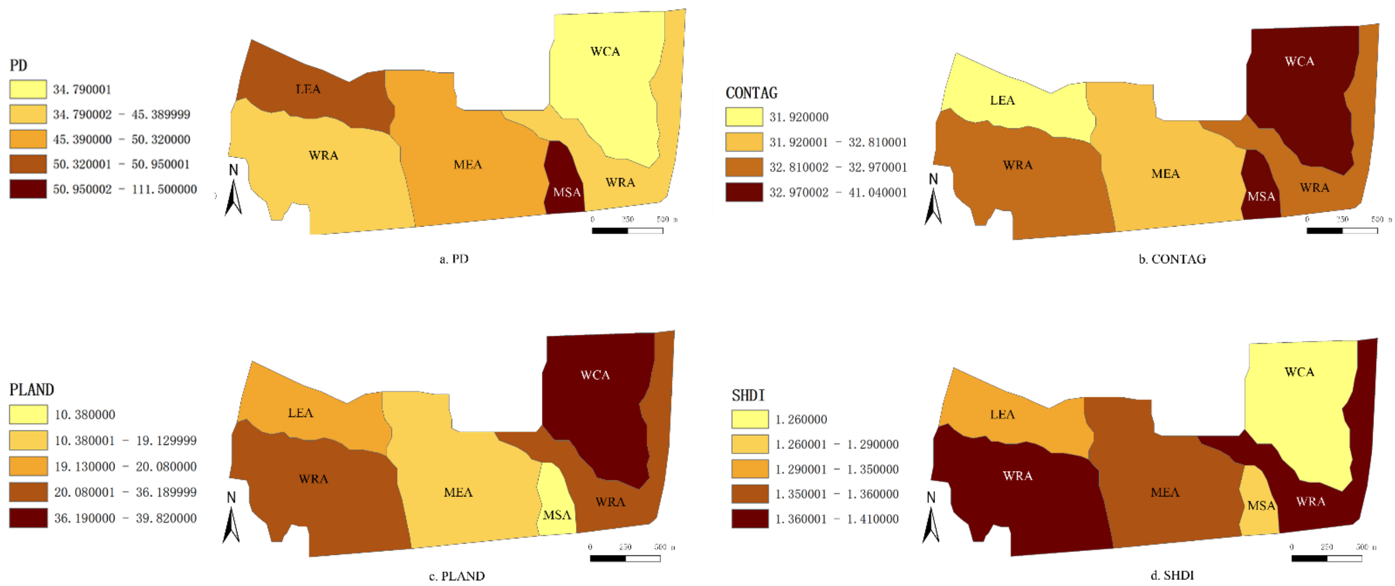

Figure 9. Landscape index analysis of different functional areas in Pan'an Lake Wetland.

Table 5. Landscape index analysis of different functional areas of Pan'an Lake Wetland.

Functional Division	**Landscape Fragmentation**	**Value**	**Landscape Aggregation**	**Value**	**Landscape Dominance**	**Value**	**Landscape Diversity**	**Value**
	PD		**CONTAG**		**PLAND**		**SHDI**	
WRA	45.39	Low	32.97	High	36.19	High	1.41	Highest
MEA	50.32	General	32.81	General	19.13	Low	1.36	High
MSA	111.50	Highest	19.15	Lowest	10.38	Lowest	1.29	Low
WCA	34.79	Lowest	41.04	Highest	39.82	Highest	1.26	Lowest
LEA	50.95	High	31.92	Low	20.08	General	1.35	General

3.2. Assessment and Analysis of Water Quality in the Study Area

3.2.1. Evaluation of Nutrient Indexes (TN and TP)

The nutritional index consists of total nitrogen (TN) and total phosphorus (TP). TN is used to express the degree of water pollution by nutrients, which is one of the important indicators to measure water quality. The main sources of TP are domestic sewage, chemical fertilizers, organophosphorus pesticides and phosphate cleaning agents used in modern detergents. TP contributes to the proliferation of algae, causing eutrophication of water and destroying the ecological balance of water.

The TN concentration in all functional areas in February 2020 was significantly higher than that in other periods, with an average concentration of 1.34 mg/L. The TN concentrations of WRA, MEA, WCA, LEA and MSA were 0.84 mg/L, 1.04 mg/L, 0.95 mg/L, 0.96 mg/L and 1.11 mg/L, respectively, which met the standard of class iii water. WCA and WRA belong to key ecological reserves with good ecological buffer zones around them, and the index fit degree is high (Table A1). MEA and LEA had more human interference, and individual indexes deviated from the overall indexes. The TP concentration in all functional areas of Pan'an Lake was not high, and it basically met the class iii water quality standards except for some periods. The comprehensive pollution index of WCA and MEA were 0.45 mg/L and 0.48 mg/L, respectively, which met class ii water quality standards. WRA and MEA have a gradient stratification phenomenon, which is greatly influenced by the recharge water of open water system and local crops and cash crops, respectively. MSA had no obvious wetland characteristics, and TP was greatly influenced by the abundance, distribution, flowering period and other factors of plants in the artificial landscape (Table 6).

Table 6. TN and TP indicators.

Index	Functional	Monthly Average				Annual Value				Evaluation				Value
		Max	Mth	Min	Mth	Max	Mth	Min	Mth	Annual Mean	P_{imax}	$\overline{P}$	P_i	
TN mg/L	WRA	1.18	2	0.58	6	1.50	1	0.50	6	0.84	0.77	0.78	0.78	Lowest
	MEA	1.47	2	0.80	3	1.70	2	0.50	4	1.04	0.98	0.84	0.91	Highest
	MSA	1.60	2	0.70	5	1.60	2	0.70	5	1.11	0.80	0.81	0.81	Low
	WCA	1.40	2	0.45	4	1.40	2	0.40	4	0.95	0.93	0.82	0.88	High
	LEA	1.30	2	0.75	4	1.30	1	0.60	4	0.96	0.68	0.83	0.85	General
TP mg/L	WRA	0.06	2	0.03	4	0.08	2	0.02	6	0.04	0.60	0.42	0.52	General
	MEA	0.06	3	0.03	7	0.08	3	0.02	7	0.03	0.57	0.37	0.48	Low
	MSA	0.06	7	0.02	5	0.06	7	0.02	6	0.04	0.60	0.55	0.58	High
	WCA	0.05	12	0.03	6	0.05	10	0.03	5	0.04	0.50	0.39	0.45	Lowest
	LEA	0.08	5	0.03	1	0.08	6	0.03	1	0.05	0.75	0.47	0.62	Highest

Note: The number of samples was 816 for WRA, 648 for MEA, 264 for MSA, 432 for WCA, LWA.

3.2.2. Evaluation of Biological Indicators (DO and COD)

Dissolved oxygen (DO) and chemical oxygen demand (COD) were selected as biological indexes. The content of DO in water is an index to measure the self-purification ability of a water body, which is closely related to atmospheric pressure, water temperature and water quality. When the DO value in water drops to 5 mg/L, fish will have dyspnea [45]. COD is related to both climate and microbial community activity, and the higher the species richness, the lower the COD value [46].

The results of water quality monitoring (Table 7) showed that the DO concentration in each functional area of Pan'an Lake was low. The DO concentration of WRA was higher (12.44 mg/L) and LEA was lower (10.73 mg/L). The lower the temperature was, the higher the oxygen solubility was. MSA and WCA had better indexes in November and December in winter, while WRA and MEA released a large amount of oxygen to water through plant photosynthesis, and the indexes were significantly increased. The DO concentration of LEA did not change significantly. The indices of WCA and WRA had a high degree of fit (Table A1), the overall water environment was good, and the growth and distribution of aquatic plants were more balanced. The annual mean COD concentrations of MEA and LEA were 12.72 mg/L and 12.36 mg/L, respectively, while the annual mean COD concentrations of WRA and WCA were 13.51 mg/L, respectively. From the different time, the COD concentration of each functional area was greater than 15 mg/L in March and April, and the rest of the time all waters met the class I water quality standard. The average COD concentration of MSA water was 13.49 mg/L (Table 7).

Table 7. DO and COD indexes.

Index	Functional	Monthly Average				Annual Value				Evaluation				Value
		Max	Mth	Min	Mth	Max	Mth	Min	Mth	Annual Mean	P_{imax}	$\overline{P}$	P_i	
DO mg/L	WRA	15.95	6	10.21	3	18.9	6	9.69	3	12.44	2.13	1.66	1.91	Highest
	MEA	14.52	6	10.03	9	15.24	6	9.68	3	11.66	1.94	1.56	1.76	High
	MSA	12.91	11	8.06	1	12.91	11	8.06	1	11.10	1.72	1.48	1.61	General
	WCA	12.76	12	10.03	8	13.74	12	9.75	8	11.13	1.70	1.48	1.60	Low
	LEA	13.08	10	9.49	6	13.19	10	8.60	6	10.73	1.74	1.43	1.59	Lowest
COD mg/L	WRA	17.79	3	10.50	12	18.50	3	9.30	10	13.51	0.89	0.81	0.85	General
	MEA	16.84	4	9.00	12	17.35	3	9.80	12	12.72	0.84	0.78	0.82	Low
	MSA	18.25	3	10.10	11	18.25	3	10.10	11	13.49	0.91	0.83	0.87	High
	WCA	18.13	4	9.65	12	18.56	4	9.40	12	13.51	0.91	0.83	0.89	Highest
	LEA	17.23	4	8.50	12	19.25	4	8.30	12	12.36	0.86	0.78	0.81	Lowest

Note: The number of samples was 816 for WRA, 648 for MEA, 264 for MSA, 432 for WCA, LWA.

3.2.3. Evaluation of Environmental Indicators (pH and Cond)

Environmental indicators include pH and electrical conductivity (Cond). The pH of water is greatly affected by pesticide residues, rainfall and minerals in the soil, and the phosphate fertilizer is alkaline and strong alkali and weak acid salts. There is a certain correlation between Cond and the number of electrolytes contained. In a certain concentration range, the larger the concentration of ions, the more charge they carry [47].

The water quality of the functional areas of Pan'an Lake wetland is slightly alkaline, with the annual mean pH between 7.0 and 9.0, and the water pH is in the normal range. In summer, the rainfall is heavy and acidic, and the alkalinity degree decreases, so the acidity index of MSA water quality increases. There was no significant difference in pH of each functional area in the wetland, and the degree of fit of each index was high (Table A1). MSA and WRA have higher annual Cond values, more salt components, ion components, impurity components, and so on. The range and standard deviation are large, and the seasonality is obvious. WCA and LEA were polluted by agricultural non-point sources and the spring dry season, respectively, which led to the rise in TN and TP indexes, resulting in rapid algal propagation and increased Cond (Tables 8 and 9).

Table 8. Cond indexes.

Index	Functional	Monthly Average				Annual Value				Evaluation				Value
		Max	Mth	Min	Mth	Max	Mth	Min	Mth	Annual Mean	P_{imax}	$\overline{P}$	P_i	
Cond µs/cm	WRA	314.25	12	249.5	2	442.00	10	268.00	1	286.43	64.75	18.59	0.06	Lowest
	MEA	292.67	12	228.33	1	320.00	11	198.00	1	256.29	64.33	19.25	0.08	Low
	MSA	295.00	9	199.20	11	295.00	9	199.20	11	249.77	95.80	32.91	0.13	General
	WCA	282.00	3	192.05	11	295.00	4	191.90	11	233.00	89.95	32.19	0.14	Highest
	LEA	274.50	4	193.50	2	286.00	4	192.00	2	213.18	81.00	27.08	0.13	High

Note: The number of samples was 816 for WRA, 648 for MEA, 264 for MSA, 432 for WCA, LWA.

Table 9. pH indexes.

Index	Functional	Monthly Average				Annual Value				Evaluation				Value
		Max	Mth	Min	Mth	Max	Mth	Min	Mth	Difference Value	P_{imax}	$\overline{P}$	P_i	
pH	WRA	8.44	3	7.78	6	8.68	3	7.49	6	1.19	0.66	0.18	0.02	General
	MEA	8.43	3	7.92	6	8.59	3	7.85	6	0.74	0.51	0.12	0.01	Lowest
	MSA	8.45	4	7.75	7	8.45	4	7.75	8	0.70	0.70	0.20	0.02	General
	WCA	8.45	3	7.55	6	8.51	3	7.51	6	1.00	0.90	0.24	0.03	Highest
	LEA	8.33	10	7.72	6	8.31	10	7.65	6	0.66	0.60	0.18	0.02	General

Note: The number of samples was 816 for WRA, 648 for MEA, 264 for MSA, 432 for WCA, LWA.

3.3. Correlation Analysis between Landscape Structure and Water Quality

The correlation between landscape patch density and water environmental quality was analyzed (Table 10). Grassland patch density was significantly positively correlated with DO and negatively correlated with pH. Forest patch density was negatively correlated with pH. The density of cultivated land patch was positively correlated with COD. The patch density of construction land is positively correlated with TN, negatively correlated with DO, and negatively correlated with COD.

According to the RDA analysis of landscape patch density and water environmental quality (Figure 10), water patch density was negatively correlated with TP in the wet season and had a low correlation with water quality indicators in the normal and dry seasons. Grassland was positively correlated with DO and Cond in wet season and negatively correlated with pH in wet season and TN in normal season. Forestland was positively correlated with DO in wet season, COD and Cond in normal season. Construction land is highly correlated with pH in wet season, positively correlated with Cond, TN and TP, and negatively correlated with DO in wet season and COD in normal season. Arable land was positively correlated with Cond in dry season, and negatively correlated with TP in wet season, pH in normal season, COD and pH in dry season.

Table 10. Correlation analysis between landscape patch density (PD) and water quality.

Index	Rainy Season			Normal Season			Dry Season		
	Types	R	P	Types	R	P	Types	R	P
TN	Agriculture	0.928	0.032	Built-up land	0.983	0.017		/	
DO	Grassland	0.973	0.027		/		Built-up land	−0.986	0.014
COD		/		Built-up land	−0.998	0.002	Agriculture	0.924	0.048
pH	Forest	−0.951	0.049	Grassland	−0.953	0.047		/	

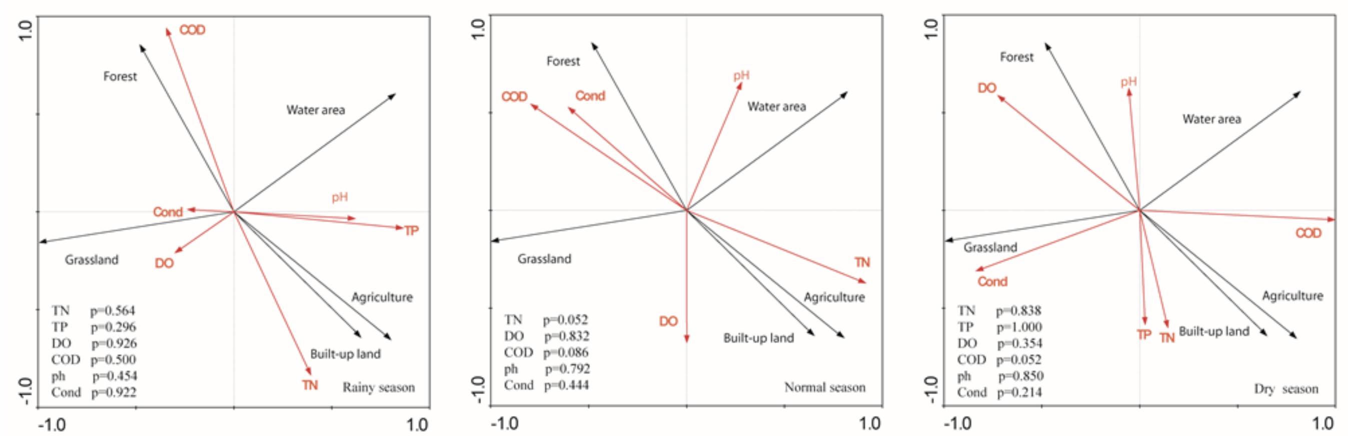

Figure 10. Ranking diagram of patch density (PD) and water quality index RDA.

It was found that the higher the patch density of landscape, the worse the overall water quality index was; the grassland and woodland only had patch density, and the higher the DO concentration, the better (Table 11). These studies indicate that the greater the patch density, the more detrimental it is to the fixation and interception of pollutants in wetland. In particular, the increase of cultivated land patch density will increase the risk of TN and TP on surrounding water loss, which is consistent with previous research results [41]. In terms of time, the rainfall in dry season and normal season is less, and the water quality is disturbed by many factors. The patch density of construction land, arable land, water area and garden land will affect the concentration of water quality index. During the wet season, there is plenty of rainfall, which is greatly influenced by the replenishment of the surrounding rivers. The water level of Pan'an Lake wetland rises accordingly, the shallowest part can reach 2 m, the deepest part can reach 8 m, the average water depth is 6 m, and the perennial water level is 28.0 m (Yellow Sea elevation). Only the density of cultivated land patch has a great influence on the concentration of water quality index.

Table 11. Impacts of landscape patch density (PD) and water quality indicators and ecological effects.

Index	Agriculture		Forest		Grassland		Water Area		Built-Up Land	
	Water Season	Ecological Effect (P)	Water Season	Ecological Effect (P)	Water Season	Ecological Effect (P)	Water Season	Ecological Effect (P)	Water Season	Ecological Effect (P)
TN	/	/	/	/	Normal	+ (0.052)	/	/	Normal	− (0.017)
TP	Rainy	+ (0.296)	/	/	/	/	Rainy	+ (0.296)	Rainy	− (0.296)
DO	/	/	Rainy	+ (0.926)	Rainy	+ (0.027)	/	/	Dry	− (0.014)
COD	Dry	− (0.048)	Normal	− (0.086)	/	/	/	/	Normal	− (0.002)
Cond	Dry	− (0.214)	Normal	− (0.444)	Dry	− (0.214)	Dry	− (0.214)	Rainy	− (0.922)

Note: + Positive ecological effect; − Negative ecological effect; / The correlation is not obvious.

By analyzing the correlation between landscape patch area percentage index and water environmental quality, it can be seen (Table 12) that woodland patch area percentage is positively correlated with COD and pH in the wet season, and negatively correlated with TN in the wet season. The percentage of grassland patch area was positively correlated with Cond in the dry season and negatively correlated with COD in the dry season. The percentage of cultivated patch area was negatively correlated with COD and positively correlated with TN in the normal season. The percentage of patch area was positively correlated with pH in the normal season, and negatively correlated with DO in the wet season and Cond in the dry season. There was a significant negative correlation between COD and Cond of construction land and normal water period.

Table 12. Correlation analysis between percentage of patch area (PLAND) and water quality.

Index	Rainy Season			Normal Season			Dry Season		
	Types	R	P	Types	R	P	Types	R	P
TN	Forest	0.928	0.049	Built-up land Agriculture	0.983 0.971	0.016 0.028		/	
DO	Water area	0.973	0.027		/		Built-up land	−0.988	0.012
COD	Forest	0.952	0.048	Agriculture Built-up land	−0.963 −0.962	0.037 0.038	Grassland Water area	−0.979 −0.956	0.021 0.043
Cond		/		Built-up land	−0.988	0.012	Grassland	0.975	0.028

/ The correlation is not obvious.

According to the analysis of landscape patch area percentage index and water environmental quality RDA (Figure 11), woodland patch area percentage was positively correlated with COD in the normal water period, DO and pH in the dry water period, and negatively correlated with TN in the wet season. The percentage of grassland patch area was negatively correlated with Cond and COD in the dry season but had no significant correlation with water quality indexes in the wet and normal seasons. The percentage of patch area was negatively correlated with DO and Cond in the wet season and dry season. Arable land was negatively correlated with COD in the wet season, COD and Cond in the normal season, DO in the dry season, and positively correlated with TP in the wet season, TN and DO in the normal season, TN and COD in the dry season. The percentage of built-up land and patch area was negatively correlated with COD in the wet season, Cond in the normal season and DO in the dry season.

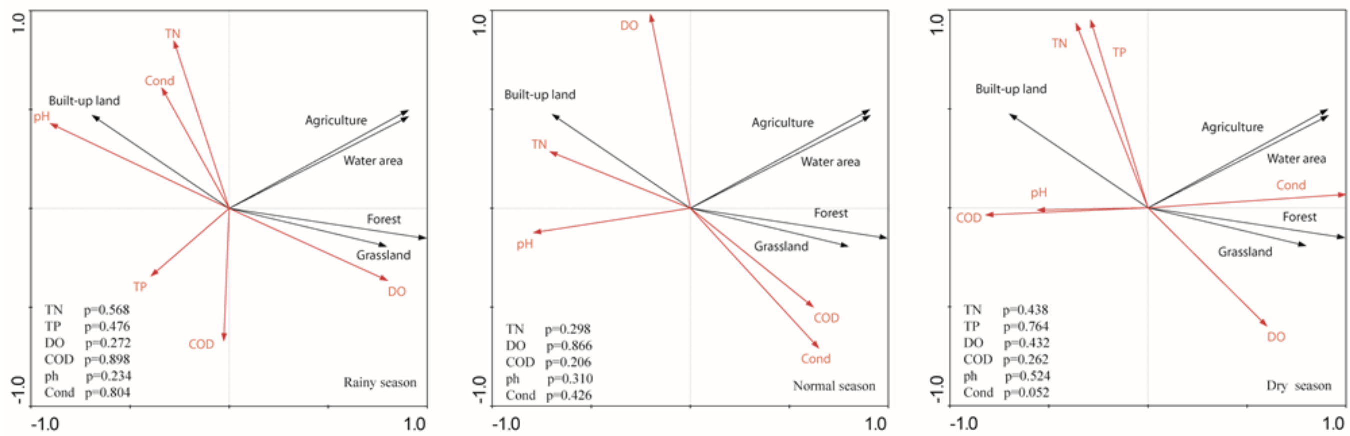

Figure 11. Percentage of patch area (PLAND) and RDA ranking of water quality indicators.

The changes in landscape area percentage and water quality index in time showed that the larger the water area proportion in the dry season, the better the ecological effect of Cond index was (Table 13), and the higher the forest area proportion in the wet season, the more significant the optimization effect of TN index was, but the consumption of

COD would be increased. The proportion of construction land and cultivated land area has a high impact on water quality indicators in each water period, indicating that the higher the proportion of artificial patch area, the more detrimental to water quality self-purification and optimization, which is consistent with previous research results [48]. In terms of landscape type and spatial distribution, the proportion of grassland, water area and construction land area had less influence on water quality nutrition index, while the proportion of cultivated land area had more influence on water quality nutrition index, and the proportion of each landscape type had greater influence on water quality biological index and environmental index.

Table 13. Effects of percentage patch area (PLAND) on water quality and ecological effects.

Index	Agriculture		Forest		Grassland		Water Area		Built-Up Land	
	Water Season	**Ecological Effect (P)**	**Water Season**	**Ecological Effect (P)**	**Water Season**	**Ecological Effect (P)**	**Water Season**	**Ecological Effect (P)**	**Water Season**	**Ecological Effect (P)**
TN	Normal	− (0.028)	Rainy	+ (0.049)	/	/	/	/	/	/
DO	Dry	− (0.866)	/	/	/	/	Rainy	− (0.027)	Dry	− (0.432)
COD	Normal	+ (0.037)	Rainy	− (0.048)	Dry	+ (0.021)	/	/	Normal	+ (0.038)
Cond	Normal	+ (0.426)	/	/	Dry	− (0.028)	Dry	+ (0.043)	Normal	+ (0.012)

Note: + Positive ecological effect; − Negative ecological effect; / The correlation is not obvious.

3.4. Spatial Distribution Characteristics of Water Quality in Pan'an Lake Wetland

Based on the monitoring data of water quality index in ArcGIS10.5 software platform, Inverse Distance Weighting (IDM) was used to perform spatial interpolation analysis on the water quality data of the monitoring points (Figure 12). The main results are as follows:

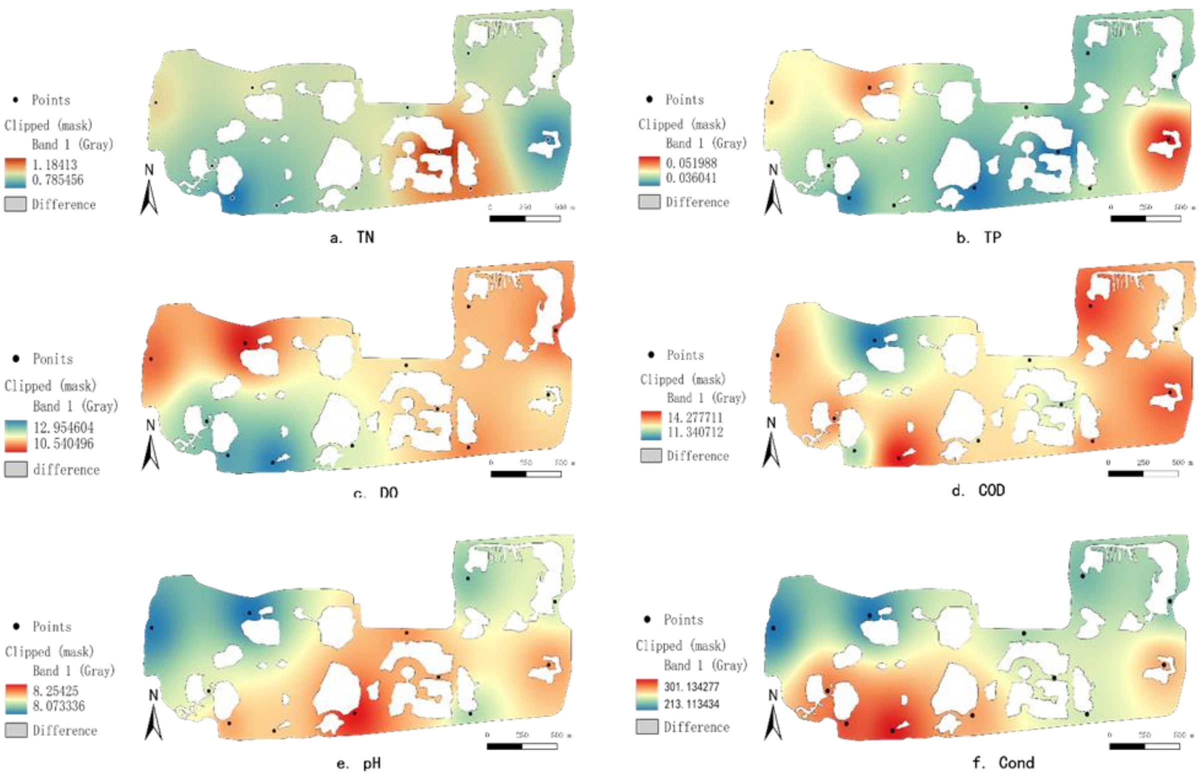

Figure 12. Analysis of water quality monitoring results of Pan'an Lake Wetland.

The comprehensive water quality of wetland functional areas in Pan'an Lake coal mining subsidence area was WCA > WRA > LEA > MEA > MSA from good to bad. The nutritional indexes from good to bad were WRA > WCA > MEA > MSA, LEA; the biological indexes from good to bad were WRA > MEA > WCA > LEA, FEQ; the order of environmental indicators from good to bad is WCA > LEA > MSA > WRA > MEA. The effect of landscape type on water quality purification from good to bad was woodland > grassland > water area > cultivated land > construction land. The main existing problems can be summarized as follows: (1) there are similarities and differences in the water environment in each functional area, and affected by the plain constructed wetland the water circulation between each functional area is poor, and the pollutant fixation and interception effect is obvious; (2) due to the influence of cultivated land and construction land in wetland edge areas, land-based pollution has a great impact on water quality in the wetland; and (3) there are endogenous pollutants such as industrial, mining and storage in the original ecological base of each functional area, which aggravate the pollution of wetland sediment after long-term accumulation effect.

4. Discussion

4.1. Analysis of Research Conclusions

In this paper, the water pollution and landscape of each functional area of Xuzhou Pan'an Lake wetland were evaluated by constructing an analysis model of "water environment and landscape structure". At present, the habitat landscape structure of WCA and WRA organisms is fragmented and islanded, which is limited by geographical space and cannot exchange material capacity. We should continuously improve the network connectivity of wetland ecological landscape in the longitudinal section. A complete ecological network is an important guarantee for the sustainable development of natural habitats [49]. Affected by non-point source pollution, there are many slow flow and still water areas in WRA, and the retreat water from farmland brings a large amount of nutrients such as N and P. MSA is dominated by artificial patches, which are greatly affected by the abundance of plants in artificial landscape, flowering period and climate change. The range and standard deviation of pH and Cond are large, and the seasonal characteristics are significant. MEA is an artificial–natural complex ecological space with high artificial interference attraction and development heat.

4.2. Implications and Limitations of Research Methods

This study is based on the correlation analysis of "water quality–landscape structure" in Pan'an Lake wetland. The landscape pattern index and Nemerov pollution index were selected as the evaluation indexes of landscape structure and water quality in functional areas, to achieve the purpose of quantitative study of landscape structure characteristics and water environment quality in each functional area. Pearson's Correlation Analysis and Redundancy Analysis are introduced into the study, which is conducive to studying the internal relationship between water ecological environment and landscape structure, and to building a bridge between water quality and functional zoning. Finally, the introduction of Inverse Distance Weighting Analysis is beneficial to visually show the distribution of water quality in various functional areas and to analyze the water quality differences in various functional areas with multiple dimensions.

However, there are some limitations in this study, which are mainly shown as follows: (1) the size of each functional area and the difficulty of obtaining water samples are different, and the number of sampling points in the functional area is different, which results in errors between the water quality monitoring results and the actual situation; (2) it is difficult to collect the relevant original data before the ecological restoration of the coal mining subsidence area (2010) by referring to relevant data, and this study only reflects the water environmental quality and optimization strategy of each functional area after the restoration; and (3) in addition to the restoration of water environment, which is the most important part of wetland ecosystem restoration, land use structure and wildlife distribution are also factors affecting functional zoning. This study mainly characterized the impact of wetland water environment problems on the optimization of functional zones. In the future research, it is urgent to expand the data source channels to ensure that the analysis results are more objective and reasonable, and it is also necessary to conduct dynamic research on the optimization of wetland functional areas with more dimensions, multiple factors and multiple periods.

4.3. The Guiding Significance of Research Results for Decision-Makers

From the findings of this study, the following observations and suggestions on the optimization of wetland functional areas are emphasized: (1) It is recognized that the network connectivity between WCA and WRA should be strengthened. By dredging the water system, constructing a water circulation treatment system, restoring a natural ecological community by planting wetland tree species such as metasequoia, duckweed and Sophiphyllum japonica [50], and establishing buffer space from single ecological circulation to bidirectional ecological element flow. (2) Reduce the human interference of MEA on WRA. Low disturbance management and maintenance mode should be adopted in the restoration area. Ecological overlay cofferdams should be added between the two areas, and compound islands should be constructed within 50 m~450 m from the shore to reduce the interference of terrestrial organic matter to the wetland. (3) Construction of LEA and MEA artificial corridors. The shuttling boats directly disturb the water bodies. By constructing pedestrian corridors, the times of shuttling boats should be properly limited, and the resources such as wetland landscape, history and culture should be fully utilized, taking into account the needs of ecological protection and economic development. (4) Improve the artificial revetment of MSA and MEA. Hard pavement leads to poor surface permeability and water purification efficiency. Considering the impact of extreme weather runoff such as rainstorm on the environment [51], it is necessary to build vegetation buffer and percolation zones to enhance the blocking ability of terrestrial pollutants, improve the filtration and decontamination ability of shallow water in wetlands, and improve the ecological stability and resilience of wetland islands. (5) Strengthen the control of land use in wetland edge areas. An ecological buffer zone should be established to strictly avoid adverse effects on the water environment quality of adjacent functional areas and the water quality of the watershed, and time classification management should be carried out in agricultural production season and non-agricultural production season [52,53] (Figure 13).

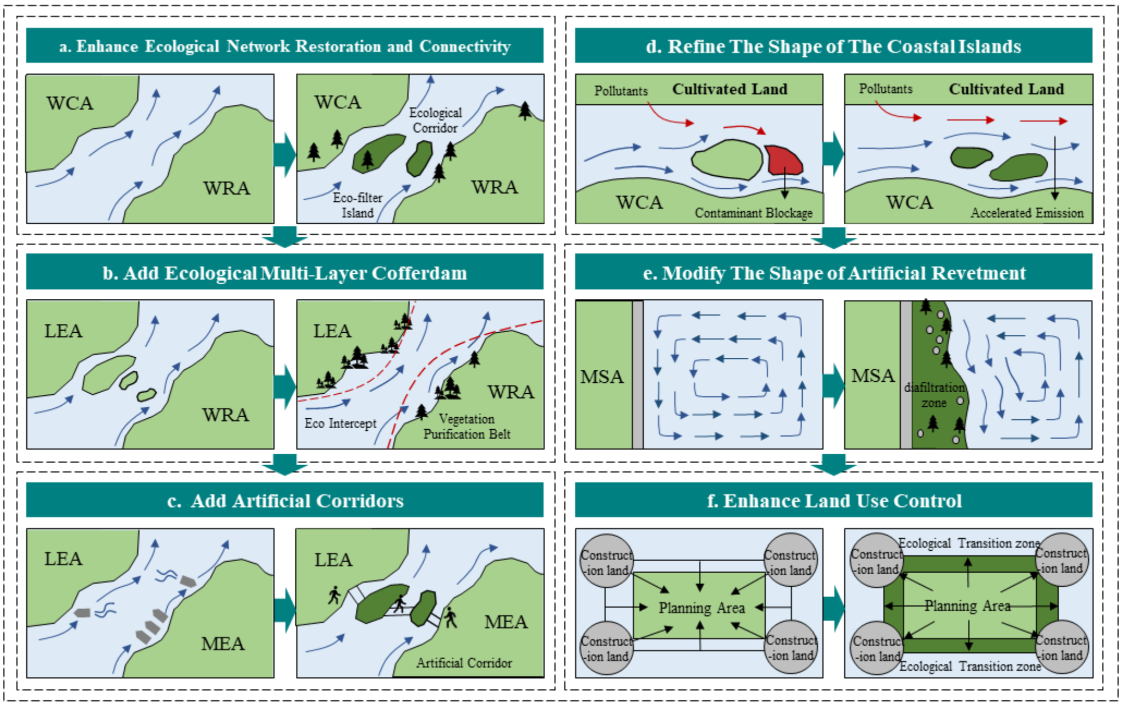

Figure 13. Optimization strategy for functional area of Pan'an Lake Wetland.

5. Conclusions

This paper takes Xuzhou Pan'an Lake National Wetland Park as the research object and discusses its water environmental quality and influencing factors, which is a supplement to the "post-assessment" research system of wetland restoration and makes up for the deficiencies of existing research to a certain extent. The main research conclusions are as follows:

(1) The comprehensive water quality of each functional area of Pan'an Lake wetland was WCA > WRA > LEA > MEA > MSQ from good to bad. The nutritional indexes from good to bad were WRA > WCA > MEA > MSQ, LEA. The biological indexes from good to bad were WRA > MEA > WCA > LEA, FEQ. The order of environmental indicators from good to bad is WCA > LEA > MSQ > WRA > MEA. The effect of landscape type on water quality purification from good to bad was woodland > grassland > water area > cultivated land > construction land;

(2) The order of landscape fragmentation of Pan'an Lake wetland from high to low was MSQ > LEA > MEA > WRA > WCA. The order of landscape agglomeration from high to low was WCA > WRA > MEA > LEA > MSQ. Landscape dominance from high to low was WCA > WRA > LEA > MEA, MSQ. The order of landscape diversity from high to low was WRA > MEA > MSQ > WCA > LEA. Landscape diversity and aggregation should be strengthened;

(3) The larger the proportion of water area in dry season, the better the ecological effect of Cond index is, and the higher the proportion of forest area in wet season, the more significant the optimization effect of TN index is, but it will aggravate the consumption of COD. The proportion of built-up land and cultivated land area had a high impact on water quality indicators in each water period, indicating that the higher the proportion of artificial patch area, the more detrimental to water quality self-purification and optimization. Especially, the increase in cultivated land patch density would increase the risk of TN and TP losing to surrounding water bodies;

(4) The water quality of MSA was the worst among all functional areas, and its influence after ecological restoration should be paid more attention. WCA water environment quality fluctuated greatly under the influence of seasons, which was consistent with the seasonal natural succession of aquatic vegetation. The relationship between different adjacent functional areas should be strengthened or interference should be avoided. For example, ecological corridors should be built between WCA and WRA, artificial corridors should be built between MEA and LEA, and ecological interceptions should be set between MEA and WRA. Interference from internal and external sources is still faced in the wetland planning area. Interference sources should be identified, and buffer zones and vegetation purification belts should be set in WCA and WRA;

(5) Construct a WLF research model and combine functional area optimization research with landscape structure and water quality indicators. The model takes the wetland landscape pattern as a link to provide a quantitative research method for the optimization of functional areas under water environmental quality.

Author Contributions: T.L. analyzed the data and wrote the paper; X.J. participated in the revision of the paper; Y.G. designed the research framework and analyzed the data; T.L. participated in the revision of the paper. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Water quality monitoring general table of each functional area.

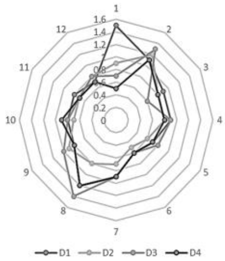
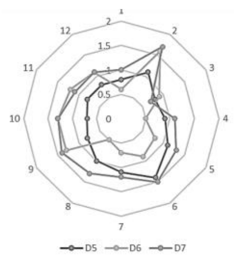
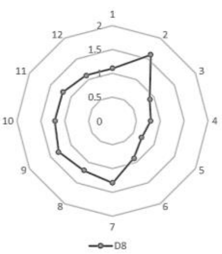
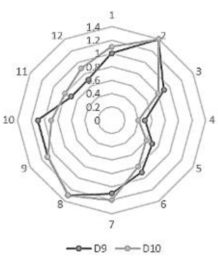
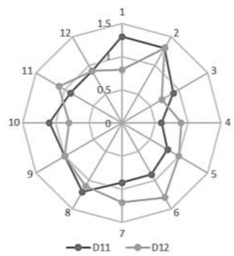
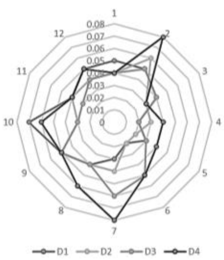
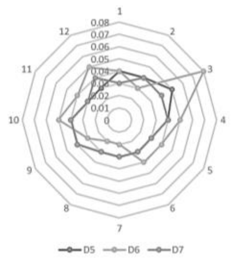
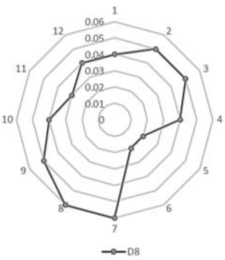
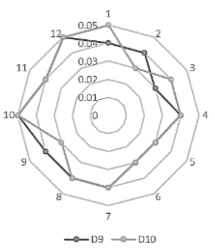
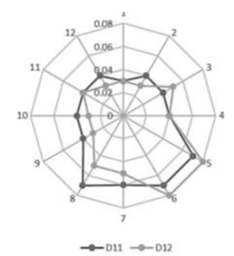
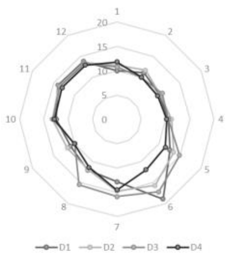
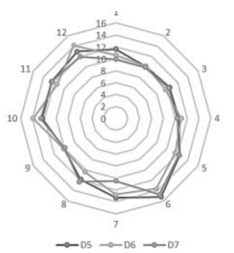
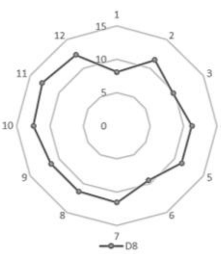
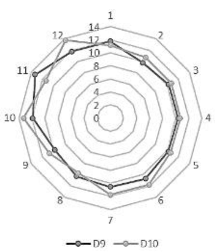
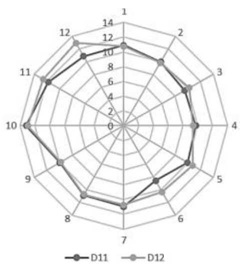
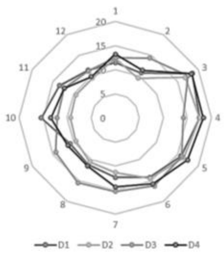
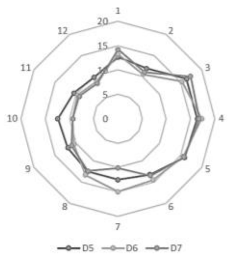
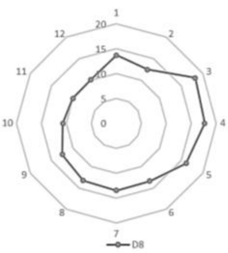
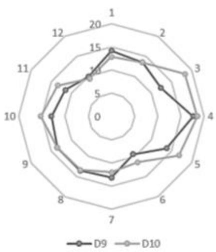
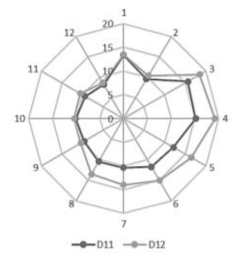
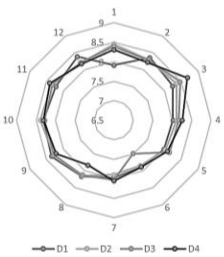
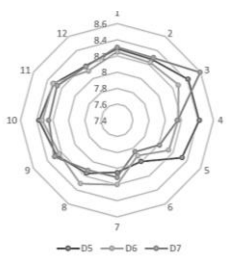
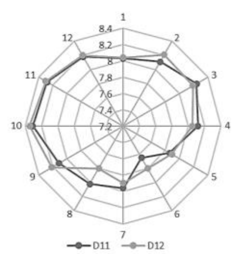
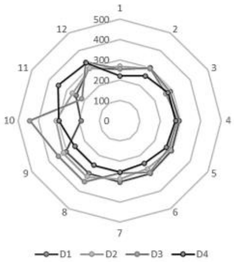
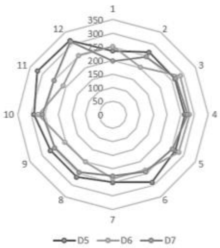
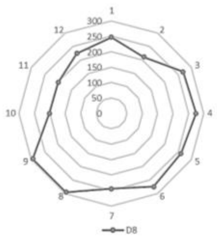
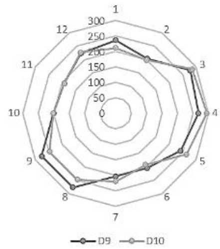
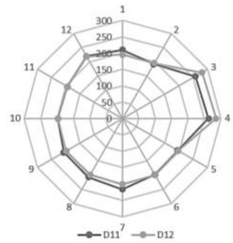
Index	a. WRA	b. MEA	c. MSA	d. WCA	e. LEA
TN mg/L					
TP mg/L					
DO mg/L					
COD mg/L					
pH					

Table A1. *Cont.*

Index	a. WRA	b. MEA	c. MSA	d. WCA	e. LEA
Cond µs/cm					

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