Eco-environmental quality evaluation of Wuleidaowan national wetland based on Analytic Hierarchy Process(AHP) approach

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Abstract. Wetland ecosystem can be influenced by many eco-environmental indexes, which will affect the ecological environment quality to varying degree. In this study, weights of different indexes that will have a influence on wetland ecosystems can be determined using Analytic Hierarchy Process (AHP) approach. Based on the field survey of Wuleidaowan National wetland and distribution of 400 questionnaires to environmental experts and workers managing wetland, of these 398 were returned, the environmental evaluation of wetland system can be fully conducted. The target of the study was divided into four main evaluation criteria, ecological resources($B_1$), wetland landscape($B_2$), infrastructure($B_3$), management($B_4$), and the four evaluation criteria were further divided into 17 indexes at the bottom level. The results of target index layer sorted by combination weight analyses indicated that species diversity, ecosystem typicality, overall style and wetland water resources have the greatest influence on determining the ecological environmental quality of Wuleidaowan National wetland. In addition, the comprehensive evaluation index(CEI) of Wuleidaowan National wetland is 0.9443, namely 0.7<CEI<1.0, showing ecological environment in Wuleidaowan wetland is very excellent on the whole. However, based on the findings, there is a need further to strengthen community co-management, regulate conservation of recovery, improve science value and aesthetic value and optimize the mission facilities to plan, manage and protect the Wuleidaowan National wetland ecosystem.

Keywords: Wuleidaowan National Wetland, Ecological Environment Evaluation, Questionnaire survey, Analytic Hierarchy Process(AHP), Environmental quality, Wetland ecosystem, Comprehensive Evaluation Index(CEI).

1. Introduction
Wetland is one of the most important ecosystems for human beings. Internationally, it is defined as areas of marsh, fen, peatland water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 m’. It plays an indispensable role as a bond between aquatic ecosystem
and terrestrial ecosystem, which is able to adjust the regional climate, maintain the diversity of species, retard the flood and conserve the water resource.

This essay will analyze Weihai Wuweidaowan National Wetland, which is located in Nanhai New District, Weihai City, Shandong Province (figure 1). Wuweidaowan National Wetland is comprised of Xianghe River, the Jinhua River, Changyang River, intertidal zone of Wulei Island Bay and their intermediate zone. The total area is 3660.83 hectare. For the geological structure, it belongs to the Jiaodong uplift area and the second Huaxia uplift belt. The geology is simple and the terrain is flat. The wetland is north high and south low and the height difference is just 15 m. Situated in the northern temperate zone, this wetland belongs to the continental monsoon climate. Therefore, the annual average temperature is 11℃ and the annual average precipitation is 824.2 mm, which is mainly concentrated on summer.

Wuleidaowan wetland park is a comprehensive wetland park, consisting of 7 functional areas. They are species reserve, tourist area, leisure area, educational area, science research area, service area and wetland conservation and recovery area, shown in figures as follows. (The figures below are all made by ArcGIS)

(1) Species reserve (Fig. 2) could provide plenty of habitats for animals. (2) With beautiful landscape, tourist area (Fig. 3) attracts a lot of visitors. (3) Leisure area (Fig. 4) is the place where people could relax their body. (4) Educational area (Fig. 5) is beneficial for students to learn the natural knowledge. (5) Science research area (Fig. 6) could allow students from local universities research the wetland resource. (6) There are some facilities in the service area (Fig. 7), such as tourist service centers, medical service stations, restaurants. (7) Wetland conservation and recovery area (Fig. 8) has a high self-recovery.

2. Method

2.1. Introduction to Analytical Hierarchy Process approach

In order to establish the wetland ecological evaluation index system, this paper adopts AHP (Analytical Hierarchy Process), a mathematical model developed by Saaty[1], which can divide
complex, unstructured and multi factor problems into several orderly levels, establish an evaluation index system, and allocate index weights. AHP is used to rank a group of indicators of an overall goal, which is decomposed into a group of standards and indicators. AHP includes three basic steps: (I) design of decision hierarchy, (II) pairwise comparison of hierarchy elements, and (III) construction of overall priority[2].

2.2. Determination of index relative weights
The basic measurement mode of AHP is pairwise comparison. The comparison consists of three steps: (I) establishing a comparison matrix at each level of the hierarchy from top to bottom, (II) calculating the weight of each element in the hierarchy, and (III) estimating the consistency ratio. In order to determine the relative weight, it is usually required to use a 1-9 preference scale for paired comparison (see Table 1). And typical judgement matrix showing pair-compared results of various indexes is shown in figure 9.

Table 1. Scale of relative importance suggested by Saaty [3].

| Intensity of Importance | Definition | Explanation |
|------------------------|------------|-------------|
| 1                      | Equal importance | Two activities contribute equally to objective |
| 3                      | Weak importance of one over another | Experience and judgment slightly favor one activity over another |
| 5                      | Essential or strong importance | Experience and judgment strongly favor one activity over another |
| 7                      | Demonstrated importance | An activity is strongly favored and its dominance demonstrated in practice |
| 9                      | Absolute importance | The evidence favoring one activity over another is the highest possible order of affirmation |

Then once judgement matrix formed by pair-wise comparison is obtained, as for the pair-compared results in the judgement matrix, where element $b_{ij}$ is the paired comparison rating of index I and J and the diagonal elements values of matrix A are the same, in addition, $b_{ij} = a_{ji}^{-1}$; $b_{ij} = 1$, where $i = j$[4]. In order to determine consistency of matrix, eigenvector of matrix A, w and $\lambda_{max}$ need to be solved, w can be calculated by assigning each element a related importance, and w can be translated into normalized weight vector $W=(w_1, w_2, ..., w_n)$ by the following steps:

1. Calculating the product of each line factor of the judgment matrix:

   $$M_i = \prod_{j=1}^{n} a_{ij} \quad (i = 1, 2, \ldots, n).$$

2. Calculating the n times root of $M_i$: 
Vector $\mathbf{W}_i = [\mathbf{W}_{i1}, \mathbf{W}_{i2}, \ldots, \mathbf{W}_{in}]^T$ normalization.

$$\mathbf{W}_i = \mathbf{W}_i / \sum_{i=1}^{n} W_i \quad (i = 1, 2, \ldots, n)$$

Where $\mathbf{W} = [\mathbf{W}_1, \mathbf{W}_2, \ldots, \mathbf{W}_n]^T$ is the characteristic vector. The component $W_i$ of feature vector $\mathbf{W}$ is the index weight of each index evaluation factor.

(4) Calculating the maximum characteristic root:

$$\lambda_{\text{max}} = \sum_{i=1}^{n} (\mathbf{AW})_i n W_i$$

where $\mathbf{A}$ is the judgement matrix, $\mathbf{W}$ is the normalized weight vector and $\lambda_{\text{max}}$ is the maximum eigenvector of matrix $\mathbf{A}$.

(5) Calculating the consistency index (CI):

$$\text{CI} = \frac{\lambda_{\text{max}} - n}{n - 1}$$

(6) Further, consistency ratio (CR) can be calculated, which is defined as follows:

$$\text{CR} = \frac{\text{CI}}{\text{RI}}$$

where RI is the random consistency index of a randomly generated judgement matrix and RI depends on the number of elements being compared, shown in table 2. The consistency ratio (CR) is designed in such a way so that if CR < 0.10, indicating a reasonable level of consistency of judgement matrix, when CR ≥ 0.10, showing indicative of inconsistent judgments. In such cases, the original values in the pairwise comparison matrix A should be reconsidered and revised.

The calculation of $\lambda_{\text{max}}$ and $\mathbf{W}$ is mainly completed by statistical analysis software Matlab and Excel.

$\textbf{Table 2.}$ Random inconsistency indices (RI) for $n = 1, 2, \ldots, 12[5]$.

| N | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI| 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.52 | 1.54 |

2.3. Overall ranking of indexes
After setting up the pair-compared of indexes and establishing the judgement matrix, the global value of the priority of the indexes can be calculated as follows:

$$W_{(BC)_i} = W_{Bi} \times W_{Ci}$$

(7)
Where $W_{BCi}$ is the weight for the alternative level of the hierarchy, $W_{Ci}$ is the weight of the ith indices under the corresponding criteria, $W_{Bi}$ is the weight of the ith criteria under the goal layer. Consistency test is required to evaluate the consistency of overall sorting level.

3. Establishment and analysis of Wuleidaowan national wetland index system

3.1. Establish the hierarchical structure of wetland evaluation

The evaluation index need to be established based on actual situation of Wuleidaowan national wetland’s ecological system. Due to complex structure of Wuleidaowan national wetland, establishment of wetland evaluation index system will be based on scientific, comprehensive, objective, dominant, operable principle [6]. Therefore, in terms of above principle, AHP can be utilized to establish wetland evaluation index system and assign weights to each indexes to show degree of importance. And evaluation index system includes goal layer(A), which indicates AHP comprehensive evaluation of Wuleidaowan national wetland is the overall goal of establishing the index system of wetland ecological environment quality; criteria layers(B), which adopt ecosystem resources(B1), wetland landscape(B2), infrastructure(B3), management(B4) to reflect value of aim layer; index evaluation layers(C) can reflect multiply indexes of main factor B specifically, so 17 specific evaluation factors are confirmed (seen in figure 9).

![Fig. 9 A hierarchy for eco-environmental evaluation of wetland ecosystem.](image)

3.2. Establishment of judgement matrix and consistency test

For goal layer(A) and criteria layers B(B1,B2,B3,B4), the judgement matrix need to be established based on degree of importance of each evaluation layers which shown from marks given by experts. Using the scale method, the judgment matrix of the goal layer A for the relevant factors of the criteria layer B is shown in Table 3.
Then take $b_{21}$ and $b_{12}$ from table 3 as an example. $b_{12}=3$ indicates that, in the evaluation of ecological environment quality of Wuleidaowan National Wetland, ecological resources index is slightly more important than wetland landscape index; inversely, $b_{21}=1/3$ indicates wetland landscape index is slightly less important when compared with ecological resources index. Then through calculation using equation 4, eigenvalue of maximum $\lambda_{\text{max}}$ is 4.1172. Then through equation 5, the coincident index(CI) can be solved as 0.0391, mean randomly consistency index(RI) is 0.9, and according to equation $\text{CR}=\text{CI}/\text{RI}$, randomly consistency ratio(CR) is 0.04389<0.1, which shows the judgement matrix accords with property of consistency.

Then using the method above, the normalized feature vector, consistency check and $\lambda_{\text{max}}$ etc of indexes layers for corresponding criteria layers, and calculation results are shown in table 4, 5, 6 and 7 as follows.

| Table 3. Normalized matrix A-B |
|-------------------------------|
| A | B1 | B2 | B3 | B4 | weight | rank | $\lambda_{\text{max}}$ | CI | CR |
| B1 | 1 | 3 | 5 | 7 | 0.5638 | 1 | 4.1172 | 0.0391 | 0.04389<0.1 |
| B2 | 1/3 | 1 | 3 | 5 | 0.2634 | 2 |
| B3 | 1/5 | 1/3 | 1 | 3 | 0.1178 | 3 |
| B4 | 1/7 | 1/5 | 1/3 | 1 | 0.05502 | 4 |

| Table 4. Normalized matrix B1-C |
|-------------------------------|
| B1 | C1 | C2 | C3 | C4 | C5 | weight | rank |
| C1 | 1 | 7 | 5 | 2 | 4 | 0.4663 | 1 |
| C2 | 1/7 | 1 | 1/2 | 1/5 | 1/3 | 0.0490 | 5 |
| C3 | 1/5 | 2 | 1 | 1/3 | 1 | 0.1010 | 4 |
| C4 | 1/2 | 5 | 3 | 1 | 2 | 0.2597 | 2 |
| C5 | 1/4 | 3 | 1 | 1/2 | 1 | 0.1242 | 3 |

$\lambda_{\text{max}}=5.0438$ CI=0.01095 RI=1.12 CR=0.0098<0.1

| Table 5. Normalized matrix B2-C |
|-------------------------------|
| B2 | C6 | C7 | C8 | C9 | C10 | weight | rank |
| C6 | 1 | 1/6 | 1/2 | 1/3 | 1 | 0.0726 | 4 |
| C7 | 6 | 1 | 4 | 3/7 | 0.5161 | 1 |
| C8 | 2 | 1/4 | 1 | 1 | 3 | 0.1612 | 3 |
| C9 | 3 | 1/3 | 1 | 1 | 3 | 0.1652 | 2 |
| C10 | 1 | 1/7 | 3 | 3 | 1 | 0.0491 | 5 |

$\lambda_{\text{max}}=5.0416$ CI=0.0104 RI=1.12 CR=0.0093<0.1

| Table 6. Normalized matrix B3-C |
|-------------------------------|
| B3 | C11 | C12 | C13 | C14 | weight | rank |
| C11 | 1 | 1/3 | 1/5 | 1/4 | 0.0753 | 4 |
| C12 | 3 | 1 | 1/2 | 1 | 0.2320 | 1 |
| C13 | 5 | 2 | 1 | 2 | 0.4433 | 3 |
| C14 | 4 | 1 | 1/2 | 1 | 0.2493 | 2 |

$\lambda_{\text{max}}=4.0211$ CI=0.00705 RI=0.89 CR=0.00792<0.1

| Table 7. Normalized matrix B4-C |
|-------------------------------|
| B4 | C15 | C16 | C17 | weight | rank |
| C15 | 1 | 3 | 5 | 0.6483 | 1 |
| C16 | 1/3 | 1 | 2 | 0.2297 | 2 |
| C17 | 1/5 | 1/2 | 1 | 0.1220 | 3 |

$\lambda_{\text{max}}=4.0211$ CI=0.00705 RI=0.89 CR=0.00792<0.1

3.3. **Overall ranking levels**

By using the weights of each factors of criteria layer B to goal layer and weights of each factors of indexes evaluation layer C to correspondingly criteria layer B, the weights and order of each evaluation factors can be calculated as Table 8.
Table 8. The weights and order of every evaluation factors

| Main factor layers B(weight) | evaluation layer C | weight($W_{mc}$) | rank |
|-----------------------------|--------------------|------------------|------|
| B1(0.5638)                  | C1                 | 0.2629           | 1    |
|                             | C2                 | 0.2076           | 11   |
|                             | C3                 | 0.0569           | 5    |
|                             | C4                 | 0.1464           | 2    |
|                             | C5                 | 0.0700           | 4    |
| B2(0.2634)                  | C6                 | 0.0191           | 13   |
|                             | C7                 | 0.1359           | 3    |
|                             | C8                 | 0.0425           | 8    |
|                             | C9                 | 0.0488           | 7    |
|                             | C10                | 0.0171           | 14   |
| B3(0.1178)                  | C11                | 0.0089           | 16   |
|                             | C12                | 0.0273           | 12   |
|                             | C13                | 0.0522           | 6    |
|                             | C14                | 0.0294           | 10   |
|                             | C15                | 0.0357           | 9    |
|                             | C16                | 0.0126           | 15   |
|                             | C17                | 0.0067           | 17   |

According to the ranking result of normalized weight values of each indexes, the 17 indexes can be divided into three categories: important index($\geq0.1$), secondary index (0.06–0.1) and general index ($\leq0.6$), the results are shown in figure 10.

![Fig. 10 Index finger of Wuleidaowan National Wetland eco-environmental quality appraisal factor](image)

3.4. Index value assignment

According to the evaluation score vector $V=(4,3,2,1)^T$, a questionnaire survey of ecological typicality($C_1$) was conducted, and the results revealed that 93% of respondents thought wetland ecological typicality was good, 7% of respondents felt ecological typicality was moderate and none of the respondents thought ecological typicality was poor or very poor. Therefore, the membership degree of first evaluation index which was an evaluation of ecological typicality, $R_1=(0.93, 0.07, 0, 0)$, then through equation as follows:

$$W_i = R_i \times V, W_1$$  \hspace{1cm} (8)

$W_1$ can be calculated as $W_1 = R_1 \times V = 3.93$. 

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According, based on the same method above, corresponding membership degrees of species diversity, water resources and 14 other evaluation indexes were determined as \( (R_{2j}, R_{3j}, \ldots, R_{17j}) \). Again, wetland ecosystem evaluation index score is \( W = (3.93, 3.67, 3.75, 3.85, 3.77, 3.49, 3.93, 3.64, 3.71, 3.47, 2.85, 3.3, 3.6, 3.38, 3.94, 3.41, 2.92) \)

3.5. **comprehensive evaluation of indexes**

To obtain further ecological evaluation results, it is necessary to choose the commonly used assessment method which is composite evaluation index (CEI) to reflect current ecological situation, and CEI is as follows:

\[
\text{CEI} = \frac{1}{4} \sum (I_i W_{c_i})
\] (9)

Where CEI is the composite evaluation index, \( W_{c_i} \) is the weight of index \( C_i \), and \( I_i \) is the score of the individual index[7].

The wetland ecosystem comprehensive evaluation index (CEI) is into five levels: \( 0.85 \leq \text{CEI} < 1.0 \), which indicates that the wetland ecosystem quality is extremely excellent; \( 0.7 \leq \text{CEI} < 0.85 \), which indicates a relatively good wetland ecosystem quality; \( 0.55 \leq \text{CEI} < 0.7 \), which indicates moderate wetland ecosystem quality; \( 0.4 \leq \text{CEI} < 0.55 \), which indicates relatively bad wetland ecosystem quality and \( \text{CEI} < 0.4 \), which indicates an extremely bad wetland ecological quality[8]. According to equation 9, wetland ecosystem has CEI=0.9443>0.85. Based on the finding, we believe that Wuleidaowan national wetland ecosystem quality belongs to extremely excellent level, human activities have less impact on wetland and human has a reasonable exploitation and utilization of wetland resources.

4. **Discussion**

Through ecological evaluation of Wuleidaowan National Wetland using AHP method, the evaluation result shows weight of ecological resources (0.56) is the largest indicating ecological resources have a important impact on wetland ecological environment; second-important evaluation index is wetland landscape (0.26); third-important index is infrastructure (0.12), followed by management (0.055). And when considering specific factors of index evaluation layer, species diversity (0.15), wetland typicality (0.26), overall style (0.14) and water resources (0.07) account for relatively large proportion and play an important role in determining the value of wetlands. Actually, Wuleidaowan National Wetland is a composite wetland system composed of offshore and coastal wetlands, river wetlands, artificial wetlands and includes two rivers entering the sea and the offshore bay area. Therefore, it is obvious from constitute of Wuleidaowan National Wetland that the characteristics of the tidal flat system and good integrity of the wetland ecosystem of Wuleidaowan National Wetland represent the typical formation of rivers and offshore wetlands in Shandong Province and even the northern coastal areas of China. The fact that Wuleidaowan National Wetland has typical characteristics of coastal wetlands leads to ecosystem typicality is the most important factor when evaluation of wetland ecological quality.

In addition, due to the establishment of species reserve, favorable layout of natural habitat and rich wetland conditions, the wetland provide abundant habitats for different rare wildlife and endangered plants, good places for birds to reproduce and migrate over the winter. At the same time, some factors like suitable wetland size and well-designed connectivity between different habitats during construction of wetland reserve also contribute to locally special biocenosis and abundant diversity of species. Therefore, based on the excellent condition of environment, there are 263 species of wild vascular plants in 66 families, 182 genera, and 302 species in 87 families and 87 families of vertebrates, as well as many more national-level protected birds distributed here. So species diversity become important factors affecting ecological quality of wetland.
5. Conclusion
In this study, AHP method can quantify ecological-environment quality index which is difficultly quantitative using relative importance of the pairwise comparison between each index and assigned CEI value for each index, and then AHP can be well applied to evaluate the ecological quality of the wetland in Wuleidaowan and importance of each evaluation index according to corresponding vector and score vector of membership degree of each evaluation index assignment results calculating from establishment of reasonable hierarchy model, which accords with the status of the wetland ecosystem in the delta. So the impact strength on wetland ecosystem can be determined based on the sorting of each evaluation index weight, which will provide importantly quantitative reference for the planning, management and protection of Wuleidaowan national wetland.

Wuleidaowan wetland has a comprehensive evaluation index of CEI=0.94, indicating wetland eco-environmental quality is very well. This is mainly due to local perfect environmental management which can efficiently prevent seriously polluted water resources in wetland caused by sewage from industrial production, agricultural consumption and residential area. In addition, Wuleidaowan wetland consists of plenty of constructed wetland, which can protect locally origin natural wetland and speed up restoration of natural wetland function. However, according to index value assignment and overall weight of each specific index, some indexes have low scores and weights such as wetland area ratio. This is because filling land reclamation causing wetland area was narrowed. Therefore, considering further development of Wuleidaowan wetland, dynamic monitoring of wetland should be carried out, including monitoring of wetland area, water temperature, water quality, air pressure, water level, precious animals and plants, so as to effectively protect wetland resources [9].

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