Selection of Municipal Wastewater Treatment Process Based on Improved Analytic Hierarchy Process

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Abstract. The improved AHP (analytic hierarchy process) method adopts three scale method. Compared with traditional AHP, it is more scientific and operational. This paper uses improved AHP to establish an evaluation system with 4 layers, 8 indexes and 5 schemes for analysing the technical performance, the economic benefit and the environmental impact of 5 municipal wastewater treatment process. The results show that the total results of oxidation ditch process, improved AAO process, multi-mode AAO process, MBR process and SBR process are 0.7718, 0.3145, 0.1628, 0.3243 and 0.3678. Considering the technical performance, the economic benefit and the environmental impact, multi-mode AAO process is the most suitable process and oxidation ditch process is the least recommended process.

1. Introduction

With the increasingly prominent problem of water pollution, the state and government pay more and more attention to the wastewater treatment work in our country. In recent years, a large number of new wastewater treatment plants have been invested. Considering the long-term ecological sustainability, the goal of wastewater treatment system should not only be limited to technical performance, but also consider the optimization of energy and resource consumption[1]. At present, whether the traditional AHP method or the improved AHP method used in the selection of wastewater treatment process, whose factors considered are conventional, without environmental impact. This study incorporates environmental impact into the improved AHP to provide reference for the selection of wastewater treatment process.

2. Materials and Methods

2.1 Establishment of analytic hierarchy process

This paper establishes a hierarchical structure model of 4 layers, 8 indicators and 5 schemes. In terms of technical performance, the effect of nitrogen and phosphorus removal and average removal rate are considered. In terms of economic benefits, total investment, operation cost and area occupied are considered. In terms of environmental impact, greenhouse gas emissions, energy consumption and sludge production are considered. From top to bottom, the target layer A, criterion layer B, indicator layer C and scheme layer D are in turn. The description of specific indicators is shown in Table 1.

| General index           | Special index                        |
|------------------------|--------------------------------------|
| Technical performance  | Nitrogen and phosphorus removal      |
Five kinds of municipal wastewater treatment processes including oxidation ditch process, improved AAO process, multi-mode AAO process, MBR process and SBR process were selected in this paper. Nitrogen and phosphorus removal, removal effect of other indicators, total investment, operating costs, area covered, power consumption and sludge output of the municipal wastewater treatment processes are normalized from actual data provided by sewage treatment plants. Greenhouse gas emissions are calculated by using the relevant statistical data provided by Gabi database. The special index values of the five processes are shown in Table 2.

Table 2. The special index values of the five processes

| General index          | Special index                  | Oxidation ditch | Improved AAO | Multi-mode AAO | MBR  | SBR  |
|----------------------|-------------------------------|----------------|--------------|----------------|------|------|
| Technical performance| Nitrogen and phosphorus removal | 1.00           | 0.53         | 0.28           | 0.00 | 0.53 |
|                      | Removal effect of other indicators | 1.00           | 0.17         | 0.07           | 0.00 | 0.17 |
| Economic benefits    | Total investment              | 0.39           | 0.00         | 0.05           | 1.00 | 0.42 |
|                      | Operating costs               | 0.28           | 0.29         | 0.00           | 1.00 | 0.17 |
|                      | Area covered                  | 0.42           | 1.00         | 0.15           | 0.25 | 0.00 |
|                      | Greenhouse gas emissions      | 0.46           | 0.01         | 0.03           | 1.00 | 0.00 |
| Environmental impact | Power consumption             | 0.29           | 0.00         | 0.12           | 1.00 | 0.02 |
|                      | Sludge output                 | 0.99           | 1.00         | 0.58           | 0.00 | 0.37 |

2.2 Establishment of comparing matrix
The judgment matrix represents the comparison of relative importance between factors at the upper level and those related to it. The establishment of comparison matrix is based on the three-scale method, and the important ranking index of each comparison matrix is calculated[2].

\[
a_{ij} = \begin{cases} 
2 & \text{Factor } i \text{ is more important than factor } j \\
1 & \text{Factor } i \text{ is as important as factor } j \\
0 & \text{Factor } i \text{ is not as important as factor } j 
\end{cases}
\]

\[
A_{ij} = (a_{ij}) = \begin{bmatrix} 
a_{11} & \ldots & a_{1n} \\
\vdots & \ddots & \vdots \\
a_{n1} & \ldots & a_{nn}
\end{bmatrix}
\]

2.3 Establishment of judgment matrix
The judgment matrix B is constructed according to the following formula, where \( k = \frac{r_{\text{max}}}{r_{\text{min}}} \).

\[
b_{ij} = \begin{cases} 
\frac{r_i - r_j}{r_{\text{max}} - r_{\text{min}}} * (k - 1) + 1 & r_i \geq r_j \\
\left( \frac{r_{\text{max}} - r_{\text{min}}}{r_i - r_j} \right)^{-1} * (k - 1) + 1 & r_i < r_j 
\end{cases}
\]
2.4 Establishing the most transfer matrix C of judgment matrix B

\[ c_{ij} = \frac{1}{n} \sum_{k=1}^{n} \left( \log \frac{b_{ik}}{b_{jk}} \right) \]

2.5 Establishment of quasi-optimal consistent matrix D

\[ d_{ij} = 10^{c_{ij}} \]

Finally, the eigenvectors corresponding to the maximum eigenvalue of quasi-optimal consistent matrix D are calculated by using the software of Matlab, and the weights of each factor are obtained by normalizing the eigenvectors.

3. Results

3.1 A-B level

Comparison Matrix Established between Layer A and Layer B is

\[ A = \begin{bmatrix} 1 & 2 & 2 \\ 0 & 1 & 2 \\ 0 & 0 & 1 \end{bmatrix} \]

and the eigenvectors corresponding to the maximum eigenvalues are calculated by using Matlab software and normalized. The weights between A and B layers are (0.64, 0.26, 0.10).

3.2 B-C level

3.2.1 B1-C1 and C2. Comparison Matrix Established between Layer B1-C1 and C2 is

\[ B_1 = \begin{bmatrix} 1 & 2 \\ 0 & 1 \end{bmatrix} \]

and the eigenvectors corresponding to the maximum eigenvalues are calculated by using Matlab software and normalized. The weights between B1-C1 and C2 are (0.75, 0.25).

3.2.2 B2-C3, C4 and C5. Comparison Matrix Established between Layer B2-C3, C4 and C5 is

\[ B_2 = \begin{bmatrix} 1 & 2 & 2 \\ 0 & 1 & 2 \\ 0 & 0 & 1 \end{bmatrix} \]

and the eigenvectors corresponding to the maximum eigenvalues are calculated by using Matlab software and normalized. The weights between B2-C3, C4 and C5 are (0.64, 0.26, 0.10).

3.2.3 B3-C6, C7 and C8. Comparison Matrix Established between Layer B3-C6, C7 and C8 is

\[ B_3 = \begin{bmatrix} 1 & 2 \\ 0 & 1 \\ 0 & 0 \end{bmatrix} \]

and the eigenvectors corresponding to the maximum eigenvalues are calculated by using Matlab software and normalized. The weights between B3-C6, C7 and C8 are (0.64, 0.26, 0.10).

3.4 A-C level

By calculating the weight of the sewage treatment process evaluation system with the software of Matlab, the total weight of eight indexes to the total target layer is as follows. For the method of ranking and calculating the weight, the evaluation method of Luo's technical performance and economic benefit is referred to[3], and environmental impact refers to the energy consumption evaluation system of Wang[4]. The calculation formula of the evaluation system for sewage treatment process selection is as follows.

\[ A_i = 0.48C_{i1} + 0.16C_{i2} + 0.1664C_{i3} + 0.0676C_{i4} + 0.026C_{i5} + 0.064C_{i6} + 0.026C_{i7} + 0.01C_{i8} \]

Ci1-Nitrogen and phosphorus removal, Ci2-Removal effect of other indicators, Ci3-Total investment, Ci4-Operating costs, Ci5-Area covered, Ci6-Greenhouse gas emissions, Ci7-Power consumption, Ci8-Sludge output
Ai- (i=1 oxidation ditch process, i=2 improved AAO process, i=3 multi-mode AAO process, i=4 MBR process, i=5 SBR process)

The results show that A1 = 0.7718, A2 = 0.3145, A3 = 0.1628, A4 = 0.3243, A5 = 0.3678.

4. Discussion

The proportion of technical performance, economic benefit and environmental impact of the general indicators of sewage treatment process selection in this study is 64%, 26% and 10%. Among them, the proportion of technical performance is the largest and the proportion of environmental impact is the smallest, which accords with the actual situation of sewage treatment process selection in China[5]. However, there are differences with some foreign studies. Molinos-Senante et al. used AHP method to analyze the economic benefits, social effects and environmental impacts of seven sewage treatment processes. The results show that the proportion of environmental impacts, economic benefits and social impacts is 47.1%, 30.8% and 22.1%[6]. Bottero et al. analyzed the economic benefit, environmental impact and technical performance of three sludge disposal technologies, anaerobic digestion, phytoremediation and composting, using AHP method. The results showed that the proportion was 47%, 43% and 10%[7].

According to the order of eight index weight values, the effect of nitrogen and phosphorus removal and the proportion of total investment are the largest. In recent years, the local municipal Party committee and government attach great importance to water control work. The pace of water control and rejuvenation has been accelerated, and the water environment quality has been improved. Therefore, in order to improve the quality of water environment, the effect of nitrogen and phosphorus removal is the first consideration when choosing municipal wastewater treatment process in this area, which is basically consistent with the situation in most areas of China[8]. Secondly, the total investment is considered. The main reason is that the total investment cost plays a positive role in the normal operation of sewage treatment plants, promoting pollution reduction, improving sewage treatment technology and promoting water price reform[9].

5. Conclusion

Considering the technical performance, economic benefit and environmental impact, multi-mode AAO process is the most suitable process and oxidation ditch process is the least recommended process.

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