Comprehensive evaluation of the main technology for new sewage treatment plants in small towns along the Duliujian river basin

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Abstract: In recent years, water contamination problem has been becoming more and more serious due to increasing wastewater discharge. So our country has accelerated the pace of constructing sewage treatment plant in small towns. But in China it has not been issued any corresponding technical specifications about the choice of treatment technology. So the article is based on the basin of Duliujian river, through field research, data collection and analysis of relevant documentations, preliminarily elects seven kinds of technology: Improved A\textsuperscript{2}/O, Integrated oxidation ditch, Orbal oxidation ditch, CASS, A/O+refined diatomite, BIOLAK and UNITANK as alternatives for Tianjin sewage discharge local standard. Then the article use the analytic hierarchy process (AHP) to evaluate the seven kinds of alternatives, finally it is concluded that CASS technology is most suitable for the main technology of new sewage treatment plants in small towns along the Duliujian River basin.

1. Introduction

As an important estuary of Haihe river basin, Duliujian river is located in the southeast of Tianjin economic development zone. The wastewater quantity in the area is high and it’s quality is serious, most of them are inferior V water\cite{1}. Theses small towns along the basin are in the rapid urbanization process, more and more wastewater is discharged. To improve the water environment in the river basin, the constructing of corresponding sewage treatment plant and sewage system is very necessary. Therefore, choosing a suitable main technology is crucial for these small towns.

The article concerns on the area of Tianjin Duliu River Basin. In order to provide data support for subsequent comprehensive evaluation, the author consults the literature material from the national library, relevant authoritative website and the paper query site, summarizes the statistical yearbook and data of each province from 2008 to 2015, and conducts field research on the social and economic condition, hydrological environment, sewerage system, water quality and wastewater treatment technology of small towns in the Duliujian river basin.
2. Establishing prevailing technologies
The author has made data statistics for the application of the main technology in 237 urban sewage treatment plants with capacity of less than or equal to $1 \times 10^4 \text{m}^3/\text{d}$ which have been put into operation, according to the "List of National Urban Sewage Treatment Facilities Which Has Been Put into Operation in 2015 " announced by the Ministry of Environmental Protection. According to the statistics, activated sludge technology and biofilm technology were used in a large majority of small sewage treatment plants which have been put into operation. These two types of technology cover more than 95% of small urban sewage treatment facilities in our country. Having made data statistics for situation of technology adoption in sewage treatment plants in Beijing, Tianjin, and Hebei, it was found that the activated sludge method accounted for 85%. Considering strict water standard in Tianjin and the economic conditions of the nearby township in Duliujian River area, this article sorts out the following seven secondary treatment technology as alternative technology after comprehensive analysis and comparison.

3. Evaluation of the optimal technology
Comprehensive evaluation is an objective, reasonable and fair evaluation of a research object. There are many ways for comprehensive evaluation, such as TOPSIS method, linear programming method, Analytic Hierarchy Process (AHP), Comprehensive indicator method, etc. AHP can organically combine qualitative methods with quantitative methods to make people's thought process mathematical and systematic, make it easily acceptable for people[2]. Therefore, in the article it was decided to adopt AHP method to set up a comprehensive evaluation model which can make comprehensive evaluation for new sewage treatment plants in small towns along Duliujian River.

3.1. Establish an evaluation system
According to the technical characteristics of the main technology of urban sewage treatment plants, this paper divides the evaluation system into four layers, that is, A, B, C and D. A Layer refers to total target layer: main technology operated in new sewage treatment plants in small towns along Duliujian River; B Layer refers to the first-level indicator layer: B1 refers to pollutant control indicator, B2 refers to economic indicator, B3 refers to technical indicator, B4 refers to environmental indicator; C Layer refers to the second-level indicator under each first-level indicator layer(not summarize it here, as shown in Figure 1); D layer refers to the alternatives layer: D1 refers to improved A\(^2\)/O technology (pre-anoxic tank), D2 refers to integrated oxidation ditch (pre-Anaerobic tank and pre-anoxic tank), D3 refers to Orbital oxidation ditch, D4 refers to CASS, D5 refers to A/O + refined diatomite technology technology, D6 refers to BIOLAK technology, and D7 refers to UNITANK technology. Specific evaluation system is shown in Figure 1.
3.2. Calculation of the weight

The analytic hierarchy process is used to determine the weight of the judgment matrix by using 1-9 and its reciprocal, the scale of relative importance and its implications are shown in Table 1[3].

| The weight of relative importance | Implication                                      |
|-----------------------------------|-------------------------------------------------|
| 1                                 | The two factors are of equal importance         |
| 3                                 | One factor is slightly more important than the other |
| 5                                 | One factor is obviously more important than the other |
| 7                                 | One factor is mightily more important than the other |
| 9                                 | One factor is extremely more important than the other |
| 2, 4, 6, 8                        | Intermediate state of the above adjacent evaluation criteria |

Constructing the judgment matrix of layer B to A layer, layer C to B layer through AHP is shown in Table 2 to Table 6.
The maximum feature root $\lambda$ of each judgment matrix is obtained by MATLAB software. After normalization of the eigenvectors corresponding to the maximal feature root lambda, the subjective weight of each indicator is obtained [4]. Finally, examine the data according to the consistency of the test judgment matrix formula:

$$CI = (\lambda_{\text{max}} - n) / (n-1)$$

(1)

Consult the consistency indicator $RI$ [5] shown in Table 7, its consistency ratio CR is:

$$CR = CI / RI$$

(2)

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**Table 2.** Judgment matrix of layer B to A.

|   | A   | B1  | B2  | B3  | B4  |
|---|-----|-----|-----|-----|-----|
| B1| 1   | 3   | 4   | 4   |
| B2| 1/3 | 1   | 2   | 2   |
| B3| 1/4 | 1/2 | 1   | 1   |
| B4| 1/4 | 1/2 | 1   | 1   |

**Table 3.** Judgment matrix of layer C to B1.

|   | B1  | C1  | C2  | C3  | C4  | C5  | C6  |
|---|-----|-----|-----|-----|-----|-----|-----|
| C1| 1   | 3   | 1/5 | 1/5 | 1/4 | 1/3 |
| C2| 1/3 | 1   | 1/7 | 1/7 | 1/5 | 1/5 |
| C3| 5   | 7   | 1   | 3   | 3   | 4   |
| C4| 5   | 7   | 1/3 | 1   | 3   | 3   |
| C5| 4   | 5   | 1/3 | 1/3 | 1   | 3   |
| C6| 3   | 5   | 1/4 | 1/3 | 1/3 | 1   |

**Table 4.** Judgment matrix of layer C to B2.

|   | B2  | C7  | C8  | C9  |
|---|-----|-----|-----|-----|
| C7| 1   | 1   | 3   |
| C8| 1   | 1   | 3   |
| C9| 1/3 | 1/3 | 1   |

**Table 5.** Judgment matrix of layer C to B3.

|   | B3  | C10 | C11 | C12 | C13 | C14 |
|---|-----|-----|-----|-----|-----|-----|
| C10| 1   | 3   | 2   | 4   | 4   |
| C11| 1/3 | 1   | 1/2 | 2   | 3   |
| C12| 1/2 | 2   | 1   | 3   | 4   |
| C13| 1/4 | 1/2 | 1/3 | 1   | 2   |
| C14| 1/4 | 1/3 | 1/4 | 1/2 | 1   |

**Table 6.** Judgment matrix of layer C to B4.

|   | B4  | C15 | C16 | C17 |
|---|-----|-----|-----|-----|
| C15| 1   | 1/3 | 1   |
| C16| 3   | 1   | 3   |
| C17| 1   | 1/3 | 1   |
Table 7. Average random consistency indicator.

| Order | 2   | 3   | 4   | 5   | 6   | 7   |
|-------|-----|-----|-----|-----|-----|-----|
| RI    | 0   | 0.58| 0.96| 1.12| 1.24| 1.32|

According to the test, the CR value of each layer is less than 0.1, so the consistency of each weight judgment matrix can be accepted and the weights of each indicator can be applied.

By calculation, the weights of each indicator are calculated as shown in the table 8:

Table 8. The weights of each level indicator.

| B layer indicator | B layer weights | C layer indicator | C layer weights | C Total weights |
|-------------------|----------------|-------------------|----------------|-----------------|
| B1 Pollution control | 0.5382 | C1 | 0.0541 | 0.0291 |
|                    |       | C2 | 0.0301 | 0.0162 |
|                    |       | C3 | 0.394  | 0.2121 |
|                    |       | C4 | 0.2577 | 0.1387 |
|                    |       | C5 | 0.1629 | 0.0877 |
|                    |       | C6 | 0.1012 | 0.0545 |
| B2 economy         | 0.2194 | C7 | 0.4285 | 0.0940 |
|                    |       | C8 | 0.4285 | 0.0940 |
|                    |       | C9 | 0.1428 | 0.0313 |
| B3 Technology      | 0.1212 | C10| 0.4053 | 0.0491 |
|                    |       | C11| 0.1612 | 0.0195 |
|                    |       | C12| 0.2638 | 0.032  |
|                    |       | C13| 0.1043 | 0.0126 |
|                    |       | C14| 0.0655 | 0.0079 |
| B4 Environment     | 0.1212 | C15| 0.2000 | 0.0242 |
|                    |       | C16| 0.6000 | 0.0727 |
|                    |       | C17| 0.2000 | 0.0242 |

3.3. Secondary indicator assignment

Through data access and field research, the article makes statistical analysis of 182 sewage treatment plants with a scale of less than 50 thousand t/d in small cities and towns, including Tanjin, and gets average from C1 to C9 for every technology. As for C1 to C9, Delphy Scoring method is adopted to assign to them. The assignment results are shown in the following table 9.

However, since different indicator has different dimension and dimensional unit, therefore, to eliminate the incomparability caused by different dimension and dimensional unit[6], the article applies dimensionless treatment method to these data. The processing results are shown in table 10.
### Table 9. Indicator assignment.

| Indicator | Technology | D1 | D2 | D3 | D4 | D5 | D6 | D7 |
|-----------|------------|----|----|----|----|----|----|----|
| C1 (%)    |            | 85.4| 83.2| 81.4| 80.7| 83.1| 75.3| 85.1|
| C2 (%)    |            | 94.2| 89.5| 92.9| 91.8| 94.6| 81.2| 90.5|
| C3 (%)    |            | 62.6| 55.6| 57.9| 58.4| 63.5| 54.5| 45.2|
| C4 (%)    |            | 99.2| 95.9| 96.2| 98.4| 98.7| 73.7| 97.6|
| C5 (%)    |            | 83.3| 75.8| 75.1| 82.3| 88.3| 69.8| 64.5|
| C6 (%)    |            | 93.8| 89.4| 90.3| 87.9| 94.7| 83  | 86.9|
| C7 (Yuan/t) |          | 1520| 1216| 1616| 1349| 1421| 600 | 1376|
| C8 (Yuan/t/d) |       | 0.64| 0.51| 0.67| 0.59| 0.63| 0.4  | 0.65 |
| C9 (m³/m³)|            | 1.29| 1.12| 1.25| 0.81| 1.22| 0.93 | 0.80 |
| C10       |            | 0.5 | 0.7 | 0.3 | 0.1 | 0.5 | 0.3  | 0.5  |
| C11       |            | 0.7 | 0.7 | 0.7 | 0.1 | 0.3 | 0.3  | 0.7  |
| C12       |            | 0.9 | 0.9 | 0.7 | 0.9 | 0.3 | 0.7  | 0.9  |
| C13       |            | 0.7 | 0.7 | 0.7 | 0.9 | 0.3 | 0.7  | 0.7  |
| C14       |            | 0.1 | 0.1 | 0.7 | 0.5 | 0.1 | 0.7  | 0.1  |
| C15       |            | 0.9 | 0.9 | 0.9 | 0.1 | 0.9 | 0.9  | 0.9  |
| C16       |            | 0.7 | 0.3 | 0.7 | 0.1 | 0.9 | 0.7  | 0.7  |
| C17       |            | 0.5 | 0.5 | 0.7 | 0.1 | 0.5 | 0.3  | 0.5  |

### Table 10. Dimensionless numerical value of each indicator.

| Indicator | Technology | D1    | D2    | D3    | D4    | D5    | D6    | D7    |
|-----------|------------|-------|-------|-------|-------|-------|-------|-------|
| C1        |            | 1.0000| 0.7822| 0.6040| 0.5347| 0.7723| 0.0000| 0.9703|
| C2        |            | 0.9701| 0.6194| 0.8731| 0.7910| 1.0000| 0.0000| 0.6940|
| C3        |            | 0.9508| 0.5683| 0.6940| 0.7213| 1.0000| 0.5082| 0.0000|
| C4        |            | 1.0000| 0.8706| 0.8824| 0.9686| 0.9804| 0.0000| 0.9373|
| C5        |            | 0.7899| 0.4748| 0.4454| 0.7479| 1.0000| 0.2227| 0.0000|
| C6        |            | 0.9231| 0.5470| 0.6239| 0.4188| 1.0000| 0.0000| 0.3333|
| C7        |            | 0.0945| 0.3937| 0.0000| 0.2628| 0.1919| 1.0000| 0.2362|
| C8        |            | 0.1111| 0.5926| 0.0000| 0.2963| 0.1481| 1.0000| 0.0741|
| C9        |            | 0.0000| 0.3469| 0.0816| 0.9796| 0.1429| 0.7347| 1.0000|
| C10       |            | 0.2500| 1.0000| 0.7500| 0.2500| 0.0000| 0.5000| 0.2500|
| C11       |            | 1.0000| 0.7500| 0.7500| 0.7500| 0.0000| 0.2500| 0.2500|
| C12       |            | 0.3333| 1.0000| 1.0000| 0.6667| 0.6667| 0.0000| 0.6667|
| C13       |            | 0.0000| 0.6667| 0.6667| 0.6667| 1.0000| 0.0000| 0.6667|
| C14       |            | 1.0000| 0.0000| 0.0000| 0.7500| 0.0000| 0.0000| 0.7500|
| C15       |            | 0.2500| 1.0000| 1.0000| 0.0000| 1.0000| 0.0000| 1.0000|
| C16       |            | 0.0000| 0.7500| 0.2500| 0.7500| 0.0000| 1.0000| 0.7500|
| C17       |            | 1.0000| 0.6667| 0.6667| 1.0000| 0.0000| 0.6667| 0.3333|
3.4. Comprehensive evaluation result
Multiplying Dimensionless numerical value of each indicator to Corresponding weight can get the evaluation score of each technology from C1 to C17, then summing these scores can get the final score of each technology. The specific results are shown in the Table 11.

Table 11. Total scores of each technology.

| Indicator | D1   | D2   | D3   | D4   | D5   | D6   | D7   |
|-----------|------|------|------|------|------|------|------|
| Total scores | 0.6047 | 0.6481 | 0.5273 | 0.6528 | 0.5993 | 0.4808 | 0.3877 |

4. Conclusions
From table 11, it can be found that the total score is ranked from high to low: CASS, Integrated oxidation ditch, Improved A²/O technology, A/O + refined diatomite, Orbal oxidation ditch, BIOLAK, UNITANK. CASS technology has a stable treatment effect, high pollutant removal efficiency, stronger ability for resisting shock load, and still has a good treatment effect in low temperature conditions. Therefore, CASS technology is most suitable for the main technology of wastewater treatment plants in small towns along Duliujian river basin.

Different small towns have different economic conditions, social conditions, local characteristics, and wastewater discharge standard, so we need to adjust the weight of each indicator for different regions of the small towns. For example, in tight land areas, the weight of occupied area should be increased; in areas of high total nitrogen of wastewater quality, the weight of the total nitrogen removal rate should be increased. Therefore, the evaluation of sewage treatment technology should be evaluated according to the local specific situation.

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