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# Analysis on the Characteristics of Black and Odorous Water Body Indicators in Coal-based Cities: Taking Suzhou City as an Example

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**Abstract: In this study, ten rivers in the main urban area of Suzhou City were selected for field sampling and comprehensive investigation. The single pollution index method and black-odorous water evaluation model were applied to systematically analyze the pollution characteristics and current status of the water bodies. The results showed that ammonia nitrogen was the main pollutant in the rivers with the content of 1.6~31mg/L. The exceedance rate of sample points was 80% under the environmental quality standard of V water of GB3838-2002. The river black and odorous index is 0.23~29.17, and those belonging to heavy black odorous are Yunliang River, Huiyuan Ditch and Railway Transport, and those belonging to light black odorous are Sanba River, and the degree of black odorous pollution is Railway Transport > Yunliang River > Huiyuan Ditch > Sanba River > Long River > Sanba Ditch > Sumeng Ditch > Huancheng River > Tuo River > Huancheng Yinhe. Rivers within the Nemerow comprehensive water quality index black odorous index of 0.37 ~ 2.98, belonging to the heavy black odorous is the Sanba Ditch, Huiyuan Ditch, Sanba River, Railway Transport, belonging to the light black odorous is the Huancheng River, Yunliang River, Long River, Sumeng Dtich, the degree of black odorous pollution for the Saba River > Railway Transport > Sanba Ditch > Huiyuan Ditch > Long River > Yunliang River > Sumeng Ditch > Huancheng River > Huancheng Yinhe > Tuo River.**

**Keywords: Black and Odorous Water; Water Quality Indicators; Black Smelly Index Method; Suzhou City**

## 1. Introduction

As an extreme phenomenon of water pollution, the black and odorous water is mainly caused by the lack of dissolved oxygen in the water body. Due to the mass proliferation of hypoxic or anaerobic bacteria, a series of physical and chemical reactions occur in organic matter, and then decomposition into ammonia nitrogen, humus, etc., making the water black and odorous [1]. Urban black and odorous water refers to the water with unpleasant color or unpleasant odorous in urban built-up area [2]. As a special water quality evaluation, there is no unified special evaluation standard and method for the evaluation of black and odorous water. At present, many scholars and experts at home and abroad have conducted research and analysis on black and odorous water in urban areas from different angles [3-6]. For example, Liang Jiancheng, Cheng Guanwen and Feng Haopin from Guilin University of Technology adopted the Nemerow Pollution Index Method to evaluate and analyze the black and odorous degree of inland rivers on the north bank of the Yongjiang River. Wei Wenlong, Jing Hongwei, Xu Qian, Tao Lei and others from the Beijing Municipal Environmental Monitoring Center selected the Multi-factor Index Evaluation Method and used multiple linear regression to conduct a graded evaluation of blackening in urban river water bodies in Beijing. In this paper, single pollution index method, black and odorous index method and Nemerow comprehensive black and odorous index method are used to evaluate the black and odorous water in the main urban area of Suzhou City.

## 2. Materials and Methods

### 2.1 Overview of the Research Area

Suzhou City water system belongs to Huai River Basin, with total water resources of about 3.48 billion m3 and per capita occupation of 556 m3, less than 1/2 of the whole province. Water resources are rather scarce [7]. Rivers in the

main urban area of Suzhou City include Huancheng River, Tuo River, Xinbian River, Hui River and Xinsui River. The water quality of rivers is poor. The surface water mainly contains ammonia nitrogen compounds, heavy metals and hard-to-decompose organic matters. There are a lot of residents living around the river, and they also attach great attention to the management of the river.

### 2.2 Sample Collection and Testing

Ten representative black and odorous water in Suzhou City are selected as the research objects for the specific locations. According to the "Guidelines for the Remediation of Urban Black and Odorous Waters", the water quality monitoring and evaluation indicators investigated are transparency, dissolved oxygen, oxidation-reduction potential and ammonia nitrogen. The transparency is determined by the black-and-white disk method, the dissolved oxygen is determined by the electrochemical method, the oxidation-reduction potential is determined by the electrode method, and the ammonia nitrogen is determined by the Nessler's reagent photometric method. The measured data and the basic overview of the river are shown in Table 1.

**Table 1. Overview and Monitoring Index of Rivers in Main Urban Area**

| Sampling point | Huancheng River | Tuo River | Huancheng Yinhe | Yunliang River | Sanba River | Huiyuan Ditch | Sanba Ditch | Railway Transport | Long River | Sumeng Ditch |
|---|---|---|---|---|---|---|---|---|---|---|
| Area (m2) | 123000 | 600000 | 7440 | 125000 | 40000 | 18000 | 90000 | 101200 | 87500 | 25500 |
| Length (m) | 4100 | 9100 | 620 | 5000 | 2400 | 1800 | 3600 | 9200 | 3500 | 1700 |
| Transparency (cm) | 50 | 62 | 50 | 44 | 32 | 20 | 38 | 37 | 34 | 35 |
| Dissolved oxygen (mg/L) | 7.4 | 5.4 | 6.7 | 0.42 | 4.1 | 1.3 | 4.7 | 0.32 | 3.5 | 4 |
| Oxidation-reduction potential (mV) | 131 | 145 | 149 | 14 | 101 | —27 | 88 | —67 | —9.6 | 76 |
| Ammonia nitrogen (mg/L) | 12 | 1.6 | 1.64 | 14.2 | 31 | 19.2 | 23 | 21 | 19 | 14 |

## 3. Evaluation Models

### 3.1 Single Pollution Index Method

The single pollution index method [8] refers to comparing the measured value with the national standard value (GB3838-2002), see Formula (1).

$$P_i = C_i / C_{i0} \quad (1)$$

Pi is the single pollution index of pollutant i; Ci is the measured value of pollutant i; Ci0 is the standard value of pollutant i. If the single pollution index Pi > 1, the index of the river exceeds the standard; if ≤ 1, the river meets the standard.

Due to the difference properties between dissolved oxygen and other index, the higher the dissolved oxygen concentration in a water body, the lower the degree of blackness and odor. Conversely, the lower the dissolved oxygen concentration, the more severe the blackness and odor. This indicates an inverse relationship between dissolved oxygen concentration and the degree of black and odorous water. It adopts Formula (2) to calculate.

$$\begin{cases} S_{DO,j} = \frac{|DO_f - DO_j|}{|DO_f - DO_s|}, DO_j \gg DO_s \\ S_{DO,j} = 10 - 9\frac{DO_j}{DO_s}, DO_j \ll DO_s \end{cases} \quad (2)$$

DOf=468/(31.6+T), T is water temperature, DOs is the evaluation standard of dissolved oxygen, and DOj is the detection value of dissolved oxygen at sampling point j.

### 3.2 Black and Odorous Index Method

There are many causes of black and odorous water bodies, and descriptions of blackness and odor vary due to differences in individual sensory perception. The black-odor weighted index evaluation method can weight multiple black-odor factors [9], thereby more objectively reflecting the black and odorous conditions of rivers. Therefore, the black-odor index is used to quantitatively describe the black and odorous phenomenon of water quality, as shown in Formula (3).

$$I = \frac{NH_4^+ - N}{DO(\%) + 0.4} \quad (3)$$

NH4+-N is the measured value of ammonia nitrogen; DO (%) is the percentage of the measured value of DO and the saturation value of DO at the measured water temperature. When the index I≥5, it can be characterized as black and odorous; when the pollution index I≥7.5, it can be characterized as severe black and odorous, indicating that the water quality is seriously polluted.

### 3.3 Nemerow's Comprehensive Black and Odorous Index Method

The black-odor index method is simple and feasible for evaluation. It can distinguish between non-black-odor, slight black-odor, and severe black-odor conditions in river water. However, it cannot rank the black-odor levels of

multiple rivers, which is not conducive to river planning and decision-making in the main urban area. Therefore, quantitative processing is required. The comprehensive Nemerow black-odor index method [10] is modeled in accordance with the classification criteria and indicators specified in the "Guidelines for the Remediation of Urban Black and Odorous Water Bodies" (see Table 2). It can more accurately reflect the black-odor grades, rank the black-odor pollution levels of rivers, and enable targeted treatment of severely polluted rivers.

The linear relationship of the black and odorous index Pi transparency (SD), dissolved oxygen (DO), oxidation-reduction potential (ORP) and ammonia nitrogen (NH4+-N) is shown in Formula (4-7), when 0<Pi (P comprehensive) ≤ 1, the water is not black and odorous, when 1<Pi (P comprehensive) ≤ 2, the water is mild black and odorous, and when 2<Pi (P comprehensive) ≤ 10, the water is severe black and odorous.

$$P_{SD}\begin{cases}\frac{25}{C_{SD}}, & C_{SD}\gg 25\\ -\frac{1}{15}C_{SD}+\frac{8}{3}, & 10<C_{SD}<25\\ -\frac{4}{5}C_{SD}+10, & 0\ll C_{SD}\ll 10\end{cases} \quad (4)$$

$$P_{DO}\begin{cases}\frac{2}{C_{DO}}, & 2\ll C_{DO}\ll C_{DO\max}\\ -\frac{5}{9}C_{DO}+\frac{19}{9}, & 0.2\ll C_{DO}<2\\ -40C_{DO}+10, & 0\ll C_{DO}\ll 0.2\end{cases} \quad (5)$$

$$P_{ORP}\begin{cases}\frac{50}{C_{ORP}}, & 50\ll C_{ORP}\ll C_{ORP\max}\\ -\frac{1}{250}C_{ORP}+\frac{6}{5}, & -200<C_{ORP}<50\\ \frac{8(C_{ORP}+200)}{200+C_{ORP\min}}+2, & C_{ORP\min}\ll C_{ORP}\ll -200\end{cases} \quad (6)$$

(6) Where in the formula: CORPmax is the oxidation limit of water; CORPmin is the reduction limit of water.

$$P_{NH_4^+-N}\begin{cases}\frac{C_{NH_4^+-N}}{8}, & 0\ll C_{NH_4^+-N}\ll 8\\ \frac{1}{7}\left(C_{NH_4^+-N}-1\right), & 8<C_{NH_4^+-N}<15\\ \frac{1}{65}\left(8C_{NH_4^+-N}+10\right), & 15\ll C_{NH_4^+-N}\ll 80\end{cases} \quad (7)$$

**Table 2. Classification Standard of Urban Black and Odorous Water Pollution Degree**

| Degree of black and odorous | No black and odorous | mild black and odorous | Severe black and odorous |
|---|---|---|---|
| Transparency (cm) | ≥25 | 25-10* | <10* |
| Dissolved oxygen (mg/L) | ≥2 | 0.2-2.0 | <0.2 |
| Oxidation-reduction potential (mV) | ≥50 | —200-50 | <—200 |
| Ammonia nitrogen (mg/L) | ≤8 | 8.0-15 | >15 |

Note:*When the water depth is less than 25cm, this index shall be taken as 40% of the water depth.

After calculating each single-factor black and odorous index Pi, the Nemerow black and odorous index Pcomprehensive can be calculated from Formula (8).

$$\mathbf{P_{comprehensive}}=\sqrt{\frac{\boldsymbol{P_{max}}^2+\boldsymbol{P_{ave}}^2}{2}} \quad (8)$$

(8) Where in the formula, Pmax is the maximum value of the single-factor black and odorous index Pi, and Pave is the average value of the single-factor black and odorous index Pi.

## 4. Results and Discussion

### 4.1 River Water Quality Assessment in the Main Urban Area

This study adopts Class III and Class V water quality standards from the "Environmental Quality Standards for Surface Water (GB 3838-2002)" as benchmarks. This is because the main functions of rivers in the main urban area of Suzhou are landscape water and agricultural water, for which meeting Class V water standards is sufficient. With the improvement of living standards, residents of Suzhou now pursue higher-quality Class III water bodies, so that urban river water can reach a level suitable for fish farming.

The single-factor pollution index was calculated using Formula (1) and Formula (2), with the results shown in Table3. A high dissolved oxygen (DO) content indicates favorable conditions for the growth of aerobic microorganisms and stronger water self-purification capacity. Low dissolved oxygen promotes the vigorous reproduction of anaerobic microorganisms, leading to water quality deterioration. Therefore, dissolved oxygen serves as an important indicator for judging water pollution.

According to the Class V surface water standard, the single-factor pollution indices of dissolved oxygen in the Yunliang River, Huiyuan Ditch, and Railway Transport are greater than 1, meaning that dissolved oxygen in these three rivers fails to meet the functional requirements for Class V surface water specified in the national standard. Dissolved oxygen in the other seven rivers meets the requirements, with the

proportion of rivers exceeding the standard being 30%. Based on the Class III surface water standard, the dissolved oxygen single-factor pollution indices of the Yunliang River, Sanba River, Huiyuan Ditch, Sanba Ditch, Railway Transport, Long River, and Sumeng Ditch are greater than 1. Dissolved oxygen in these seven rivers does not meet the functional requirements for Class III surface water, while the remaining three rivers meet the standard, resulting in an over-standard ratio of70%.

Ammonia nitrogen ($NH_4^+$-N) in water mainly originates from domestic sewage, agricultural fertilizers, and industrial wastewater. Ammonia nitrogen in water can be converted into nitrate under the action of nitrifying bacteria, which poses health risks to humans upon ingestion. Ammonia nitrogen also affects aquatic organisms: excessive concentrations cause fish mortality and induce water eutrophication. Thus, ammonia nitrogen is also a critical indicator for assessing water pollution.

Under the Class V surface water standard, among the ten monitored rivers, only the Tuo River and Huancheng Yinhe River have ammonia nitrogen single-factor pollution indices less than 1, meeting the national standard. Ammonia nitrogen in the other eight rivers exceeds the national standard, accounting for80% of the total. According to the Class III surface water standard, all ten monitored rivers exceed the national standard, with an over-standard rate of 100%. Relevant departments should pay attention and take measures to reduce ammonia nitrogen in rivers.

Based on the above indicators, only the Tuo River and Huancheng Yinhe River meet the Class V standards for dissolved oxygen and ammonia nitrogen as specified in the "Environmental Quality Standards for Surface Water" (GB 3838-2002), indicating good water quality. The remaining 8 rivers fail to meet the Class V standards for certain indicators, showing relatively poor water quality. Ammonia nitrogen in all ten rivers exceeds the Class III standard. Applying the most unfavorable principle, none of the ten rivers meet the Class III standard. From the perspective of single-factor pollution indices, the river water bodies in the main urban area of Suzhou are at the Class V water quality level.

**Table 3. Single Pollution Index of River pollutants in the Main Urban Area**

| National standard | Single pollution index | Huancheng River | Tuo River | Huancheng Yinhe | Yunliang River | Sanba River | Huiyuan Ditch | Sanba Ditch | Railway Transport | Long River | Sumeng Ditch | Exceeding standard rate of sample point |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Class V standard | PDo | 0.24 | 0.52 | 0.34 | 8.11 | 0.70 | 4.15 | 0.62 | 8.56 | 0.79 | 0.72 | 30% |
| | PNH4+-N | 6 | 0.8 | 0.82 | 7.1 | 15.5 | 9.6 | 11.5 | 10.5 | 9.5 | 7 | 80% |
| Class III standard | PDo | 0.41 | 0.90 | 0.58 | 9.24 | 2.62 | 7.66 | 1.54 | 9.42 | 3.70 | 2.80 | 70% |
| | PNH4+-N | 12 | 1.6 | 1.64 | 14.2 | 31 | 19.2 | 23 | 21 | 19 | 14 | 100% |

### 4.2 Evaluation of Main Urban River Black and Odorous Index Method

According to the results of river black and odorous index I (Table 4), it can be seen that the rank order of black and odorous degree of 10 rivers is Railway canal > Yunliang River > Huiyuan Dagou > Sanba River > Long River > Sanba Gou > Sumeng Dagou > Huancheng River > Tuo River > Huancheng Diversion River, among which the rivers belonging to severe black and odorous include Railway Canal, Yunliang River and Huiyuan Dagou, and the rivers belonging to black and odorous are Sanba River. The rest of the river is not black and odorous.

The maximum value of the river black odorous index appears in the Railway Canal, which is 29.17, which is far higher than the standard value of 7.5 for severe black and odorous. Suzhou Economic Development District and Suzhou Boyang Industrial Park (mainly engaged in textile industry) are located near the north section of the Railway Transport. The textile wastewater discharging is the main cause of the river black and odorous. There are many old residential areas near the Yunliang River, and the household garbage generated by residents may be the main cause of river pollution. Huiyuan Ditch is located in Suzhou High-tech Zone, and the discharge of the factory is the main cause of the black and odorous of the river. The minimum value of the black and odorous index of the river appears in the Huancheng Diversion River, which is 0.23. There are many residential areas near the Huancheng Diversion River, and the population is large. Suzhou City has always attached great importance to this river, and spends a high cost every year to treat this section of the river, so the water quality of the river is good. The government needs to focus on the heavily black and odorous Railway Canal,

Yunliang Rivers, and Huiyuan Dagou. The Sanba River also showed black and odorous. Many new communities have been built near the river, and the economic development has also brought environmental pollution, which needs to be brought to the attention of the government to prevent the water quality from continuing to deteriorate.

Among the 10 rivers (Figure 1), 60% were not black and odorous, 10% were black and odorous, and 30% were severe black and odorous. This shows that most of the rivers in the main urban area of Suzhou City are not black and odorous pollution, but the water quality is seriously polarized [11].

**Table 4. Black and Odorous Index of Rivers in Main Urban Area**

| Sampling point | Huancheng River | Tuo River | Huanchang Diversion River | Yunliang River | Sanba River | Huiyuan Dagou | Sanba Gou | Railway Canal | Long River | Sumeng Dagou |
|---|---|---|---|---|---|---|---|---|---|---|
| Black and odorous index I | 1.54 | 0.28 | 0.23 | 17.32 | 6.89 | 11.29 | 4.51 | 29.17 | 4.87 | 3.18 |
| Black and odorous judgment category | No black and odorous | No black and odorous | No black and odorous | Severe black and odorous | Black and odorous | Severe black and odorous | No black and odorous | Severe black and odorous | No black and odorous | No black and odorous |

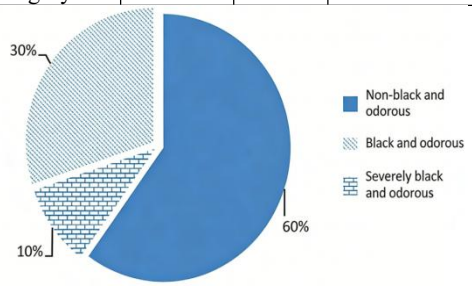



**Figure 1. Evaluation of River Black and Odor Index in Main Urban Area**

### 4.3 Evaluation of Nemerow Comprehensive Water Quality Index

According to Formulas (4-7), the single-factor Nemerow black-odor indices for rivers in the main urban area of Suzhou were obtained, with the calculation results shown in Figure 2.

It can be seen that only the transparency Nemerow index of Huiyuan Ditch is above 1, while those of the other 9 rivers are below 1, with an over-standard rate of 10%. Visually, the 10 rivers in the main urban area of Suzhou generally show no unpleasant color and present good transparency. The decomposition of organic matter in Huiyuan Ditch leads to the decrease of water transparency.

The dissolved oxygen Nemerow indices of Yunliang River, Huiyuan Ditch and Railway Canal are above 1, with an over-standard rate of 30%. Dissolved oxygen in these three rivers is relatively insufficient, resulting in poor self-purification performance, hypoxia in some river reaches, poor water quality and malodorous phenomena.

The oxidation-reduction potential Nemerow indices of Yunliang River, Huiyuan Ditch, Railway Canal and Long River are above 1, with an over-standard rate of 40%, while those of the other six rivers are below 1. A low oxidation-reduction potential indicates low microbial activity, making it difficult for aerobic microorganisms to survive, while anaerobic or hypoxic microorganisms become active, causing blackening and odor of water.

As for the ammonia nitrogen Nemerow index, only those of Tuo River and Huancheng Yinhe River are below 1. Sanba River, Huiyuan Ditch, Sanba Ditch, Railway Canal and Long River have values above 2, indicating severe black-odor. Huancheng River, Yunliang River and Sumeng Ditch have values above 1, indicating slight black-odor, with an over-standard rate of 80%. It can be seen that ammonia nitrogen in rivers of the main urban area of Suzhou exceeds the standard on the whole.

In normal oxygen-rich water bodies, ammonia nitrogen can be oxidized to nitrite by microorganisms and further to nitrate, marking the completion of water self-purification. During this process, ammonia nitrogen can be transformed into nitrosamines, a strong carcinogen that exerts adverse effects on aquatic organisms such as fish and human health.

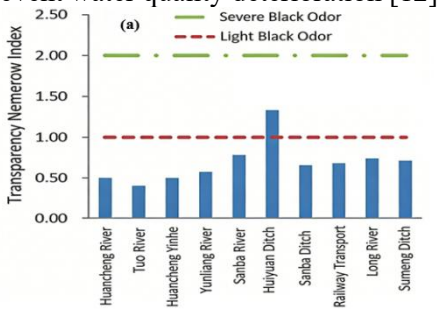
Among the four single-factor Nemerow black-odor indices, the number of rivers with excessive ammonia nitrogen is the largest. Physicochemical methods should be adopted to reduce ammonia nitrogen content in rivers of the main urban area of Suzhou. Meanwhile, control should start from the source: set discharge limits for industrial wastewater, and reduce the discharge of wastewater from farmland and livestock breeding.

The comprehensive Nemerow black-odor index ($P_{comprehensive}$) was calculated for each river, with the results shown in Figure 3, and the proportion of black-odor conditions in the main urban area of Suzhou shown in Figure 4. It can

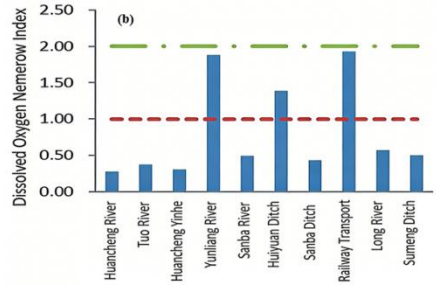
be seen from Figure 3 that the comprehensive Nemerow black-odor indices of rivers in the main urban area of Suzhou range from 0.37 to 2.98. The maximum index appears in Sanba River and the minimum in Tuo River. The black-odor degree ranks in descending order as follows:Sanba River > Railway Canal > Sanba Ditch > Huiyuan Ditch > Long River > Yunliang River > Sumeng Ditch > Huancheng River > Huancheng Yinhe River > Tuo River.

From Figure 4, 40% of all rivers suffer from severe black-odor, including Sanba River, Huiyuan Ditch, Sanba Ditch and Railway Canal; 40% are slightly black-odor, including Huancheng River, Yunliang River, Long River and Sumeng Ditch; and 20% are non-black-odor, namely Tuo River and Huancheng Yinhe River.

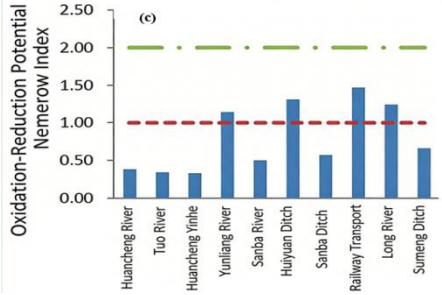
Priority and key treatment should be implemented for rivers with severe black-odor.For slightly black-odor rivers, measures should be taken to reduce pollution and restore them to non-black-odor status. For non-black-odor rivers, protective development is required to prevent water quality deterioration [12].



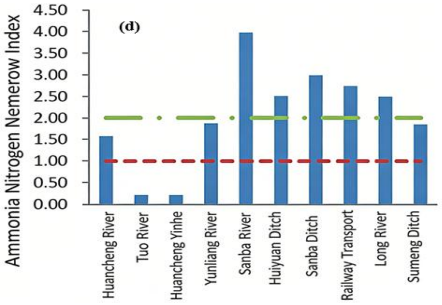

(a) Transparency Nemerow Index




(b) Dissolved Oxygen Nemerow Index




(c) Oxidation-Reduction Potential Nemerow Index




(d) Ammonia Nitrogen Nemerow Index

**Figure 2. Nemerow Single Black and Odorous Index of Each River in the Main Urban Area**

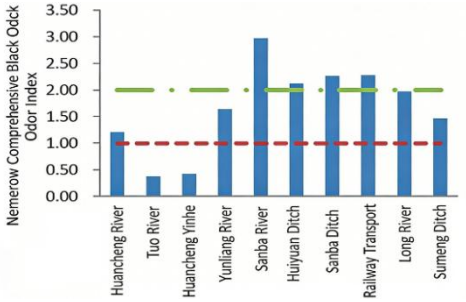



**Figure 3. Nemerow Comprehensive Black and Odorous Index of River in Main Urban Area**

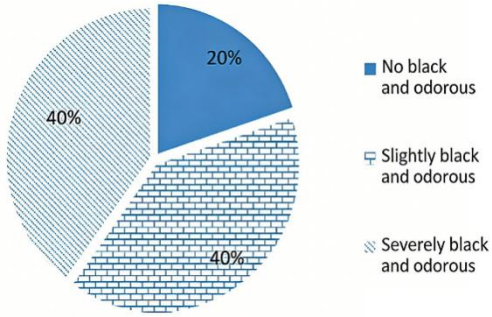



**Figure 4. Evaluation of River Black Odorous Index in Main Urban Area of Suzhou City**

## 5. Conclusion

The single-factor pollution index method was applied to analyze the water quality of rivers in the main urban area. Only the Tuo River and Huancheng Yinhe River met the Class V surface water standard, while the other rivers did not meet the standard. None of the rivers reached the Class III surface water standard. Overall, the water quality in the main urban area of Suzhou was poor. Ammonia nitrogen pollution was particularly severe and requires attention.

The black-odor index method was used to comprehensively evaluate the black-odor conditions of the rivers. The ranking of black-odor degree was as follows: Railway Canal > Yunliang River > Huiyuan Ditch > Sanba River > Long River > Sanba Ditch > Sumeng Ditch > Huancheng River > Tuo River > Huancheng Yinhe River. Among them, the

Railway Canal, Yunliang River and Huiyuan Ditch reached severe black-odor levels with serious pollution. The Sanba River exhibited black-odor conditions with relatively severe pollution.

The Nemerow black-odor index was adopted for comprehensive evaluation of the black-odor status of the rivers. The black-odor degree ranked in descending order: Sanba River > Railway Canal > Sanba Ditch > Huiyuan Ditch > Long River > Yunliang River > Sumeng Ditch > Huancheng River > Huancheng Yinhe River > Tuo River. Among them, the Sanba River, Huiyuan Ditch, Sanba Ditch and Railway Transport reached severe black-odor levels and urgently need treatment to reduce their adverse impacts on nearby residents. The Huancheng River, Yunliang River, Long River and Sumeng Ditch showed slight black-odor, which requires attention to prevent further deterioration of water quality.

In view of the black and odorous water problems in rivers of the main urban area of Suzhou, the following scientific suggestions are proposed based on water quality monitoring results. First, control pollution at the source. Strictly regulate the discharge of industrial wastewater and agricultural breeding wastewater, set discharge limits, promote centralized treatment of domestic sewage, and reduce the input of pollutants such as ammonia nitrogen. Second, implement targeted treatment. For severely black and odorous rivers, use physical and chemical methods to reduce ammonia nitrogen content, add microbial agents to enhance water self-purification capacity, and dredge river sediment to reduce pollution caused by organic matter decomposition. Third, establish long-term management and protection. Set up a regular river monitoring mechanism, inspect sewage outlets regularly, enhance riverbank greening, carry out environmental publicity, and guide public participation, so as to form an integrated system of "source control–treatment–management" and gradually improve river water quality.

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