Diagnosis and assessment of black and odourous water and a comprehensive strategy for urban areas

Huiqing Yu1,2*, Guijun Shi1,2, Jing Yin1,2, Yongti Shan1,2
1 CCCC First Highway Consultants Co., Ltd., Xi’an, Shaanxi, 710065, China
2 Xi’an Zhongjiao Environmental Engineering Co., Ltd, Xi’an, 710075, China
*Corresponding author’s e-mail: 41126370@qq.com

Abstract. To fundamentally solve the problems associated with black and odourous water pollution in Chinese urban areas, the Xixiang River and the Xianshui Surge were selected to diagnose and assess the pollution characteristics of black and odourous water. Based on the results, a comprehensive strategy with a scientific basis was proposed for the improvement of Chinese urban water quality.

1. Introduction
With continued economic development and accelerated urbanization, populations in Chinese urban areas are rapidly growing and sewage discharges are sharply increasing. In recent years, a seasonal to year-round black and odourous water phenomenon has occurred in some areas, which continues to cause increasingly serious problems. In 2015, the "Action Plan for Prevention and Control of Water Pollution" issued by the State Council proposed the following objectives: by 2020, the quantity of black and odourous water bodies in urban areas will be reduced by 10%, and by 2030, the black and odourous water bodies in urban areas will be eliminated. Therefore, it is imperative to treat and restore black and odourous water.

At present, research on urban black and odourous water mainly focuses on the treatment of the water environment and the development of ecological restoration technology [1-7], but the necessary mechanisms, causes, diagnoses and prevention strategies are not completely clear [8-10]. Therefore, addressing the black and odourous water problem is key to the long-term stability of the local waterways, but it also poses difficulties for improving urban water quality. The Xixiang River and Xianshui Surge are selected as study objects in this paper. After investigation and analysis of the current water pollution levels, the source and contribution of major pollutants were analysed in depth, and a comprehensive strategy was proposed based on the results of the diagnosis and assessment. These results may provide a technical reference for the treatment of different black and odourous waters.

2. Materials and methods
2.1. Overview of the study area
The Xixiang River, which is part of the Pearl River System, is located at Xixiang Street, Bao’an District, Shenzhen and is one of the main flood discharge passages of the Tiegang Reservoir. This river’s drainage area is 15.82 km², and its length is 7.64 km. The Xixiang River passes through an urbanized central area. The Xianshui Surge, adjacent to the Xixiang River, is also located at Xixiang
Street, Bao'an District. The surge’s catchment area is 8.77 km², and its length is 4.37 km. The Xianshui Surge eventually flows into the Pearl River Estuary.

2.2. Research methods
To study the pollution characteristics of black and odourous water, water quality was monitored within the study area. As shown in figure 1, thirteen sampling points (R1-R13) were set up in the Xixiang River, and three sampling points (R14-R16) were set up in the Xianshui Surge.

3. Results and discussion

3.1. Diagnosis and assessment of black and odourous water pollution characteristics

3.1.1. Status of black and odourous water
According to the “Guidelines for the Remediation of Urban Black and Odorous Water”, the evaluation indices of urban black and odourous water classification include transparency, DO, ORP and ammonia nitrogen. According to the degree of its black odour, it can be divided into “mild black odour” and “severe black odour”.

As shown in figure 2, monitoring points R7, R10, R12 from the Xixiang River and R15 and R16 from the Xianshui Surge are classified as severe black odour, and the other monitoring points are classified as mild black odour. R7 is located in the small bend of the Xixiang River, where the black odour is caused by the release of pollutants, such as ammonia nitrogen, into the sediment due to the dredging of the Street Park, located upstream. R10 is located south of Xixiang Park, where the river flows gently upstream and becomes turbid due to the presence of abundant green algae and floating objects. This affects the transmission of light, reduces the transparency of the water, and results in the black odour. R12 is located north of Baoyuan Road, and its black odour is caused by an increase in ammonia nitrogen and the discharge of domestic sewage from the Xixiang market, located upstream. R15 and R16, which are located in the middle and upper reaches of the Xianshui Surge, appear black and odourous mainly due to the large amount of ammonia nitrogen in domestic sewage that is discharged from the coast. Therefore, ammonia nitrogen is a key factor that affects the black odour of the Xixiang River and Xianshui Surge, and it is mostly caused by domestic pollution.
3.1.2. Physical and chemical characteristics of rivers and diagnosis of organic pollutants

Referring to the V standard of Surface Water Environmental Quality Standards, the single-factor assessment method is adopted to evaluate physicochemical indices and the measured organic concentrations.

As shown in Table 1, the pollutant concentrations of both the Xixiang River and Xianshui Surge exceeded the V standard of surface water quality. Organics are responsible for the black colour of the water when the organic content reaches a certain level. This is especially true for sulfur-containing organics, which can make the water darken in 7 to 13 days. Sulfur-containing organics can exacerbate black and odourous water. In addition, after a large number of external pollutants, such as organic pollution, nitrogen, and phosphorus, enter the water, the water appears to be in an anoxic or anaerobic state because the oxygen consumption rate is greater than the reoxygenation rate during the oxidative decomposition process. Subsequently, anaerobic microorganisms multiply quickly, which promotes decomposition, consumption and fermentation of the organics and produces odourous gases such as CH₄ and H₂S [11-13]. The odourous gases escape from the surface of the water into the atmosphere, causing the water to become black and odorous. The data also show that the faecal coliform measurements are over-standard at the highest rate and show the maximum excess of multiple items. This finding indicates that the Xixiang River and Xianshui Surge are seriously polluted by the discharge of untreated domestic sewage along the coast.
Table 1. Physical and chemical characteristics of rivers and diagnosis of organic pollutants

| items                      | Minimum | Maximum | Over-standard rate /% | Maximum excess multiple | Excess point |
|----------------------------|---------|---------|-----------------------|-------------------------|--------------|
| pH                         | 6.95    | 8.3     | 0                     | 0                       | /            |
| Water temperature /℃       | 28.3    | 38      | /                     | /                       | /            |
| Turbidity /degree          | 10      | 100     | /                     | /                       | /            |
| Conductivity /μS/cm        | 132     | 526     | /                     | /                       | /            |
| Permanganate index /mg/L   | 1.98    | 28.2    | 18.75                 | 0.88                    | R14-R16      |
| TN /mg/L                   | 1.38    | 45.2    | 75                    | 21.6                    | R1、R6-R16   |
| TP /mg/L                   | 0.07    | 4.98    | 68.75                 | 11.45                   | R6-R16       |
| BOD5/mg/L                  | 2.5     | 95.7    | 62.5                  | 8.57                    | R7-R16       |
| COD/mg/L                   | 12      | 416     | 62.5                  | 9.4                     | R7-R16       |
| Petroleum /mg/L            | 0.1     | 1.08    | 12.5                  | 0.08                    | R15、R16     |
| Volatile phenol /mg/L      | 0.0006  | 0.0021  | 0                     | 0                       | /            |
| Cl⁻ /mg/L                  | 14.2    | 756     | /                     | /                       | /            |
| Fluoride /mg/L             | 0.161   | 1.54    | 6.25                  | 0.03                    | R14          |
| Sulfide /mg/L              | 0.012   | 2.22    | 6.25                  | 1.22                    | R16          |
| Faecal coliform / One /L   | 2.7×10³ | 9.2×10⁶ | 75                    | 229                     | R1、R4、R6-R16|
| LAS /mg/L                  | 0.06    | 1.76    | 62.5                  | 4.87                    | R7-R16       |

3.1.3. Diagnosis of heavy metal pollution characteristics

In reference to the V standard of the Surface Water Environmental Quality Standard, the single-factor assessment method is adopted to evaluate heavy metal index measurements.

As shown in table 2, the pollutant concentrations of both the Xixiang River and Xianshui Surge exceeded the V standard of surface water quality. Mn is the chief heavy metal pollutant, and it is excessive in R7, R9 and R11-R16; the over-standard rate is 50%, and the maximum excess multiple is 3.56. Based on both domestic and international research results, manganese pollution is an important factor related to the blackening of water. Mn is reduced under anoxic conditions, and it reacts with sulfides to form negatively charged colloids such as MnS. These colloidal particles come to the surface of the water, turning the water black. This is consistent with the results shown in figure 2.

Table 2. Diagnosis of heavy metal pollution characteristics

| items                      | Minimum | Maximum | Over-standard rate /% | Maximum excess multiple | Excess point |
|----------------------------|---------|---------|-----------------------|-------------------------|--------------|
| Hg                         | 0.00004 | 0.002   | 0                     | /                       | /            |
| Cr⁶⁺                       | 0       | 0       | 0                     | /                       | /            |
| As                         | 0.0004  | 0.0022  | 0                     | /                       | /            |
| Cu                         | 0.002   | 0.006   | 0                     | /                       | /            |
| Pb                         | 0.05    | 0.05    | 0                     | /                       | /            |
| Cd                         | 0       | 0       | 0                     | /                       | /            |
| Mn                         | 0.038   | 0.456   | 50                    | 3.56                    | R7、R9、R11-R16|
| Zn                         | 0.06    | 0.07    | 0                     | /                       | /            |
| Na                         | 11.2    | 480     | 0                     | /                       | /            |
| Fe³⁺                       | 0.05    | 0.47    | /                     | /                       | /            |
| Fe²⁺                       | 0.04    | 1.75    | /                     | /                       | /            |

3.1.4. Source and contribution of major pollutants

According to the characteristics and diagnosis of above, the 15 over-standard items are selected to comprehensively assess the water quality of the Xixiang River and Xianshui Surge using the principal component analysis method for 11 polluted sampling points: R6-R16.
(1) Source and contribution of major pollutants in the Xixiang River

The gravel test is a method for determining the number of factors based on a scree plot. The horizontal axis represents the order of every eigenvalue in descending order, and the vertical axis represents the value of the eigenvalue. As shown in Figure 3, fifteen different indicators from the sampling points are studied using the factor analysis method for the Xixiang River. The scree plot shows that the first three eigenvalues of the line constitute a "cliff", while the remaining points appear as gravel under the "cliff". As such, it is appropriate to extract three common factors.

As shown in Figure 4, the cumulative contribution rate of the first, second, and third principal components is 86.118%, which meets the analysis requirement of >85%. Therefore, three principal components are selected for analysis and evaluation. According to the load of the principal component, the first principal component can be expressed as:

\[
F_1 = -0.38X_1 - 0.845X_2 + 0.936X_3 + 0.497X_4 + 0.889X_5 + 0.843X_6 - 0.785X_7 + 0.047X_8 \\
+ 0.963X_9 + 0.569X_{10} + 0.888X_{11} - 0.847X_{12} + 0.671X_{13} - 0.077X_{14} + 0.891X_{15} \tag{1}
\]

The contribution rate of the first principal component is 54.047%, which has strong positive correlations to X3 (permanganate index), X5 (ammonia nitrogen), X6 (TN), X9 (COD), X11 (Mn), and X15 (LAS) and has a strong negative correlation to X2 (DO) and X12 (chloride). This indicates that these variables comprehensively reflect the direct discharge of sewage and the secret discharge of industrial wastewater into the river. Accordingly, the first principal component can be considered pollution sourced from sewage.

The second principal component can be expressed as

\[
F_2 = 0.641X_1 - 0.377X_2 - 0.138X_3 + 0.68X_4 - 0.354X_5 - 0.501X_6 - 0.453X_7 - 0.76X_8 \\
- 0.172X_9 - 0.617X_{10} + 0.379X_{11} - 0.506X_{12} + 0.269X_{13} + 0.126X_{14} - 0.319X_{15} \tag{2}
\]

The contribution rate of the second principal component is 21.284%, which has strong positive correlations to X1 (transparency) and X4 (ORP) and has a strong negative correlation to X8 (BOD5) and X10 (petroleum). After a short period of initial rainfall, clean rainwater discharged into the river can dilute the concentration of pollutants. The concentration of transparency and ORP of water are increased, while BOD5 and petroleum are decreased. These variables comprehensively reflect pollution from rainwater outlets. Therefore, the second principal component can be considered representative of pollution sourced from rainwater outlets. The third principal component can be expressed as

\[
F_3 = -0.575X_1 - 0.235X_2 - 0.275X_3 + 0.446X_4 - 0.136X_5 - 0.046X_6 + 0.057X_7 + 0.616X_8 \\
- 0.103X_9 - 0.304X_{10} + 0.031X_{11} - 0.005X_{12} + 0.394X_{13} - 0.456X_{14} - 0.297X_{15} \tag{3}
\]

The contribution rate of the third principal component is 10.787%, which has a strong positive correlation with X8 (BOD5) and a strong negative correlation with X1 (transparency). These two variables comprehensively reflect the ecology and sediment of the river itself. As such, the third principal component can be considered to be representative of pollution sourced by the river itself.
Through the diagnosis and assessment of pollution in the Xixiang River, it is concluded that the pollution sources of sewage outfalls, rainwater outlets and the river itself are the key factors that impact pollution levels in the Xixiang River. Therefore, comprehensively improving the water environment of the Xixiang River requires increasing the speed at which pipes are laid for sewage collection, improving the sewage treatment capacity, implementing rain and sewage diversions, increasing initial rain diversion, and performing river dredging.

Water pollution components can be ordered according to the integrated score of the principal component, in which the higher the score, the more serious the pollution. As shown in table 3, the current status of water pollution at the eight sampling points along the Xixiang River, in descending order, is R10>R6>R9>R8>R11>R13>R7>R12, wherein R10 is the most polluted location. Transparency, DO, permanganate index and petroleum are the primary influences at R10; TP, ORP and chloride are primary influences at R6; LAS and ammonia nitrogen are the primary influences at R9; and petroleum and faecal coliform are the primary influences at R8. Key measures should be taken to address the most influential indices near these points.

| Table 3. Principal component score and comprehensive score of the Xixiang River |
|---------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| index                          | R6     | R7     | R8     | R9     | R10    | R11    | R12    | R13    |
| Do                             | 1.131  | -0.850 | -0.746 | 0.149  | 1.896  | -0.249 | -1.483 | 0.151  |
| Permanganate index             | 0.212  | 0.030  | 0.381  | -0.027 | -1.778 | 0.469  | -0.490 | 1.203  |
| ORP                            | -2.098 | 1.740  | 0.594  | -0.414 | -0.066 | -0.188 | -0.165 | 0.598  |
| Ammonia nitrogen               | 0.525  | 0.024  | 0.118  | 1.049  | -0.468 | 0.098  | -1.384 | 0.038  |
| TN                             | 1.176  | -0.228 | -0.444 | -0.845 | -0.254 | -0.353 | 0.743  | 0.205  |
| TP                             | -3.647 | 2.952  | -0.983 | -0.963 | -0.374 | 0.688  | 1.738  | 0.590  |
| BOD₅                           | -1.203 | 0.409  | 0.412  | 0.741  | 0.501  | -0.105 | -0.536 | -0.218 |
| COD                            | 0.947  | -0.533 | -0.558 | 0.210  | -0.178 | 0.889  | -0.079 | -0.699 |
| Petroleum                      | -0.908 | 0.313  | -1.544 | -0.316 | -1.557 | 1.297  | 1.531  | 1.183  |
| Mn                             | 0.757  | -0.493 | 0.029  | 0.538  | -0.336 | 0.318  | -0.473 | -0.340 |
| Chloride                       | -1.605 | 0.431  | -0.900 | -0.845 | -0.134 | 0.947  | 1.723  | 0.383  |
| Sulfide                        | -0.654 | -0.409 | 0.085  | 0.356  | -0.761 | 0.056  | 1.075  | 0.252  |
| Faecal coliform                | -1.095 | -0.044 | 1.241  | 0.989  | 0.771  | -0.720 | -0.733 | -0.409 |
| LAS                            | 0.230  | 0.463  | 0.724  | -1.263 | 1.218  | -1.095 | -0.464 | 0.186  |
| Integrated score               | 0.490  | -0.508 | -0.128 | 0.419  | 1.270  | -0.341 | -0.804 | -0.398 |
| Order                          | 2      | 7      | 4      | 3      | 1      | 5      | 8      | 6      |

(2) Sources and contribution of major pollutants in the Xianhshui Surge
As shown in Figure 5, the cumulative contribution rate of the first and second principal components is 100%, which meets the analysis requirement of >85%. Therefore, two principal components are selected for analysis and assessment. According to the load of the principal component, the first principal component can be expressed as
\[
F_1 = -0.953 X_1 + 0.998 X_2 + 0.665 X_3 + 0.629 X_4 + 0.947 X_5 + 0.889 X_6 + 0.993 X_7 - 0.572 X_8 \\
- 0.062 X_9 + 0.848 X_{10} - 0.157 X_{11} - 0.942 X_{12} + 0.943 X_{13} - 0.953 X_{14} + 0.998 X_{15}
\]

The contribution rate of the first principal component is 61.455%, which has a strong positive correlation to \( X_2 \) (DO), \( X_5 \) (ammonia nitrogen), \( X_7 \) (TP), \( X_{13} \) (sulfide), and \( X_{15} \) (LAS). It has a strong negative correlation with \( X_1 \) (transparency), \( X_{12} \) (chloride) and \( X_{14} \) (faecal coliform). These variables comprehensively reflect external pollution from coastal sewage outlets and seawater that is recirculated to deteriorate water quality. Therefore, the first principal component can be considered to be representative of external pollution.

The second principal component can be expressed as
\[
F_2 = 0.304 X_1 - 0.069 X_2 + 0.747 X_3 + 0.778 X_4 - 0.321 X_5 - 0.458 X_6 + 0.117 X_7 - 0.82 X_8 \\
+ 0.998 X_9 - 0.53 X_{10} - 0.983 X_{11} + 0.337 X_{12} + 0.333 X_{13} + 0.304 X_{14} - 0.069 X_{15}
\]

The contribution rate of the second principal component is 38.545%, which has a strong positive correlation to \( X_9 \) (COD) and a strong negative correlation to \( X_{11} \) (Mn). These two variables comprehensively reflect internal pollution, such as organic matter and heavy metals, in the sediment. Therefore, the second principal component can be considered to be representative of internal pollution.

Through the diagnosis and assessment of pollution in the Xianshui Surge, it is concluded that external pollution and internal pollution are the key influencing factors in the Xianshui Surge. Therefore, improving the water environment in the Xianshui Surge requires comprehensively treating the pollution at its source, controlling the pollutants entering the river, preventing saltwater incursion, and dredging the river.

As shown in Table 4, the current status of water pollution at the three sampling points along the Xianshui Surge, in descending order, is R16>R15>R14, where R16 is the most polluted. The permanganate index, petroleum, TP and ammonia nitrogen are the primary influences at R16; the permanganate index, sulfide and Mn are the primary influences at R15; and petroleum, ammonia nitrogen, TP and chloride are the primary influences at R14. Key measures should be taken to address the most influential indices near these points.
Table 4. Principal component scores and comprehensive scores of the Xianshui Surge

| index                | R14    | R15    | R16    |
|----------------------|--------|--------|--------|
| transparency         | -0.744 | 0.531  | 0.213  |
| Do                   | -0.074 | -0.457 | 0.531  |
| Permanganate index   | 0.290  | -1.735 | 1.445  |
| ORP                  | -0.018 | -0.459 | 0.477  |
| Ammonia nitrogen     | 0.290  | -1.735 | 1.445  |
| TN                   | -0.700 | 0.270  | 0.430  |
| TP                   | 1.130  | 0.017  | -1.147 |
| BOD₅                 | -0.217 | -0.338 | 0.555  |
| COD                  | -0.969 | -0.648 | 1.617  |
| Petroleum            | 1.633  | -0.296 | -1.336 |
| Mn                   | 0.522  | -1.135 | 0.613  |
| chloride             | 1.034  | -0.518 | -0.516 |
| Sulfide              | -0.747 | 1.249  | -0.503 |
| Faecal coliform      | -0.077 | 0.235  | -0.158 |
| LAS                  | 0.930  | -0.107 | -0.823 |
| Integrated score     | -0.486 | 0.150  | 0.336  |

3.2. Comprehensive strategy

(1) Pipe-laying and sewage collection. To address the direct discharge of sewage and the secret discharge of industrial wastewater, intercepting pipelines should be constructed and incorporated into the sewage collection system.

(2) Sewage treatment. A series of measures, including establishing new wastewater treatment plants, expanding the scale of wastewater treatment plants, improving the effect of wastewater treatment, and promoting the compliance rate of water quality, should be adopted. The wastewater of the sewage collection system should be treated directly, and the water should attain a standard of discharge so that it can be comprehensively utilized.

(3) Rain and sewage diversion. For the combined drainage pipeline, the measures for rain and sewage diversion should be adopted, and pollutant sources should be cleaned to avoid sewage discharge into the water through the confluence pipeline and river pollution.

(4) Rain basins. Environmentally friendly rainwater outlets should be added to the rainwater outlets of the community. Initial rain diversion wells or storage tanks should be extensively constructed before rainwater reaches the estuary. Initial rain interception should be performed in high-pollution areas, and collected rain should be treated according to requirements for meeting the standards to reduce pollution in the river.

(5) River dredging. A certain thickness of river sediments should be cleaned up by mechanical dredging or hydrodynamic dredging, which can rapidly reduce the internal pollutants of the water and fundamentally reduce the influence of the sediment on the overlying water. In this way, the deterioration of water quality induced by internal pollution can be addressed.

(6) Ecological remediation. To restore the water ecosystem, improve the river self-purification capacity, and to improve the river water quality, ecological remediation measures such as water purification, ecological remediation of shoreline, natural habitat restoration of the riverbed, biodiversity regulation, and ecological water supply are proposed to improve the water environment quality.

(7) Prevent seawater backflow. For tidal rivers in coastal areas, it is suggested to comprehensively renovate the pollution sources from the sea and the river, control overflow pollution, and prevent pollution by tidal waters during high tide.
4. Conclusion
(1) Through analysis of the source and contribution rates of major pollutants, external pollution sources such as sewage outfall, rainwater outlets, and recirculated seawater, as well as internal pollution from sediment, are found to be the key factors that affect water pollution. It is suggested to select the emphasized sections of the river based on the comprehensive scores of the sampling points. Ecological restoration measures are proposed based on the principal component scores of the reference indices.

(2) According to the characteristics of water pollution and the key influencing factors, it is recommended to comprehensively improve black and odourous water by means of laying pipes and enhancing sewage collection, sewage treatment, rain and sewage diversion, initial rain diversion, river dredging, ecological restoration and the prevention of seawater backflow.

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References
[1] Chen Weiyan, Yin Li, Qiao Lili, et al, Research on application of black and malodorous pond water in-situ restoration technology. Industrial Water & Wastewater., 49(2018)32-35.
[2] Kong Deying, Discussion on design of treatment scheme for black odor river in Erkengxi, Nanning. Environment and Development., 30 (2018):46-47.
[3] Liang Yicong, Hu Zhanbo, Tu Yuling, Lu Hui, Jiang Zhe, Liu Yuhua, Effectiveness of carbon fiber based biofilm carrier remediation technology on urban black-odorous water. Chinese Journal of Environmental Engineering., 9(2015)603-608.
[4] Liu Xiaobo, Gao Qijing, Zhu Wenjun, Zhao Yan, Shen Wengang, Removal of water pollutants by Vallisneria and Ceratophyllum. Water &Wastewater Engineering., 54 (2018)82-88.
[5] Wu Guangqian, Liu Qianling, Zhou Peiguo, Zhang Wenxi, Xu Wei, Remediation of polluted water and sediment by using immobilized microorganism technology. Technology of Water Treatment., (2008)26-29.
[6] Yin Li, Zhang Pengyu, Chen Weiyan, Qiao Lili, Zhong Huichuan, Jiang Wei, Repairment of the black and odorous water by immobilized bacteria process. Water&Wastewater Engineering., 54(2018)51-55.
[7] Zhao Yue, Yao Ruixia, Xu Min, Song Lingling, Study on the Practice and Route of Combating Urban Black-and-malodorous Water Body. Environmental Protection., 43(2015)27-29.
[8] Li Xuepeng, Study on the cause of the black odor water body and its comprehensive treatment. Modern Chemical Research., (2016)85-86.
[9] Wang Xu, Wang Yonggang, Sun Changhong, Pan Tao, Formation mechanism and assessment method for urban black and odorous water body. Chinese Journal of Applied Ecology., 27(2016)1331-1340.
[10] Wu Yinwei, Guo Jianhui, Wang Xiaoling, Cause of formation and control considerations on black and malodorous water body in rivers and lakes. China Environmental Protection Industry., (2018) 48-51.
[11] Ginzburg B, Dor I, Chalifa I, et al, Formation of dimethyloligosulfides in Lake Kinneret: Biogenic formation of inorganic oligosulfide intermediates under oxic conditions. Environmental Science and Technology., 33(1999)571-579.
[12] Gun J, Goifman A, Shkrob I, et al, Formation of polysulfides in an oxygen rich freshwater lake and their role in the production of volatile sulfur compounds in aquatic systems. Environmental Science and Technology., 34(2000)4741-4746.
[13] Lu Xin, Feng Ziyan, Shang Jingge, Fan Chengxin, Deng Jiancai, Black water bloom induced by different types of organic matters and forming mechanisms of major odorous compounds. Environmental Science., 33(2012)3152-3159.