Water quality assessment and analysis for rehabilitate and management of wetlands: a case study in Nanhai wetland of Baotou, China

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Abstract. Wetland plays an irreplaceable role in many aspects and waters are important part of wetland, the water quality can easily reflect the situation of Wetland. In this study, water quality was assessed on the basis of 5 parameters (DO, NH_4^+-N, TN, TP and CODcr) that were monitored monthly at 5 sites (N_1,N_2,N_3,N_4 and N_5)from April, 2014 to March, 2015 of the Nanhai Lake in Baotou, China by water pollution index method and comprehensive water quality identification index method. The twelve monitoring months were divided into wet season (Mar., Aug. and Sep.), normal season (Jan., Feb., Apr., Nov. and Dec.) and dry season (May., Jun. and Jul.). The assessment results determined using the water pollution index method showed that the water quality of all the five monitoring sites were inferior Ⅴ, the main contamination was COD. The comprehensive water quality identification index showed that the water quality of the Nanhai Lake were classes Ⅴ, except for the N_2 in wet season and dry season, the N_1 in dry season and the N_5 in normal season, which were classes inferior Ⅴ. All the five monitoring sites don't achieving the desired water quality standard. According to the analysis, domestic discharge, industrial activities and developed recreation were major threats to water quality of Nanhai Lake.

1 Introduction

Wetlands have huge environmental functions in maintaining ecological balance and regional stability due to their particular characteristics in hydrology, soil, plant, as well as landscape ecological structures. Baotou Yellow River wetland is a vital wetland resource in Inner Mongolia, Nanhai wetland is a part of it, which well known as northern west Lake. Managing the limited water resource and dealing with the relationship between water resources and ecological environment well are the foundation for the protection, management and utilization of wetlands. In recent years, due to the development of tourism and the increase of the surrounding human activities, water quality of the Nanhai Lake is gradually turns bad. It's essential to assess the water quality of Nanhai Lake. As to the method of water quality assessment, such as single-factor assessment method, water quality grading method, nemerow pollution index, comprehensive pollution index, principle component analysis, fuzzy comprehensive evaluation method, water pollution index method and comprehensive water quality identification index[1,2] each have their own characteristics and apply to different waters.

Water pollution index method (WPI) has been widely used to assess water quality in America[3], China [4], and Spain [5]. It overcomes the problem of single factor evaluation and comprehensive water evaluation method. In this method, the water quality is quantified, and can reflect the main pollution parameters. The comprehensive water quality identification index is a relatively new tool for general water quality assessment of surface waters, It evaluates general water quality both qualitatively and quantitatively, and also evaluates water quality inferior to V, identifying whether the waters malodorous and black[6]. In recently years, this method was applied widely to assessed the water quality lake and river [7,8].In this study, Water pollution index method and comprehensive water quality identification index method were selected to assess water quality of Nanhai Lake.

2 Materials and methods

2.1 Study area

The Nanhai wetland (109°59'02″～110°02'26″E, 40°30'-08″～40°33'32″N) is one of the largest lake scenic areas located in the South of Baotou, China, the north shore of the Yellow River, with a total area of 2104.6hm^2(Fig.1), in which protected waters area 333 hm^2 and floodplain wetlands area 1,000 hm^2. The main geomorphology of Nanhai wetlands is Yellow River alluvial plain, with an average altitude of 1020m, including the waters, marshes, shrub and grassland. The region is in a semiarid continental monsoon climate with a large diurnal and seasonal range of temperature, an uneven distribution rainfall seasonally and a different wind direction between winter and

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summer. The annual average rainfall is 307.4mm with most precipitation occurring between Jun. and Aug., but the annual evaporation is 2343mm. The annual average temperature is 8.5℃, with the mean lowest temperature -12.7℃ and the highest 22.2℃ come from the coldest month Jan. and the warmest Jul., respectively. In 2008, Nanhai wetland was named the national grade 4A tourist scenic spot, and the same year was authorized to be a provincial nature reserve of the Yellow River Wetland by the Inner Mongolia Autonomous Region. In recent years, due to the development of tourism and the increase of the surrounding human activities, the water quality of the Nanhai Lake is gradually turns bad. It is essential to evaluate the water quality of the Nanhai Lake for the quality of water environment directly affects the growth status of each species.According to the location and function of wetland, 5 monitoring sites are arranged in the study area.

2.2 Field sampling and Laboratory analysis

Water samples were collected every month from Apr., 2014 to Mar., 2015 (the twelve months are divided into wet season(Mar., Aug. and Sep.), normal season(Jan., Feb., Apr., Nov. and Dec.) and dry season(May., Jun. and Jul.)) at five sampling sites on Nanhai Lake, in the condition that without extreme weather, such as large scale rain and sand dust storm within seven days and no sudden pollution events. The sampling sites concrete spot position locates with GPS. All water samples were taken at 0.5m below the surface. Preservation, transportation and storage were performed according to the Chinese National Standard Methods (SEPA,2002). Six water quality parameters were selected due to their continuity in measurement and importance for assessing the water quality conditions of the Nanhai Lake: pH,dissolved oxygen (DO), biochemical oxygen demand index(COD), ammon-ium nitrogen(NH_4^+-N), total nitrogen(TN) and total phosphorus(TP).The specific methods are summarized in Table1.

2.3 Water quality assessment methods

2.3.1 Water pollution index method

In this method, the seriously polluted parameter is taken as water quality classification criteria like single factor evaluation. It can quantify the water quality, according to which intuitively identify the water quality grades of river and directly reflect the change of water quality in time and in space. The assessment was performed as follows: (1)calculating the WPI value of each parameter using interpolation method based on water quality grades and its corresponding WPI value (Table 2); (2)selecting the highest one as the WPI value of monitoring sites. I. If the classification of water quality is between class I and class V according to GB3838-2002, as to each variable except DO,

$$WPI(i) = WPI_{ij-1}(i) + \frac{WPI_{ij}(i) - WPI_{ij-1}(i)}{C_{ij}(i) - C_{ij-1}(i)}(C(i) - C_{ij-1}(i)) \quad (1)$$

$$C_{ij-1}(i) < C(i) \le C_{ij}(i)$$

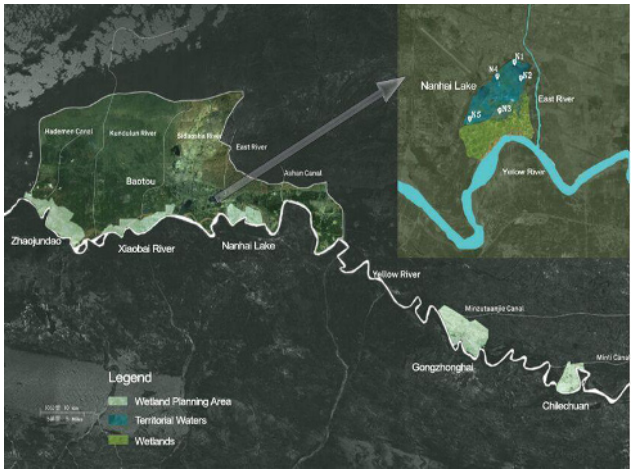

Figure 1. Baotou Yellow River wetland and monitoring sites of the Nanhai Lake

where $C(i)$ is the measured value of parameter i, $C_{ij-1}(i)$ and $C_{ij}(i)$ is the standard value of parameter i for class j-1and j, respectively, $WPI_{ij-1}(i)$ and $WPI_{ij}(i)$ is the standard WPI value of parameter i for class j-1and j, respectively.

In addition, if the standard value of two class is equal, the lower value interval is selected[9].

As to DO ≥ 7.5mg/L, WPI=20; (2)

As to 2 ≤ DO <7.5mg/L,

$$WPI(i) = WPI_{ij-1}(i) + \frac{WPI_{ij}(i) - WPI_{ij-1}(i)}{C_{ij-1}(i) - C_{ij}(i)}(C_{ij-1}(i) - C(i)) \quad (3)$$

II. If the classification of water quality is inferior to class V according to GB3838-2002, as to each variable except DO,

$$WPI(i) = 100 + \frac{C(i) - C_5(i)}{C_5(i)} \times 40 \quad (4)$$

As to DO<2mg/L,

$$WPI(DO) = 100 + \frac{2.0 - C(DO)}{2.0} \times 40 \quad (5)$$

III.As to W value of a monitoring site,

WPI=max(WPI(i)) (6)

2.3.2 Comprehensive water quality identification index method

The comprehensive water quality identification index is a relatively new method, which derives from Single factor water quality identification index. It evaluates general water quality both qualitatively and quantitatively, and also evaluates water quality inferior to V. it classifies general water quality conditions into five classes: type I , type II, type III, type IV, type V, inferior to class V and inferior to V and malodorous and black[6]. The assessment criteria (Table 2).

The water quality identification index comprises integral digits and three fractional digits. The structure is as follows:

$$I_{wq}=X_1.\ X_2X_3X_4 \quad (7)$$

The meaning and calculation method for each digit are as follows:

I. X_1 indicates the comprehensive classification of water quality, generally compared the monitor data with national standard data to determine the location of the

Table 1 measurement methods of parameters

parameters	measurement methods	apparatus
pH	Precise pH instrument	handy Precise pH instrument(AZ8601)
DO	Water analysis apparatus	multiparameter Water analysis apparatus(WTW Multi 340i, Germany)
TP	Ammonium molybdate spectrophotometric	UV rays visible spectrophotometer UV-3200(meipuda, Shanghai)
TN	Alkaline potassium persulfate method	UV rays visible spectrophotometer UV-3200(meipuda, Shanghai)
NH_4^+-N	Pay reagent luminosity law	UV rays visible spectrophotometer UV-3200(meipuda, Shanghai)
COD_{cr}	Potassium dichromate method	UV rays visible spectrophotometer UV-3200(meipuda,Shanghai)

Table 2 the classification standards for water quality

Comprehensive water quality identification index					Water pollution index	
Comprehensive water quality assessment standard		qualitatively assessment standard				
classification	X_1. X_2	$X_2 \neq 0$	$X_2=0$	conclusion	classification	WPI
I	(1.0, 2.0]	f- $X_1 \geqslant 1$	f- X_1-1$\geqslant$1	excellent	I	$\leqslant$20
II	(2.0, 3.0]	$X_1=f$	X_1-1=f	favorable	II	20-40
III	(3.0, 4.0]	X_1-f=1	X_1-f-1=1	Slightly pollution	III	40-60
IV	(4.0, 5.0]	X_1-f=2	X_1-f-1=2	Moderately pollution	IV	60-80
V	(5.0, 6.0]	X_1-$f \geqslant 3$	X_1-f-1$\geqslant$3	Heavily pollution	V	80-100
Inferior V	(6.0, 7.0]				Inferior V	>100
Inferior V,malodorous black	>7.0					

monitoring value, thus obtaining the value of X_1. X_2 is the location of water quality within the variation range of Class X_1, so as to evaluate the water quality that in the same Class more specifically. $X_1.X_2$ can be calculated as follows:

(1)If the classification of water quality is between class I and class V according to GB383-2002,as to each variable except DO,

$$(X_1.\ X_2)_i=j+(C_i-C_{ij-1})/(C_{ij}-C_{ij-1}) \quad (8)$$

As to DO,

$$(X_1.\ X_2)_i=j+(C_{ij}-C_i)/(C_{ij}-C_{ij-1}) \quad (9)$$

(2) If the classification of water quality is inferior to class V according to GB3838 -2002, as to each variable except DO,

$$(X_1.\ X_2)_i=6+(C_i-C_{i5})/C_{i5} \quad (10)$$

As to DO,

$$(X_1.\ X_2)_i=6+(C_{i5}-C_i)/C_{i5} \quad (11)$$

where C_i is the measured value of parameter i, C_{ij} is the standard value of parameter i for class j, and $(X_1.\ X_2)_i$ is the single-factor water quality identification index of j =1,2,3,4,and 5 for classes I, II, III, IV,and V, respectively.

Finally, calculate the comprehensive water quality index $X_1.X_2$, The weight distribution of each single-factor water quality identification index influences the comprehensive water quality index, affecting the results and the accuracy of the assessment. Through improving and comparing methods previously used, the following three methods are initially selected [8].

$$\text{(A)} \quad X_1.X_2=\frac{1}{n}\sum_{i=1}^{n}(X_1.X_2)_i \quad (12)$$

Where n is the number of the single-factor water quality identification index.

$$\text{(B)} \quad X_1.X_2=\frac{1}{2}((X_1.X_2)_a+(X_1.X_2)_{\max}) \quad (13)$$

$$(X_1.X_2)_a=\frac{1}{n}\sum_{i=1}^{n}(X_1.X_2)_i \quad (14)$$

$$\text{(C)} \quad X_1.X_2=\frac{1}{m+1}(\sum_{i=1}^{m}(X_1.X_2)_i+\frac{1}{n-m}\sum_{j=1}^{n-m}(X_1.X_2)_j) \quad (15)$$

where m is the total number of parameters that are inferior to the water quality standard for the region, and absolutely n-m is the total number of the rest parameters.

I. X_3 is the total number of parameters that do not meet the water quality standard for the region.

II. X_4 is used to identify whether the comprehensive water quality classification is inferior to the desired water quality standard for the region, usually is one or two significant digits. There are three kinds of situations:

(1) If the comprehensive water quality is inferior to the desired water quality standard and $X_2 \neq 0$

$$X_4=X_1-f \quad (16)$$

(2) If the comprehensive water quality is inferior to the desired water quality standard and X_2 =0

$$X_4=X_1-f-1 \quad (17)$$

(3) If the comprehensive water quality is superior or equal to the desired water quality standard

$$X_4=0 \quad (18)$$

where f is the desired water quality standard for the region.

3. Results and discussion

The assessment results determined using the water pollution index method showed that the water quality of all the five monitoring sites were inferior V(Table 3), the main contamination was COD in both the five monitoring sites because of high WPI (COD) which ranged from 176.8 to 244.2 as presented in fig.2. TN was another main conta-

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mination of the Nanhai Lake, varied from 109.6 to 153.4 over the year. Owing to more domestic sewage and industrial wastewater from surrounding residents and industry branches directly discharged into the Nanhai Lake[10,11].

From the time point of view, the degree of pollution of NH_4^+-N in wet season was slightly higher.This perhaps results from the rainfall in Aug. and Sep., and the pollution of agricultural area and other nonpoint source pollutants washed into the water body under the action of the rain[12]. However, the pollution of TN, TP and DO were higher in dry season because of the high demand for nitrogen and phosphorus in wet season, the high growth period of aquatic plants, the nutrient elements and DO are fully utilized, and the water was purified to some extends.

The comprehensive water quality index X_1. X_2 was calculated as listed in table3 in three methods. It is observed that X_1. X_2 calculated by method1 was smallest because of the same weight of all the parameters. Calculated by method2 was biggest due to the too much emphasis on parameters inferior to the water quality standard.So the method3 was selected to determine the comprehensive water quality index, but if all the parameters were inferior to the water quality standard, select the method 1 instead.

The comprehensive water quality identification index showed that the water quality of the Nanhai Lake were classes V, except for the N_2 in wet season and dry season , the N_1 in dry season and the N_5 in normal season, which were classes inferior V. The five monitoring sites were't achieving the desired water quality standard. But single-factor index of some parameters reached, so the standard achieving rate of each monitoring sites in each flow season and the comprehensive standard achieving rate of the Nanhai Lake in each flow season were calculated, it's easy to find that the comprehensive standard achieving rate of normal season>wet season>dry season. In wet season, the Yellow river replenishing water to Nanhai Lake,contaminations were diluted and the water quality was better than dry season[10], but the rainfall in wet season made pollutants washed into the water body result in the water quality worse than normal season. In addition, qualitatively assessment of water quality was basically consistent with the quantitatively assessment.

It is clear that the domestic discharge, industrial activities and developed recreation were major threats to water quality of Nanhai Lake. It's essential to take some measures to protect the Nanhai Lake from domestic sewage, industrial wastewater and solid waste from tourists. In addition, plants can consume nitrogen, phosphorus and organic matter, result in the water quality improved, so rehabilitate of wetlands is a vital measures.

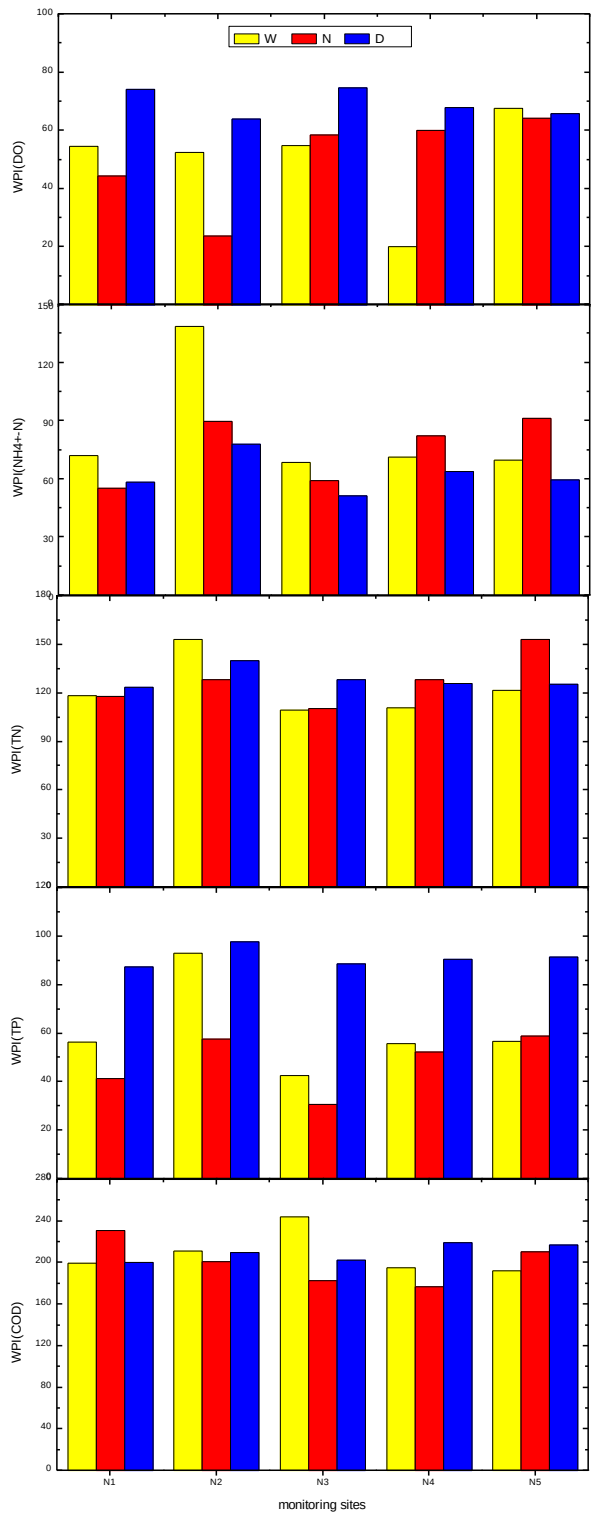

Figure 2. The WPI values of DO, NH_4^+-N, TN, TP and CODcr

4. Conclusions

(1) COD and TN were the main contaminations of the Nanhai Lake, result from domestic discharge, industrial activities and developed recreation.

(2)The water quality classes of the five monitoring sites of the Nanhai Lake were inferior Vbut not malodorous and black, neither of them achieved the desired water quality standard. Single-factor index of some parameters reached, the comprehensive standard achieving rate of normal season>wet season>dry season.

(3) Water pollution index method is simply calculated but can't assesses the water quality inferior V specifically. Comprehensive water quality identification index method can be applied to judge whether the water quality meets environmental water functions and suitable for assessment of the overall water quality when the water is seriously polluted.

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Table 3 Water quality assessment results comparing the two assessment methods

flow seasons	monitoring sites	desired water quality classes	Comprehensive water quality identification index												Water pollution index method		
			$(X_1.X_2)_i$					$X_1.X_2$			I_{wq}	Water quality classes	Standard achieving rates (%)	qualitatively assessment	WPI	Water quality classes	main pollution parameter
			DO	NH_4^+-N	TN	TP	COD_{cr}	Method 1	Method 2	Method 3							
W	N_1	IV	3.7	4.6	6.5	3.8	8.5	5.4	6.9	5.8	5.831	V	40	Slightly polluted	199.3	Inferior V	COD
	N_2	IV	3.6	7.0	7.3	5.6	8.8	6.5	7.6	6.5	6.542	Inferior V	20	Moderately polluted	211.6	Inferior V	COD
	N_3	IV	3.7	4.4	6.2	3.1	9.6	5.4	7.5	5.9	5.931	V	40	Slightly polluted	244.1	Inferior V	COD
	N_4	IV	1.0	4.6	6.3	3.8	8.4	4.8	6.6	5.4	5.431	V	40	Slightly polluted	195.4	Inferior V	COD
	N_5	IV	4.4	4.5	6.5	3.8	8.3	5.5	6.9	5.5	5.541	V	20	Slightly polluted	192.5	Inferior V	COD
N	N_1	IV	3.2	3.8	6.5	3.1	9.3	5.2	7.2	6.4	6.422	Inferior V	60	Moderately polluted	230.8	Inferior V	COD
	N_2	IV	2.2	5.5	6.7	3.9	8.5	5.4	6.9	5.9	5.931	V	40	Slightly polluted	201.2	Inferior V	COD
	N_3	IV	3.9	3.9	6.3	2.5	8.1	4.9	6.5	5.9	5.921	V	60	Slightly polluted	182.8	Inferior V	COD
	N_4	IV	4.0	5.1	6.7	3.6	7.9	5.5	6.7	5.9	5.931	V	40	Slightly polluted	176.8	Inferior V	COD
	N_5	IV	4.2	5.6	7.3	3.9	8.8	6.0	7.4	6.0	6.041	Inferior V	20	Slightly polluted	210.4	Inferior V	COD
D	N_1	IV	4.7	3.9	6.6	5.4	8.5	5.8	7.2	5.8	5.841	V	20	Slightly polluted	200.4	Inferior V	COD
	N_2	IV	4.2	4.9	7.0	5.9	8.8	6.1	7.4	5.1	6.152	Inferior V	0	Moderately polluted	210.1	Inferior V	COD
	N_3	IV	4.7	3.6	6.7	5.4	8.6	5.8	7.2	5.8	5.841	V	20	Slightly polluted	202.8	Inferior V	COD
	N_4	IV	4.4	4.2	6.7	5.5	9.0	5.9	7.5	5.0	5.951	V	0	Slightly polluted	219.4	Inferior V	COD
	N_5	IV	4.3	4.0	6.6	5.6	8.9	5.9	7.4	5.9	5.941	V	20	Slightly polluted	217.0	Inferior V	COD