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Environmental monitoring and assessment of the water bodies of a pre-construction urban wetland

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Abstract It is planned that the Dayanghan Wetland in China will be transformed into a national park but little is known about its current water quality and pollution status. Thus, we monitored the physical and chemical characteristics of the Dayanghan Wetland, which showed that the water quality was generally good. However, the chemical oxygen demand was more than double the reference value, which may be attributable to previous tillage for vegetable crops and other farmlands. In addition, nickel and chromium caused low-level pollution in the water bodies of the Dayanghan Wetland. The mean trophic level index and nutrient quality index were 39.1 and 2.69, respectively. Both indices suggest that the water bodies of the Dayanghan Wetland are in a mesotrophic state and that no eutrophication has occurred. The study would provide a precise report on the status of environmental quality of the water bodies of a typical pre-construction wetland for the administration and decision of the local government and the planning agent.

Keywords Dayanghan Wetland · Environmental monitoring · Eutrophication · Heavy metal · Pollution assessment

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Introduction

Urban wetlands are complex social-economic-natural ecosystems, which are known to provide many valuable ecological benefits such as water purification, flood control, and local microclimate adjustment, as well as scenery creation and cultural heritage. Both natural and constructed wetlands are economic systems for treating wastewater. Wetland plants may assist with the removal of chemicals by biological adsorption, decomposition, transformation, and stabilization, and wetland microorganisms can decompose any organic matter present in the water (Vesk et al. 1999; Wang et al. 2009). For example, the culture of common water hyacinth (*Eichhornia crassipes*) in a pond that received urban run-off in Sydney, Australia, was shown to stabilize certain heavy metals. In particular, iron was present at high levels on the root surfaces but the levels decreased centripetally across the root and were higher in the cell walls than within cells. Trace metals (copper, zinc, and lead) were not localized on the root surface (Vesk et al. 1999). In addition, it has been reported that changes in land use and agricultural intensification caused wetlands on the quaternary aquifer of Vitoria-Gasteiz to disappear some years ago, and the nitrate concentration in the groundwater increased very rapidly. However, restoration of the Zurbano Wetland allowed the recovery of its biogeochemical function, which reduced the nitrate concentration in water. The nitrate concentration exceeded 50 mg/L in the groundwater entering the wetland, whereas the level was <10 mg/L at the outlet (Garcia et al. 2003). Constructed wetlands are now used widely as tertiary treatment systems for urban storm water. Wetlands have major advantages compared with other forms of treatment because they remove dissolved organic compounds and heavy metals, as well as other pollutants (Singh et al. 2011).

At present, many projects are focused on wetland research. Jia et al. (2011) proposed a wetland for the Beijing central region based on the following main criteria: the appropriate locations of urban wetlands, calculation of the urban wetland areas, determination of the spatial distributions of urban wetlands, and a method for estimating the ecological water requirements. They classified urban wetlands as flood control wetlands, water purification wetlands, and cultural or scenic wetlands. Zhou et al. (2010) mapped and monitored changes in land cover in an urban wetland using high spatial resolution IKONOS images acquired during June 2003 and January 2006, which delivered 83.2 and 86.3 % of classification accuracy, respectively. Furthermore, some studies have begun to focus on the environmental quality and ecological status of urban wetland. For example, high cadmium and lead levels ($P \leq 0.0003$) were detected in crops of cocoyam (*Colocasia esculenta*) and sugarcane (*Saccharum officinarum*), which were cultivated in an urban wetland on the Uganda side of Lake Victoria (Mbabazi et al. 2010). The heavy metal levels of manganese, zinc, cadmium, and lead were also significantly higher in vegetables grown on the urban wetland soils compared with those in similar food crops grown in rural control sites, although only cadmium and lead exceeded the World Health Organization (WHO) maximum permissible levels (Kwetegyeka et al. 2010). In addition to water pollution, the composition of wetland plant species growing in modified wetland habitats has been addressed. For example, the species diversity increased after urbanization and subsequent beautification of the lakes in an aquatic ecosystem, whereas most of the naturally occurring aquatic species disappeared (Shital et al. 2009).

However, there have been few reports of the environmental background conditions in urban wetlands. Wu et al. (2012) analyzed the residues of hexachlorocyclohexane isomers (HCHs) and dichlorodiphenyltrichloroethane metabolites (DDTs) in the soils and sediments of Dayanghan Wetland in Wuhu, China, and found that beta-HCH, delta-HCH, and o,p′-DDT were dominant. However, no previous studies have focused on the water quality characteristics and pollution status before the construction of urban wetlands. Therefore, we selected Dayanghan Wetland as a case study. We investigated the water quality parameters of the wetland and assessed its pollution status.

Materials and methods

Study location

Dayanghan Wetland is located in the Yangtze River Delta, China (31° 22′ 209″ N, 118° 25′ 145″ E), whose details were shown in Wu et al. (2012). In influent, effluent, and central water sections of Dayanghan Wetland, each grid of 0.25 km^2 (0.5 km×0.25 km) was scaled out and its center was designed as the sampling location. Thus, we investigated 20 sampling points in the wetland before its transformation into an urban wetland park, as shown in Fig. 1.

Sample collection and analyses

In the Dayanghan Wetland, the water depth range was 3–5 m. On May 2011, three water samples were collected from each site at a water depth of 50 cm. The three samples from each site were mixed and divided into three representative samples, thereby yielding a total of 60 samples. These samples were placed immediately into boxes, which were maintained at 5 °C using liquid nitrogen and transported to the laboratory for analysis.

The samples were measured to determine their physical indices, including the water temperature, suspended solids (SS), turbidity, chrominance, and dissolved oxygen (DO) using a thermometer, electronic balance, photoelectric turbidimeter, the platinum-cobalt method, and a DO analyzer, respectively. Chemical indices, i.e., the chemical oxygen demand (COD) using $KMnO_4$ (COD_{Mn}), biochemical oxygen demand at 5 days (BOD_5), pH, metal element contents (K, Na, Ca, Mg, Fe, Zn, Mn, Cu, and Mo), F^-, S^{2-}, Cl^-, SO_4^{2-}, CO_3^{2-} (HCO_3^-), and B were determined using the potassium dichromate method, dilution and inoculation, an acidimeter, flame atomic adsorption spectrophotometry, an ion-selective electrode, methylene blue spectrophotometry, nitrate radical titration method, ion-exchange chromatography, titration, and spectrophotometry, respectively.

Pollutants such as heavy metals (Ni, Pb, Cr, Cd, Hg, and Ti), As, Se, CN^-, and the total bacteria were determined by spectrophotometry, silver diethyldithiocarbamate spectrophotometry, atomic fluorescence spectrometry, flow injection spectrophotometry, and using plate

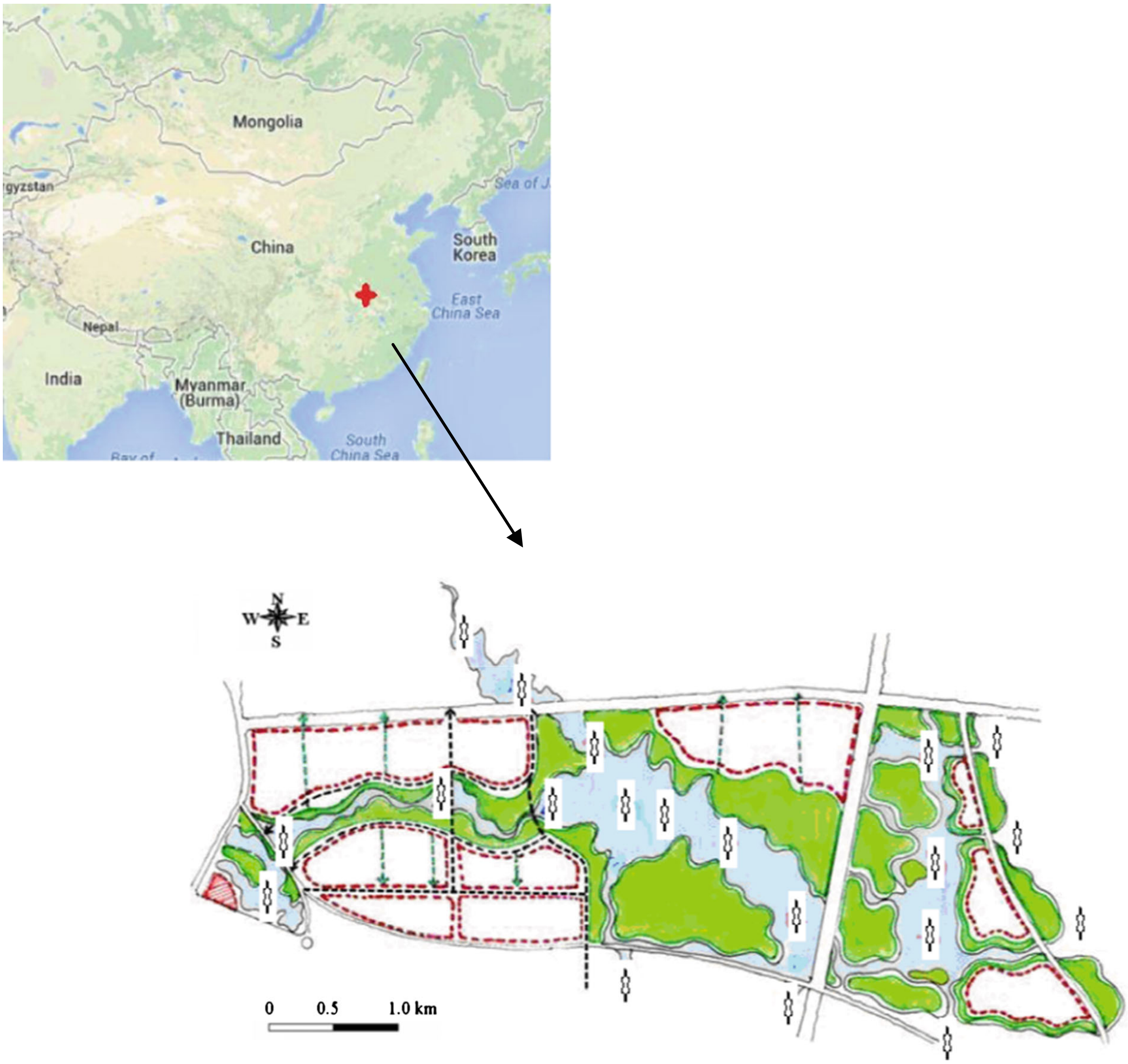

Fig 1 Water quality sampling sites ( ) in the Dayanghan Wetland

counts, respectively. Eutrophication indicators such as ammonia-nitrogen (NH_3–N), Kjeldahl nitrogen (K-N), nitrite (NO_2–N), nitrate (NO_3–N), total nitrogen (TN), soluble orthophosphate (S-OP), dissolved total phosphorus (D-TP), total phosphorus (TP), chlorophyll a (Chla), and total organic carbon (TOC) were analyzed by salicylic acid spectrophotometry, selenium catalytic mineralization, diazo-coupling reaction spectrophotography, UV spectrophotometry, alkaline potassium persulfate digestion UV spectrophotometry, Mo–Sb anti-spectrophotometry, molybdoantimonyl phosphoric acid photometry, ammonium molybdate spectrophotometry, spectrophotometry, and nondispersive infrared absorption spectrometry, respectively.

All of these methods in the determination of physical, chemical, and biological indictors, as well as in the quality assurance and the duplicates, are recommended by the Ministry of Environmental Protection of China (MEPC) (2002b).

Statistical analysis

Based on four standard parameters, i.e., Chla (mg/m^3), TP, TN, and COD_{Mn} (mg/L), the eutrophication status of

Table 1 Eutrophication category based on Carlson's method (1977)

Category	Eutrophication status	TLI (∑)	NQI	Qualitative assessment of nutrient pollution
I	Oligotrophic	TLI (∑)≤30	NQI<2	Clean
II	Mesotrophic	30<TLI (∑)≤50	2≤NQI<3	Normal
III	Light eutrophication	50<TLI (∑)≤60	3≤NQI<4	Light
IV	Medium eutrophication	60<TLI (∑)≤70	4≤NQI<5	Medium
V	Hyper eutrophication	70<TLI (∑)≤100	NQI≥5	Severe

TLI trophic level index, *NQI* nutrient quality index

the Dayanghan Wetland was assessed quantitatively using two indexes: the trophic level index (TLI) and nutrient quality index (NQI). TLI and NQI were calculated using the method of Carlson (1977). The eutrophication status was divided into five categories based on TLI (∑), as shown in Table 1. Statistical

Table 2 Physicochemical properties of the water system in the Dayanghan Wetland[a]

Property	Parameter	Detection frequency (%)	Concentration (mg/L)		Reference values		
			Mean	Range	China[b]	USA[c]	The Netherlands[d]
Physical	Water temperature	100	17.5 °C	14.5~19.1 °C	<1 to 2 °C[e]	–	25
	SS	100	65.1	40~90	–[g]	–	–
	Turbidity	100	4.459	2.93~6.92	–	–	–
	Chrominance	100	16.7	11.5~25	–	15	–
	DO	100	5.1	4.4~5.6	5~7.5	–	6
Chemical[f]	COD	100	42.76	30.62~67.73	15~20	–	–
	BOD_5	100	4.38	3.2~5.9	3~4	–	–
	pH	100	7.88	7.16~8.87	6~9	6.5~8.5	7~8.5
	K	100	4.68	2.59~8.54	–	–	–
	Na	100	26.26	21.75~30.71	–	–	90
	Ca	100	33.47	21.76~39.77	–	–	–
	Mg	100	11.78	10.56~14.64	–	0.05	–
	Fe	100	0.98	0.37~1.81	0.3	0.3	0.1
	Zn	100	0.016	0.001~0.031	0.05~1.0	5	0.2
	Mn	100	0.027	0.008~0.102	0.1	–	0.05
	Cu	30	0.001	nd~0.0065	0.01~1.0	1.3	0.02
	F^-	100	0.73	0.60~0.93	1.0	2	0.7
	S^{2-}	100	0.006	0.0022~0.01	0.05~0.2	–	–
	Cl^-	100	48.69	40.94~69.11	250	250	150
	SO_4^{2-}	100	37.06	17.88~46.37	250	250	100

[a] In Tables 2, 3, and 4, the quality assurance (QA) and the duplicates was conducted based on the referenced methods by the Ministry of Environmental Protection of China (MEPC) (2002b)

[b] Ministry of Environmental Protection of China (MEPC) (2002a)

[c] U. S. Environmental Protection Agency (1988)

[d] Dutch (2009)

[e] The variation range of water temperature=1~2 °C

[f] CO_3^{2-}, HCO_3^-, B, and Mo were not detected (nd)

[g] In Tables 2 and 3, "–" meant no reference value

Table 3 Chemical and nutritional pollution of the water system in the Dayanghan Wetland

Status	Parameter	Detection frequency (%)	Concentration (mg/L)		Reference values		
			Mean	Range	China[a]	USA[b]	The Netherlands[c]
Pollutants	Ni	100	0.0283	0.002~0.072	0.02	–	0.03
	Pb	60	0.0025	nd~0.011	0.01~0.05	0	0.030
	Cr	100	0.0613	0.023~0.093	0.01~0.05	0.1	0.020
	Cd	0	nd	–	0.001~0.005	0.005	0.001
	As	0	nd	–	0.05	0	0.010
	Hg	0	nd	–	0.00005~0.0001	0.002	0.0003
	Se	0	nd	–	0.01	0.05	0.01
	Ti	0	nd	–	0.1	–	–
	CN^-	0	nd	–	0.005~0.2	0.2	0.050
	Total bacteria	100	6.4 CFU/mL	2~14	200~10,000	–	–
Eutrophication	NH_3–N	100	3.724	2.122~7.531	–	–	0.2
	K-N	100	4.290	3.143~5.601	0.15~1	–	–
	NO_2–N	100	1.178	0.503~2.743	–	1	–
	NO_3–N	100	5.411	4.383~7.283	–	10	25
	TN	100	9.819	8.436~11.498	0.2–1	–	–
	S-OP	100	0.302	0.292~0.314	–	–	–
	D-TP	100	0.440	0.343~0.727	–	–	–
	TP	100	0.566	0.414~0.770	0.02–0.2	–	–
	Chla	100	0.243	0.120~0.323	–	–	–
	TOC	100	2,358.13	1,583.3~3,110	–	–	–

nd not detected, *CFU/mL* colony-forming units per milliliter

[a] Ministry of Environmental Protection of China (MEPC) (2002a)

[b] U. S. Environmental Protection Agency (1988)

[c] Dutch (2009)

comparisons were performed using an analysis of variance (ANOVA) at $P<0.05$ with Statistical Product and Service Solutions software (SPSS) 15.0. The results were expressed as the mean±standard error (SE).

Results and discussion

The water temperature varied greatly between the sampling sites, where the difference was 14.5–19.1 °C. Field

Table 4 Comparison of the nutrient pollution levels of the water system in the Dayanghan Wetland with those in other water bodies

Region (country)	Sampling year	TLI mean (range)	NQI mean (range)	Nutrient pollution status	Reference
Dayanghan Wetland (China)	2011	39.1 (35.2~45.5)	2.69 (2.0~5.2)	Mesotrophic	This study
Taihu Lake (China)	2008~2010	ND (51.3~55.6)	ND	Light eutrophication	Sun et al. 2013
Deepor Beel (India)	2009	>70.0 (ND)	ND	Medium eutrophication	Nibedita et al. 2009
Qinshan Lake (China)	2011	53 (ND)	ND	Light eutrophication	Zhang et al. 2011
Okaro Lake (New Zealand)	2010	ND (30~100)	ND	Hyper eutrophication to mesotrophic	Özkundakci et al. 2010

TLI trophic level index, *NQI* nutrient quality index, *ND* not determined observations indicated that the water bodies in Dayanghan Wetland were very clean and transparent. Furthermore, the SS, turbidity, and chrominance values were low. DO and BOD_5 were similar to the reference values from the governmental websites (Table 2). However, COD was more than double the reference value, which indicated reducing conditions. The COD of the Dayanghan Wetland indicated that the water bodies contained reducing compounds, so it could be polluted by herbicides, pesticides, fertilizers from farmland and vegetable plots, and sewage effluent from the factories around the lake. This agreed with the study reported by Wu et al. (2012), which detected residues of HCHs and DDT metabolites in the soils and sediments of the Dayanghan Wetland.

Overall, the results (Table 2) indicated a good physical water environment. The pH 7.16–8.87 was within the normal range. The values of Ca^{2+} and Mg^{2+} suggested a reasonable level of hardness so the water may be considered as a possible alternative drinking water resource. The macro-elements, K, Na, Fe, Cl^{-}, and SO_4^{2-}, and the trace elements, Mn and Zn, were present at low values, which were consistent with the background values from the geological records. The levels of CO_3^{2-}, HCO_3^{-}, B, and Mo were below the detection limits. The detection frequency of Cu was low (30 %), but the concentration was very low and it matched the water quality requirement for the wetland. Therefore, all of the physicochemical properties satisfied the environmental guidelines for China, the USA, and the Netherlands (Table 2).

Among the heavy metals, Ni and Cr were the dominant pollutants. In a study of the soils in Dayanghan metropolitan wetland park, Wang et al. (2013) discovered that the contents of Zn, Pb, Cd, Ni, and Cr (mean 88.45, 49.06, 0.82, 37.13, and 85.46 $mg \cdot kg^{-1}$, respectively) exceeded their background levels (67.64, 39.53, 0.12, 35.15, and 72.53 $mg \cdot kg^{-1}$, respectively), where the levels of Pb and Cd were 40 and 173 % higher than the reference values in China, respectively. In our study, Pb was present in the wetland water, but its detection frequency was very low and its concentration met the wetland water quality requirements. Other pollutants such as Cd, As, Hg, Se, Ti, and CN^{-} were below the detection limits. Bacteria were detected at all sampling sites, but the counts were normal. The non-metal pollutants mainly comprised nutrient nitrogen and phosphorus. The Chla content of 0.243 mg/L suggested that there was low water productivity and no possibility of harmful algal blooms. However, all of the nitrogen and phosphorus indices had high values, which far exceeded the reference values. This indicated that there is a high risk of water eutrophication in the Dayanghan Wetland (Table 3).

Many of the parameters linked to eutrophication were several times higher than the reference levels, but the water bodies in the Dayanghan Wetland exhibited no signs of eutrophication. The meanings of TLI and NQI values were similar, and they showed that the water environment of the Dayanghan Wetland was in a mesotrophic state (Table 1). It implied that the nutrient pollutants would not cause eutrophication and the subsequent harmful algal bloom in the aquatic ecosystem of Dayanghan Wetland. The trophic levels of other water bodies have been assessed efficiently and accurately using the same analytical method. For example, Taihu, Qinshan, and Okaro lakes exhibited the potential for eutrophication in previous studies. In particular, Okaro Lake exhibited severe eutrophication, which depended on the sampling location (Table 4).

Conclusions

Based on the field investigation, physicochemical property and nutrient status of the water system of Dayanghan Wetland were assessed. At present, the physical characteristics stayed in a good condition. Similarly, most chemical indicators showed a normal status. But, chemical oxygen demand was more than double the reference value, which implied a strong reductive environment. In addition, only Ni and Cr caused low-level pollution in the water bodies of the Dayanghan Wetland. Furthermore, the mean trophic level index and nutrient quality index were 39.1 and 2.69, respectively. Both indices suggest that the water bodies of the Dayanghan Wetland are in a mesotrophic state and that no eutrophication has occurred. The study would provide a precise report on water environmental quality of a typical pre-construction wetland for the administration and decision of the local government and the planning agent. So, it is necessary to remove these reductive pollutants and two heavy metals abovementioned in the future. If the polluted water environment was restored, it was adaptive for Dayanghan Wetland to transform into an urban wetland park.

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