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Relationship between phytoplankton and environmental factors in landscape water supplemented with reclaimed water

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ABSTRACT

The water quality of Feng-qing Lake, which is a landscape lake supplemented with reclaimed water, was surveyed to investigate the relationship between phytoplankton and environmental variables. A total of 29 water samples were collected to analyze temporal variations of phytoplankton and environmental factors from July 2013 to June 2014. Six phyla and 39 genera of phytoplankton were identified when the lake was supplied with reclaimed water. Among these, Cyanophyta and Chlorophyta account for 38.46% and 30.77% of phytoplankton, respectively. The dominant species in the lake are *Pseudanabaena limnetica* and *Chlorella vulgaris*, which are present the entire year. Other leading species include *Cosmarium* sp. and *Raphidiopsis curvata*. Principal component analysis (PCA) was conducted to analyze the relationship among environmental factors. Canonical correspondence analysis (CCA) was performed to investigate the relationship between environment factors and dominant species. The PCA result showed that temperature (T), total phosphorus (TP), total nitrogen (TN), transparency, and dissolved oxygen are the main factors that affect the eutrophication level of the lake. The CCA result revealed that TN, PO_4^{3-}–P, chemical oxygen demand (COD), T, and chlorophyll a exhibit a close relation with dominant species. In particular, TN, salinity, and COD influence the growth of *P. limnetica*; T and COD influence the growth of *R. curvata*; and T, PO_4^{3-}–P, NH_3–N, and pH influence the growth of *C. vulgaris* and *Cosmarium* sp.

1. Introduction

Urban rivers and lakes play important roles in landscaping and local weather modification. Xi'an, the capital of Shaanxi province, located in northwestern China, has a population of 843 million at the end of 2009. The increasing population and changing climatic conditions have made the urban district of the city very often extremely hot in recent years. Thus, the government of Xi'an has released a 571028 Plan in 2012 that will make 28 artificial lakes in the urban district to improve ecological conditions and alleviate the heat island effect in the metropolitan area of Xi'an. To realize its normal scenic environment function, landscape water requires an adequate and reliable water supply.

Water scarcity in China is becoming increasingly severe (Jiang, 2009). China is among the 13 countries in the world with the lowest water availability, and the per capita water availability of China is about a quarter of the world average (Yi et al., 2011). Moreover, a majority of the available water is concentrated in the south, leaving the northern and western China to experience perpetual droughts. Xi'an, being a semi-arid city, has an estimated total water resource availability of 24.22 hundred million cubic meters per year. Although Xi'an is facing severe water shortage, the city is also being planned to be developed into the third international metropolis of China by 2020. By then, one of the dominant social and economic problems in rapid urbanization of Xi'an will be its population, which is estimated to be more than 1280 million. When huge population and high population density is considered, its average annual water availability per capita will decline greatly. Therefore, Xi'an will not be able to meet the water demand in the near future.

Wastewater reclamation and reuse have drawn increasing attention as integral components of water resource management to address the water resource crisis (Chu et al., 2004). Reclaimed water is widely used nowadays, resulting in a trend in which landscape lakes are supplemented with reclaimed water (Wei et al., 2011), such as the main lake of SOF Park in Beijing, China. As early as 2002, faced with water shortage, Xi'an has begun conveying and utilizing reclaimed wastewater in industrial cooling systems. However, the amount of reclaimed wastewater in industry is still very limited compared with the production capacity of 17.5×10^4 m^3/d in the

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Table 1
Water quality standard for scenic environment reuse of urban wastewater and the quality of reclaimed water in this study.

Water quality items of reclaimed water	BOD_5 (mg/L)	pH value	Residual chlorine (mg/L)	DO (mg/L)	TP (mg/L)	TN (mg/L)	NH_3–N (mg/L)
Standard	6	6–9	0.05	2.0	0.5	15	5
Actual application	0.07–5.02	6.82–7.57	0.01–0.29	1.63–7.51	0.08–0.28	4.58–27.41	0.21–17.18

The People's Republic of China State Administration of Quality Supervision Inspection and Quarantine (2002).

centralized location of Xi'an. To expand the market of reclaimed wastewater, the potential users, ornamental lakes in public parks, were selected for replenishment with recycled water according to the Wastewater Reclamation and Reuse Plan during the Twelfth Five-Year Period (2011–2015) of Xi'an. Given that the scenic environment water are scattered across the entire city, the necessary pipeline networks for reclaimed water distribution, approximately 55 km, have been finished. Our research site, Feng-qing Lake, is one of the demonstration projects in Xi'an and is replenished with reclaimed wastewater from Qingyuan Wastewater Treatment and Reuse Ltd. Co. through a pipeline of 8 km.

However, the safety of reclaimed water has become a source of dispute since the beginning of wastewater reuse because various toxic chemicals and nutrient elements remain in wastewater even after traditional reclamation treatment processes. These chemicals cannot be completely eliminated, and they can accumulate and pose potential risk to human health and the ecological system (Asano et al., 2007; Wang et al., 2014; Rizzo et al., 2013). Furthermore, a high concentration of nutrients in reclaimed water can cause eutrophication because most urban lakes are shallow with low-velocity water flow. For example, previous researchers found that landscape water supplemented with reclaimed water faces a high risk of algal bloom during summer through simulation experiments (Li et al., 2011). Some investigators also found that the dominant alga phyla in eutrophicated lakes supplemented with reclaimed water are Cyanophyta and Chlorophyta (Li et al., 2005). Currently, knowledge on reclaimed water reuse in scenic environment is still insufficient.

New technologies in multivariate environmental studies have been reported in recent years. Environmental flow diagram (EFD) is a user-friendly software that can be used in all industrial companies and civil and energy projects for gathering detailed knowledge of pollution level of an area to solve environmental crises (Valipour et al., 2012a,b). EFD is a necessary and useful multivariate statistical technique for the evaluation and interpretation of data with a view to obtain better information about the water quality (Valipour et al., 2013). Principal component analysis (PCA), one of the multivariate methods, is often used to obtain a few independent variables that can explain most of the variance from the original variables (Jagadamma et al., 2008; Qiu et al., 2010). Another analysis technique is canonical correspondence analysis (CCA), which is a direct gradient analysis technique and always used in aquatic ecological studies (Çelekli et al., 2014).

In the present study, an urban landscape lake supplemented with reclaimed water was selected to investigate the relationship between environmental factors and phytoplankton community structure. Water quality and phytoplankton communities were continuously monitored for a year. PCA and CCA were conducted to analyze the relationships among environmental factors as well as between environmental factors and dominant species, respectively.

2. Materials and methods

2.1. Landscape water and reclaimed water

The landscape water selected for this study was Feng-qing Lake, an artificial lake with an area of 38,000 m^2 and an average water depth of 1.0 m. The lake is located in Feng-qing Park, Xi'an City, China. This lake is an ideal site for recreation and sightseeing. The volume of water in the lake is approximately 38,000 m^3, which is provided by a reclaimed water pipeline from a wastewater reclamation treatment plant in Xi'an. The quality of the reclaimed water is presented in Table 1, and the total volume of reclaimed water provided to the lake was 41,643 m^3 for one year during this study.

2.2. Sampling methods

The samples were collected using a water sampler (1000 mL) at a depth of 0.5 m around the lake. Four sites (Fig. 1) were chosen for each sampling from July 2013 to June 2014, in accordance with the Standard Methods for Observation and Analysis in Lake Eutrophication (Jin and Tu, 1990). The samples were collected five times a month in summer (July, August, and September), twice a month in spring and autumn (October, November, April, May, and June), and once a month in winter (December, January, February, and March). All samples were collected at approximately 11:00 AM to 11:30 AM.

The physicochemical characteristics of surface water, including water temperature (T), dissolved oxygen (DO), pH value, and transparency (Secchi disk clarity, SD), were measured in situ using a DO meter (HI9146, HANNA in China, Italy), a portable pH meter (PH-HJ90 MODELB, Aerospace Computer Company, China), and a Secchi disk (diameter: 20 cm). Phytoplankton samples were immediately preserved in Lugol's iodine solution and concentrated to approximately 50 mL. Then, the phytoplankton samples were kept for further taxonomic analysis and counting under a microscope (ECLIPSE 90i, Nikon, Japan) in the laboratory. Meanwhile, a water sample of approximately 2 L was kept in a cool and dark environment was and then transferred to the laboratory to measure the concentrations of nutrients and organic matter.

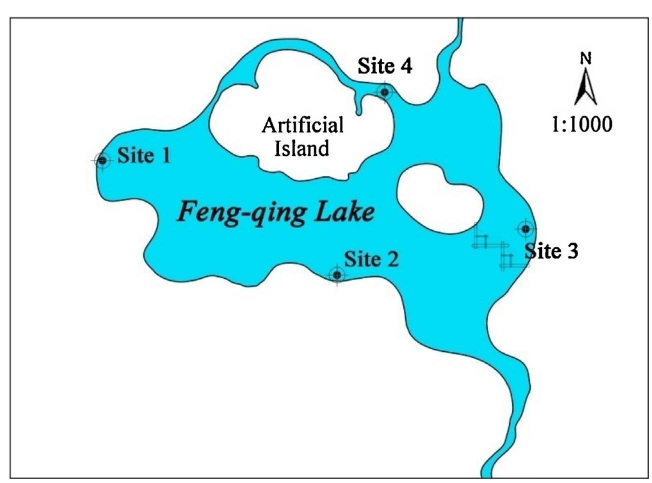

Fig. 1. Four sampling sites around Feng-qing Lake. Water sample was collected simultaneously from four sites around Feng-qing Lake and mixed together as the final sample for measurement.