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Research paper

The establishment of season-specific eutrophication assessment standards for a water-supply reservoir located in Northeast China based on chlorophyll-a levels

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ABSTRACT

Eutrophication has become the primary problem facing most surface water bodies worldwide, especially when the water body serves as a water supply source. Substantial efforts have been made to prevent and control eutrophication from decades ago. Among them, the establishment of eutrophication assessment standards was rather essential. However, until now, there is no authoritative standard established for the assessment of eutrophication level in developing countries such as in China. For water bodies located in the Northeast China, the level of chlorophyll-a (Chl-a), which is proportional to phytoplankton biomass, tends to be subjected to evident seasonal variations as the phytoplankton biomass and species composition are greatly impacted by the seasonally alternated climate, hydrology and pollutants source, which in turn complicated the eutrophication problem. The establishment of season-specific eutrophication assessment standards was thus extremely significant for water bodies located in regions with large air temperature variations. In this study, water quality parameters were detected over five consecutive years (2011–2015) to assess the seasonal trophic state of a water-supply reservoir located in Northeast China. Bivariate and multiple regression were performed between Chl-a and other water quality parameters in different seasons. The trophic state of each season was evaluated by the comprehensive trophic level index and the season-specific eutrophication assessment standards were established. The results showed that phosphorus was the predominant limiting nutrient of eutrophication and the Chl-a levels were seasonally different. The reservoir was generally in a light-eutrophic state. Mesotrophic assessment standards were established for spring, summer and autumn and light-eutrophic assessment standards for autumn based on the water quality data collected. As the predominant nutrient, the concentrations of total phosphorus for the mesotrophic state for spring, summer and autumn were 0.044, 0.028 and 0.038 mg/L, respectively. Moreover, as shown by the mesotrophic and light-eutrophic standards of the autumn, the discrepancy of different parameters between the standards of different trophic level was were not necessarily varied in the same trend. In conclusion, the establishment of season-specific eutrophication standards for water bodies located in regions with large air temperature variations was significant for scientific trophic state evaluation and effective eutrophication control.

1. Introduction

Eutrophication has become the primary problem facing most surface water bodies worldwide, especially when the water body serves as a water supply source (El-Otify, 2015; Huo et al., 2013; Park et al., 2015). Reservoirs play essential roles in many socioeconomic development aspects such as water supply, flood control, irrigation, electric power generation and tourism (Yan et al., 2016). In recent years, excessive nutrients were discharged into reservoirs along with the rapid development of industry and agriculture, which promoted the growth and reproduction of algae and resulted in eutrophication (Xu et al., 2012; Wang et al., 2013). The water quality of these eutrophic reservoirs thus greatly deteriorated and posed severe threats to the stability of the aquatic ecosystem and the human health (Noyma et al., 2016; Yang

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et al., 2016). According to a nationwide monitoring performed in 61 lakes/reservoirs of China in 2015, the proportions of the oligotrophic, mesotrophic, light-eutrophic and mid-eutrophic of these lakes/reservoirs were 9.8%, 67.2%, 19.7% and 3.3%, respectively (Ministry of Environmental Protection of the People's Republic of China, 2015). This indicated that if not properly regulated and controlled, there will be a great potential for these lakes and reservoirs becoming mid-eutrophic, high-eutrophic or even hypereutrophic and finally loss all of their ecological functions.

Primary production, especially that of phytoplankton, is used as a sensitive and accurate indicator for eutrophication assessment (Liu et al., 2010; Park et al., 2015). Chl-a has become the most popular estimator of phytoplankton biomass, because it was specific to algae and proportional to algal biomass even in the presence of non-algal organic and inorganic particles (Carlson, 2007). Rosa and Michelle (2007) pointed out that Chl-a was the best measure of an actual eutrophication problem and Carlson (1977) developed an index of trophic state based on Chl-a as the primary estimator of algal biomass. Thus, Chl-a level has become one of the most important parameters for eutrophication evaluation (Boyer et al., 2009; Carlson, 2007; Matsushita et al., 2015; Park et al., 2015). Chl-a level is closely related to diverse environmental factors and thus the correlation investigations between Chl-a concentration and other water quality parameters could reflect the integrated effects of various factors influencing eutrophication.

A great deal of researches has been performed to investigate the impacts of various water chemistry factors on phytoplankton growth through the detection of Chl-a concentration. Cao et al. (2011) investigated the impacts of light intensity (LI) on algal growth through the detection of Chl-a levels. Wang et al. (2013) reported the influence of residence time on the algae blooms based on the monitoring of Chl-a concentration in the Yanghe Reservoir. The research performed on Little Vermilion Bay, Louisiana demonstrated that both nitrogen and phosphorus were found to have strong relationships with phytoplankton growth as the Chl-a concentrations were found to be strongly dependent on total nitrogen (TN) and total phosphorus (TP) in the water column (Alam et al., 2016). In brief, the Chl-a level is related to a great number of hydrological, geochemical and ecological variables that impact phytoplankton growth (Park et al., 2015). Investigations on factors regulating the Chl-a level for a specific water body during a particular period are essential for illustrating eutrophication mechanisms and exploring its regulation and control strategies.

Substantial efforts have been made to prevent and control eutrophication from decades ago. Among them, the establishment of eutrophication assessment standards was rather essential. However, until now, there is no authoritative standard established for the assessment of eutrophication level in many developing courtiers such as in China. To the best of our knowledge, current standards for eutrophication assessment in China are listed as follows: (1) the eutrophication assessment standard based on TN and TP concentrations presented in the national enacted "Environmental Quality Standards for Surface Water (GB3838-2002)"; (2) the uniform national eutrophication assessment standards proposed by Jin Xiangchan based on data collected from 26 Chinese main lakes/reservoirs (Jin, 1995; Xu et al., 2012); (3) region-specific lake eutrophication assessment standards (Huo et al., 2013); (4) eutrophication assessment standards for individual lake or reservoir, such as Dianchi Lake, Tai Lake and Hulun Lake (Chuai et al., 2012). These standards may not be broadly representative for the trophic state evaluation and eutrophication control of all types of reservoirs. Meanwhile, relatively less attention was paid to the eutrophication of water bodies located in the northern region of China compared with that located in the southern region, while the latter ones were supposed to have greater eutrophication bloom potentials as the climate were more temperate. Also, there is no season-specific eutrophication assessment standard being established so far. It was suggested that chl-a level tended to be subjected to evident seasonal variations as the phytoplankton biomass and species composition are greatly impacted by the seasonally alternated climate, hydrology and pollutant sources (Elliott et al., 2016; Wu et al., 2013; Xu et al., 2013). Accordingly, for water bodies located in regions with large air temperature variations, the development of season-specific eutrophication assessment standards based on investigating factors closely related to eutrophication was essential to provide fundamental information for trophic state classification and eutrophication control.

In this study, Xinlicheng Reservoir, which serves as a drinking water source in Northeast China (E 125°19′–125°24′ and N 43°33′–45°41′), were selected as the study case. The water quality parameters, which involved water temperature (WT), pH, Secchi depth (SD), the concentration of dissolved oxygen (DO), TN, TP, permanganate index (PMI) and Chl-a, were detected over five consecutive years (2011–2015). Bivariate and multiple regression were performed between Chl-a concentration and other water quality parameters in different seasons to identify the key factors regulating eutrophication. Finally, the season-specific eutrophication assessment standards were established based on the data distribution attributed to different levels of trophic states. The objectives of this study are: (1) identify key factors correlated with the phytoplankton biomass in different seasons; (2) establish season-specific eutrophication assessment standards for better prevention and control of the eutrophication problem in Xinlicheng Reservoir, hoping to provide reference for water bodies located in regions with wide air temperature variations.

2. Materials and methods

2.1. Site description, sampling and measurement

Xinlicheng Reservoir is formed by intercepting the main stream of the Yitong River and serves as an important source of drinking water for Changchun City, Jilin Province, China with a daily water supply capability of 1.8×10^5 m^3. Its functions also include flood control, irrigation and fish-farming. The capacity of Xinlicheng Reservoir is 5.92×10^8 m^3, with a watershed of 1970 km^2 and an average depth of 7.6 m. The reservoir is located in a region with a typical north temperate continental monsoon climate, while the average daily temperature during 2011–2015 varied between −20–28 °C and the ice-cover period lasted for five months (from November to March). The average annual precipitation was around 600 mm, 68% of which was distributed in summer (from June to August). As required by GB3838-2002, the water quality parameters of Xinlicheng Reservoir should meet the Class III standard (i.e., average weekly increase of WT caused by human activity ≤ 1 °C and reduction ≤ 2 °C, pH = 6 ~ 9, DO ≥ 5 mg l^{-1}, TN ≤ 1.0 mg l^{-1}, TP ≤ 0.05 mg l^{-1} and PMI ≤6 mg l^{-1}).

The reservoir is mainly surrounded by farmland and forestry and the population in its 192 upstream rural towns is around 346000. The annual application amounts of nitrogenous fertilizer and phosphate fertilizer in the reservoir watershed were estimated around 6358.8 t and 1193.3 t (Bukebayier, 2009) and the loss of nitrogen and phosphorus by fertilizers became one of the principle sources of external nutrients input of the reservoir. Meanwhile, the majority of the rural towns were not installed with proper wastewater collection and treatment facilities, and thus the diffuse pollution caused by the random discharge of domestic wastewater and livestock manure also accelerated the development of eutrophication. During the flood period in 2007 and 2008, the overgrowth of cyanobacteria resulted in large-scale bloom outbreak and serious eutrophication problem, which posed great threat to the drinking water safety.

Monthly sampling campaigns were performed over five consecutive years (2011–2015). The sampling site was located at the water intake of Changchun City Water Supply Company (approximately N43°42′02″, E125°20′57, shown in Fig. 1) and the surface water (< 0.5 m depth) was collected. If the thickness of the ice cover was higher than 0.5 m, the water was sampled below 0.5 m of the ice cover after chiseling. The WT, pH and DO were measured onsite using a portable Multi-parameter

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