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Analysis of isotope tracing of domestic sewage sources in Taihu Lake—A case study of Meiliang Bay and Gonghu Bay

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ABSTRACT

Due to the difficulty of quantifying the temporal and spatial variations of the sewage sources of Taihu Lake, this paper collected water samples from Gonghu Bay and Meiliang Bay, in the northeast of Taihu Lake and from the inflow river of Wangyu River from January to December in 2012 and applied stable isotope techniques to trace the sources of the nitrogen pollutants. At the same time, a two-end-member mixing model of isotopes was used to determine the sources of domestic sewage. According to the results of nitrogen isotope values in the sampling points, the annual proportion of the sewage sources of the Meiliang Bay, Gonghu Bay and Wangyu River is 17.2%, 15.3% and 19.7%, respectively. More than 80% of the nitrogen pollution sources are from non-domestic sewage, which indicates that domestic sewage is not the primary source of nitrogen pollution in Taihu Lake. In addition, these three regions have demonstrated higher ratios of sewage sources during the winter season than during other seasons. Therefore, domestic sewage that flows into Taihu Lake during the winter season should be strictly limited. In the meantime, it is necessary to strengthen the treatment of nitrogen sources other than domestic sewage sources.

1. Introduction

Over the past 10 years, Taihu Lake has encountered frequent outbreaks of large-scale cyanobacteria blooms. The situation in the Meiliang Bay and Gonghu Bay, which are located in North Taihu Lake, is especially serious. Since the late 1990s, approximately 4–5 outbreaks of cyanobacteria blooms have occurred in these two regions every year (Yuwei Chen et al., 2003; Xiangming Tang et al., 2010). More specifically, the outbreaks during May and June of 2007 have seriously impacted the supply of water for more than 4 million people in Wuxi (Qinglong Wu et al., 2008). Meiliang Bay, which is located at North Taihu Lake, is one of the regions that suffers the most serious eutrophication events. The water quality of Gonghu Bay, which is close to Meiliang Bay, has also been severely affected. In addition, Gonghu Bay is the water source of two drinking water plants of Wuxi. Because Gonghu Bay relies on Wangyu River to direct water from the Yangtze River into the lake, Wangyu River could significantly affect the sources and concentrations of nitrogen and phosphorus pollutants (Chun Ye et al., 2007). With respect to these two regions, one suffers from serious outbreaks of cyanobacteria blooms and pollution events and the other functions as the water source for Wuxi with frequent water exchange. For the entire Taihu Lake, these two regions are highly representative.

A cyanobacteria bloom is one of the main consequences of water eutrophication. In most of the lakes, a cyanobacteria bloom is caused by an increase in the nitrogen and phosphorus nutrients. Based on earlier studies about the eutrophication of the water environment in Taihu Lake (Chun Ye et al., 2007; Boqiang Qin et al., 2007; Guangwei Zhu, 2008; Yiping Li et al., 2004; Yanyan Zhang, 2009), the average concentration of TN in Taihu Lake is approximately 2 mg/L, and the average concentration of TP is approximately 0.1 mg/L. According to China's "Environmental quality standards for surface water" (GB3838-2002), the concentration of TN shows that the water quality of Taihu Lake belongs to Grade V and even V-, and the concentration of TP shows that the water quality belongs to Grade III–IV. It can be observed that TN is the most significant pollutant in Taihu Lake, and its concentration is considerably higher than that of TP. At the same time, TN and TP are the direct cause of cyanobacteria blooms in Taihu Lake. Therefore, to control the process of cyanobacteria blooms and eutrophication in Taihu Lake, the primary task is to control the total amount of nitrogen nutrients (Jinqi Zhu and Hengli Xu, 2008); more specifically, the key is to control the pollution sources. In this regard, it is necessary to understand the contribution of various types of pollution sources to the total pollutants in Taihu Lake. Due to the high degree of dispersion and uncertainty of industrial wastewater,

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domestic sewage, agricultural non-point sources and aquaculture wastewater discharge, the contribution of nitrogen and other pollutants to Taihu Lake is difficult to measure accurately. Thus, the accurate determination of the primary sources of nitrogen has a significant meaning with respect to the control of water pollution and cyanobacteria blooms in Taihu Lake.

The conventional methods of nitrogen source identification are mainly statistical methods; specifically, the various types of wastewater and their respective percentages are estimated based on the large amount of data on pollutant concentrations and water flow. Because the discharge of pollutants is not uniform, the accuracy of these methods is quite low, and the workload is notably large. At the same time, these methods cannot reveal the annual variation and spatial variation of the pollution sources; thus, it is impossible to obtain comprehensive information on pollution sources. In 1971, Kohl et al. (Kohl et al., 1971) used ^{15}NN-NH_4^+ to evaluate the effect of farmland chemical fertilizers on the nitrate nitrogen in rivers. This study was the first time that ^{15}N was introduced to trace nitrogen sources in water, which generated a good solution to the problem above. Stable isotopes can provide a direct and effective means of nitrogen source identification based on the characteristic nitrogen isotope values of the different nitrogen pollution sources (Vinagre et al., 2011; Mora, 2008). In recent decades, scholars have applied nitrogen stable isotope technology to single or complex systems, such as plant, soil, groundwater and surface water, to conduct various nitrogen source identification studies. For example, Burns et al. (Johannsen et al., 2008) found that 82% to 100% of the nitrates in rivers of US northeastern forests are derived from soil nitrification. Johannsen et al. (Parnell et al., 2008) observed that the concentrations of nitrate δ^{15}N and δ^{18}O in the rivers are higher in summer than in winter, while the concentration of nitrate is higher in winter than in summer; this finding is probably related to the isotopic fractionation caused by high microbial activity and high absorption of aquatic plants in summer. Panno et al. (Panno et al., 2008) analyzed the sources and time variation of nitrate in the Illinois River. Li et al. (Siliang Li et al., 2010) found that the nitrates in the Yangtze River and its primary tributaries arise mainly from the nitrification of soil organic nitrogen and sewage. Mayer et al. (Bernhard et al., 2002) applied nitrogen stable isotope technology to study the nitrogen sources of 16 different water systems in the northeast of the US; their study showed that the correlation between the concentration of nitrate and the concentration of nitrate δ^{15}N can reveal the reason why the δ^{15}N value increases. All of these studies suggest that the nitrogen stable isotope technology has become an effective method to identify nitrogen sources in environmental pollution. Analysis of the nitrogen source contribution rates and the identification of nitrogen transformations in water bodies can provide a good clue for determining nitrogen sources and tracing the geochemical cycle of nitrogen. In turn, it can provide a decision-making basis for the effective control of nitrogen pollution.

In recent years, nitrogen stable isotope technology has been gradually applied in the pollution control of Taihu Lake. For example, Lin Lin et al. (Lin Lin et al., 2012) compared the $\delta^{15}NNH_{4+}$-N and $\delta^{15}NNO^-$-N values of the surface water samples of Taihu Lake with the nitrogen pollutant isotope values reported in the literature and found that the nitrogen sources of East Taihu Lake are primarily derived from aquaculture, and the nitrogen sources of the Meiliang Bay are primarily derived from domestic sewage; the nitrogen sources varied in different seasons, but their study did not clarify the specific sources for each season. Zeng Qingfei et al. (Qingfei Zeng et al., 2012) proposed that the $\delta^{15}N_{POM}$ value can be used as an effective indicator of nutrient salt differences to trace nitrogen sources, and the δ15 N value has a significant negative correlation with the concentrations of inorganic nitrogen and ammonium ions in the water body. Townsend-Small A et al. (Townsend-Small et al., 2007) proposed that rainfall is the main source of nitrogen in Taihu Lake in summer and domestic sewage is the main source of nitrogen in the lake regions near cities. At the same time, this study noted that future research should further quantify the amount of domestic sewage and other sources of emissions, to specify the temporal and spatial variation of the nitrogen sources in Taihu Lake. Chen et al. (Zixiang Chen et al., 2012) identified the nitrogen sources of Taihu Lake based on ^{15}N and ^{18}O and analyzed the biogeochemical cycling process of Taihu Lake. They suggested that domestic sewage and organic fertilizer are the main sources of nitrogen in North Taihu Lake, while soil organic nitrogen is probably the main source of nitrogen in East Taihu Lake. In summer, the nitrogen sources of the entire Taihu Lake are controlled by atmospheric deposition and domestic sewage/organic fertilizer, while microbial nitrification is the main source of nitrogen in winter. All of the abovementioned studies applied the nitrogen stable isotope technology to identify nitrogen sources in Taihu Lake. These studies have covered a variety of subjects, including the nitrogen sources of Taihu Lake in different seasons or regions, the reliability of using δ^{15}N to trace the nitrogen sources, and the effect of inlet rivers on the nitrogen sources of Taihu Lake. However, the studies did not classify the types of pollution sources reasonably and did not consider the transformation of nitrogen in the lake environment. As a consequence, the results appear to be inconsistent with respect to the nitrogen sources in different seasons and different regions, and the nitrogen contributions of the various pollution sources have not been quantified.

In view of the situation mentioned above, this study is based on earlier research outcomes and classifies pollution sources into wastewater from domestic sewage treatment plants, tail water from urban sewage treatment plants, agricultural wastewater, rain water and aquaculture wastewater and neglects the transformation of nitrogen in the lake environment. Then, the nitrogen isotope of TN is used to trace and determine the main sources of nitrogen in Taihu Lake. This study detected the TN concentration and the $\delta^{15}N_{TN}$ value in two representative regions of Taihu Lake, Meiliang Bay and Gonghu Bay, throughout the year 2012, and the isotope mixing model is applied to calculate the sources of nitrogen. Thus, the annual variation in the source of domestic sewage in Taihu Lake can be accurately quantified, and the nitrogen sources of the aforementioned two regions can be analyzed in detail.

2. Materials and methods

2.1. Sampling position

A total of 10 sampling points were established, including 2 points in the Meiliang Bay, ML1(31°27.210′ N, 120°10.194′ E) at the lake center and ML2(31°25.327′ N, 120°12.523′ E) at the lakeside, 4 points in the Gonghu Bay, GH4(31°20.090′ N, 120°15.905′ E) at the lake center; GH1(31°26.799′ N, 120°23.878′ E),GH2(31°26.918′ N, 120°19.388′ E) and GH3(31°24.068′ N, 120°13.685′ E) at the lakeside, 1 point near the inlet of the Wangyu River WY(31°26.125′ N, 120°21.466′ E), the sampling point at the agricultural pollution source (fertilizer) NY(31°24.217′ N, 120°11.761′ E) and a rainfall water sampling point YS(31°24.077′ N, 120°11.758′ E) (these two points are located in the Taihu Lake ecosystem research station of Chinese Academy of Sciences) as well as the inlet and tail water sampling point at the domestic sewage treatment plant WS (31°34.817′ N, 120°19.317′ E), located in a sewage treatment plant in the city of Wuxi. Sampling was conducted on September 10th and October 20th, 2013, respectively. Out of these 10 sampling points, the cyanobacteria bloom at ML1 is the most serious. Sampling points ML2, GH1, GH2 and GH3 are located at the lakeside, which is easily affected by human activities. Sampling point GH4 is located at the center of the Gonghu Bay, but the phenomenon of the