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Assessing river water quality using water quality index in Lake Taihu Basin, China

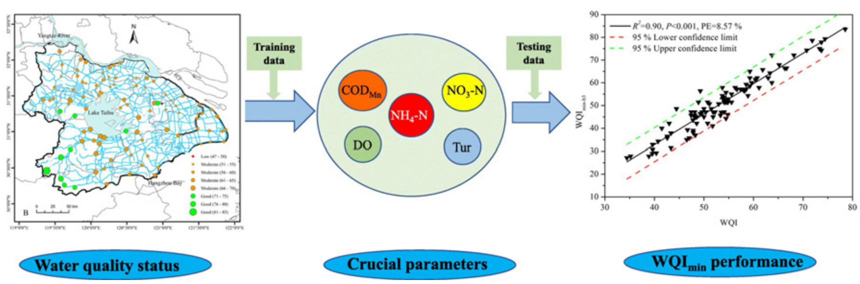
Zhaoshi Wu *, Xiaolong Wang, Yuwei Chen, Yongjiu Cai *, Jiancai Deng

State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, PR China

HIGHLIGHTS

- We assessed water quality and its spatial variations in rivers of Lake Taihu Basin.
- The water quality was considered as generally “moderate” in this basin.
- Significant difference was observed among the 6 river systems.
- NH_4-N, COD_{Mn}, NO_3-N, DO, and tur are the most effective water quality parameters.
- Weighs should be fully considered when using the minimum water quality index method.

GRAPHICAL ABSTRACT



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ABSTRACT

Lake Taihu Basin, one of the most developed regions in China, has received considerable attention due to its severe pollution. Our study provides a clear understanding of the water quality in the rivers of Lake Taihu Basin based on basin-scale monitoring and a water quality index (WQI) method. From September 2014 to January 2016, four samplings across four seasons were conducted at 96 sites along main rivers. Fifteen parameters, including water temperature, pH, dissolved oxygen (DO), conductivity, turbidity (tur), permanganate index (COD_{Mn}), total nitrogen, total phosphorus, ammonium (NH_4-N), nitrite, nitrate (NO_3-N), calcium, magnesium, chloride, and sulfate, were measured to calculate the WQI. The average WQI value during our study period was 59.33; consequently, the water quality was considered as generally “moderate”. Significant differences in WQI values were detected among the 6 river systems, with better water quality in the Tiaoxi and Nanhe systems. The water quality presented distinct seasonal variation, with the highest WQI values in autumn, followed by spring and summer, and the lowest values in winter. The minimum WQI (WQI_{min}), which was developed based on a stepwise linear regression analysis, consisted of five parameters: NH_4-N, COD_{Mn}, NO_3-N, DO, and tur. The model exhibited excellent performance in representing the water quality in Lake Taihu Basin, especially when weights were fully considered. Our results are beneficial for water quality management and could be used for rapid and low-cost water quality evaluation in Lake Taihu Basin. Additionally, we suggest that weights of environmental parameters should be fully considered in water quality assessments when using the WQI_{min} method.

1. Introduction

Adequate amounts of suitable quality water resources provide a precondition for economic development and ecological integrity. Numerous stresses influence water quality, such as natural processes

* Corresponding authors.
E-mail addresses: zswu@niglas.ac.cn (Z. Wu), wangxl@niglas.ac.cn (X. Wang), ywchen@niglas.ac.cn (Y. Chen), caiyj@niglas.ac.cn (Y. Cai), jcdeng@niglas.ac.cn (J. Deng).

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(e.g., weathering, precipitation, soil erosion, etc.), anthropogenic activities (e.g., agricultural, urban and industrial activities) and the increased utilization of water resources (Carpenter et al., 1998; Singh et al., 2005; Todd et al., 2012). Due to the multifaceted effects noted above, water quality deterioration has become a serious issue worldwide. Notably, freshwater resources may become scarce in the future, which would threaten water resource use, especially for drinking water and economic development (Cheng et al., 2009; Vorosmarty et al., 2010). According to a study conducted by the World Health Organization (WHO, 2008), approximately 1.1 billion people worldwide do not have access to a reliable source of drinking water. Rivers provide the main water resources for domestic, industrial, and irrigational purposes; however, they are easily polluted because of their critical roles in transporting municipal and industrial pollution and runoff from agricultural land (Singh et al., 2005). Because of their pivotal roles in ecological and human health and economic development, it is essential to prevent and control declining water quality in rivers. Therefore, reliable information regarding water quality variations must be collected for effective management; this has already been conducted in many countries and regions (Astel et al., 2006; Behmel et al., 2016; Romero et al., 2016). The highly heterogeneous water quality variations in rivers should be analyzed at a sufficient spatial scale using hydrochemical monitoring methods (Qadir et al., 2008; Singh et al., 2005). Additionally, water quality evaluation is important for pollution control and resource management. Specifically, the status and trends of water quality can be determined by evaluation, and water quality assessment is critical for identifying the major contributors to spatial and temporal variations in quality, which can benefit water resource management. Furthermore, based on information from assessments, the public is more likely to implement protective measure to improve the conditions of water bodies.

The water quality index (WQI) method has been widely used in water quality assessments of both groundwater and surface water, particularly rivers, and it has played an increasingly important role in water resource management (Debels et al., 2005; Lumb et al., 2011; Mohebbi et al., 2013; Sutadian et al., 2016). Using a method that combined the WQI method and geographic information systems, Sener et al. (2017) assessed spatial variations in water quality in the Aksu River, Turkey. Compared with traditional water quality evaluation, WQI methods combine multiple environmental parameters and effectively convert them into a single value reflecting the status of water quality. Thus, instead of comparing the different assessment results of various parameters, the WQI method is an effective approach to water quality assessment and management and provides integrated information regarding the overall quality.

A minimum WQI (WQI_{min}) is of great importance in light of simplification based on crucial environmental parameters that influence water quality. WQI_{min} results have been shown to be highly linearly correlated with those of the WQI (Akkoyunlu and Akiner, 2012; Sanchez et al., 2007), indicating that the WQI_{min} approach is powerful with respect to the rapid determination of WQI. With the use of limited parameters, WQI_{min} is particularly beneficial to decreasing the analytical cost of measuring a large number of environmental parameters, especially in developing countries. Generally, the parameters selected for WQI_{min} calculation should be representative of other environmental parameters and must be easily measured (Pesce and Wunderlin, 2000). In this context, the key parameters used for WQI_{min} calculation vary and depend on the characteristics of water bodies. For example, the use of the dissolved oxygen deficit was suggested for rapid determination of the WQI in watersheds of Las Rozas, Madrid (Spain) (Sanchez et al., 2007). Simoes et al. (2008) proposed a WQI_{min} method based on turbidity, total phosphorus and dissolved oxygen (DO) to evaluate degradation in the Medio Paranapanema Watershed, Sao Paulo State, Brazil. Another version of WQI_{min} was developed by Sun et al. (2016) based on the pH, temperature, total suspended solids, ammonium, and nitrate to evaluate the spatial and temporal variations in the water quality of the Dongjiang River, China.

A WQI_{min} based on the mean value of three parameters (turbidity, DO, and either conductivity or dissolved solids) after normalization was originally proposed by Pesce and Wunderlin (2000). The same calculation was adopted by Simoes et al. (2008). In later development, Kocer and Sevgili (2014) defined the calculation of WQI_{min} as being similar to WQI, while weights were partially considered. The use of weights in the calculation of WQI_{min} was also partially considered in recent studies (Avigliano and Schenone, 2016; Naveedullah et al., 2016). By contrast, consistency in the calculation of WQI and WQI_{min} has been observed in a limited number of studies (e.g., Zhao et al., 2013). Therefore, the performance of WQI_{min} with and without considering the weights of environmental parameters needs further evaluation.

Lake Taihu Basin, which is one of the most developed regions in China, has received considerable attention due to its economic role, as well as the severe pollution resulting from agricultural, urban and industrial activities in this area. Notably, Lake Taihu, the third largest freshwater lake in China, located in the center of the basin, experiences numerous ecological problems, especially eutrophication and cyanobacterial blooms (Chen et al., 2003; Paerl et al., 2011; Qin et al., 2007). Additionally, rivers, especially inflows, have an important influence on the water quality of the lake. Pollution control and natural resource management in Lake Taihu Basin represent notable challenges for the local government. As an issue of national concern, numerous studies in this basin have focused on physical, chemical (e.g., total nitrogen, total phosphorus, heavy metals, etc.), and biological (e.g., phytoplankton, benthic macroinvertebrates, etc.) parameters, as well as land use influences (Bian et al., 2016; Huang and Gao, 2017; Mu et al., 2015; Wu et al., 2011; Wu et al., 2016). Moreover, some studies have addressed the spatial variations in water quality in Lake Taihu Basin. For example, Li et al. (2013) assessed the surface water quality of the Tiaoxi River based on support vector machine classification models; however, the models could not analyze the water quality characteristics throughout the entire basin. Based on benthic macroinvertebrates, Wu et al. (2011) and Huang et al. (2015) assessed the ecological conditions in Lake Taihu Basin using different indexes; however, the accuracy of these assessments depended on the macroinvertebrate knowledge of professionals, and the methods were time consuming. Furthermore, evaluation results varied when single-factor or different biological indexes were applied (Li et al., 2013; Wu et al., 2011). Therefore, a study based on the whole basin and a more suitable method of water quality assessment are needed in this basin.

In this study, the WQI method was applied to assess the water quality and its spatial variations in rivers in Lake Taihu Basin. Our study was based on a data set of 15 parameters measured four times at 96 sampling sites that covered the entire basin. The primary objectives of this study were (1) to determine the water quality status and its spatial variation across the basin and (2) to explore the critical parameters in the development of a WQI_{min} method for simple and cost-effective water quality evaluation. We expect that the performance of WQI_{min} will improve with full consideration of parameter weights.

2. Material and methods

2.1. Study area

Lake Taihu Basin (30°7′19″–32°14′56″ N, 119°3′1″–121°54′ 26″ E) is located in the lower portion of the Yangtze River (Fig. 1) and encompasses a watershed area of 36,895 km^2. The basin covers parts of Jiangsu and Zhejiang Provinces and Shanghai municipality, which are highly developed and populated areas. The population and population density are 59.20 million and 1600 inhabitants km^{-2}, respectively. With 4.4% of the national population, Lake Taihu Basin contributed to 10.4% of China's gross domestic product (GDP) in 2012 (RMB 5418.8 billion) (Lake Taihu Basin Authority, 2012).

The total length of the rivers in Lake Taihu Basin is approximately 120,000 km. >200 rivers are distributed across the basin, and most of them connect to Lake Taihu. Generally, these rivers can be divided into