Available online at www.sciencedirect.com
ScienceDirect
Journal of Environmental Sciences 2013, 25(10) 2014–2022
JOURNAL OF ENVIRONMENTAL SCIENCES
ISSN 1001-0742
CN 11-2629/X
www.jesc.ac.cn

Establishing eutrophication assessment standards for four lake regions, China

Shouliang Huo[1,*], Chunzi Ma[1], Beidou Xi[1,*], Jing Su[1], Fengyu Zan[1,2], Danfeng Ji[1], Zhuoshi He[1]

1. State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Science, Beijing 100012, China
2. College of Environmental Science and Engineering, Anhui Normal University, Wuhu 241000, China

Received 12 December 2012; revised 28 January 2013; accepted 01 February 2013

Abstract

The trophic status assessment of lakes in different lake regions may provide important and fundamental information for lake trophic state classification and eutrophication control. In this study, a region-specific lake eutrophication assessment standard was established through a frequency distribution method based on chlorophyll-*a* concentration. The assessment standards under the oligotrophic state for lakes in the Eastern plain, Yungui Plateau, Northeast Plain and Mountain Mongolia-Xinjiang regions are total phosphorus of 0.068, 0.005, 0.011, 0.005 mg/L; total nitrogen of 1.00, 0.16, 0.37, 0.60 mg/L; Secchi depth of 0.60, 8.00, 1.55, 3.00 m; and COD_{Mn} of 2.24, 1.00, 5.11, 4.00 mg/L, respectively. Moreover, a region-specific comprehensive trophic level index was developed to provide an understandable assessment method for the public. The results indicated that the frequency distribution analysis based on chlorophyll-*a* combined with trophic level index provided a useful metric for the assessment of the lake trophic status. In addition, the difference of eutrophication assessment standards in different lake regions was analyzed, which suggested that the sensitivities of algae to nutrients and the assessment standard of trophic status possessed significant regional differences for the four lake ecoregions. Lake eutrophication assessment standards would contribute to maximizing the effectiveness of future management strategies, to control and minimize lake eutrophication problems.

Key words: lake trophic state; assessment standard; lake region; chlorophyll-*a*; comprehensive trophic level index
DOI: 10.1016/S1001-0742(12)60250-2

Introduction

Eutrophication has led to severe water quality problems in aquatic ecosystems throughout the world, including serious health problems in areas where lake water is used as drinking water supply (Paerl, 1988; Qin et al., 2010). The efforts to manage the negative effects of eutrophication have substantially widened from decades ago in China. For example, the Ministry of Environmental Protection of China issued Environmental Quality Standards for Surface Water (GB 3838-2002) to regulate the water quality of lakes and surface waters in early 2002. However, lake eutrophication and subsequent deterioration of water quality were still often reported (Du et al., 2011; Liu et al., 2011). Because some parts of the country have naturally high background concentrations and different precipitation regimes, the application of such a general consensus approach has to be adjusted by region (Gibson et al., 2000). Moreover, different regions can be characterized by various algal-nutrient relationships resulting from geographical diversity of catchments (climate, geology, and altitude) and lake factors (e.g. depth, area, water color, water chemistry, and hydrology) (Carvalho et al., 2008). Therefore, a regional lake eutrophication assessment standard is necessary to estimate eutrophication appropriately to each of the different geographical and climatological areas of the country.

Establishing a lake eutrophication assessment standard in different regions would help in setting target nutrient concentrations to reach desirable trophic states, which should be compatible with the various water uses. The eutrophication assessment standard can be compared with the observed concentrations in a certain aquatic system, assessing the corresponding trophic state. Moreover, it is possible to compare the values of the assessment standard with the actual concentrations and determine the required reduction in incoming nutrient loads (Cunha et al., 2012).

Chlorophyll-*a* (Chl-*a*) has become the most popular estimator of phytoplankton biomass, because it is specific to algae and can measure algal abundance even in the pres-

* Corresponding author. E-mail: huoshouliang@126.com (Shouliang Huo); xibeidou@263.net (Beidou Xi)

ence of non-algal organic and inorganic particles (Carlson, 2007). It is the best measure of an actual eutrophication problem (Rosa and Michelle, 2007). Carlson (1977) developed an index of trophic state based on chlorophyll as the primary estimator of algal biomass. The index itself is numerical rather than using qualitative trophic types, giving the possibility of a greater sensitivity to change in trophic status. The more variables are measured, the more information we can gather about the trophic status. Some variables, such as total phosphorus and nitrogen, are causal variables and link loading estimates of nutrients to trophic state (Carlson, 2007). Thus, an internationally accepted eutrophication scale based on Chl-*a* concentration (Aizaki, 1981; Jin and Tu, 1990) is applied. The objective of this study is (1) to establish region-specific lake eutrophication assessment standards through a frequency distribution method based on Chl-*a* concentration; (2) to develop a comprehensive trophic level index (TLI($\sum$)) to provide an understandable assessment approach, and (3) to compare eutrophication assessment standards in different lake regions.

1 Material and methods

1.1 Study area

The lakes have been divided into five lake regions according to the geographical and climate differences in China: East Plain lake region, Yungui Plateau lake region, Northeast Plain and Mountain lake region, Mongolia-Xinjiang lake region and Qingzang Plateau lake region (Ma et al., 2011). In this study, an eutrophication assessment standard will be developed for four of the lake regions, leaving out the Qingzang Plateau lake region due to its good water quality and the lack of data. A total of more than 107, 39, 26 and 29 lakes were respectively selected for establishing lake eutrophication assessment standards in the East Plain lake region, Yungui Plateau lake region, Northeast Plain and Mountain lake region and Mongolia-Xinjiang lake region. Distribution and characteristics of the four regions' lakes can been seen in previous publications (Jia et al., 2004; Ma et al., 2011).

1.2 Data sources and data quality

In defining the trophic state of lakes, nutrients such as total phosphorus (TP) and total nitrogen (TN) are generally considered and described as causal variables, and Chl-*a*, Secchi depth (SD) and permanganate index (COD_{Mn}) as response variables (Dodds et al., 2006; Gibson et al., 2000). Data for causal and response variables were collected from lakes across the four regions as part of the ambient monitoring network maintained by the local Department of Environmental Protection, China. A total of more than 201 lakes with surface area of more than 10 km^2 were selected for this analysis, with data mainly from 2000 to 2010. Data were included from lakes that had at least three surveys (in wet, level and dry water periods) in every year over this time interval. Approximately 100 lakes were sampled on a rotational schedule as part of a fixed ambient water quality network. The remaining lakes were sampled as part of several synoptic surveys, special projects and other non-routine sampling efforts. The causal and response variables were measured according to the standard methods (PRC EPA, 2002).

For this analysis, minimum reporting limits were 0.01 mg/L for TP and 0.1 mg/L for TN. Observations in the database below detection limits were replaced with values equal to one-half the detection limits since these observations were encountered infrequently (Suplee et al., 2007). The method of one-half the detection limit was reported to be sufficiently accurate for determining descriptive statistics like the mean and standard deviation (Dodds et al., 2006; Hornung and Reed, 1990; Suplee et al., 2007; US EPA, 2006).

1.3 Statistical analysis

Considering modified Carlson's trophic state index (TSI_M) (Aizaki, 1981) and trophic state classification (Jin and Tu, 1990), a eutrophication scale was developed based on Chl-*a* concentrations as classified into six grades: 0–1.6 μg/L representing oligotrophic, 1.6–10 μg/L mesotrophic, 10–26 μg/L light-eutrophic, 26–64 μg/L mid-eutrophic, 64–160 μg/L high-eutrophic, and >160 μg/L hypereutrophic. Lake trophic states for corresponding designated uses of water body are listed in **Table 1**. The frequency distribution analysis was used to describe the concentration patterns of each trophic state. TN, TP, SD and COD_{Mn} were used for quantitative evaluation of trophic state for lake eutrophication.

Table 1 Lake trophic state for corresponding designated uses of water body (Zheng et al., 2009)

Trophic state	TSI_M	Standard scale	Designated uses
Oligotrophic	0–30	I	National natural protection region and rural distributed life drinking water source, etc.
Mesotrophic	30–50	II	The first-grade protection zone of centralized drinking water source, rare aquatic habitats, fish and prawn production field, etc.
Light-eutrophic	50–60	III	The second-grade protection zone of centralized drinking water source; fish and prawn wintering grounds, migration channel, aquaculture etc.
Mid-eutrophic	60–70	IV	Industrial water and human indirect contact recreation water
High-eutrophic	70–80	V	Agricultural irrigation water and general landscape water
Hypereutrophic	> 80	VI	Loss of water ecological functions