CHEMICAL ENGINEERING TRANSACTIONS

VOL. 71, 2018

A publication of AIDIC

The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216

DOI: 10.3303/CET1871112

Prediction of Water Pollution by Nutrients Based on Eutrophication Evaluation

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China's inland lakes have been faced with the problem of severe eutrophication water pollution. The purpose of this study is to predict the eutrophication level of water bodies and provide theoretical basis for water body management. To this end, by taking the 18 measuring points in Wuliangsuhai, Inner Mongolia as the object of study, this paper performs samplings and cluster analysis, to obtain the correlation relationship between chlorophyll a (Chl-a) and nutrients such as total phosphorus (TP) and total nitrogen (TN) etc. Besides, based on the empirical formula, the 2012-2014 sampling data were used to revise the slope and intercept, and then obtain the prediction model of TP in spring and chl-a concentration in summer, that is, the prediction model of water eutrophication; the 2015-2016 sampling data were used to validate the prediction model. The research results show that the relative error between the prediction model and the measured data is less than 20%, which meets the requirements of the qualified prediction model, and can predict the eutrophication of the water body. This provides theoretical support for the prediction and prevention of eutrophication for inland lakes in China.

1. Introduction

The water pollution in China's lakes is very serious. According to the water pollution survey conducted by the Hydrology Bureau of the Ministry of Water Resources in China on 52 lakes in 2015, the waters of 34 lakes were seriously polluted, and the proportion of moderately and severely eutrophic lakes reached 65% (Chen et al., 2016). Affected by human activities, the nutrients such as total phosphorus (TP) and total nitrogen (TN) in lake waters have been increasing, which accelerates the process of eutrophication for lake waters, and also brings great challenges to water pollution control (Rajeshkumar et al., 2017).

In the study of water eutrophication based on biological parameter method at home and abroad, water chlorophyll a (chl-a) is generally used as an important parameter for eutrophication (Liu and Burrage, 2011). Related studies have shown that chl-a has a significant correlation with nutrients, water temperature, and dissolved oxygen, and also its changes in water exhibits spatial and temporal differences (Szekely et al., 2011); the studies such as using eutrophication indicators for predicting red tides in the offshore waters and using linear regression equations to predict offshore algal blooms, have achieved the initial assessment of offshore eutrophication (Morgan et al., 2006). However, in the context of the eutrophication for China's inland lakes, there have been relatively few case studies on the prediction of their eutrophication.

In this paper, using chl-a concentration level as an indicator of eutrophication, the biological evaluation method was used to determine the correlation between TP/TN and chl-a in water, and establish the linear prediction model (Castellaños-Estupiñan et al., 2018). By selecting Wuliangsuhai in Inner Mongolia as the actual object of study, it revises the empirical formula based on the measured data to obtain the chl-a prediction model suitable for Wuliangsuhai. Then, it validates the accuracy of the prediction model by using the measured data (Räike et al., 2003). Studies have shown that the concentration of chl-a in Wuliangsuhai is the highest in summer, and the overall level of eutrophication in Wuliangsuhai is intermediate, so it's necessary to take measures to prevent the eutrophication of water (Wagner et al., 2011). This study provides a theoretical basis for the treatment of Wuliangsuhai and the positive reference for the water treatment of other inland lakes.

Please cite this article as: Hu Z., Liu L., 2018, Prediction of water pollution by nutrients based on eutrophication evaluation, Chemical Engineering Transactions, 71, 667-672 DOI:10.3303/CET1871112

2. Area and methods of study

2.1 Background of Wuliangsuhai Lake

Wuliangsuhai is the second largest freshwater lake in Inner Mongolia. It is a typical shallow lake in the cold and arid regions. The east-west width of the lake is 5-10km, and the north-south width is 35-40km, showing a narrow shape from north to south. It is also an important freshwater fish production base and bird protection base in Inner Mongolia. Its average annual output of reeds is 100,000 tons, as the key source of paper mills (Ruihong et al., 2004). The annual icebound period is from November to March-April of the next year, lasting up to 5-6 months. The annual highest temperature is 37.8°C, the lowest temperature is -30.9°C, the annual average temperature is 6°C, and the annual rainfall is 224mm. The rainy season is in August and September each year.

Wuliangsuhai Lake has abundant natural resources. It is of great significance to the local environment, economy and social development, and also of positive significance to the surrounding ecological environment and soil-water conservation. The main nourishment water source of Wuliangsuhai is irrigation and water withdrawal from surrounding farmland, wastewater from industrial enterprises, domestic sewage, floods and precipitation. Although the lake itself has certain pollution filtration and degradation capabilities, the eutrophication, organic pollution, salinization and swamping in the lake area have been increasingly serous according to the monitoring in recent years with the increase of human activities, the year-by-year growth of injected pollutants, and the nutrient-rich inflows such as phosphorus and nitrogen etc. (Guo et al., 2014). Thus, the water body management and ecological protection of Wuliangsuhai have attracted the attention of all parties.

2.2 Measuring point placement and monitoring location

A 2×2km grid was partitioned for Wuliangsuhai. A total of 18 measuring points were arranged for water sample measurement in consideration of water density and human factors interference etc. It’s generally classified into North zone (Zone 1) and Southern zone (Zone 2). Table 1 lists the on-site sampling instruments and test index; Table 2 lists the experimental methods for the indoor test analysis items.

Table 1: Parameters of water and instruments on the spot

Instrument name	Type	Test index
Written test PH meter	PH58	PH and Oxidation reduction potential
Written test conductivity meter	EC60	Conductivity, Total dissolved solid
Dissolved oxygen meter	AZ8403	Dissolved oxygen
Portable salinity tester	A303485	Salinity, Temperature

Table 2: The methods indoor experiments

Experimental analysis project	Analytical method
Total phosphorus	Ammonium molybdate spectrophotometer
Total nitrogen	Alkaline persulfate clock digestion UV spectrophotometry
Chlorophyll a	Acetone extraction spectrophotometry

2.3 Correlation between chlorophyll and nutrient concentration

The average concentration of TP and TN in Wuliangsuhai reached the peak in spring, and the nutrient content was the highest at the entrance of the lake due to irrigation of farmland irrigation water, while the average concentration of chl-a reached the maximum in summer (Uddling et al., 2007). Table 3 lists the descriptive statistics of the monitoring data in Wuliangsuhai, in which the total number of samples is N=108.

Table 3: Descriptive statistics of water indexes

	Minimum	Maximum	Mean	Std.Deviation
PH	8.00	9.80	8.80	0.31
Temperature	10.20	29.70	20.39	5.20
Transparence	0.24	1.60	0.74	0.40
Dissolved oxygen	0.33	9.12	2.50	1.68
Chlorophyll a	1.60	34.60	8.98	7.00
Total phosphorus	0.09	0.73	0.28	0.23
Total nitrogen	0.76	5.43	2.54	0.789

A K-S test of single sample was required before the correlation analysis of the monitoring data to determine whether the data is subject to a normal distribution. The results showed that the three indicators of chl-a, TP and TN showed a skewed distribution; according to the steps in the literature, the three indicators were normalized to satisfy the normal distribution (Wang et al., 2007).
Because of seasonal correlation between chl-a and TP/TN, the correlation of three indicators was analysed in terms of different seasons: the correlation coefficients between chl-a in summer and TP/TN in spring were 0.002 and 0.005, respectively; the correlation coefficients of chl-a in autumn and TP/TN in summer were 0.015 and 0.044, respectively, showing a significant correlation. Nutrients have become the major influence factors on chl-a (Xu et al., 2010).

3. Water pollution prediction model and model validation

3.1 Prediction empirical model of chlorophyll a concentration

The biological evaluation method was applied using the concentration level of chl-a as an indicator of eutrophication, that is, lake water pollution parameter. According to the data of lake chl-a concentration and its concentration in summer, some scholars analysed and found that with the ratio of TN to TP over 12, there exists the empirical formula for the summer chl-a C_{ca} and spring TP concentration P_s as shown in Formula 1 (Nazeer, M., & Nichol, J.E., 2016):

$$\lg C_{ca} = 1.449 \lg P_s \tag{1}$$

Substituting the 2012-2014 monitoring data at Wuliangsuhai sampling points and TP concentration into this empirical formula, the validation results can be obtained as shown in Table 4.

Table 4: Validated results of the Chlorophyll a concentration prediction model

Area 1	Chlorophyll a(Measured)	Chlorophyll a(Predicated)	Relative error (%)	Area 2	Chlorophyll a(Measured)	Chlorophyll a(Predicated)	Relative error
2012	30.73	0.44	-98.56	2012	18.18	0.44	-97.56
2013	23.30	0.66	-97.17	2013	21.34	0.37	-98.28
2014	26.38	0.51	-98.17	2014	12.31	0.4	-96.76

It can be seen that from the data in the table, the relative error between the predicted value and the measured value is greater than 96%, failing to meet the requirements. So, it’s necessary to adjust the empirical model of chl-a concentration prediction based on the monitoring data and establish a suitable concentration prediction model (Mazzelli et al., 2018).

3.2 Prediction model of chlorophyll a concentration in Wuliangsuhai

The monitoring data of TP, TN and chl-a concentration at 18 measuring points in Wuliangsuhai were averaged in terms of different seasons such as spring (5-6 months), summer (July-August) and autumn (9-10 months); then, a regression linear equation was established (Fig.1-4).

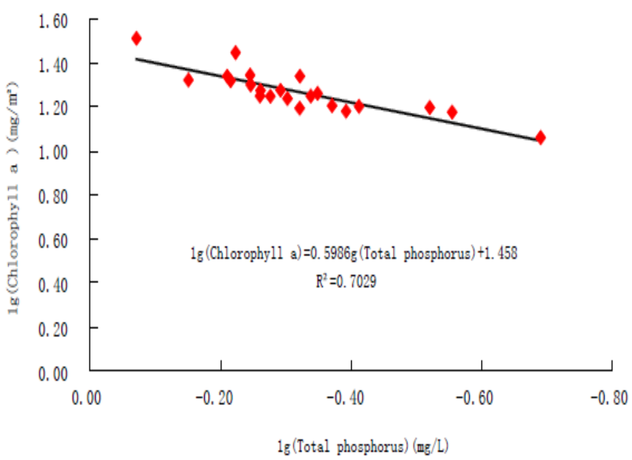

Figure 1: Regression curve of Total phosphorus in spring and Chlorophyll a in summer

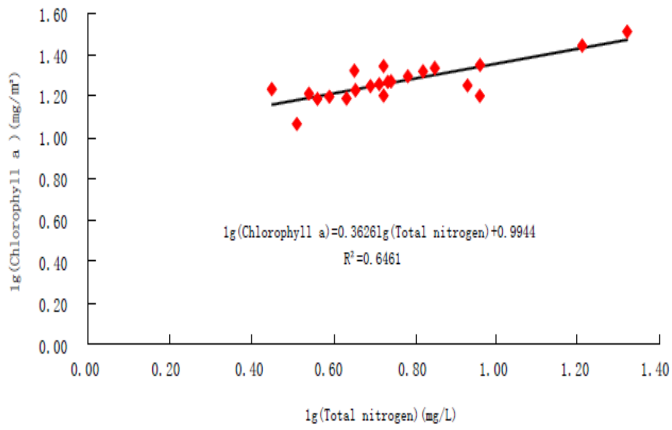

Figure 2: Regression curve of Total nitrogen in spring and Chlorophyll a in summer

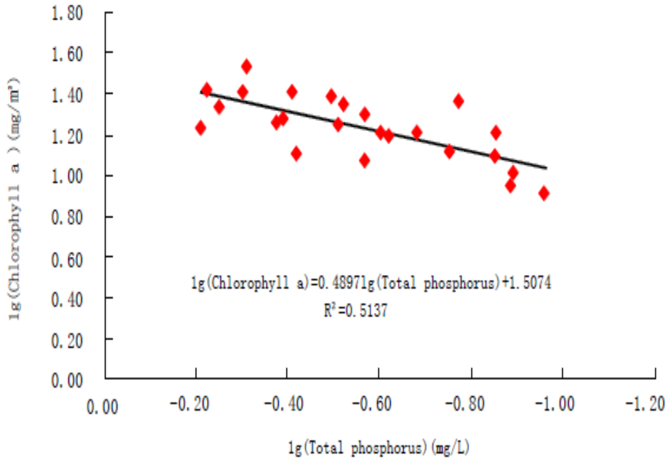

Figure 3: Regression curve of Total phosphorus in summer and Chlorophyll a in autumn

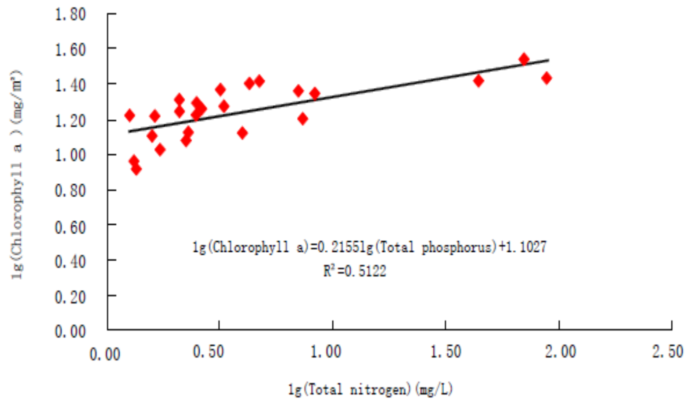

Figure 4: Regression curve of Total nitrogen in summer and Chlorophyll a in autumn

From the regression linear equation in the figures, it can be seen that the TP in spring has a good fitting effect with the chl-a determination coefficient R^2=0.7029 in summer, while the fitting effects of other regression equations are worse than the TP in spring and Chlorophyll in summer which was then selected as the prediction model of chlorophyll concentration.

$\lg C_{ca} = 0.5986 \lg P_s + 1.4580$ (2)

3.3 Prediction model of chlorophyll a concentration in Wuliangsuhai

Substituting the measured data of 2015 and 2016 into the modified chl-a concentration prediction model, the accuracy of the prediction model was validated.

Table 4: Validated results of the amendatory Chlorophyll a concentration prediction model

Area 1	Chlorophyll a(Measured)	Chlorophyll a(Predicated)	Relative error (%)	Area 2	Chlorophyll a(Measured)	Chlorophyll a(Predicated)	Relative error
2015	23.91	26.63	11.38	2015	19.67	22.74	15.61
2016	12.27	14.64	19.32	2016	12.05	12.26	15.76

The relative error between the predicted value and the measured value of the corrected chl-a concentration prediction model is less than 20%. Considering the changing mechanism of eutrophication in the field and the difficulty in predicting the change of environmental factors, it's believed that the accuracy of the prediction model meets the requirements. This model can be used to predict the chl-a concentration of Wuliangsuhai and the prediction of water pollution.

3.4 Wuliangsu water pollution evaluation

Through the analysis of the nutrients and chl-a concentration of water in 2012-2016, it can be seen that the water body of Wuliangsuhai showed the variation of eutrophication, moderate nutrition, and poor nutrition with seasonal changes. The proportion of the three nutrition levels is shown in Fig.5.

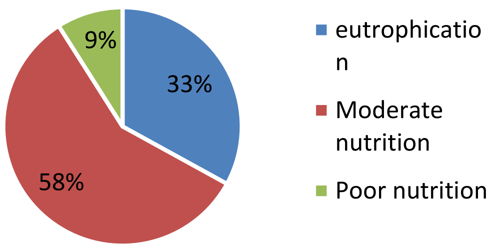

Figure 4: Different level of eutrophication of the lake

The frequency of the eutrophication level each month in Wuliangsuhai shows that the moderate nutrition and eutrophication occur every month in Wuliangsuhai. The highest occurrence frequency of eutrophication is in September, because in autumn, Wuliangsuhai area enters the autumn irrigation period, and the agricultural irrigation wastewater will carry a large amount of nitrogen, phosphorus, and other nutrients into the Wuliangsuhai, resulting in nutrient enrichment and eutrophication pollution in this area. The proportion of poor nutrition in lakes is 9%, that of moderate nutrition is 58%, and that of eutrophication is 33%, indicating that Wuliangsuhai is a moderately eutrophic lake, requiring relevant departments to take measures against lake waters pollution and prevent the water pollution.

4. Conclusions

The study of water pollution and eutrophication in inland lakes is of great significance for the protection of inland lakes and the surrounding ecological environment. In this paper, based on the biological evaluation method, the concentration of chl-a was used as the index of lake water eutrophication, and the chl-a concentration prediction model was established according to historical detection data and empirical model by taking Wuliangsuhai of Inner Mongolia as the object of study. The main conclusions are as follows:

(1) The determination coefficient of total phosphorus in spring and chlorophyll a in summer R^2=0.7029 has the best fitting effect;

(2) Substituting the TP of historical monitoring data into the prediction model, the predicted value of chl-a was obtained. The relative error between the predicted value and the measured value is less than 20%, indicating higher prediction accuracy;

(3) The prediction model of this paper can be applied to the eutrophication prediction research in different types of lakes, which has important theoretical guiding significance.

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