Research on ANN-based Pre-warning Water Bloom Model of LiuHai Lake in Beijing

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Abstract

Aimed at the Problems of water bloom erupting often in the cities of our country, a Pre-Warning Model for water bloom is developed by using the ANN method; in order to adopt the emergency response measures and avoid erupting water bloom, and provide scientific basis for improving the water environment of river and lake system. The results of the research indicates: (1) water system dynamic condition is the main factor causing the water bloom, the change of water system dynamic condition is the best way for avoiding the eruption of water bloom. (2) The present concentration of Chl-a is main pre-warning index, if the water bloom has erupted, the measure of emergency allocation water may relax the tension of water bloom, so far as to reduce red into green pre-warning situation. (3) The velocity of flow is the decisive factor of water bloom eruption. When the velocity of flow is great enough the water bloom erupts seldom; and when the velocity is zero, even if the concentration is not very big, the water bloom will erupt possibly after 7 days. (4) The temperature of water is not the essential condition of water bloom. Even if the temperature is very lower, when the velocity of flow is very slow and the nutrition level is great enough, the water bloom will erupt possibly. (5) The eutrophication is not the inevitable factor. Under the good water dynamic condition, even if the nutrition level is very high, the water bloom will not erupt. Only when the temperature is suitable and velocity of flow is slow, the water bloom will erupt.

Keywords: River and Lake in Cities; Water Bloom; Early Warning; “Liu Hai” of Beijing; ANN

1. Introduction

In recent years, water bloom flooded in many lakes of China. At present, the water of lakes which are more than 70% is in the eutrophication that the area, the strength and the microcystin content are in substantial growth. For example, there were several severe outbreaks of algal blooms in the DianChi Lake, Han River emerged a very rare phenomenon of water bloom. Dianchi Lake, Taihu Lake and Chaohu Lake, which are called “three lakes” in China, are equally swamped with algal blooms in the trend and have been included in the national environmental management focus. China's algal blooms spreading speed and the difficulty of treatment have reached the stage that
is called "eco-cancer". Whether in China or abroad, the outbreak of water bloom has become a kind of environmental disasters.

Security problems of water environment caused by eutrophication aroused sufficient attention in the past ten years. Most researches are about early warning of red tide, rarely involving in pre-warning of water bloom in the inland rivers and lakes. Most researches on the pre-warning of water bloom of the inland rivers and lakes at home and abroad are merely remain in the water bloom of the factors[1], pathogenesis[2,3], and evolution trend prediction phases[4-6].

For the red tide pre-warning, some scholars[7] have set off from its cause, which is the fundamental way to a pre-warning of red tide. Water bloom factors include water temperature, nutrients, light, salinity, etc. Analysing dominant or limit factors of red tide in some place, through the establishment of a fixed mathematical model, can be used for forecasting or pre-warning. J.H.W Lee and others[8], for tracking and monitoring of marine aquaculture zones representative of chlorophyll, dissolved oxygen and other water and weather conditions change, established an automated real-time remote monitoring system. Using this system can give pre-warning of red tide outbreaks. From 2000 to 2003, the system successfully tracked 19 times water blooms. Gilbert C.S. Luia and others[9] used the vector auto regression model on behalf of the endogenous variables to establish red tide simulation forecasting model, whose accuracy could reach 83%. Compared to the artificial neural network model, its predictions were better. There were also some scholars[10] who carried out an pre-warning of red tide, based on the prediction of the amount of plankton.

The second method was always used for the pre-warning of water bloom of the inland rivers and lakes. The first method is establishing "alert level" or "alert value" of the outbreak of water bloom, as a basis for pre-warning. In 1995, Australian academics[11] had made a concept --"water bloom alert level", which was targeted mainly for the purposes of algal bio-density. Dayuan Liu and others[12] put forward a “alert value” of water bloom concept and water bloom pre-warning vision on the Han River.

The second is using historical data to establish correspondence between the indicators of characterization and the causations of the outbreak of water bloom, giving pre-warnings of that whether there will be outbreaks of water bloom in the future. Zeng Yong and others[13] used ID3 decision tree method to divide the causes of the outbreak of water bloom into different intervals in the space, and predicted the scenarios of the outbreak of water bloom in LiuHai Lake in Beijing by using a linear multiple regressions for different intervals. Zeng Yong used a piecewise linear method, but the cause of the outbreak of water bloom is very complex and, in essence, it is a multi-variable, highly nonlinear process. Piecewise linear is only a approximation, the mechanism, the inherent, complex and high degree of nonlinear of the outbreak of water bloom of, can be completely characterized. In addition, it is also questionable that the model of the paper selected phosphorus as the main controlling factor; LiuHai Lake is a nitrogen-limited. Finally, a pre-warning of water bloom is usually to predict the possibility of outbreak of water bloom for some time in the future. The model established in the paper is about the relationships between Chlorophyll-a and water temperature, flow rate as well as nutrient concentration in some period. As a result, the concentration of Chlorophyll-a can only be predicted according to water temperature, flow, nutrient concentrations in the future, which is obviously not achieve an early warning effect.

The outbreak of water bloom is a result of a number of factors working together, specifically including the accumulation of nutrients in water, climatic conditions, water conditions and aquatic ecosystem structure and composition. The model based on artificial neural network established for pre-warning of water bloom in this paper is used for looking for the relationship between water bloom and the factors of the outbreak of water bloom, based on the integration of monitoring information of the influencing factors of water bloom. The model further gives pre-warings of the outbreaks of water bloom, in order to take timely emergency response measures before the outbreaks of water bloom.

2. Overview of the study area

LiuHai Lake is located inside Beijing 1st Ring Rd (Fig. 1), including XiHai, HouHai, QianHai, BeiHai, ZhongHai and NanHai. It is a typical the city lake and covers an area of 1.7 million m2, depth of 1.5m to 2.0m. The geographical location of Zhongnanhai, where China's party and state leaders live and work, is very important. In recent years, due to reduction in the upstream runoff, the surrounding and upstream pollution of LiuHai Lake increases, resulting in severe eutrophication of the lake, even outbreak of water bloom, and seriously endangering
the surrounding residential and office environment. To carry out pre-warning of water bloom and emergency response has become urgent.

3. Development of an ANN-based Pre-Warning Water Bloom Model of LiuHai Lake in Beijing

In this paper, pre-warning water bloom model of artificial neural networks of LiuHai Lake in the Beijing, aims at predict whether there is a out break of water bloom seven days later, under the current hydrological, meteorological and water quality multi-source information of LiuHai Lake. Selecting 7 days as an pre-warning period is for the following reasons. Although the water bloom has burstiness, compared with sudden environmental pollution accidents caused by the leakage of toxic chemicals, it’s different. The water bloom through a recovery period(building phase) about 16 days, a logarithmic period(accumulation phase) about 7 days, then goes to the outbreak period and autonomy recession. The number of algae in the logarithmic period grows exponentially, and water bloom breaks out. Meanwhile, the pre-warning aims at emergency response. Selecting 7 days, left some time for maneuver of emergency response measures.

3.1. Analysis of reasons of water bloom in LiuHai

Through analysis of the relationship between reasons of the outbreaks of water bloom in the LiuHai and 120 Chlorophyll-a samples collected from 2003 to 2004 by using Chlorophyll-a concentration as a indicator of outbreak of water bloom and regression analysis method, the result is shown in Table 1.

According to the results of correlation analysis, the reason which has great related coefficient with the outbreaks of water bloom was selected a model input, including water temperature (°C), pH value, dissolved oxygen (mg.L-1), CODMn (mg.L-1); TN (mg.L-1), Transparency(m), Daily flow of TieLing Floodgate(m3.s-1) and Chlorophyll-a of that day(mg.L-1). The output is the Chlorophyll-a concentration 7 days later.

Fig.2 shows the ratio of nitrogen and phosphorus in the LiuHai Lake[14]. We found that most of ratio are smaller than 17, it is Nitrogen limited (sakamoto, 1966), or nitrogen and phosphorus co-limited. Through the analysis of correlation, the correlation coefficient of nitrogen and chlorophyll-a is greater than the correlation coefficient of phosphorus and chlorophyll-a. So, the total nitrogen is selected as the representative of nutrients, not P (phosphorus).

Table 1 The Correlativity between the Chl-a after 7days and the Cause of Water Bloom
| Reasons of water bloom | Correlation coefficient | Reasons of water bloom | Correlation coefficient |
|------------------------|-------------------------|------------------------|-------------------------|
| Water temperature      | 0.98                    | Transparency           | 0.76                    |
| pH                     | 0.88                    | Daily precipitation (mm) | 0.38                    |
| Dissolved oxygen       | 0.75                    | Daily average wind velocity (0.1 m.s⁻¹) | 0.24                    |
| CODₐₘₜ                   | 0.45                    | Daily average flow of TieLing Floodgate | 0.88                    |
| NH₃-N                   | 0.37                    | Present Chl-a          | 0.68                    |
| TP                      | 0.33                    | TN                     | 0.87                    |

Fig.2 TN/TP Value of LiuHai Lake

3.2. Development of ANN-based Pre-Warning Water Bloom Model

In this paper, a feedforward back-propagation network (BP network) is established for the pre-warning model for water bloom. The structure of the BP network shown in Fig.3 includes an input layer, an output layer and a hidden layer.

![Fig.3 The Structured Figure of ANN-based Pre-Warning Model of Water Bloom of Liu Hai Lake in Beijing](image-url)
The reasons of the outbreak of water bloom are selected as inputs of the BP network, and the indicators of the outbreak as outputs of the BP network. When the BP network is established, the samples which identify the relationship of complex non-linear mapping of factors of the outbreak of water bloom and indicators of water bloom are supervised for learning. When the parameters of BP network are appropriate, the results are able to converge to a smaller mean square error. It is a one-way connection network.

\[ r_j = f(p_j + q_j) = f(a_j), \quad p_j = \sum_j w_{ij} b_j \quad (1) \]

\( r_j \) : output signals of neuron (indicators of the outbreak of water bloom); \( b_j \) : input signals of neuron (reasons of the outbreak of water bloom); \( w_{ij} \) : connection weights; \( q_j \) : bias items. Function is acted by S-type non-linear function, network is trained with quasi-linear. Because of the differentiability of the transfer function, its difference formula can be derived out according to the principle of gradient descent method. If the top-level neuron associated with the output is defined as layer I, the others in the same order, according to gradient descent method, the correction formula of connection weight between layer \( x \) and layer \( x+1 \) is expressed as :

\[
[w_{x, x+1}(k+1)] - [w_{x, x+1}(k)] = AD_{x, x+1} r_{x+1}^T
\quad (2)
\]

\( [w_{x, x+1}] \) : connection weight matrix between layer \( x \) and layer \( x+1 \); \( A \) : learning parameter; \( r_{x+1}^T \) : neuron output vector transpose in the layer \( x+1 \). The above formula can be used for between multi-layers of quasi-linear networks, but for the layer I and x, the formula is expressed as:

\[
D_I = < f'_j(a_j) > < \delta >
\quad (3)
\]

\( \delta \) : the difference between the network output and the desired output. Because the output of neurons is the input signal of neurons of the next layer, for the adjustment of matrix between the bottom layer and the input, the input vector \( b \) was used instead of \( r_{x+1} \).

In order to reduce a larger error caused by excessive weight coefficient adjustment for that a training sample is converted into another training, a inertia, \( B \) is introduced. On the one hand movement in the direction of the previous adjustment is maintained in a certain degree; on the other hand this can remove the error adjustment caused by high-frequency variation in the bias plane. So,

\[
[w(k+1)] - [w(k)] = AD_{x}^T + B[n[k] - w[k-1]]
\quad (4)
\]

In general, \( A<1,0 <B <1 \) are taken and \( k \) means the number of iterations. Mean square error of the entire network, that is, the average error of all training samples.

\[
E(w) = \lim_n \left\{ (1/n) \sum_{k=1}^n S_k \right\} = \sum_k \sum_j (d_j - r_q)^2
\quad (5)
\]

\( d=(d_1, \ldots, d_j, \ldots) \), it means expected output. For \( i \), \( d_i=1, d_j=0, j \neq i. \) n means the number of training samples. \( \delta \) rule is that from a certain initial weight matrix \( [w(1)] \), each training sample pairs in the training set is successively acted on the network. Through the error back propagation to adjust the weight coefficients of neurons in each layer, \( E(w) \) is decreased, until the total deviation is less than a specified value or continuous two-cycle training network change
in the total deviation is less than a certain threshold, then the training is suspended. Finally, a weight matrix that is more in line with each training can be found.

The weight should be kept same when a pre-warning of water bloom is carried out. Each inputted set of predictors can be calculated to get a set of network output values; the node with the maximum number of output value is the forecast value.

3.3. Class and Range of Pre-warning of Water Bloom

Options of class and range of pre-warning of water bloom, are determined by referring to the Beijing hydrographic vibration history, and the value of environment management experience of urban lake and river management departments. In accordance with the concentration of chlorophyll-a of lakes and rivers, the class of pre-warning of water bloom is divided into red, yellow and green three levels. The class and range of pre-warning of water bloom are shown in Table 2. When the pre-warning is in the green state, the routine operation and water quality are kept. When the pre-warning is in the yellow state, a pre-warning scheduling should be carried out. Through a joint scheduling, the occurrence of water bloom can be prevented. When the pre-warning is in the red state, it indicates that water bloom has already broken and the water should be taken to emergency management measures to eliminate the risk of outbreak of water bloom.

| Class of pre-warning | Range of pre-warning | Scheduling methods       |
|----------------------|----------------------|--------------------------|
| Red                  | Concentration of Chl-a is more than 0.10 mg/l. | Emergency scheduling     |
| Yellow               | Concentration of Chl-a is between 0.06 mg/L and 0.10 mg/L. | Alert scheduling         |
| Green                | Concentration of Chl-a is less than 0.06 mg/L. | Conventional Scheduling  |

4. Training and Validating of the Pre-warning Model of Water Bloom

4.1. Training of the Pre-warning Model of Water Bloom

In this paper, water quality, meteorological and hydrological monitoring data of LiuHai Lake in 2003 and 2004 are selected as the training samples. The training samples are divided into two groups, with 2/3 (approximately 120 samples) used for training of the pre-warning model of water bloom, and the results of the model parameters are adjusted based on feedback. Eventually, parameters at the error within the allowable range of pre-warning model for water bloom are shown in Table 3. The other 1/3 samples are used for subsequent validation of the pre-warning model of water bloom.

Table 3 The Parameters
4.2. Validating of the Pre-warning Model of Water Bloom

The samples that are independent of the training samples are selected for validating the pre-warning model of water bloom. Results of validation are shown in Fig.4 (a)-4(f). Errors of the results of pre-warning model of water bloom in various lakes are as follows: 14% in XiHai, 23% in HouHai, 12% in QianHai, 29% in BeiHai, 16% in ZhongHai and 7% in NanHai. It meets the requirement of model error.
5. Analysis of Results of Pre-Warning

XiHai is taken for an example. According to the 2006 hydrological, meteorological and water quality monitoring data, using this established pre-warning model of water bloom, a pre-warning of the possibility of the outbreak of water bloom seven days later is given. The results are shown in Table 4. The results of pre-warning model in suggest that:

Table 4 The Results of the Pre-warning Water Bloom of LiuHai in Beijing
| Sample number | Water temperature (°C) | pH | DO (mg/L) | TN (mg/L) | Transparency (m) | Daily average flow of TieLing Floodgate (m³/s) | Concentration of chl-a on the day (mg/L) | Concentration of chl-a 7 days later (mg/L) |
|---------------|------------------------|----|-----------|------------|------------------|---------------------------------------------|----------------------------------------|----------------------------------------|
| 1             | 23                     | 7.7| 5.6       | 2.17       | 0.7              | 0.6                                         | 0.003                                  | 0.009                                  |
| 2             | 31                     | 8.2| 22        | 1.16       | 0.45             | 0.2                                         | 0.018                                  | 0.023                                  |
| 3             | 27                     | 7.9| 7.7       | 2.01       | 0.5              | 0.7                                         | 0.005                                  | 0.08                                   |
| 4             | 32                     | 7.9| 21.8      | 1.01       | 0.3              | 0.7                                         | 0.267                                  | 0.009                                  |
| 5             | 23.9                   | 8   | 22.46     | 1.541      | 0.22             | 0.2                                         | 0.347                                  | 0.296                                  |
| 6             | 19.3                   | 8.4| 19.85     | 1.329      | 0.29             | 0.1                                         | 0.224                                  | 0.152                                  |
| 7             | 17.1                   | 8.4| 9.79      | 3.412      | 0.7              | 0.1                                         | 0.068                                  | 0.076                                  |
| 8             | 26                     | 8.2| 9.7       | 1.81       | 0.4              | 0.3                                         | 0.045                                  | 0.05                                   |
| 9             | 28.1                   | 8.3| 12.05     | 1.561      | 0.26             | 0.1                                         | 0.054                                  | 0.049                                  |
| 10            | 26.3                   | 8.5| 11.7      | 1.477      | 0.38             | 0                                           | 0.087                                  | 0.136                                  |
| 11            | 27.1                   | 7.9| 11.08     | 2.413      | 0.36             | 0.1                                         | 0.08                                   | 0.096                                  |
| 12            | 23.7                   | 8   | 9.34      | 0.721      | 0.39             | 0.1                                         | 0.073                                  | 0.069                                  |

1) The concentration of Chlorophyll-a on the day is a major indicator of pre-warning of outbreak of water bloom. The occurrences of red alert are 5, 6 and 10 scene, and the concentration of Chl-a of two of them are at the red alert state. If no emergent measure is taken, water bloom will not disappear in the seven days. Through increasing the daily average flow of TieLing Floodgate (sample 4), that is emergency water, the water bloom problem can be solved in the near future.

2) The daily average flow of TieLing Floodgate is the decisive factor in the outbreak of water bloom. When water bloom occurred in three samples (sample 5, 6 and 10), the daily average flow of TieLing Floodgate were low; On the contrary, a large number of flow samples (sample 1, 3 and 4) induced the green alert status except sample 3. As a result of high concentration of TN and suitable temperature for the water bloom, there is a yellow alert in sample 3. Even if the concentration of Chl-a of the day is not high, there is still a yellow alert status, water bloom also might break out 7 days later. So, to change hydrodynamic conditions, that is, to improve the flow of rivers and lakes and water exchange cycle is the best way to avoid water blooms.

3) Although correlation coefficient of the water temperature and Chl-a is large, from the results of pre-warning, the water temperature is not an essential factor of the outbreak of water bloom. In the scene of low water temperature (sample 6 and 7), low flow and high nutrition levels, alarm of water bloom (sample 7) may also be seen. If water bloom occurs, the temperature is low and not affect the growth of algae, water bloom will not disappear soon (sample 6). This would normally have been the understanding of water bloom, explains the complexity of the outbreak of the mechanism of water bloom.

4) Eutrophication is not a necessary factor in the outbreak of water bloom. Water bloom may not break out if the hydrodynamic condition is well, even though energy levels are high (sample 1). But once in the scene of right temperature, very slow flow and long period of water exchange, water bloom will break out.

6. Conclusion

The outbreak of water bloom is sudden, and the question arises the need for pre-warning of water bloom. Through the pre-warning of water bloom, emergency response measures can be taken timely. The mechanism of
outbreak of water bloom is very complex, so far, a lot of problems (such as low in temperature conditions there is also possible outbreak of water bloom) have not been resolved. In the circumstance that the mechanism has not yet defined, using ANN as the representative of the intelligent algorithm for the pre-warning of water bloom has opened up a new feasible way. It has a characteristic of rapid pre-warning model, at the same time, through self-learning function, the model can be continuously improved the accuracy.

Pre-warning models are different from other forecasting models, which require a certain chronergy, and a rapid pre-warning for timely emergency response measures in the situation of outbreak of water bloom. A traditional complex hydraulic, water quality or ecological model cannot achieve. Although the complex mechanism of water ecology model can be more clearly simulate the process of algal bloom outbreaks, because the mechanism of water bloom is too complicated, its data parameters calling for a decision of its modeling needs time and a lot of manpower and material resources. Pre-warning of water bloom calls for precision and more emphasis on rapidness.

The outbreak of water bloom is a result of a number of factors working together, specifically including the accumulation of nutrients in water, climatic conditions, water conditions and aquatic ecosystem structure and composition. The pre-warning model of water bloom in this paper is used for looking for the relationship between water bloom and the factors of the outbreak of water bloom, based on the integration of monitoring information of the influencing factors of water bloom. The model further gives pre-warings of the outbreaks of water bloom, in order to take timely emergency response measures before the outbreaks of water bloom.

Hydrodynamic conditions are the primary factor in bloom occurred. When the flow in the rivers and lakes is large, very few of water blooms break out. To change hydrodynamic conditions is the best way to avoid water blooms. Emergency water may ease the short-term momentum in water bloom, and decrease the red alert warning to the green. The water temperature is not even an essential factor of the outbreak of water bloom. In the scene of low water temperature, low flow and high nutrition levels, alarm of water bloom may also be seen. Eutrophication is not a necessary factor in the outbreak of water bloom. Water bloom may not break out if the hydrodynamic condition is well, even though energy levels are high (sample 1). But once in the scene of right temperature, very slow flow and long period of water exchange, water bloom will break out.

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