Research on hybrid mechanism modeling of algal bloom formation in urban lakes and reservoirs

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ABSTRACT

Algal bloom in urban lakes and reservoirs breaks out more frequently in recent years, making it a serious environmental problem in the world. Ecological dynamic model and data-driven model are two most representative methods to describe algal bloom formation mechanism; however, they both have certain drawbacks. In this paper, on the basis of deep analysis on formation mechanism of algal bloom, a hybrid mechanism modeling method was proposed, which synthesized the advantages of both models mentioned above. In order to obtain an appropriate model, a function model library (FML) of key impact factors (IFs) in algal bloom formation was first established, and then Tabu Search (TS) and Genetic Algorithm (GA) were applied for model structure optimization and parameters calibration, respectively. Simulation results show that the proposed method can effectively characterize the formation mechanism of algal bloom in different urban lakes and reservoirs, and it is also with higher modeling speed and wider extendibility.

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1. Introduction

With the development of economy and society, a great deal of nitrogen, phosphorus and other nutrients flow into lakes, leading to increasing eutrophication and more frequent algal bloom. Water ecological security now confronts serious threats, which will directly affect city development and urban residents living. Therefore, further research on formation mechanism of algal bloom and effective prevention of such unconventional emergencies is necessary, and has great significance in promoting water environment protection and technology progress (Ding et al., 2005).

Researchers have already done some work on mechanism modeling of algal bloom formation. Ecological dynamic model and data-driven model are two most representative types. Ecological dynamic model describes the formation mechanism through the interaction mechanism of different subsystems in the ecosystem (Liu et al., 2007). Jorgensen et al. (1978) proposed an ecological model, with nutrients (such as carbon, nitrogen and phosphorus) as loop variables and zooplankton and phytoplankton as key variables. This model laid the foundation of research on ecological dynamic model, and on the basis of this, Lake Sobygaard in Denmark was well described (Jorgensen, 1986). Narasimhan et al. (2010) built a model of eutrophication in Cedar River, which simulated

relationship between nutrient load and chlorophyll a concentration in nonpoint source. Related studies were also carried out here in China. An ecological model for Chaohu was derived by Xu et al. (1999), including sub-models of the nutrients, zooplankton, phytoplankton and sediment. Kong et al. (2009) proposed a hypothesis of four stages in algal bloom formation, and based on this, Wang et al. (2013a,b) built an ecological model of algal bloom in Taihu with the ELCOM–CAEDYM coupling model framework. Data-driven model, mainly including mathematical statistics model and artificial intelligence model, is to discover the inherent law hidden in the system from a large amount of data, and therefore is particularly applicable to high-dimensional nonlinear complex systems with unclear mechanism. Anderson et al. (2010) established a logarithmic generalized linear prediction model of algal bloom in Chesapeake Bay, with the hydrological monitoring data as well as the cell abundance. Chau (2005) analyzed the variation trend of algal bloom using a perceptron model trained by particle swarm optimization algorithm. Obenour et al. (2014) predicted the phosphorus load of west Erie Lake with the Bayesian model. Bruder et al. (2014) studied the quantitative relationship of cyanobacteria metabolites based on adaptive network fuzzy inference system. Wang et al. (2013a,b) proposed a multi-cycle and multi-variable autoregressive model, and explored the changing rules of different factors that affect algal bloom growth process. Some researchers studied the method for chlorophyll a concentration prediction based on artificial intelligence (Tong et al., 2011; Zhang et al., 2013).

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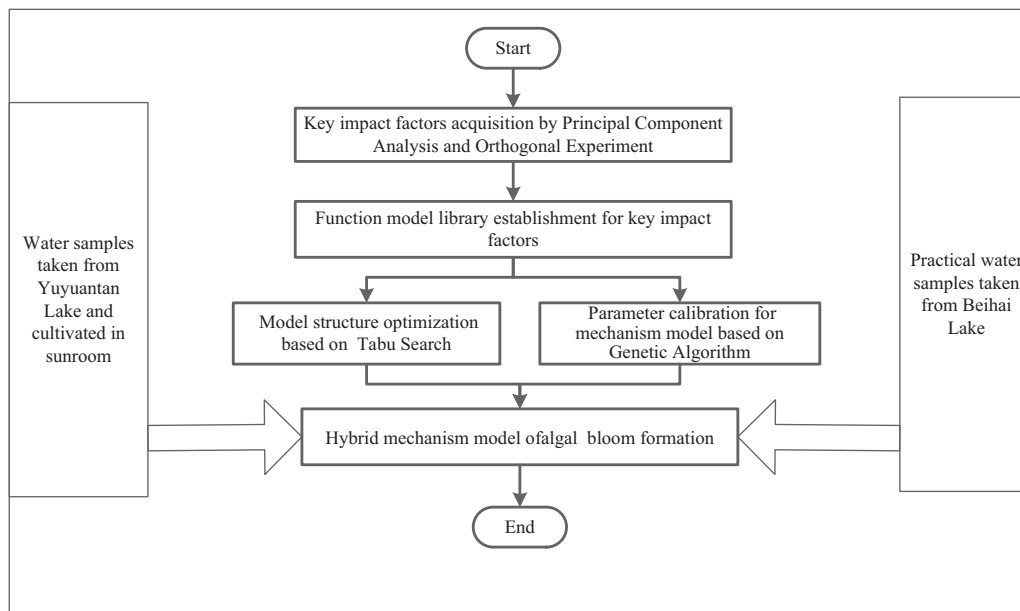*E-mail address:* sdwangxy@163.com (W. Xiaoyi).

Fig. 1. Conceptual diagram of the hybrid mechanism modeling method.

However, the two modeling methods mentioned above both have certain drawbacks. Ecological dynamic model mainly emphasizes the effect of chemical, physical, nutritional factors on formation mechanism of algal bloom in specific water body. Since various parameters are involved and they all show high uncertainty and nonlinearity, building such kind of model becomes quite difficult and complex, and its application scope is also limited. Data-driven model is highly dependent on observation data, and is lack of theoretical support. It cannot fully reveal the formation mechanism of algal bloom and reflect the influence of impact factors on algal bloom formation, which affects the effectiveness of such model to some extent. In response to these problems, a hybrid mechanism modeling method was proposed in this paper, which synthesized the advantages of both models above. In order to build such kind of model, a function model library (FML) of key impact factors (IFs) in algal bloom formation was first established, and then Tabu Search (TS) and Genetic Algorithm (GA) were applied for model structure optimization and parameters calibration, respectively. It needs to be pointed out that, when selecting different key IFs to modify the model, it could effectively describe the formation process of algal bloom in different urban lakes and reservoirs.

2. Mechanism modeling of algal bloom formation

2.1. Modeling process of algal bloom formation

Modeling process of algal bloom formation is shown in Fig. 1. At the very beginning, key impact factors (IFs) were acquired by principal component analysis (PCA) and orthogonal experiment, and the FML of key IFs in algal bloom formation was established thereafter. Then TS and GA were applied for model structure optimization and parameters calibration, respectively. And the hybrid mechanism model of algal bloom formation was finally obtained. In order to validate the effectiveness of the proposed model, laboratory data of Yuyuantan Lake (water samples taken from Yuyuantan Lake and cultivated in sunroom) and practical data of Beihai Lake were used in this paper. The former samples were used after a cultivation process, while the latter ones were carefully chosen with the occurrence of algal bloom.

2.2. Key IFs acquisition and analysis on algal bloom formation

2.2.1. Simulation experiment of algal bloom formation

In order to obtain the possible IFs in algal bloom formation, an outdoor sunroom (as shown in Fig. 2) was built to simulate the process of algal bloom formation in natural environment. The main equipments applied in this process include: transparent glass tank, illumination incubator, online multi-parameter water quality sonde (YSI6600), weather station, and visible spectrophotometer. Water samples used in this experiment were taken from Yuyuantan Lake in Beijing, and they were preprocessed before the experiment. After total nitrogen and phosphorus concentration were observed, samples were cultivated in the illumination incubator, with the temperature at 20 °C, illumination intensity at 6000 lx, proportion of light and darkness as 12 h:12 h, total nitrogen concentration and total phosphorus concentration as 1.445 mg L^{-1} and 0.2 mg L^{-1}, respectively. When the algal density reached 106 cell L^{-1}, the samples could be then used in the simulation experiment. Algal bloom formed in the experiment was shown in Fig. 3.

According to the simulation experiment, the change of algal density tends to be coincided with that of chlorophyll a concentration

Fig. 2. The outdoor sunroom for algal bloom formation simulation experiment.