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Water quality assessment analysis by using combination of Bayesian and genetic algorithm approach in an urban lake, China

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ABSTRACT

Since Eutrophication has become a serious water pollution problem on urban lake in China. Therefore, more accurate and efficient methods are necessary for water quality assessment. Although Bayesian methods are widely used in water quality modelling and uncertainty analyses, the algorithm efficiency often limits their application in multi-parameter eutrophication models. In this study, a genetic algorithm was integrated into a Bayesian method to improve sampling performance during the parameter calibration process. An eutrophication model of an urban lake in north China (Tianjin) is established based on biological processes and external loads. A Markov chain Monte Carlo method coupled with a genetic algorithm (MCMC-GA) is developed to sample the posterior parameter distributions and calculate the simulation results. Then, the performances of the MCMC-GA and classical MCMC are compared and analyzed. Finally, a water quality assessment is conducted for eutrophication management. The results are as follows: (1) the MCMC-GA displays a better convergence efficiency during parameter sampling, higher Markov chain quality, and narrower 95% upper and lower confidence intervals than the classical MCMC method; and (2) rainwater runoff nutrient loading must be controlled for urban lake restoration.

1. Introduction

Urban water bodies have been widely used to improve the quality of urban environments (Chen and Wang, 2009). However, the risk of eutrophication in urban water bodies is considerably high due to low environmental capacity and excessive nutrient loading (Qin et al., 2014; Liu et al., 2014). Eutrophication control usually focuses on reduction of external nutrient loadings to restrict excess phytoplankton blooms and associated effects (Browder and Xie, 2007; Zhao et al., 2009; Cerco et al., 2010). Eutrophication models have become powerful tools for nutrient loading control because they can reflect quantitative relationships between nutrient loading control and water quality improvement, enabling stakeholders to conduct scenario analyses in decision-making processes (Domingues et al., 2005; Hiriart-Baer et al., 2009; Zhao et al., 2013).

Bayesian methods are widely used in uncertainty analyses of eutrophication modeling (Borsuk et al., 2004; Arhonditsis et al., 2007; Arhonditsis et al., 2008; Ramin et al., 2011; Ramin et al., 2012; Yang et al., 2015). Markov chain Monte Carlo (MCMC), the basic algorithm of Bayesian methods, has been used for years, especially under the condition of limited and highly variable ecological data. There are two main problems in environmental modeling involving uncertainty analysis. First, the application of any model involves substantial uncertainty contributed by the model structure, model parameters, and other associated inputs (Ramin et al., 2011). Second, some models that depict the average ecosystem behavior are inadequate for water quality analysis (Borsuk et al., 2004). The MCMC method can effectively solve these problems by generating a parameter's posterior distribution and quantifying the uncertainty of model prediction.

However, in previous studies, the starting value of MCMC calculations, i.e., the initial value of the Markov chain, is usually chosen manually from a prior distribution. The non-optimized initial value will influence the Markov chain quality and lead to slow convergence of the posterior distribution. The MCMC calculation takes a tremendous amount of time in the case of an environmental model with multiple parameters (Malve et al., 2007). Moreover, the confidence intervals of water quality indexes are oversized, indicating bad convergence efficiency of the posterior distribution for model prediction.

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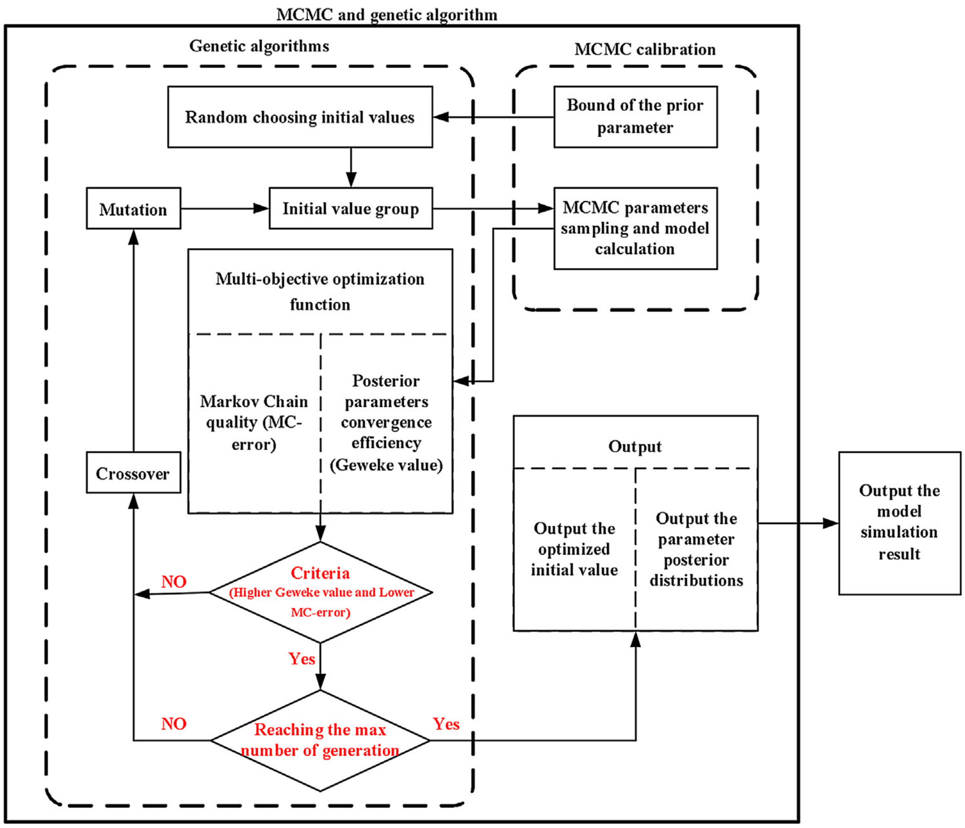

Fig. 1. Flow chart of the MCMC-GA.

Genetic algorithms are feasible for information extraction and optimization in environmental modeling (Leardi, 2000). Genetic algorithms and Bayesian Neural Networks were integrated to forecast a probabilistic hydrologic model in a past study (Zhang et al., 2011). In this study, a genetic algorithm was applied to optimize the initial value of the Markov chain in the MCMC calculation process. The MCMC method integrated with the genetic algorithm (MCMC-GA) was developed to improve sampling performance. This new algorithm based on Bayesian methodology is used to calibrate the eutrophication model parameters and produce model simulations. Then, by comparing the posterior distributions of parameters and simulation results between the MCMC-GA and classical MCMC method, the advantage of the new algorithm is discussed. Finally, a water quality assessment is also conducted for eutrophication management based on an urban lake in North China.

2. Methods

This section focuses on the basic conceptual design of the MCMC-GA algorithm and the eutrophication model used in this study.

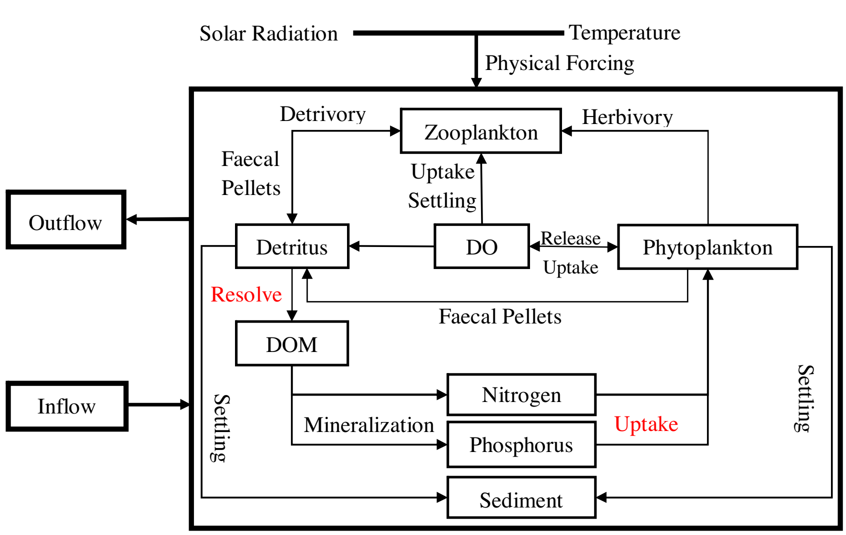

Fig. 2. The nutrient-detritus-phytoplankton-zooplankton model is used to reproduce urban lake dynamics. Arrows indicate flows through the system. Temperature and solar radiation are the external drivers of phytoplankton growth. Zooplankton has two food sources: detritus and phytoplankton. The basal metabolism excreted by phytoplankton and zooplankton is detritus. DO is consumed by phytoplankton, zooplankton, and detritus. Phytoplankton and detritus settle in exogenous inflows and outflows.

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