JOURNAL OF ENVIRONMENTAL SCIENCES 26 (2014) 1783–1790

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Uncertainty analyses on the calculation of water environmental capacity by an innovative holistic method and its application to the Dongjiang River

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ARTICLE INFO

Article history:
Received 28 October 2013
Revised 4 April 2014
Accepted 8 April 2014
Available online 9 July 2014

Keywords:
Water environmental capacity
Model uncertainty
Holistic approach
Dongjiang River

ABSTRACT

The estimation and allocation of water environmental capacity (WEC) are essential to water quality management and social–economic interests. However, there is inevitable uncertainty in the capacity estimation due to model conceptualization, data collection and parameter calibration. An innovative holistic approach was developed, which took both independence and relevance between parameters into account to analyze the uncertainties in WEC calculation and estimate the margin of safety. The Dongjiang River was taken as the case to demonstrate the method, focusing on the chemical oxygen demand and NH_4^+–N that were the two major water quality problems in the river. The results showed that the proposed holistic approach is very promising and applicable compared to traditional methods of uncertainty analysis.

Introduction

Management of water environmental capacity (WEC) (Wang et al., 1995; Han et al., 2010; Li et al., 2010) is a key factor in pollution control of water bodies (Arrow et al., 1995; Keller and Cavallaro, 2008). Based on the estimation of WEC, the total allowable amount of pollutants discharged into water bodies can be obtained and allocated properly among different industries and areas (Burn and Lence, 1992), in order to make sure that the emission quantities are within the water environmental carrying capacity.

However, there exist uncertainties in the process of calculating WEC, originating from water quality model conceptualization, parameter calibration and input data (Radwan et al., 2004; Lindenschmidt et al., 2007). Analysis and estimation of the safety interval of WEC in different hydrological periods can ensure the precision and reliability of the load allotment (Liu et al., 2012). If the safety interval is too small, it will increase the risk of exceeding water quality standards (Rezaie et al., 2007); while simply enlarging the safety interval could affect the use of the WEC and hence social–economic activities. Therefore, a proper safety interval must be provided for WEC management (Rezaie et al., 2009), which involves identifying major uncertainty sources, quantifying their degree and relative importance, and determining the safety interval of WEC (Tutmez, 2009; Warmink et al., 2010). Among different sources of model uncertainties, parameter uncertainty (Van Griensven et al., 2006; Shen et al., 2010; Li et al., 2010) is predominant and also widely present due to the increase of model complexity, which greatly increases the number of parameters involved.

Many approaches have been applied to analyze the parameter uncertainty, such as Bayesian updating (Borsuk and Stow, 2000; Borsuk et al., 2004), Monte Carlo simulation (Rezaie et al., 2007; Mannina and Viviani, 2010), probabilistic approach (Borsuk et al., 2002) and the methods based on them. Van Griensven et al. (2006) developed an automatic parameter calibration and uncertainty assessment method using response surfaces for evaluating the impacts of parameter uncertainty. Blasone et al. (2008a, 2008b) proposed the Markov Chain Monte Carlo (MCMC) method, which generates parameter values from a carefully constructed Markov

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http://dx.doi.org/10.1016/j.jes.2014.06.025
1001-0742/

chain; Stein (1987) and Owen (1992) introduced the Latin hypercube stratified sampling technique to the Monte Carlo method for global sensitivity and uncertainty analysis of parameters and input data in a soil organic carbon dynamics model at plot scale and river basin scale. Wang (2002) developed a method that embedded use of a neural network (NN) in a genetic algorithm to analyze the multiple-pattern parameters for robust water quality modeling. However, most of these methods are based on the statistical characteristic of a parameter, which is usually unknown *a priori*. Besides, they assume independence between multiple parameters, which is often not the case in reality.

This study developed an innovative holistic approach that took both independence and relevance between the parameters into account to analyze the uncertainties in WEC calculation and estimate the margin of safety. The mainstream of the Dongjiang River and its major tributaries were taken as the study case.

1. Materials and methods

The study built up a one-dimensional water quality model for chemical oxygen demand (COD) and NH_4^+–N, and used the monitoring data to calibrate the model. The validated model was used to estimate the daily WEC of COD and NH_4^+–N under typical dry flow conditions. Finally the safety intervals of WEC were determined by an innovative holistic method.

1.1. Study area

The Dongjiang River basin (113°52′E–115°52′E, 22°38′N–25°14′N) is located in the northeast of the Pearl River Delta. The total area of the basin is 35,340 km^2, 90.1% of which resides in Guangdong Province. It covers six cities, including Heyuan, Huizhou, Dongguan, Shenzhen, Shaoguan and Meizhou. The rainfall in the basin is very rich, with an annual average of 1950 mm. The rainfall decreases from downstream to upstream (Fig. 1).

The Dongjiang River originates in Xunwu of Jiangxi Province. The main stream flows through Heyuan, Huizhou, and Shilong and discharges into the South China Sea. The river is 562 km long, and 77.4% of it is in Guangdong Province. The river supplies almost 90% of the total water consumption of Hong Kong, which makes it highly important. The water quality in the river is at present fairly good; however, there is an increasing trend of COD and NH_4^+–N concentrations. The study focuses on these parameters in the mainstream and the major tributaries (Fig. 1).

1.2. Hydro-environmental model

A one-dimensional water quality model is developed which contains a flow module and an advection–diffusion-reaction

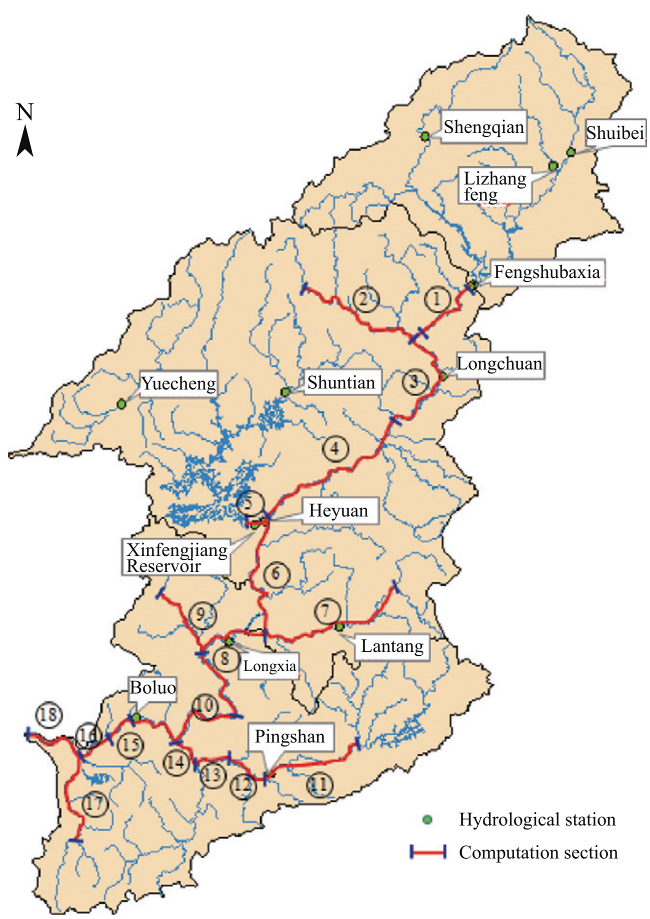

Fig. 1 – Control unit of water environment capacity for main stream and tributaries of the Dongjiang River. The 1–18 means the calculation segments.