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Modeling the purification effects of the constructed *Sphagnum* wetland on phosphorus and heavy metals in Dajiuhu Wetland Reserve, China

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ABSTRACT

Wetlands play a significant role in the dilution of contamination, purification of wastewater, and the transformation of toxic substances. In the Chinese Dajiuhu Wetland Reserve, a simple and practical simulation box was used to examine the purification effects of a simulated *Sphagnum* wetland (SW) on phosphorus (KH_2PO_4) and bivalent metal ions (Cd^{2+}, Cu^{2+}, Pb^{2+}, and Zn^{2+}) at four different concentrations (20, 40, 80, and 160 mg l^{-1}). The modified pseudo-first order kinetics model (Model I) and the pseudo-second order kinetics model (Model II) were used to simulate the purification effect. The results indicated that the purification ability of the SW was remarkable for all of the contaminants; 80.8–98.3% of phosphorus, 71.0–85.4% of Zn^{2+}, 96.8–99.3% of Pb^{2+}, 93.9–99.8% of Cu^{2+}, and 81.4–96.9% of Cd^{2+} were removed from contaminated water after 2 h. The time required for the heavy metal ions to reach equilibrium had a significant positive correlation with their initial concentrations ($p = 0.004–0.048 < 0.05$), whereas the correlation was poor for phosphorus ($p = 0.308 > 0.05$). The dilution effect of the SW played an important role during the first 5 min; average contribution ratio of dilution effects (CRDE) value of each contaminant ranged from 43.0% to 77.4%. Model II had a better quality of fit than Model I based on the correlation coefficients and the average relative deviation between the purification ratio at the 120th minute (PR_{120}) and the purification ratio calculated by the model at the 120th minute ($PR_{120,c}$). Empirical formulas for predicting the purification ability of the SW were derived using the parameters of Model II, which could be used for evaluating the purification value of the SW and for providing the scientific basis for the protection and proper utilization of the Dajiuhu *Sphagnum* wetland.

1. Introduction

Wetlands are known as "Earth's kidney", and they serve many functions, such as water conservation, runoff regulation, peat accumulation, carbon sequestration, pollution purification, toxic substance transformation, and disaster prevention for droughts and floods (Blanken and Rouse, 1996; Zhao, 1999; Chen and Lu, 2003; Peregon et al., 2007; Kayranli et al., 2010; Wang et al., 2010). Hu et al. (2008) demonstrated that the peat layer in wetlands has a significant role in the purification ability of the SW because the peat has a high specific surface area (>200 $m^2\ g^{-1}$) (Asplund et al., 1972; Babel and Kurniawan, 2003; Hu et al., 2008) and a variety of polar functional groups, such as aldehyde, carboxyl, keto, and phenolic hydroxyl groups (Adler and Lundquist, 1963; Bailey et al., 1999), which have a considerable adsorption capacity for efficiently adsorbing heavy metal ions and some nonmetal contaminants, such as cyanide, phosphate, and organic matter (Coupal and Lalancette, 1976; Ho and McKay, 2000; Ringqvist and Oborn, 2002). Since the 1950s, the Dajiuhu government has implemented an increasing number of reclamation policies, such as digging drainage ditches on a large scale and planting vegetation for pasturage and farming. These policies have caused a gradual drying up of the wetland and have decreased the wetland area from 708 ha to 179 ha (Yin et al., 2007; Xiao et al., 2009). Because the water holding capacity of the wetland has decreased, the dominant species transitioned from *Carex argyi* to *Sphagnum palustre*, which has weakened the carbon fixation ability and pollutant carrying capacity of the wetland (Coupal and Lalancette, 1976; Yin et al., 2007). Hu et al. (2008) reported that once the wetland is destroyed, the peat resource will be lost, and then the water purification ability (WPA) of the wetland would no longer exist.

Despite the function of the SW for water conservation, most researchers have only focused on its application as a peat resource (Chen et al., 1990; Gardea et al., 1996; Ho et al., 1996; Sedeh et al., 1996; Ho and McKay, 2000, 2004; Ringqvist et al., 2002; Kalmykova et al., 2008). Some researchers have conducted

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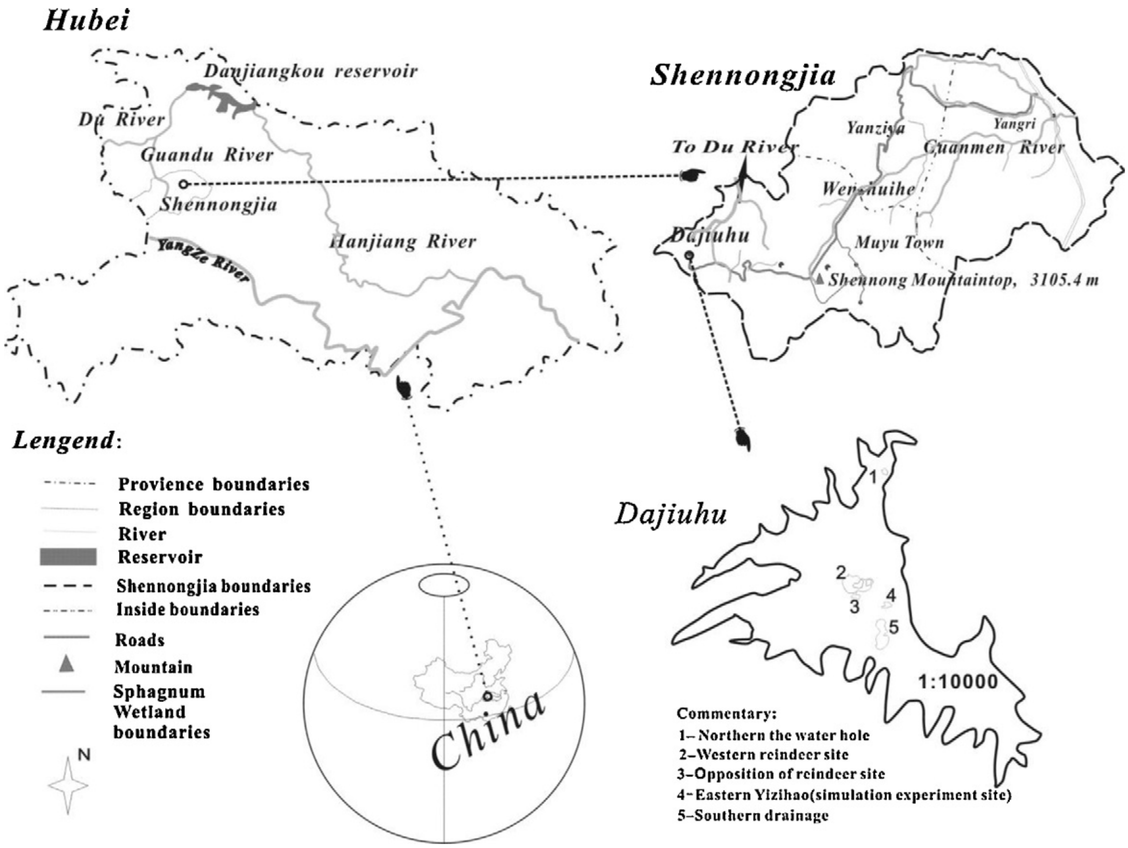

Fig. 1. The geographic location of the experimental site. The lower right-handed part of the figure is the distribution map of the SW, on which simulation experiment is located.

comparative studies of the constructed wetlands' WPA for phosphate when plants existed and when there were not any plants, and concluded that the quality of treated water with plants was better than that without plants (Brix, 1997; Lee and Scholz, 2007; Bindu et al., 2008). Some researchers have used different substrata as a purification material for obtaining the best substratum (Mann, 1997; Sakadevan and Bavor, 1998; Brooks et al., 2000; Xu et al., 2006). Peng et al. (2007) studied the adsorption and release processes under aerobic (>−50 mV) and anaerobic conditions. Some researchers have studied the accumulation and purification of organic matter and heavy metals by the constructed wetlands (von Felde and Kunst, 1997; Tanner et al., 1998; Cheng et al., 2002; Scholz, 2003; Peng et al., 2007). Although all of the above studies were important to our study, they did not directly examine the WPA of the natural SW to the contaminant.

Based on an earlier research conducted at the beginning of August 2007 in the Dajiuhu Wetland Reserve (Hu et al., 2008), this paper further studied the purification effects of the natural SW on nutritious elements of phosphorus (phosphate), cadmium(II), copper(II), lead(II), and zinc(II) through the use of kinetic models to simulate its purification process. The goal of this study was to evaluate the purification value of the SW and to provide the scientific basis for the protection and proper utilization of the Dajiuhu SW. The results from this study will significantly contribute to keeping the water clean for the water source.

2. Materials and methods

2.1. General situation of the study area

The Dajiuhu wetland park is a sub-alpine wetland park, and it is located in the west of the Shennongjia National Nature Reserve in the western Hubei province of China (Fig. 1). This wetland park has an elevation of 1600–1800 m, an annual mean temperature of 7.4 °C, and a monthly mean maximum temperature of 29.0 °C. The lowest temperature ranges from −18 °C to 22 °C, and the annual mean rainfall is 1585.4 mm with 85.9% occurring between April and October. The research site, Dajiuhu SW, belongs to the north subtropical mountain wetland. The peat deposit was formed in the early Holocene Age, and it has significant scientific research value and considerable economic benefit (Li et al., 2007; Yu et al., 2008). The experimental site is located at the edge of the basin, with flat terrain and hills nearby. The geographic coordinates of the site are 31°29′18.4″N and 110°0′10.5″E. The primary vegetation type is Com. *C. argyi–S. palustre* (Zhao, 1999).

The Dajiuhu *Sphagnum* wetland (SW), which is located in Shennongjia, is a rare type of sub-alpine wetland in China and has a peat layer that is up to 2 m in depth (He et al., 2003). As the source of water for the Duhe River, which is the largest tributary of the Hanjiang River that flows into the Danjiangkou Reservoir—the water source of the Middle Line Project of Water Transfer from the South to the North (MLPWTSN) in China, the Dajiuhu wetland plays a critical role in safeguarding the water quality in the Han River basin and the Danjiangkou Reservoir (Yu et al., 2008).

2.2. Simulation device

First, a hole with a diameter of 35 (±1) mm was drilled at the bottom of the lateral wall of a household plastic box (specifications: 300 mm × 400 mm × 260 mm, wall thickness 2 mm, Jinzun Daily Necessities Co., Ltd., Shanghai, China). Secondly, the hole was blocked with a rubber plug, which contained a glass tube. Thirdly, the tube outside of the box was covered with a latex tube with a spring water stopper and the inside part was covered with gauze.