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Research papers

Acid deposition and assessment of its critical load for the environmental health of waterbodies in a subtropical watershed, China

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ABSTRACT

Atmospheric acidic deposition in subtropical watersheds poses an environmental risk of causing acidification of aquatic ecosystems. In this study, we evaluated the frequency of acid deposition in a subtropical forest ecosystem and the associated critical loads of acidity for a sensitive aquatic ecosystem. We found that out of 132 rainfall events, 33(25%) were acidic rainfall occurrences. Estimated wet acid deposition (2282.78 $eq \cdot ha^{-1} \cdot yr^{-1}$), consistent with SO_4^{2-} and NH_4^+ deposition, was high in spring and summer and low in autumn and winter. Waterbodies surrounded by mixed wood and citrus orchard experience severe acidification, mostly from S deposition because acidic deposition exceeds the corresponding critical loads of acidity. Modifications that take acid rain deposition into consideration are needed for land-use and agricultural management strategies to improve the environmental health of waterbodies in subtropical watersheds.

1. Introduction

Increasing levels of atmospheric NO_3^- and SO_4^{2-} produced by anthropogenic sources, such as fossil fuel combustion, agriculture fertilizer applications, and vehicle exhaust emissions, may result in severe acid deposition (Yu et al., 2016). The cumulative deposition from these sources can enhance the risk of acidification of terrestrial and aquatic ecosystems through a reduced acid buffering capacity and the leaching of NO_3^- and SO_4^{2-} from soil, which can act as acids in surface water (Yamashita et al., 2016). Indeed, a continuous input of anthropogenic acid may decrease the pH and buffering capacity of soil via the buffer ranges for carbonate, cation exchange, and aluminum (Yamashita et al., 2016). Decades of acid deposition have resulted in acidification of soils and surface waters (Krupa, 2003; Rosi-Marshalla et al., 2016), which impairs the health of sensitive vegetation and the water environment through mobilization of aluminum(Al) and other potentially toxic elements (Liu et al., 2010; Liang et al., 2016), declines in aquatic biodiversity (Neves et al., 2009; Bobbink et al., 2010; Bobbink and Hicks, 2014; Rosi-Marshalla et al., 2016; Richard et al., 2017), leaching of base ions in soils (Lovett et al., 1985; Krupa, 2003; Liu et al., 2010; Liu et al., 2013a; Liang et al., 2016), and forest growth (Krupa, 2003; Rosi-Marshalla et al., 2016).

Since 1982, nationwide surveys of acid rain in China have been sponsored by the National Environmental Protection Agency of China (Duan et al., 2016). Globally, China has the third highest levels of acid rain deposition after Europe and North America, with acidic depositional areas accounting for 30% of its land area (Song et al., 2005). Liu et al. (2013b) reported that the average annual bulk deposition of N in China increased by approximately 8 $kg \cdot ha^{-1} \cdot yr^{-1}$ between 1980 (13.2 $kg \cdot ha^{-1} \cdot yr^{-1}$) and 2010 (21.1 $kg \cdot ha^{-1} \cdot yr^{-1}$), while Liu et al. (2016a) showed that the annual deposition of S in China varied from 2.17 $kg \cdot ha^{-1} \cdot yr^{-1}$ to 70.55 $kg \cdot ha^{-1} \cdot yr^{-1}$, with an average of 22.99 $kg \cdot ha^{-1} \cdot yr^{-1}$ from 2000 to 2013.

The critical load of acid deposition refers to a quantitative exposure to acidic deposition below which has not the occurrences of significant harmful effects on specified sensitive elements of the environment (Nilsson, 1988). The critical load can be used to identify resources at risk and to evaluate normatively the effectiveness of regulations and to manage resources (Sullivan and Jenkins, 2014). It is also an internationally recognized scientific means for controlling acid deposition (Duan et al., 2016). In aquatic ecosystems which an acid-neutralizing capacity (ANC) less than about 50 $\mu eq \cdot L^{-1}$, diversity decreases and fish death increases obviously (Sullivan and Jenkins, 2014). Bouwman et al. (2002) estimated the critical load of acidity for red soil and water to be 100

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meq·m^{-2}·yr^{-1}. Sun and Xie (2014) proposed the maximum critical load of sulphur and nitrogen, 2–15 keq·ha^{-1}·yr^{-1} and 1.0–2.5 keq·ha^{-1}·yr^{-1} in the pearl river delta, China, a subtropical region. Li et al. (2017) reported the maximum allowed acid deposition load is less than 2 keq·ha^{-1}·yr^{-1}inmost regions of Southern China, which means the region is very sensitive to acid deposition. Many studies have shown the impacts of acid deposition on ecosystems in China (Cao et al., 2013; Tian et al., 2013; Zhang et al., 2013; Guo and Wang, 2015) and the critical loads of acid deposition for water (Rapp, 2001; Ye et al., 2002a,b,c; Shaw et al., 2013), but the relationship between the critical load threshold of acid deposition for water and land use in subtropical regions is still unclear (Li et al., 2017).

Red soil is widely distributed in southeast China and belongs to a highly weathered soil type. The red soil of the region, classed as an UdicFerrisol, consists of red sandstone and mudstone (Gao et al., 2014a; 2016b); soil pH, cation exchange capacity, and base saturation are low. Clay minerals are mainly kaolinite and iron oxide to aluminum, which lead to a poor buffering capacity of red soil. Red soil is reasonably sensitive to acid deposition (Huang et al., 2005), and the red soil region of southern China is known to be heavily polluted with acid deposition. The aims of this study are to document the seasonal changes in the chemical characteristics of acid deposition in a subtropical watershed by long-term environmental monitoring, identify the critical loads of acid deposition for water in relation to different land-uses, and evaluate the frequency of acid deposition in a subtropical forest ecosystem and the associated critical loads of acidity for a sensitive aquatic ecosystem to provide much-needed technical support and a theoretical basis for the regulation of acid deposition in the future.

2. Materials and methods

2.1. Study area

The study area is located within the Chinese Academy of Sciences' Qianyanzhou Experimental Station in the Xiangxi Watershed, Jitai Basin, Taihe County, Jiangxi Province(26°44′48″ N, 115°04′13″E; Fig. 1). The annual mean air temperature is around 16.5 °C, and precipitation is about 1542 mm over the entire region with the typical characteristics of the subtropical monsoon climate (Gao et al., 2014a,b; Hao et al., 2015a). The rainy season is mostly concentrated from March to September, with precipitation between April and June accounting for half the year's total. July and August are characterized by high temperatures, little rain, and prone to drought. The main soil type in the study area is red soil that is noticeably acidic with a pH between 5.0 and 5.5. The soil-forming parent material is mainly red sandstone, sandy conglomerate, mudstone, and river alluvial materials (Chen et al., 2012). For this study, we intensively investigated 8 sampling points in the study area and Xiangxi watershed fora total area of 98 hectare. These waterbodies have previously been studied by Gao et al. (2016a) for wash effect of atmospheric trace metals wet deposition and its source characteristic, and Hao et al. (2015a, 2017a,b) for characteristics and impacts of atmospheric nitrogen wet deposition and C:N:P ratio.

The Jia-zhu stream in the watershed flows through forests, ridge fields, and citrus orchards before emptying into the Jia-zhu River (Hao et al., 2015b). Major land uses include forestland, farmland, and orange groves. The vegetation is mainly man-made forest and secondary vegetation of grasses and shrubs; natural vegetation is rare. Vegetation communities include Masson pine forest, Slash pine forest, Chinese fir forest, mixed wood, ridge field, weed land and citrus orchard in the hills (Gao et al., 2016b).

2.2. Water sample and collection analysis

Eight sampling points in the Xiangxi watershed were selected based on land-use type, spatial distribution, and sampling process (Table 1). The base-flow samples from these sampling points were collected at 0–40 cm of surface water through manual sampling twice a month from November 2014 to May 2016 in 100 mL polyethylene bottles. An automatic sampling device for water and sediment (ISCO6712) of American Teledyne Isco Company was set up

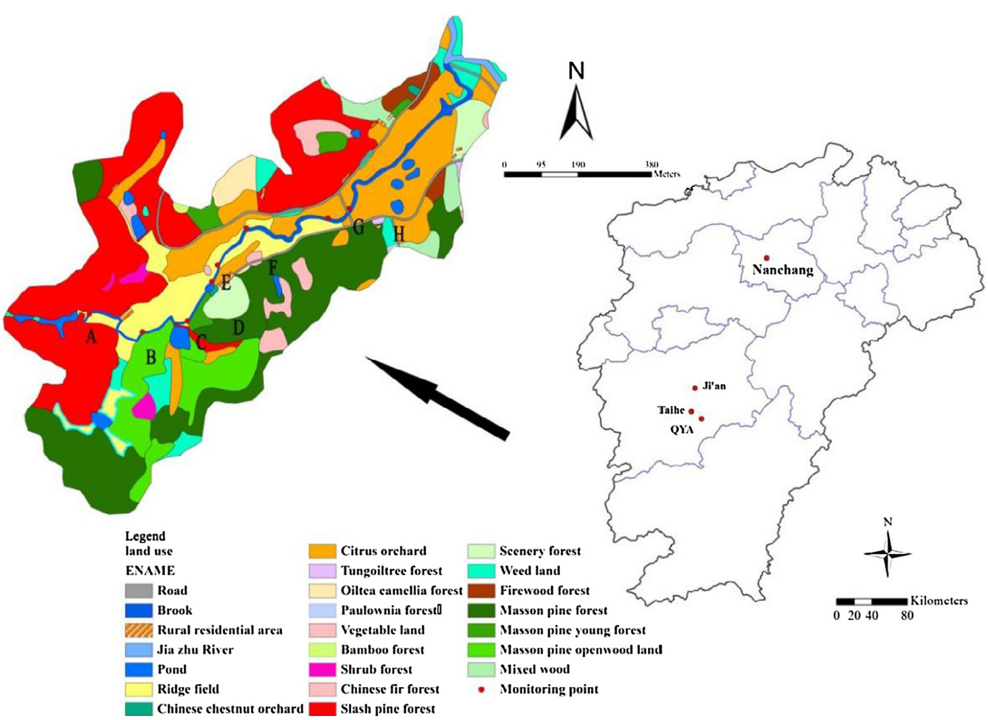

Fig. 1. Sampling point distribution and land use in subtropical Xiangxi watershed.