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Accumulation of arsenic, mercury and heavy metals in lacustrine sediment in relation to eutrophication: Impacts of sources and climate change

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ABSTRACT

Information on both the climate change and anthropogenic activities on lacustrine ecosystem is of crucial importance for understanding the current state and future development of lake systems. The sediment profiles of arsenic, mercury, other metals, and nutrients were used to investigate climate change and anthropogenic activities impacts on three lakes located on the Yunnan-Guizhou Plateau (Lake Chenghai, Qionghai) and Northeastern Plain region (Lake Jingpohu) of China. The enrichment factor (EF), geoaccumulation index (I_{geo}) and anthropogenic factor (AF) were used to assess the enrichment degree of metals. The results show that these lakes have been progressively eutrophied since the development of widespread industrialization and urbanization in these areas. The enrichment of heavy metals is generally not serious (EF < 1.5, $I_{geo} < 0$), except for Cd, Pb, and Hg in Lakes Chenghai and Qionghai. Correlation analysis shows that generally, the heavy metals characterized had significant correlations with nutrient concentrations (TOC, $\delta^{13}C$, TP), which implied the establishment of geochemical associations during transport, that they had similar anthropogenic sources (such as fertilizers), or both. Cluster analysis grouped nutrients, As, and most other metals (except Ca, Mg, Fe, Al), the annual average temperature, and annual precipitation into one category. Increases in both average annual air temperatures and total precipitation are likely influencing the input of heavy metals and nutrients to these lakes.

1. Introduction

Various anthropogenic activities affect lacustrine water quality in many parts of the world, and are likely to continue to for a long period into the future, however, it is anticipated that climatic changes will further aggravate the deterioration of water quality (Helbling et al., 2015; Xu et al., 2017; Laura et al., 2017). The quality of water, and aquatic environments generally, are influenced by climate change, but these relationships are complicated in part due to variations of associated meteorological factors, including precipitation, temperature, radiation, and wind speed/direction. For example, changes in precipitation frequency and intensity can directly impact the input of non-point source pollutants to lakes by regulating surface runoff (Prowse et al., 2006; Karim and Mimura, 2008; Horn et al., 2015). Also, global warming impacts the thermal characteristics of lakes, changing water temperatures, which can extend stratification periods, decreasing the depths of mixed layers and thermoclines, which can the reduce convective mixing (Fan and Kao, 2008; Kraemer et al., 2015; Ma et al., 2015). Lacustrine algal community structures can also be altered by climate change, which in some cases can promote algal productivity and increase the production of algal toxins (Hayes et al., 2015; Reavie et al., 2016). O'Beirne et al. (2017) showed that global warming caused an increase in surface water temperatures and longer ice-free periods, generating longer seasonal stratification, resulting in a rapid increase in primary productivity in Lake Superior, USA. Climate change has facilitated salinization, eutrophication, shrinkage, and even the total desiccation of some lakes (Hayes et al., 2015; Horn et al., 2015; Wu et al., 2017), and so it is urgent to conduct research on the impacts of climate change on lacustrine environments.

Heavy metal contamination of aquatic ecosystems is a major concern due to their toxicity, frequent bioaccumulation, environment persistence, and resulting potential ecological risks (e.g., Atici et al., 2008; Guo et al., 2015). Arsenic (As) is a carcinogenic metalloid that is widely distributed in aquatic environments in various forms, and is recognized as a major pollutant (e.g., Jain and Ali, 2000; Hasegawa et al., 2009). Heavy metals, including As, are derived from a variety of sources, including natural weathering of rocks and sediments, atmospheric deposition, soil erosion, and various anthropogenic activities,

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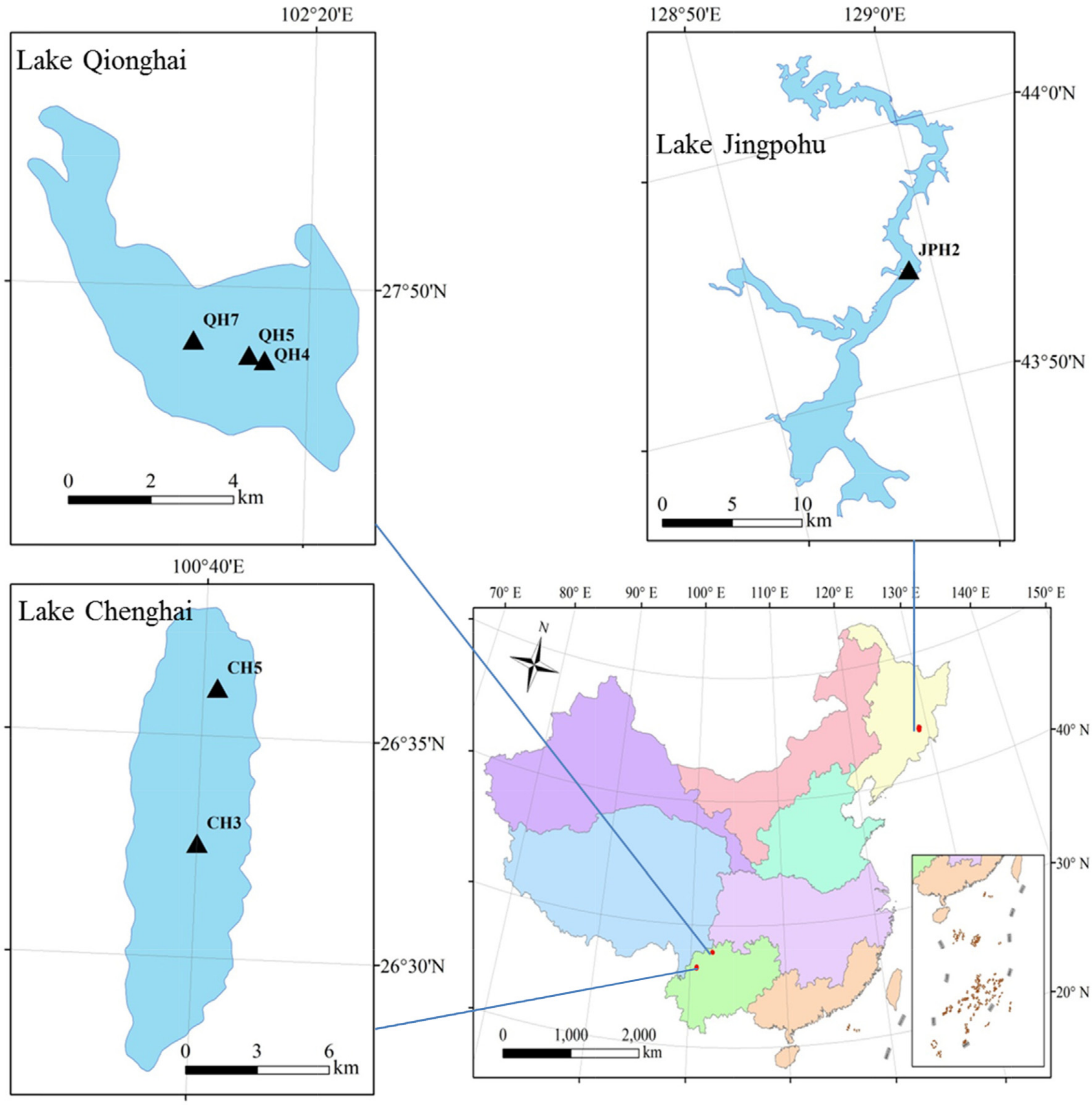

Fig. 1. Maps showing locations of sampling sites.

and they can be transported to and deposited in lacustrine sediments temporarily or permanently (Zhang et al., 2014; Guo et al., 2015a). Lake sediments often serve as effective archives of pollutants, and can provide reliable records of water quality variations over time (e.g., Thevenon et al., 2011; Lintern et al., 2016; Zan et al., 2012a,b; Zan et al., 2014). Stratified sediment cores, dated by stable isotopes, are used extensively to track the past accumulation of heavy metals and persistent organics pollutants (POPs), and reconstruct lake and coupled watershed pollution histories (e.g. Zhang et al., 2014; Li et al., 2015; Guo et al., 2015a,b; Qi et al., 2015). A body of study has focused on the spatial distributions, bioavailability, risk assessment, and source identification of heavy metals in lake sediment (e.g., Atici et al., 2008; Guo et al., 2015). However, less attention has been paid to heavy metal deposition in relation to changing nutrient conditions and/or the dual impacts of anthropogenic activities and climate change (Wu et al., 2017). For instance, trivalent arsenic (As^{3+}) and pentavalent arsenic (As^{5+}) are converted to organoarsenic compounds more frequently in eutrophic lakes than in mesotrophic lakes, which differentially affects biological activity in the water column (Hasegawa et al., 2009). Recent research has shown that the deposition of As, cadmium (Cd), cuprum (Cu), zinc (Zn), nickel (Ni), chromium (Cr), cobalt (Co), and argentum (Ag) was strongly affected and/or controlled by algal organic matter (AOM) in eutrophic, non-point source polluted lakes, suggesting that the abundance of AOM is an important factor in controlling trace metal accumulation in lake sediments (Duan et al., 2014).

Climate change can affect heavy metal deposition in lakes by modifying their input from surface sources in the watershed, by changing atmospheric wet and dry deposition via changes in precipitation, and by impacting mixing and stratification processes, or by changing water chemistry, resulting in some cases in the release of metals from bottom sediments (Visser et al., 2012; Xu et al., 2017). Increases in the amount or intensity of precipitation can drive dissolution of metal carbonates and metal sulfides in sediments, which can then increase the release of heavy metals (e.g., Nedrich and Burton, 2017). Changes in lake water levels caused by extreme rainfall or extreme heat can intensify heavy metal cycling in lake sediment (Nedrich and Burton, 2017). Furthermore, changing climate patterns can enhance the mobilization of natural metal sources in high altitude environments, as shown at Lake Bubal (Zaharescu et al., 2016). However, few investigations have focused on unraveling the mechanisms of heavy metal deposition in lakes with respect to climate change factors, explicitly. In this research, three lakes (Jingpohu, Qionghai, Chenghai) on the Northeastern Plain, and Yunnan-Guizhou Plateau regions of China were sampled to examine various metals (iron (Fe), aluminum (Al), Cu, Zn,