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Ecological risk assessment and distribution of potentially harmful trace elements in lake sediments of Songnen Plain, NE China

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ABSTRACT

In order to understand the distribution and the ecological risk of the potentially harmful trace elements (PHTEs) in lake sediments of Songnen Plain, northeast (NE) China, an integrated survey of PHTEs (As, Cd, Cr, Cu, Ni, Pb, Zn and Ti) was conducted in July 2015 in 11 shallow lakes adjacent to Qiqihar and Daqing. The enrichment factor (EF) and Index of geoaccumulation (I_{geo}) results showed that Cd was obviously enriched in all lakes and reached the moderate pollution level. A comparison of PHTE concentrations in the lake sediments from 2005 to 2015 found the PHTEs pollution status doubled. Multivariate statistical analysis identified the heavy industries of petroleum and steel in the cities close to lakes and excessive agricultural fertilizing in the region as possible pollution sources of the PHTEs. The Håkanson index method (RI) and the sediment quality guidelines (SQGs) were used to assess the potential risk of PHTEs in sediments. The risk degree of 11 lakes had reached a medium level of potential ecological risk except for one lake which had a low potential ecological risk status. The Songnen Plain has been significantly affected by anthropogenic activities and this study provides an effective reference for the environmental protection and management of lakes (heavy metal pollution and control) around the heavy industrial cities of China and the world.

1. Introduction

In the past hundred years the major factors driving global change have shifted from natural to human factors, and human activities have had a great impact on the ecological environment (Vitousek et al., 1997; Lewis and Maslin, 2015). With the rapid development of heavy industries in coal, oil and other chemical industries, the human production and living level have greatly improved. However, coal, oil and other chemical factories introduce large amounts of potentially harmful trace elements (PHTEs) into the surrounding environment (Stigter et al., 2000), which has significantly disturbed natural biogeochemical cycles (Rauch and Pacyna, 2009) and increasingly resulted in serious environmental pollution (Li et al., 2017; Wu et al., 2017). Lakes and wetlands are important ecosystems and they support human land use activities, and their sediments tend to act as sinks for the PHTEs accumulation due to less water fluidity (Han et al., 2014). The PHTEs are a typical type of depositional contaminant which are highly toxic, non-degradable, and persist in the system for long periods of time. PHTEs contaminated sediments have great ecological impact on the organisms, and pose a risk to human health through drinking of contaminated water and the food chain effects (Chapman et al., 1998). Therefore, the impact of human activities on freshwater ecological systems is an important scientific issue. The quantitative separation of the PHTEs natural background and the contribution from human activities is an important precondition for the scientific evaluation of the potential ecological risk of PHTEs and the development strategy of regional freshwater ecosystem protection (Q. Cheng et al., 2015; Lin et al., 2016).

With respect to the PHTEs risk assessment, there are many useful methods including the enrichment factors (EFs), sediment quality guidelines (SQGs), Index of geoaccumulation (I_{geo}) and so on (Håkanson, 1980; Yuan et al., 2011; Hou et al., 2013; Zhang et al., 2017). Each method fits different specific conditions. The most common methods to evaluate the ecological risk of PHTEs are I_{geo} and the Håkanson potential ecological risk index. The former takes into account the geochemical background and can directly reflect the enrichment degree of the PHTEs. The latter is based on the PHTEs' ecological, environmental and toxicology effect and can indicate the comprehensive effect of multiple pollutants (Yi et al., 2011; Goher et al., 2014). Therefore, the integrated use of both methods can evaluate the

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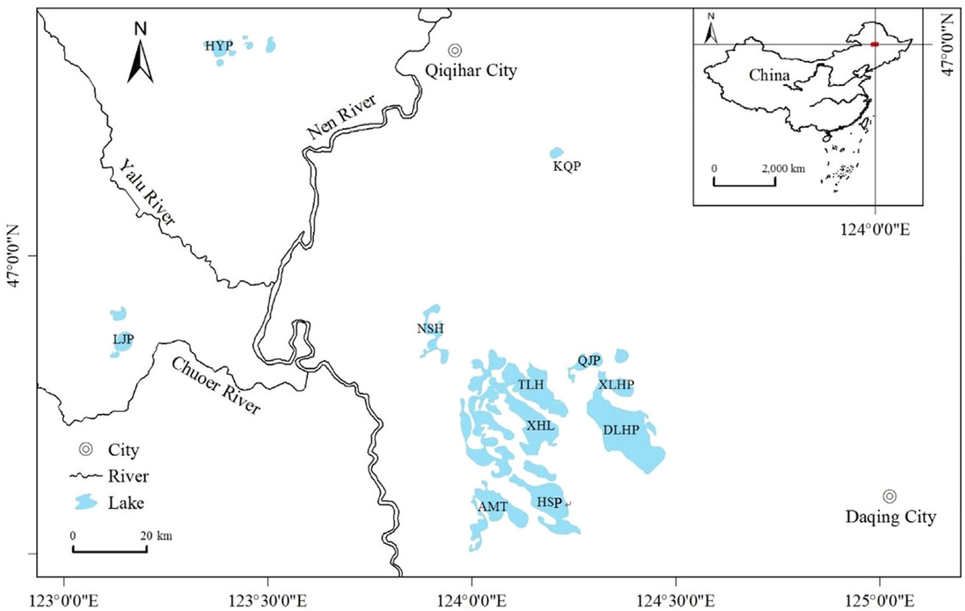

Fig. 1. The study area map showing the locations of the 11 lakes around heavy industrial city (Qiqihar city) and petroleum city (Daqing city), NE China.

pollution level and try to identify the source of pollution and the potential harm to the environment. In addition, a multivariate approach is helpful in revealing possible sources of the PHTEs and relationships between them (Bai et al., 2011; Yin et al., 2011; Zahra et al., 2014; Zamani-Ahmadmahmoodi et al., 2017).

China is currently in a period of rapid social and economic development (H. Cheng et al., 2015; Q. Cheng et al., 2015). Except for the resource consumption, one of the urgent problems that needs to be faced is the rapid development is causing significant environmental pollution and degradation. In addition, oil resources are one of the most important sources of energy driving economic development (Yu et al., 2003). Industrial production and the consumption of oil resources has been increasing, resulting in serious environmental pollution and ecological degradation (Pratte et al., 2018). In northeast (NE) China, cities like Daqing in Songnen Plain are an important oil base and have particularly serious environmental problems caused by the PHTEs, in particular the chalcophile elements (e.g., Cd, Cu, Ni, Pb, Zn) caused by the oil refining process and combustion of fossil fuels (Yu et al., 2003; Sun et al., 2013). In addition, the Songnen Plain supports a large number of lakes and wetlands, and is rich in water resources which support many kinds of fish and other aquatic animals (Zhang et al., 2012). The lakes and wetlands in this region have been affected by the PHTEs pollution for a long time (Yu et al., 2003). In addition to the oil and chemical industrial production, fish farming and agriculture are also sources of pollution and several PHTEs may be associated with the application of phosphate fertilizer, animal manure, sewage sludge and the use of waste water (Luo et al., 2009; Xu et al., 2015). Recently, the water quality of surface water in the Songnen Plain had been assessed by hydrochemical analysis of the PHTEs (Wang and Zang, 2014; Zhang et al., 2012). Geochemical assessment of agricultural soil in this region was also conducted in 2009–2010 (Sun et al., 2013). As for the lake and wetland sediments, there was a report of toxic metals in surface sediments from Dalonghu Lake and Lianhuan Lake in this region (H. Cheng et al., 2015; Q. Cheng et al., 2015), while the samples were collected in 2005 and the results would reflect the sediment status around 10 years ago. The novel understanding of the PHTEs pollution level and the potential ecological risk in the whole region is necessary and particularly important for the region because of the clean water needs in fish farming and agricultural irrigation.

Therefore, we chose 11 shallow lakes in the Songnen Plain of NE China as our research area, and analyzed the main PHTEs (As, Cd, Cu, Cr, Ni, Pb and Zn) in the surface lake sediments. The objectives of this study are 1) to identify the PHTEs distribution in the lake sediment; 2) to investigate the PHTEs pollution level in the Songnen Plain; and 3) to evaluate the potential ecological risk in the Songnen Plain. Results of this work will inform environmental management plans in the region and provides a reference to others areas with heavy industries.

2. Materials and methods

2.1. Study area

The Songnen Plain (121°27′–128°12′E, 43°36′–49°45′N) is an alluvial, lacustrine and aeolian deposit in central NE China. The plain is 1.87×10^5 km^2 and surrounded by the Changbai Mountains in the east, the Great Hinggan Mountains in the west, and the Small Hinggan Mountains in the north (Zhang et al., 2012; Sun et al., 2013). As part of the Northeast Plain, the Songnen Plain is one of the most important grain producing areas in China. The alluvial plain was formed by sedimentary deposits from the Songhua and Nen River. Thousands of tons of sediments are annually carried onto the plain by runoff from the surrounding mountains. The mean annual temperature is 4.0–5.5 °C, with the lowest temperature occurring in January at around − 18.5 °C, and the highest temperature in July at 22.4 °C. The mean annual precipitation ranges from 500 to 600 mm in the east elevated plain to 300–450 mm in the west piedmont area, with 70–80% of precipitation falling in the summer monsoon season from June to September. Long-term droughts periodically cause great losses in the agricultural production and economic development in this region. The potential evaporation depth is 700–1100 mm (Deng et al., 2001).

2.2. Sediment sampling

Sediment cores were collected from the center and the surrounding of the lakes in July 2015 using a gravity corer (Fig. 1). The number of sediment cores collected depended on the area of the lakes. Most areas of them are 10–100 km^2, and 4–6 cores were collected; except for Dalonghupao (DLHP) with 10 cores (Table S1). The latitude, longitude and altitude at the sampling sites were determined with a portable global positioning system (Garmin GPS 62SC, Garmin International, Olathe, Kansas, USA). The oxidation-reduction potential (ORP) and pH for the water-sediment interface was measured on-site with a Bante220