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Influence of ore deposits on river sediment compositions in Dan River drainage, China

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ABSTRACT

We mainly investigated trace element contamination of surface sediments in the Dan River drainage, the source of drinking water for the South to North Water Transfer Project, China, to determine trace element sources and associated levels of risk. Sediment samples were collected at 95 sites along the Dan River in connection with field surveys, and total element concentrations were determined using inductively coupled plasma-mass spectrometry (ICP-MS). Concentrations of most elements were lower than background levels; however, toxic heavy metals, such as As, Cd, Pb, and Sb, showed extremely high concentrations at sites associated with nearby metal ore deposits. Moreover, the spatial variations of contamination by some heavy metals were directly related to the distributions of metal ore deposits in the North and South Qinling terrains; sediment samples with especially high concentrations of Sb and As were from the North Qinling terrain, while sediments with especially high concentrations of Cd and Pb were from the South Qinling terrain, suggesting that metal ore distributions and associated mining activity strongly influence the distribution of heavy metals and heavy metal contamination in the Dan River drainage. Multivariate techniques, including Pearson correlation, hierarchical cluster, and factor analysis, were used to assess the sources of metal contamination. Results indicate that distributions of Al, Ba, Cu, Fe, Mg, Mn, Pb, Sn, Ti, V and Zn are controlled by natural sources; Co and Cr by a combination of geological and anthropogenic inputs; whereas As, Cd, Ni, Sb, and Pb appear to be primarily of anthropogenic origin. The ecological risk associated with heavy metal contamination of sediments was rated as moderate, based on an assessment using geo-accumulation index (I_{geo}), enrichment factor (EF), potential ecological risk index (RI) and mean probable effect concentration quotient (m_{PECQ}).

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1. Introduction

Because trace metals in sediments are partitioned from the surrounding water, they represent a potential source reservoir of metals that can be released into the hydrological cycle, thereby affecting the quality of aquatic systems. The increasing worldwide contamination of aquatic systems with thousands of industrial and natural pollutants is a critical environmental problem (Schwarzenbach et al., 2006). Sediments are regarded as the ultimate sink for heavy metal cations (Gibbs, 1973), which have therefore been widely used as environmental indicators; thus, stream sediment monitoring can present important information about the extent of pollution in drainages (Acosta et al., 2014; Mirzaei et al., 2014; Singh et al., 2002; Wang et al., 2014; Yuan et al., 2014). River systems in many parts of the world have been contaminated by high concentrations of heavy metals; these include the Yangtze River (Wen et al., 2013; Yang et al., 2014; Zhang et al., 2009), Yellow River (Zhang and Liu, 2002; Zhang and Marie, 1988), Pearl River (Cheung et al., 2003), and Songhua River (Lin et al., 2008) in China, the Seine River in France (Meybeck et al., 2007), the Medway River in the UK (Cundy et al., 2005), the Odiel River in Spain (Borrego et al., 2002) and the Ganges River in India (Singh, 2001). The presence of heavy metals in sediments suggests the possibility of both geological and anthropogenic inputs to watershed (Acevedo-Figueroa et al., 2006; Adamo et al., 2006). Weathering and erosion of deposits enriched in heavy metals naturally generate a high proportion of heavy metal-bearing particles into river systems. Thus, natural surface processes determine background levels of trace metals in river sediments, while anthropogenic activities such as mining and urbanization can lead to abnormally high accumulations of metals.

Trace metals in sediments can be released into overlying water, thereby posing risks to benthic and pelagic biota (Hudson-Edwards, 2003), as well as contaminating drinking water source areas. Hence, data on trace metal concentrations in sediments play an important role in monitoring and evaluating environmental risks, and in mitigating the risks by various remedial measures (Chapman and Wang, 2001; Foster and Charlesworth, 1996; Sarkar et al., 2004).

The South to North Water Transfer Project in China is one of the largest water projects in the world. The project was designed to address

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the water shortage issues in North China, by diverting 45 billion m^3 of water per year from the lower (via the eastern route), middle (via the middle route), and upper (via the western route) reaches of the Yangtze River in South China (Jiang, 2009; Zhang, 2009). The middle route, which has been in the process of construction for many years, has an expected annual transfer capacity of 13 billion m^3. Via this route, water is collected from Danjiangkou Reservoir on the Han River, a tributary of the Yangtze River, and diverted to North China, including to the areas of Beijing, Tianjin and other main cities along the route, where it will be used for domestic, irrigation, and industrial purposes (Dong et al., 2011d). However, as noted in previous studies, the water quality in the source areas of the Danjiangkou Reservoir, as well as in the reservoir itself and along the middle route, has been severely degraded in recent years (Bu et al., 2010; Li and Zhang, 2010a, 2010b; Li et al., 2008, 2011).

Danjiangkou Reservoir, with a water surface area of 745 km^2, is located at the juncture of Hubei and Henan provinces (Fig. 1). Since construction of the reservoir in the 1970s, water quality has improved downstream of the reservoir, indicating that sources of contamination in the drainage are in upstream regions; levels of nitrogen and COD_{Mn} in the reservoir are also relatively high (Li et al., 2009). The spatial distribution of trace elements in the upper Han River suggests that levels of contamination in Danjiangkou Reservoir are particularly high (Li and Zhang, 2010b). Li et al. (2008) found that concentrations of toxic heavy metals (e.g., As, Pb and Sb) in the water of Danjiangkou Reservoir exceeded World Health Organization (WHO) standards, and suggested that the contamination poses health risks in the region.

The water quality of Danjiangkou Reservoir is controlled mainly by inputs from the Dan River and Han River drainages, which are the primary source areas for reservoir waters. As compared with other rivers in the reservoir drainage, the Dan River is the dominant influence on water quality, as it flows directly into the reservoir; thus, heavy metal-bearing sediments are deposited directly into reservoir waters. In addition, sediments with high concentrations of heavy metals can contaminate flowing water after a period of sediment storage, resulting in later pollution of reservoir waters. While Danjiangkou Reservoir is an important source of water for both domestic consumption and agricultural irrigation, few studies have been conducted on heavy metal contamination of surface sediments in reservoir source areas.

The present study focuses on the Dan River drainage, which originates in the Shangzhou region, Shaanxi Province, and flows through the North Qinling and South Qinling geological terrains. Several metal ore deposits are located in the drainage, including for example Sb, Ni, and Pb ore bodies. This study characterized the concentration and spatial distribution of 17 trace elements and heavy metals, based on a study of total 95 sediment samples from the Dan River drainage; elements include those that are naturally occurring, as well as those with an anthropogenic origin. Sources of heavy metal pollution were identified based on an integrated geological and statistical analysis, and the sediment contamination and associated risk levels were evaluated by risk indices, including the geo-accumulation index (I_{geo}), enrichment factor (EF), potential ecological risk index (RI) and probable effect concentration quotient (m_{PECQ}), thus providing an accurate representation of sediment quality within the drainage. The research will promote and contribute to effective management and conservation strategies of drinking water sources, and also help to improve public health in populations served by the inter-basin South to North Water Transfer Project.

2. Site description and geology of the catchment area

The Dan River (formerly known as Dan Shui) drainage (109°30′–112°00′ E, 32°30′–34°10′ N), located in Shaanxi and Henan provinces, China, is the longest tributary of the Han River. The Dan River rises in Heilongkou County in the Qinling Mountains and then flows southeast through Shangluo City, Danfeng County, Shangnan County, Xixia County and Xichuan County, before flowing directly into Danjiangkou Reservoir located on the Han River. The Dan River drainage, with an area of 16,812 km^2, is ~2000 m wide and 443 km long, and spans an elevation of 200–2500 m (Fig. 1). Most of the Dan River drainage is mountainous, and well vegetated. The climate in the drainage basin can be considered as north sub-tropic monsoon, with an annual mean temperature of 11 °C–14 °C, and extreme maximum and minimum temperatures of 40.5 °C and −12 °C, respectively. The multiannual mean precipitation in the drainage is 743.5 mm, while the annual potential evaporation varies from 979.3 mm in upstream areas to 1557.5 mm in downstream areas. The temporal distribution of precipitation throughout the year is strongly heterogeneous. More than 80% of the total

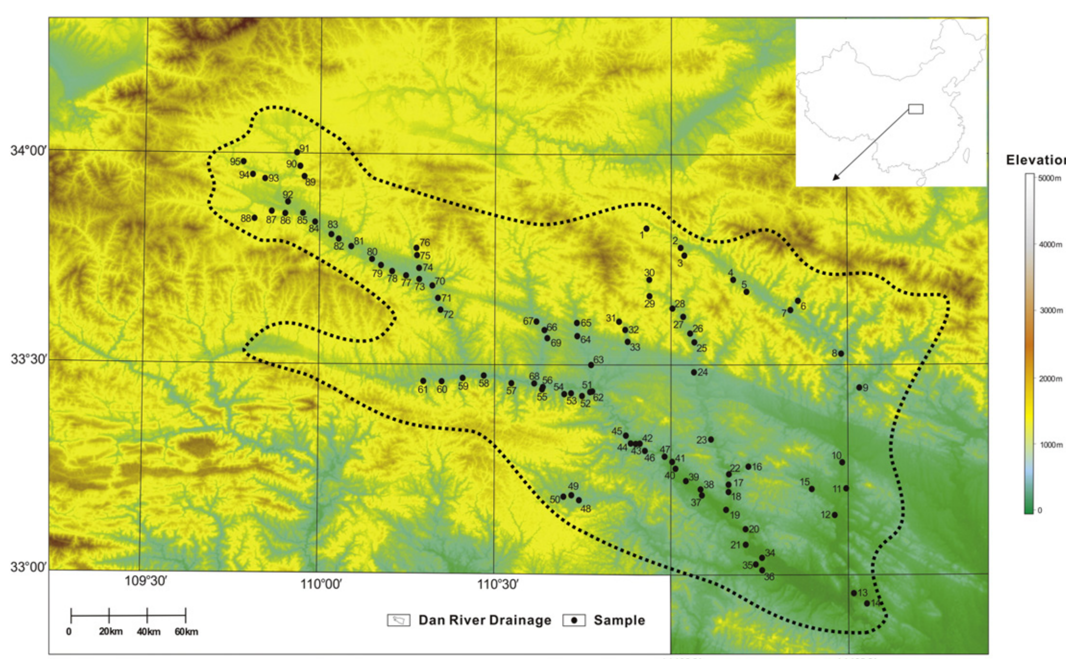

Fig. 1. Sampling sites and drainage systems of the Dan River drainage, China.

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