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Spatial variation and contamination assessment of heavy metals in sediments in the Manwan Reservoir, Lancang River

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ABSTRACT

Due to the construction and operation of Manwan Dam on the Lancang River, sediments were likely to deposit in the impoundment. In this research, sediment samples were collected from 17 sites in the whole reservoir in 2011 to investigate the distribution and sources of heavy metals (Al, As, Cu, Fe, Cd, Cr, Mn, Pb and Zn), as well as to assess the heavy metal contamination status. The results obtained using Principal Component Analysis (PCA) showed that the sources of heavy metals were mainly divided into two groups, natural factors and anthropogenic input. The anthropogenic inputs mainly came from industrial activities of the tributary rivers such as heavy metal mining and smelting, and agricultural practices such as fertilising and pesticide consumption. The sediment quality was assessed according to the sediment guidelines and the enrichment factor (*EF*). Concentrations of As, Cd, Cr, Cu, Pb and Zn in sediments at some of the sites exceeded either the Threshold Effects Level (TEL) of US National Oceanic and Atmospheric Administration (NOAA) or Effects Range-Low (ERL) of the Canadian Sediment Quality guidelines. The high levels of these heavy metals could cause adverse effects. One-way analysis of variance for spatial analysis revealed that no significant differences were found for most heavy metals at the tail, centre and head of the reservoir except that Cr showed significant differences ($P < 0.01$) at the reservoir centre and the head. Significant variations for some heavy metals were observed in the tributaries and in the mainstream. The comparative *EF* indices suggested that As, Cd, Pb, Zn and Mn were slightly enriched and Cr, Fe and Cu were not enriched but had different "high–low" orders at the tail, centre and head of the reservoir. We depicted distribution map of enrichment factors for all heavy metals and the potential ecological risk index (*RI*) was applied to produce the comprehensive risk distribution map.

1. Introduction

Hydroelectric dam construction has become one of the most controversial activities that affect the development of most countries. Hydroelectric dam construction is a major driving force for social and environmental problems (Fearnside, 2005). Research on environmental or ecological impacts caused by these anthropogenic activities becomes more important as aquatic systems suffer from the increasing pressure of hydroelectric construction (Bai et al., 2009). Heavy metals or special groups of contaminants in the water reservoir affect environmental quality by accumulating in reservoirs and resulting in serious human health hazards and significant ecological effects throughout the food chain (Loska and Wiechula, 2003). Therefore, heavy metal contamination in the water reservoir has led to increasing concerns in recent years.

Toxicity, persistence and non-degradability make the heavy metals serious pollutants in the environment (Klavins et al., 2000; Tam and Wong, 2000; Yuan et al., 2004). In the past few decades, heavy metals have been discharged into the world rivers, estuaries or reservoirs due to rapid industrialisation (Chen et al., 2004; Cobelo-García and Prego, 2003; Loska and Wiechula, 2003).The elevation of metal levels in a reservoir is caused mainly by an increase in their concentrations in the bottom sediments (Loska and Wiechula, 2003). Sediments revealed less variation in time and space (Pekey, 2006). Sediments are considered integrators and amplifiers of the concentrations of these elements in the waters which pass over and transport them (DelValls et al., 1998). Sediments provide an excellent proof of anthropogenic impact, allowing more consistent assessment of spatial and temporal contamination (Beiras et al., 2003; Caccia et al., 2003; Guevara et al., 2005). Many research projects on the spatial variation and assessment of heavy metals in sediments in coastal zones and rivers have been conducted, such as studies of Izmit Bay in Turkey (Pekey, 2006), Aqaba Gulf in Egypt (Youssef and El-Said, 2011), mangrove swamps in Hong Kong (Tam and Wong, 2000), the Keelung River in Taiwan (Huang and Lin, 2003) and the Pearl River Estuary in China (Liu et al., 2003). These investigations focused primarily on natural waters and were generally focused on the regional scale (Zhao et al., 2011). In fact, reservoir sediments have also been a great concern as they can

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shift from sink to source of heavy metals for fluvial systems by diffusion at the water-sediment interface (Blasco et al., 2000; Van Den Berg et al., 1999), bioturbation (Zoumis et al., 2001) or resuspension caused by dredging (Audry et al., 2004) or flooding. However, relatively few studies have centred on river systems which were planned or constructed with cascade hydropower dams in which the heavy metals in sediments might be affected by the formative reservoirs and prolonged water renewal time (Kummu and Varis, 2007).

Spatial surveys of metal concentrations in the sediment and comparisons between these concentrations and non-polluted baselines are a key step in the understanding of the transport and deposition of contaminant trace metals in the aquatic systems (Alexander et al., 1993). Sediment analyses play an important role in the assessment of pollution status and the determination of sources of the contaminants.

The aims of this study are to: (1) establish the level of heavy metal contamination in the sediments of the Manwan Reservoir; (2) explore the distribution of heavy metals in sediments in the main stream and tributaries and in the head, centre and tail of the reservoir; (3) assess the extent of contamination of the heavy metals using sediment quality guidelines, enrichment factors and the potential ecological risks; (4) identify sources of contamination; and (5) establish those areas that need efforts to control the levels of contaminants and perform further toxicological testing.

2. Materials and methods

2.1. Study area

The Lancang River (called the Mekong River out of China) originates from the eastern Tibetan Plateau in China and flows through China, Myanmar, Laos, Thailand, Cambodia and Vietnam, being an important international river in Southeast Asia. The study area is subject to a monsoon climate and periodic rainstorms, so the overall rainfall in this watershed is plentiful, and about 70% of the precipitation is concentrated in the summer (He et al., 2006). In the upper Lancang River Basin located in the Yunnan Province of southwest China, the elevation of the river drops dramatically. The river has a channel length of 1170 km and a decreasing elevation of 1780 m at an average gradient of 0.15%. Fourteen cascade hydropower dams along the Lancang River were planned in the 1980s (Jacobs, 2002; Zhao et al., 2012). The Manwan hydroelectric dam is located in the middle reach of the Lancang River and this dam is the first dam of the Lancang mainstream cascade development project actually constructed (Fig. 1), as well as the first multimillion kilowatt hydropower station in Yunnan Province (Zhao et al., 2000). The whole set of power plant units of Manwan Dam was completed in 1996, and the power station started to operate in 2000. The dam is 132 m high with a crest length of 418 m and a backwater of 70 km near the site of the Xiaowan Dam, with a total installed capacity of 150×10^4 kW. The measured maximum sediment concentration of the Manwan Reservoir is 14.3 kg/m^3, and the average sediment concentration is 1 kg/m^3. After dam construction, the reservoir area reaches 23.6 km^2, 2.8 times larger than before. The reservoir water surface is on average 337.1 m wide and is two times more than the water surface in the natural channel.

2.2. Sampling and analytical method

To investigate the spatial variation in heavy metals in the sediments, the samples were collected in June, 2011. Seventeen cross-sectional samples were set

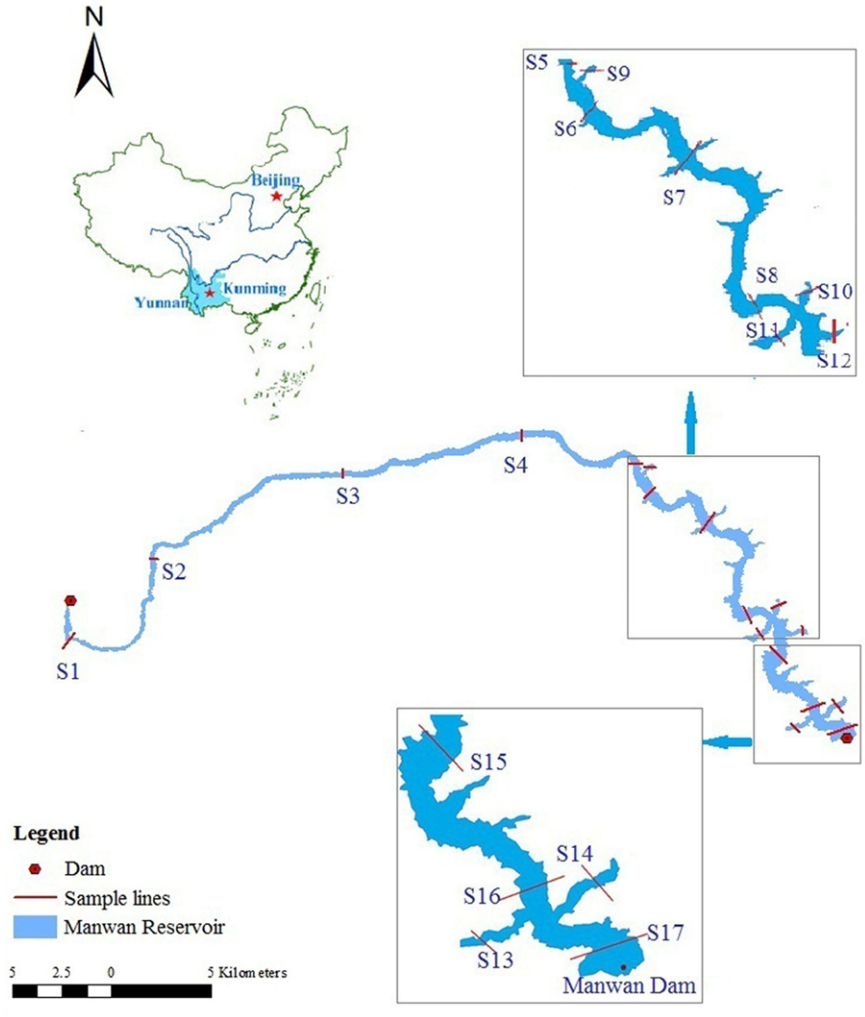

Fig. 1. Location of the Manwan Reservoir and the 17 cross-sectional sediment samples, Yunnan Province, China.