Damming effect on the distribution of mercury in Wujiang River *

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Abstract Seasonal changes in total mercury concentrations in surface water were observed for the Wujiang River, with higher values at the time of greater flow. The total mercury in this river was mostly associated with suspended particles, particulate mercury accounting for 84% of the total mercury flux on average during the high flow period, and 52% of the total mercury flux on average in the low flow period. Significant losses of Hg from the water were observed in the downstreams of the reservoir. In addition, the concentrations of particulate mercury in the downstreams of reservoir appeared to have been enhanced by sediment re-suspension and shoreline erosion caused by flood discharge, while the filtered portion decreased. These observations suggested that reservoirs played an important role in controlling the transport and fate of mercury in the Wujiang River.

Key words damming; reservoir; mercury

1 Introduction

Dam construction is a common anthropogenic intervention of rivers. It is estimated that there are now more than 40000 large dams throughout the world, with an aggregate storage capacity of about 6000 km^3 (McCully, 1996). This represents a seven-fold increase in the standing supply of natural river water (Vörösmarty et al., 1997). Through flow regulation dams provide benefits for many segments of society. Conversely, impounding of rivers also changes the characteristics of a water body from "rivers" to "reservoirs", affecting not only their hydrology, but also their physical, chemical, and biological characteristics. Reservoir construction may disrupt the natural biogeochemical cycles of metals and affect the whole catchment including downstream ecosystems.

The Wujiang River flowing in a karst environment in Guizhou Province and having two main tributaries in the upper reaches (the Sancha River and the Liucong River) is the largest tributary in the upstream of the Yangtze River basin. The drainage basin of the Wujiang River is situated at 26°10′ - 29°45′N and 104°05′ - 108°30′E. It covers a drainage area of approximately 87920 km^2, with an average stream flow of over 1650 m^3/s and an annual runoff of $534 \times 10^8\ m^3 \cdot a^{-1}$ (Han Guilin and Liu Congqiang, 2001). Several reservoirs have been constructed for hydroelectric power generation and flood control in the Wujiang River basin. Furthermore, with the development of the West-to-East Electricity Diverting Project, 11-cascade hydro-electric power stations are planed to be established along the Wujiang River basin. That is to say, the Wujiang River would become a typical "impounding" river. A background survey of mercury distribution in the Wujiang River was carried out during both the high (July, 2002) and low flow periods (December, 2002). Based on this survey, samples along the mainstream were especially selected to examine the damming effect on the distribution of mercury in the Wujiang River (Fig. 1). This study is essential in predicting future impacts of mercury cycling due to the construction of the Three-Gorges Dam in the Yangtze River basin, for this river is similar to the Yangtze River with respect to its geographical environment, reservoir morphology, hydrologic and climatic characteristics.

2 Methods and materials

Water samples were collected at 26 locations along the mainstream of the Wujiang River. Clean polyethylene gloves were worn to collect water samples using a pre-cleaned Teflon bottle. We collected water samples manually while wading slowly up stream, or collected samples by hand from a wood boat moving gently against the current during sampling, by submerging Teflon (FEP) approximately 20 cm beneath the water sur-

ISSN 1000-9426

* This work was financially supported by the "Hundred Talent Plan" and the Program sponsored by Chinese Academy of Sciences and CAS Innovation Project (KZCX2-105), and by the National Natural Science Foundation of China (No. 40173037).

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face to prevent water samples from contamination. Both filtered and unfiltered water samples were collected. Filtered samples were prepared using 0.45-μm nylon membrane filters. Water samples for mercury analysis were collected in pre-cleaned, borosilicate glass bottles. At the field site, the bottles were rinsed three times with the sampled water prior to filling, then filled, and preserved with sub-boiling distilled HCl to yield 0.5% acid solutions, and tightly sealed and doubled-bagged and stored in a wood box. Having been transported back to the laboratory, the samples were stored at +4℃ in the dark until the analyses were performed. The filters were sealed in pre-cleaned PE bags and stored deeply frozen. Analysis was performed on the wet filters. Each batch of filters and bottles were analyzed before used to check the blank.

Analyses of mercury in water samples were completed using the gold trap pre-concentration and CVAFS detection method (Tekran 2500) (Yan Haiyu et al., 2003). The successive steps to determine total particulate mercury were: (1) digesting the filters in 4 mL HNO_3/HCl (3:1 V/V) in a microwave oven in Teflon digestion vessels; (2) diluting the sample to 100 mL; and (3) analysis of a proper fraction of the sample by CVAFS as described above.

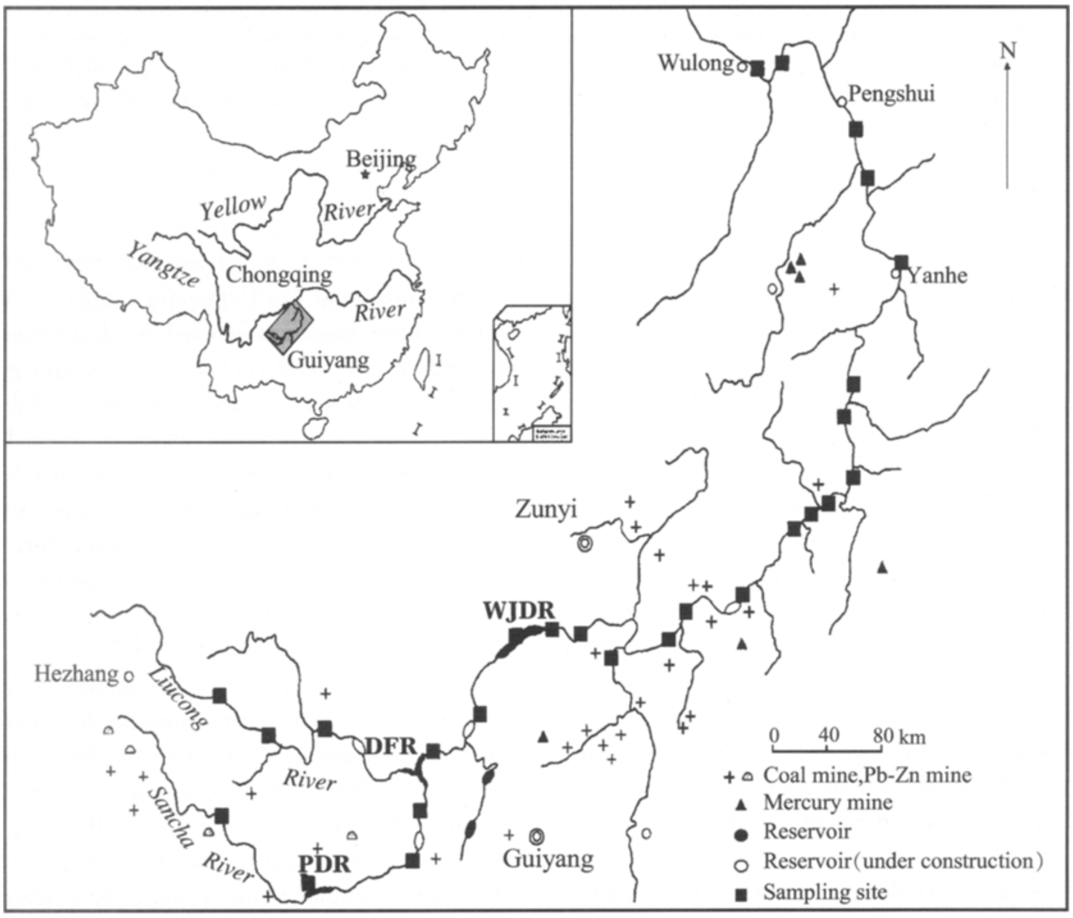

Fig. 1. The locations of lead-zinc mines, coal mines and Hg mines, as sampling sites along the mainstream of the Wujiang River. WJDR. Wujiangdu Reservoir; DFR. Dongfeng Reservoir; PDR. Puding Reservoir.

3 Results and discussion

3.1 Hg distributions

The distribution of mercury in the main course of the Wujiang River is similar to that of the whole river basin, as reported previously (Jiang Hongmei et al., 2003, 2004). Overall, higher total mercury concentrations and fluxes were observed at rainy season than at dry season (Fig. 2). Under both high and low flow conditions, total Hg concentrations in surface water exhibited a similar trend: the total mercury concentrations in the upper and middle reaches of the Wujiang River are obviously lower than in the lower reaches, for the reservoirs are located mainly in these areas.

The total mercury concentrations in whole water samples were positively correlated to particulate mercury (Fig. 3), and the particulate mercury accounts for 84% of the total mercury on average during rainy season. During dry season, however, 52% of the total mercury is present in the particulate phase, indicating that particulate-phase Hg is transported in larger amounts, especially in rainy season. Particulate Hg distributions were similar to those of total Hg in both seasons. The filter-passing Hg concentrations generally increase with increasing total concentrations, but the correlation is significant only in winter ($R = 0.82$, $\alpha < 0.01$).

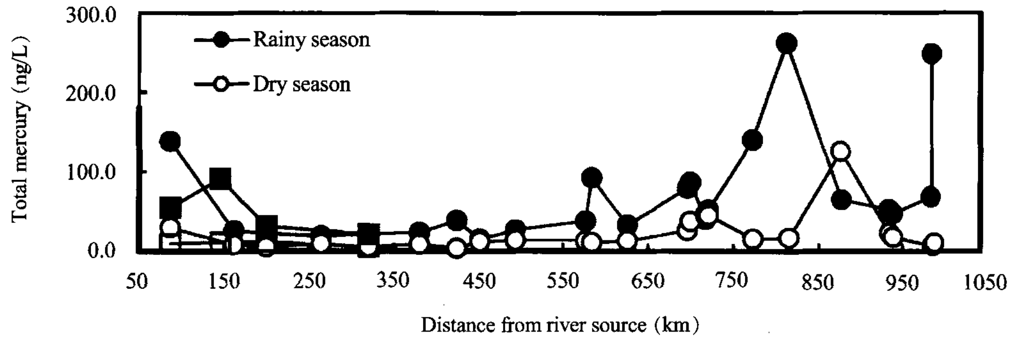

Fig. 2. Total Hg concentrations in the mainstream of the Wujiang River.

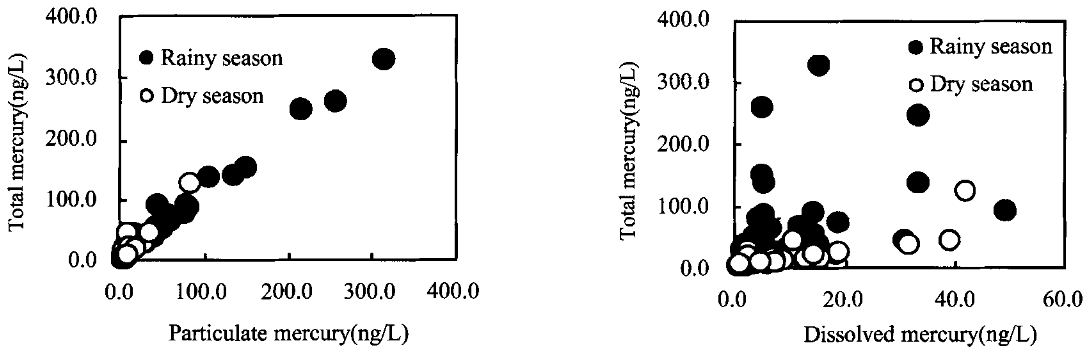

Fig. 3. Plot of HgT vs. HgP and HgD in the mainstream of the Wujiang River.

3.2 Trap effect

Comparisons of total mercury concentrations in two headwater rivers (the Sancha River and the Liucong River), showed that the reservoir behaves as an artificial terminal sink for total mercury. Water samples from the Sancha River collected before the Puding Reservoir had elevated mercury concentrations due to the proximity of the lead-zinc mines and coalmines. However, the mercury concentrations of water samples collected in and below the Puding Reservoir were lower than those of the Liucong River, though the latter did not have obvious mercury point sources (Fig. 4).

Furthermore, water samples collected below the Puding Reservoir showed that both HgP (particulate mercury) and HgD (dissolved mercury) concentrations were significantly reduced (Fig. 5). When flowing through the Puding Reservoir, the particulate mercury decreased from 104.8 ng/L to 11.3 ng/L under high flow conditions and from 27.3 ng/L to 5.2 ng/L under low flow conditions. Moreover, the dissolved mercury fell from 33.2 ng/L down to 14.2 ng/L under high flow conditions; under low flow conditions, the trap effect of dissolved mercury was not observed due to relatively low Hg concentrations. This phenomenon can be explained by that when changing a stretch of a river into a reservoir the slowdown of the flow subsequently evokes particle settling and turbidity decreases, as mercury has a high tendency to be sorbed on surfaces, a large proportion of mercury in natural waters is attached to suspended particles (Mason et al., 1993). Thus, with the sedimentation of the suspended particles, the reservoir will reduce both turbidity and Hg concentrations of water. Though the reservoir holds up the mercury from the upstream, it must be kept in mind that a large mount of mercury that sank down to the sediments may be transformed into methyl mercury under anoxic conditions. Plankton and other creatures at the bottom of aquatic food chain absorb the methyl mercury; through the process of bio-accumulation, levels of methyl mercury in the piscivorous fish at the top of the food-chain can be enhanced several times that in small organisms at the bottom of the chain. That may lead to servious methylmercury contamination.

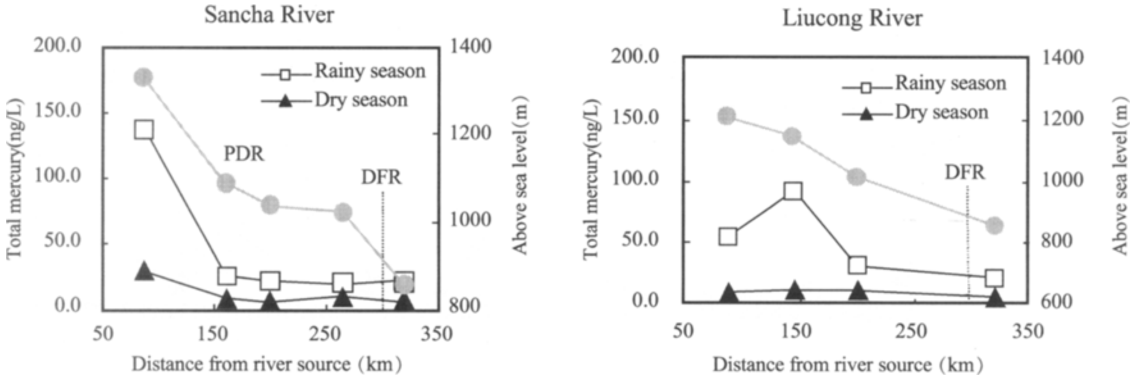

Fig. 4. The distribution of total mercury in the two headwater rivers. PDR. Puding Reservoir; DFR. Dongfeng Reservoir.

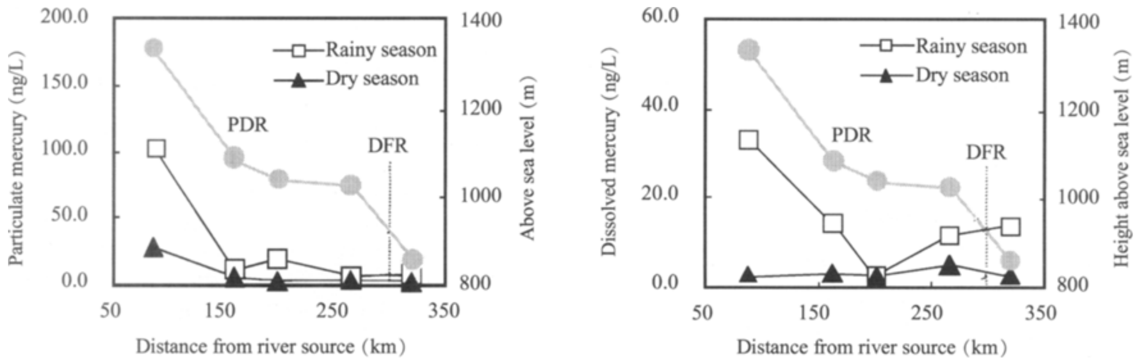

Fig. 5. The distribution of HgP and HgD in the Sancha River. PDR. Puding Reservoir; DFR. Dongfeng Reservoir.

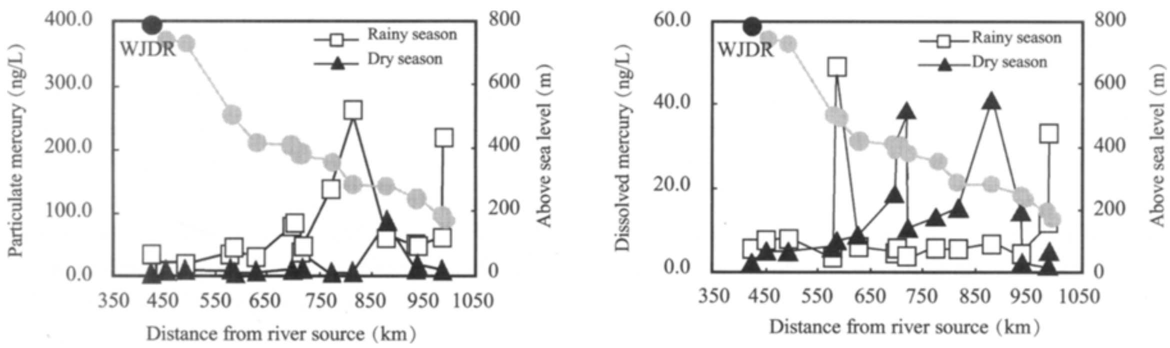

Fig. 6. The distribution of HgP and HgD in the mainstream of the Wujiang River below the Wujiangdu Reservoir. WJDR. Wujiangdu Reservoir.

3.3 Flood discharge

In order to characterize the effect of flood discharge on the distribution of mercury in the downstream of the dam, water samples were collected downstream along the Wujangdu Reservoir. The concentrations of particulate and dissolved mercury in water samples collected downstream along the Wujiangdu Reservoir exhibited different distribution patterns, with particulate mercury during high flow periods being generally higher than that during low flow periods. On the other hand, dissolved mercury displayed an opposite trend (Fig. 6).

These temporal distribution patterns are attributed mostly to the effects of flood discharge of the Wujiangdu Reservoir. Though the distance between the Wujiangdu Reservoir and the Dawujiang Town is only 200 km, the water drop is almost 400 m (Fig. 6), moreover, the course bed is composed of river course downward the Dawujiang Town has been strongly eroded after a huge flood discharge and also the bed sediments are re-suspended. Thus, particulate mercury concentrations gradually increase, with a maximum level appearing when it comes to Dejiang County. Then the particulate mercury concentrations decrease, with the second peak at Wulong County. On the contrary, dissolved mercury concentrations are obviously diluted (except the site Jiangjiehe) until the river comes to Wulong County. Relatively high dissolved mercury in the site of Jiangjiehe may have resulted from point discharge source. It could be concluded that both particulate and dissolved mercury should be of peak value at Wulong County owing to wastewater discharge from this county. The flood discharge significantly enhanced the mercury concentrations below the reservoir, if there is another reservoir downward, these large amounts of mercury may flux into the downward reservoir. It is important for us to pay much attention to methyl mercury contamination before and after construction of the cascade hydroelectric power stations.

4 Conclusions

The concentrations of mercury in the Wujiang River showed an obvious seasonal change. The particulate fraction of mercury accounts for a large portion of total mercury in both seasons. A pilot study indicated that the reservoir could act as a "trap" to reduce the mercury concentrations and fluxes in river water. On the other hand, the flood discharge of reservoirs could significantly enhance the particulate mercury and dilute the dissolved mercury in the downstream riverine environment. In short, dam construction would significantly affect the distribution of mercury in the Wujiang River drainage system.

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