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Impact of the Ertan Reservoir on reduction in sediment load in lower Jinsha River, China

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Abstract The potential effect of dam construction on fluvial hydrological processes related to changes in streamflow discharge and sediment load has been widely understood. However, the underlying mechanism may not be homogeneous, depending on storage capacity, operation mode and catchment geographic features. Gauging evidence demonstrates that sediment load in the lower Jinsha River has been reduced considerably since 1998 when impoundment of the Ertan Reservoir commenced. However, the observed sediment reduction is much greater than the sediment load discharged into the reservoir. The present paper discovered that reduction of in-stream sediment transportation capacity during major flood events resulting from water impoundment played an important role in riverine sediment regulation, in addition to the well-documented sediment trapping effect.

Key words sediment yield; dam construction; sediment transport capacity; trapping effect; Ertan Reservoir; Jinsha River

INTRODUCTION

Dam construction has taken place around the world during the past decades, with multiple objectives of water supply, hydropower generation, flood mitigation, navigation improvement and tourism, which have been already well recognized as playing an essential role in disturbing continent–ocean sediment and associated terrestrial elements transfer (Walling & Fang, 2003). Dam closure and reservoir impoundment disrupt stream channel connectivity, alter fluvial streamflow regime, cause significant sedimentation within the dammed reaches, and subsequently reduces sediment flux discharged downstream (Walling, 2006; Li *et al.*, 2011). It was estimated that more than 40% of the streamflow discharge in global rivers is currently intercepted by dams and as much as 25% of the contemporary riverine suspended sediment flux is retained within reservoirs (Vörösmarty *et al.*, 1997). The Aswan Dam on the Nile River was documented to conduct an annual average suspended sediment load reduction rate of approx. 100×10^6 t·year^{-1} (Walling & Fang, 2003). About 0.1×10^6 t·year^{-1} sediment load was transferred from the Colorado River to the California Gulf (Meade & Parker, 1985). In China, annual average suspended sediment load in the lower Yellow River has constantly decreased from 11×10^8 t·year^{-1} during the period between 1950s and 1970s, to an average of less than 2×10^8 t·year^{-1} for the subsequent period (Mou, 1996), which was preferentially contributed by sediment retention within cascade reservoirs in the upper-middle reaches (Walling, 2006). As for the Yangtze River, impoundment of the Danjiangkou Reservoir has caused a marked decrease in sediment yield at Datong hydrometric station at the basin outlet while an upward trend in sediment discharge was observed at Yichang hydrometric station at the outlet of the upper Yangtze basin (Yang, 2002).

Changes in fluvial hydrological processes related to streamflow discharge and sediment load responding to dam construction and reservoir impoundment have been widely studied. Generally, sediment load reduction within the downstream reaches may be less than sediment amount trapped within the reservoir given that direct sediment inflow from tributaries or sediment mobilization from bank scouring and bed load re-suspension within the adjacent downstream reaches may buffer the reduced sediment signal (Walling & Fang, 2003). The observed suspended sediment load in the lower Jinsha River has demonstrated a dramatic decreasing trend since impoundment of the Ertan Reservoir on the lower Yalong River, a tributary of the Jinsha. However, the amount of annual average sediment load reduction is greater than that discharged into the reservoir. It is thus unable to explicitly explain the underlying hydrological processes associated with the impoundment of the Ertan Reservoir with traditional knowledge. The present paper attempts to introduce an insightful study to the mechanism under which sediment yield within the lower Jinsha River responds to upstream Ertan Reservoir impoundment.

MATERIALS AND METHODS

Study area

The Jinsha River, main stem of Yangtze upstream of Yibing, flows through a mountainous region with an area of 50×10^4 km^2, which accounts for almost 50% of that for the upper Yangtze River basin. Annual average streamflow discharge and sediment load is 14.3×10^8 m^3·year^{-1} and 2.44×10^8 t·year^{-1}, which accounts for 33.5% and 54.2% of that for the upper Yangtze River, respectively. The specific sediment yield is 488 t·km^{-2}·year^{-1}. The upper and middle reaches (upstream from the conjunction of Yalong River at Panzhihua) has a drainage area of 28.5×10^4 km^2, annual average runoff discharge and sediment load is 5.3×10^8 m^3·year^{-1} and 0.45×10^8 t·year^{-1}, respectively. The specific sediment yield is 157.9 t·km^{-2}·year^{-1}. The lower reaches between Panzhihua and Yibing have a drainage area of 21.0×10^4 km^2. Annual average streamflow discharge and sediment load for the sub-basin is 8.74×10^8 m^3·year^{-1} and 2.03×10^8 t·year^{-1}, respectively. Specific sediment yield is 1015 t·km^{-2}·year^{-1} (Zhang & Wen, 2002). It indicates that the lower reaches are a major source area for soil erosion and sediment yield on account of deeply dissected landform, intensive human disturbance and fragmentized geological structure (Fig. 1).

The Yalong River, the biggest tributary of the Jinsha River, has a drainage catchment of 14.4×10^4 km^2 and joins the Jinsha from the left bank at Panzhihua. The Ertan Reservoir, located on the lower Yalong River, has a storage capacity of 58×10^8 m^3 and controls a drainage basin of 11.64×10^4 km^2, which accounts for 23.3% of that for the Jinsha River. Average annual inflow streamflow discharge is 5.27×10^8 m^3 and sediment load is 0.27×10^8 t, which accounts for 36.9% and 11.1% of that at Pingshan station.

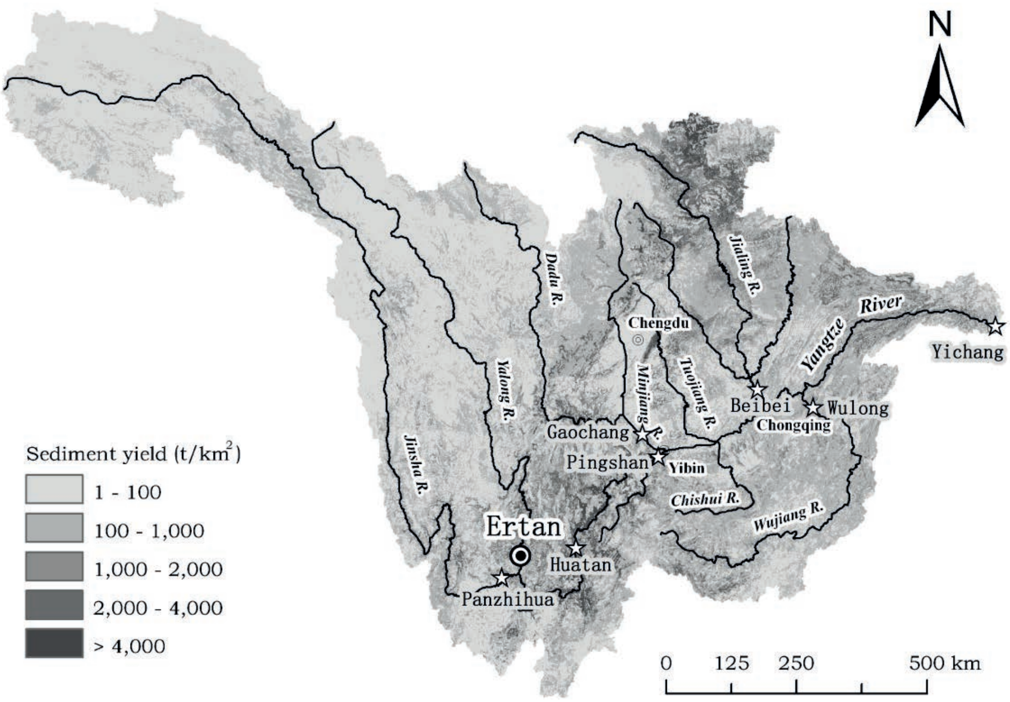

Fig. 1 A sketch map of the upper Yangtze River basin with specific sediment yields, locations of the Ertan Reservoir and the Panzhihua, Huatan and Pingshan hydrometric stations are further indicated.

Data

The dataset concerning streamflow discharge and suspended sediment load measured at Panzhihua, Huatan and Pingshan hydrometric stations in the lower Jinsha River were provided by the Yangtze River Water Conservancy Committee under Ministry of Water Resources of China. The present paper deals with suspended sediment load only due to unavailability of information on total sediment load. Sediment load here thus refers to suspended sediment load only. The hydrometric stations in this paper are basic observation stations in China and the measurements were conducted following national standard. All hydrometric stations involved are illustrated in Fig 1.

Methodologies

Linear regression lines were fitted to demonstrate the temporal trend. Additionally, double-mass curves between streamflow discharge and sediment load were plotted to illustrate the trend of the sediment flux relative to that of water discharges. If both sediment flux and runoff evidence similar trends, the slope of the double mass plot will not change, but if the sediment yields increases or decreases at a greater rate than the annual water discharge, the double mass plot will evidence a departure from its original slope.

RESULTS

Mean annual streamflow discharge and sediment load for the two periods of 1988–1998 and 1999–2007 are summarized in Table 1. Mean annual sediment load at Panzhihua was 0.59×10^8 t·year^{-1} during the period 1988–1998, which was slightly smaller than that during the subsequent period of 1999–2007 being 0.67×10^8 t·year^{-1}. Annual average streamflow discharge was 0.59×10^9 m^3·year^{-1} and 0.62×10^9 m^3·year^{-1} for the corresponding two sub-periods, respectively. The slight increase of streamflow discharge and sediment load at Panzhihua indicates that no significant hydrology-related human disturbances had occurred with the upper-middle Jinsha sub-basin. However, mean annual sediment load at Huatan and Pingshan in the lower Jinsha River have demonstrated dramatic decreases by 0.60×10^8 t·year^{-1} and 0.91×10^8 t·year^{-1}, respectively. It can be ascribed to impoundment of the Ertan Reservoir since 1998.

Table 1 Mean annual streamflow discharge and sediment load at Panzhihua, Huatan and Pingshan in the lower Jinsha River.

Station	Drainage area (10^4 km^2)	Mean annual discharge (10^9 m^3)			Mean annual sediment (10^8 t)		
		1988–1998	1999–2007	Variation	1988–1998	1999–2007	Variation
Panzhihua	28.5	0.59	0.62	+0.03(+5.1%)	0.59	0.67	+0.08(+13.6%)
Huatan	43.0	1.32	1.39	+0.0.7(+5.3%)	2.15	1.55	–0.60(–27.9%)
Pingshan	48.5	1.44	1.54	+0.10(+6.9%)	2.85	1.94	–0.91(–31.9%)

Temporal trends of annual streamflow discharge and sediment load at Panzhihua, Huatan and Pingshan in the lower Jinsha River during the period from 1988 to 2007 are graphically depicted in Fig. 2. Mean annual streamflow discharge at the three hydrometric stations demonstrated similar increasing trends during the period 1988–2007 (Fig. 2). Annual average streamflow discharge increased by 5.1% at Panzhihua station, by 5.3% at Huatan station and by 6.9% at Pingshan station during the period 1999–2007, compared with that for the preceding period of 1988–1998. Inter-periods variation of mean annual sediment load at Panzhihua station was similar to streamflow discharge, and annual average sediment load increased by 13.6%. However, the temporal pattern of sediment load at Huatan and Pingshan was different from that of streamflow discharge. Annual average sediment load decreased by 27.9% and 31.9% during 1999–2007, compared with that for the period of 1988–1998.

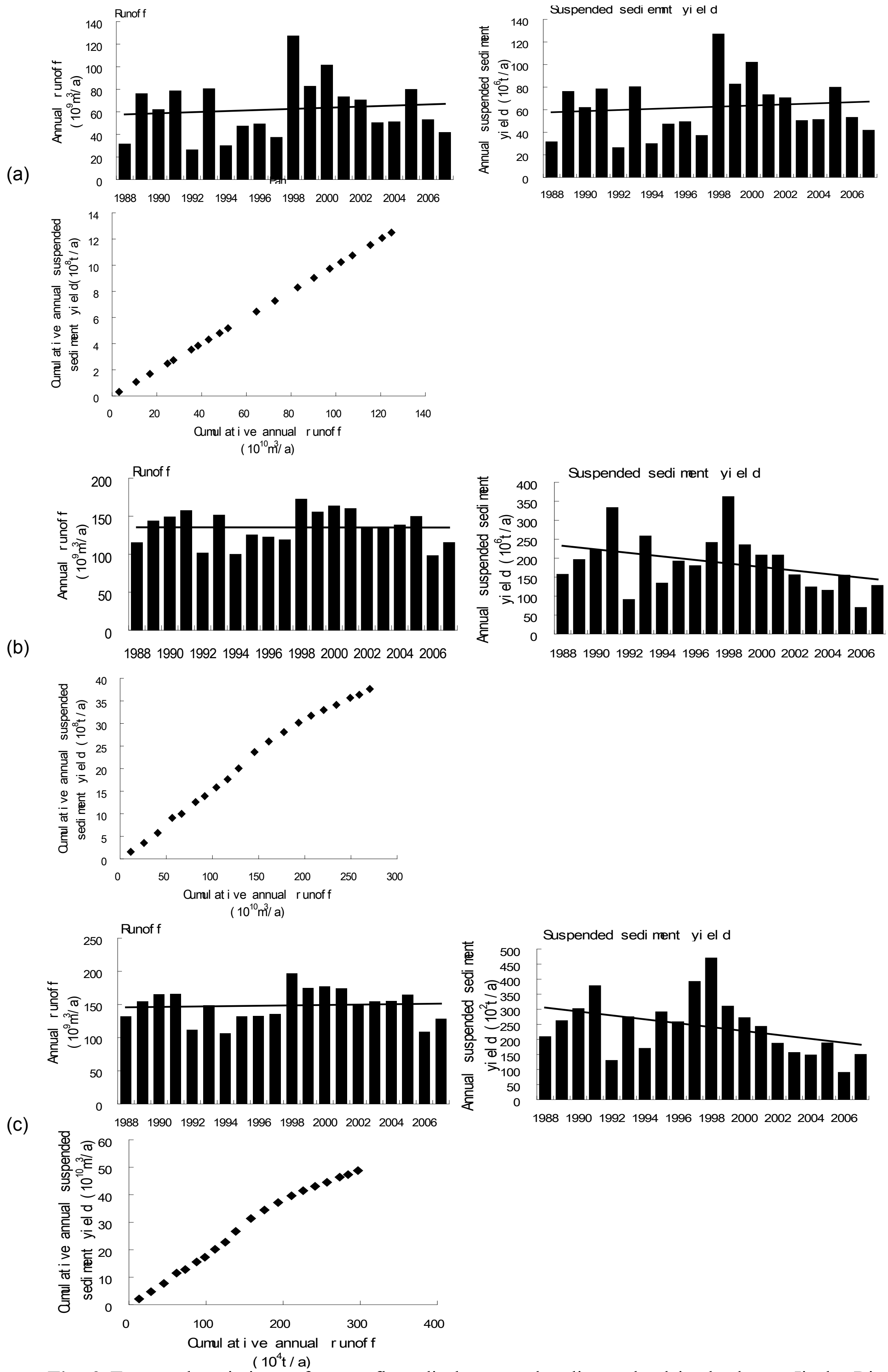

Fig. 2 Temporal variations of streamflow discharge and sediment load in the lower Jinsha River at (a) Panzhihua, (b) Huatanand and (c) Pingshan.

DISCUSSION

Generally, sediment reduction within the reaches below the dam may be less than the sediment load trapped within the reservoir (e.g. Three Gorge Reservoir, Danjiangkou Reservoir, Aswan Reservoir) because the reduced sediment signal may be compensated for by downstream fluvial hydrological processes including: (1) sediment inflow from adjacent tributaries, (2) sediment mobilization from bank scouring, (3) re-suspension of bed load. However, it was observed that the annual average sediment load reduction rate of 0. 60 × 10^8 t/year and 0.91 × 10^8 t/year at Huatan and Pingsha were much greater than mean annual sediment load of 0.27 × 10^8 t/year that was transferred into the Ertan Reservoir. These phenomena cannot be explicitly explained by traditional knowledge on the effect of reservoir impoundment on sediment mobilization and transport within fluvial drainage systems, unless considering the effect of reduction in sediment transportation capacity.

In subtropical monsoon river systems, storms and floods play an important role in upland-channel soil erosion and sediment transportation, and the sediment load transported during major flood events may contribute considerably to the annual total sediment yield. The relationship between sediment load and streamflow discharge can be empirically expressed as:

$$Q_s = KQ^{\alpha} \quad (1)$$

where Q_s is riverine sediment flux ($t \cdot s^{-1}$); K is a coefficient related to channel boundary condition; Q is the streamflow discharge ($m^3 \cdot s^{-1}$); α is exponential coefficient (α = 2).

As for the Ertan Reservoir, water impoundment plays an important role in streamflow regulation. During a flood event, peak discharge was retained, and sediment transportation capacity downstream should be reduced. Generally, reservoir impoundment did not cause the reduction amount of sediment load in the downstream greater than the trapped amount of the sediment in the reservoir, as Ertan did, because of limited sediment supply from the sides of the downstream river channel where soil erosion is not very severe. The Lower Jinsha River Basin is one of the severe erosion areas in the upper Yangtze River basin because of its fragile geological structure, deeply dissected topography, dry and hot valley climate and widespread steep cultivated land due to dense population. Specific sediment yields along Jinsha River between Panzhihua and Pingshan are mostly greater than 1000 $t \cdot km^{-2} \cdot year^{-1}$. It is suggested that combination of the significant reduction of sediment transportation capacity, due to dampening flood discharges, and the huge amount of sediment supplies from the river side-wall may result in the observed fact that the decreased amounts of the annual sediment loads in the lower Jinsha River in the period of 1999–2007, compared with that in 1999–2007, were greater than the annual inflow sediment load delivered into Ertan Reservoir. The sharp decreases of sediment loads in the Lower Jinsha River should be related to sediment accumulation and channel beds rising there, which will be focused on in future work.

CONCLUSIONS

Observed reduction in mean annual sediment load at Huatan and Pingshan in the lower Jinsha River during 1999–2007 may be ascribed to impoundment of the Ertan Reservoir on the lower Yalong River in 1998. However, underlying hydrological processes related to sediment reduction comprise sediment retaining by reservoir operation and depletion of sediment transportation capacity as a result of water impoundment.

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