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Response of the Changjiang (Yangtze River) water chemistry to the impoundment of Three Gorges Dam during 2010–2011

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ABSTRACT

The environmental impact of Three Gorges Dam (TGD) in the Changjiang (Yangtze River) is an important topic of concern for scientific communities and the public. However, the changes in river water chemistry in response to the dam construction remain poorly constrained. This study presents the seasonal variability of all major cations and some anions in the lower Changjiang during a full hydrological year from 2010 to 2011. The concentrations of all ions, except for HCO_3^-, are higher after the TGD operation than before ($p < 0.01$), implying that the TGD has modified the river water chemistry in the mid-lower mainstream. Dissolved silicate (DSi) fluxes at Datong station thus increase slightly since the beginning of TGD impoundment. The change of mixing pattern of different water sources and alteration of hydrological and biogeochemical processes could cause the change of solute concentrations in the mid-lower Changjiang after the TGD operation. The mass balance model suggests that two factors primarily account for this increase of DSi observed at Datong: 1) an increasing loading of DSi downstream TGD due to erosion by "clean water", and 2) an enhanced "Source" role of Lake Poyang in the mid-lower reaches. Our study would provide insights into the damming effect on river water chemistry and the complexity of a large river system facing rapid climate change and strong human activities.

1. Introduction

Rivers as a link between land and ocean constitutes an essential part of global water and biogeochemical cycle (Martin and Whitfield, 1983; Kawahata et al., 2004; Beusen et al., 2009; Milliman and Farnsworth, 2011; Immerzeel et al., 2013; Yang et al., 2014). Both natural and anthropogenic processes in the basin scale are recorded within the river water chemistry, and as such, chemical weathering regime and atmospheric CO_2 consumption in the watersheds can be evaluated (Gaillardet et al., 1999; Chen et al., 2002; Gupta et al., 2011; Cai et al., 2013; Wei et al., 2013). As the largest river in China, the Changjiang (Yangtze River) fosters over one half billions of population with its enormous fluvial resources, and has great impacts on the ecosystem in the East China Sea and Yellow Sea (Liu et al., 2006, 2007; Li et al., 2007; Milliman and Farnsworth, 2011; Y. Liu et al., 2016a; J. Liu et al., 2016b).

Dams built on rivers around the world have significantly altered the natural equilibrium of river systems, and eventually modified the material fluxes to the ocean (Humborg et al., 1997; Milliman, 1997; Nilsson et al., 2005; Poff et al., 2007; Dai et al., 2014; Maavara et al., 2014; Dai et al., 2016; Ran et al., 2016). The water regulation of large dams can influence the river water chemistry around the reservoir area and to its downstream (Ran et al., 2010; Barros et al., 2011; Wang et al., 2011; Jacinthe et al., 2012). The construction of the TGD, the world's largest hydropower project, has led to worldwide concerns due to its great influence on hydrologic and biogeochemical processes in riverine and coastal marine environments. A large amount of sediments is trapped in the Three Gorges Reservoir (TGR) (Hu et al., 2009; Xu and Milliman, 2009), resulting in the decline of sediment flux to the estuary (Xu et al., 2006; Zhang et al., 2006; Li et al., 2012; Dai and Liu, 2013; Yang et al., 2007, 2011, 2014). Although the TGD has a greater significance on the sediment outputs than on the water discharge (Zhang et al., 2006; Dai et al., 2011), it does alter the seasonal distributions of water discharge out of this huge dam (Yang et al., 2010; Qiu and Zhu, 2013; Deng et al., 2016; Li et al., 2016) by regulating the peak flow (Liu et al., 2008; S. Li et al., 2013b). The river flow regulation by the TGD has also led to decreasing inundation area of the two largest freshwater lakes (Lake Dongting and Lake Poyang) in the middle reaches (Feng et al., 2012, 2013; Lai et al., 2014). Also, the release of "hungry/clean water" of the TGD could enhance the channel erosion in the middle

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reaches of the Changjiang (Yang et al., 2006). These seasonal variations in discharge and associated with riverine processes might impact the river water chemistry in the mid-lower Changjiang mainstream (Xu et al., 2011; Yu et al., 2011; Gao et al., 2012; S. Li et al., 2013b; Sun et al., 2013; Ding et al., 2014; Deng et al., 2016; Li et al., 2016). Besides the sediment reduction and water discharge regulation, reservoir-triggered large scale eutrophication and other ecological issues also occurred in this huge reservoir (New and Xie, 2008; Chai et al., 2009; Duan et al., 2009; Ran et al., 2010; K. Li et al., 2013a; Xu et al., 2011).

Changes in river chemistry including DSi, Ca^{2+}, Mg^{2+} and HCO_3^- have been reported after damming in large rivers worldwide (Margolis et al., 2001; Brink et al., 2007; Gao et al., 2013; Maavara et al., 2014; Wang et al., 2015). Concentrations of major anions like Cl^-, SO_4^{2-} and NO_3^- have been proved to increase sharply compared to the long-term data before TGD along the Changjiang main channel (Chen et al., 2002; Duan et al., 2007; Chetelat et al., 2008; Ding et al., 2014). The increased contribution from human activities (e.g. unban input and change of land use) was widely accepted as the main factor for enhancing their concentrations in the Changjiang. Besides that, concentrations of $Na^+ + K^+$ after the TGD filling to 135 m water level stage were also found to increase sharply compared to the long-term data before TGD (Chetelat et al., 2008). However, most of the data were gathered in period when the TGD was not completely finished yet (Chetelat et al., 2008; Dai et al., 2011; Ding et al., 2014; Ran et al., 2016). What happened to the water chemistry after the official functioning of TGD (175 m filling stage in water level) is still unknown.

A downward evolution of riverine DSi flux was observed between 1955 and 2008 in the Changjiang River basin (Dai et al., 2011). Correspondingly, the particulate biogenic silica (BSi) fluxes near the river mouth decreased due to the retention of riverine sediment in the TGD (Ran et al., 2016). The exogenous BSi trapped in the reservoir would dissolve into DSi (Ran et al., 2016), which may influence the DSi flux in the mid-lower Changjiang. Unfortunately, the cycling mechanism of DSi and the variation of water chemistry downstream the TGD were barely studied. Hence, it is critical to investigate the river water chemistry after the officially operation of TGD in the Changjiang mainstream to better assess the environmental and ecological impacts of the increasing damming process. In this study, we analyze the concentrations of major ions including Ca^{2+}, Mg^{2+}, $Na^+ + K^+$, DSi, and HCO_3^- in the water samples collected at Datong hydrological station during the period from May 2010 to July 2011. The major purpose of this study is to: 1) identify the temporal variability of these major ions in the Changjiang water after the full operation of TGD; 2) assess the water environment change after the TGD impoundment; 3) estimate the mass balance of DSi in the mid-lower Changjiang.

2. River setting

2.1. Generals of the Changjiang

The Changjiang, originates from eastern Tibetan Plateau (Fig. 1a, b), and has a length of about 6400 km. The catchment has an area of 1.8×10^6 km^2 and covers the typical topography of China's three-grade relief terraces, from highlands in the upper valley to delta plain in the lower reaches (Fig. 1b). It consists of three sections: the upper, middle and lower reaches (Fig. 1a). The Lake Dongting and Lake Poyang, two of the largest lakes connected to the Changjiang mainstream, are located in the middle valley (Fig. 1a). The Datong hydrological station, about 650 km away from the river mouth covers about 95% of the whole catchment (Fig. 1a). Based on the precipitation and runoff patterns in the catchment, a hydrologic year of the Changjiang is usually divided into two seasons: flood season (May to October) and dry season (November to next April).

The large catchment is characterized by various types of bedrocks (Fig. 1a). Paleozoic carbonate rocks spread widely in the upper reaches. The mid-lower reaches mostly consist of Paleozoic marine, Quaternary

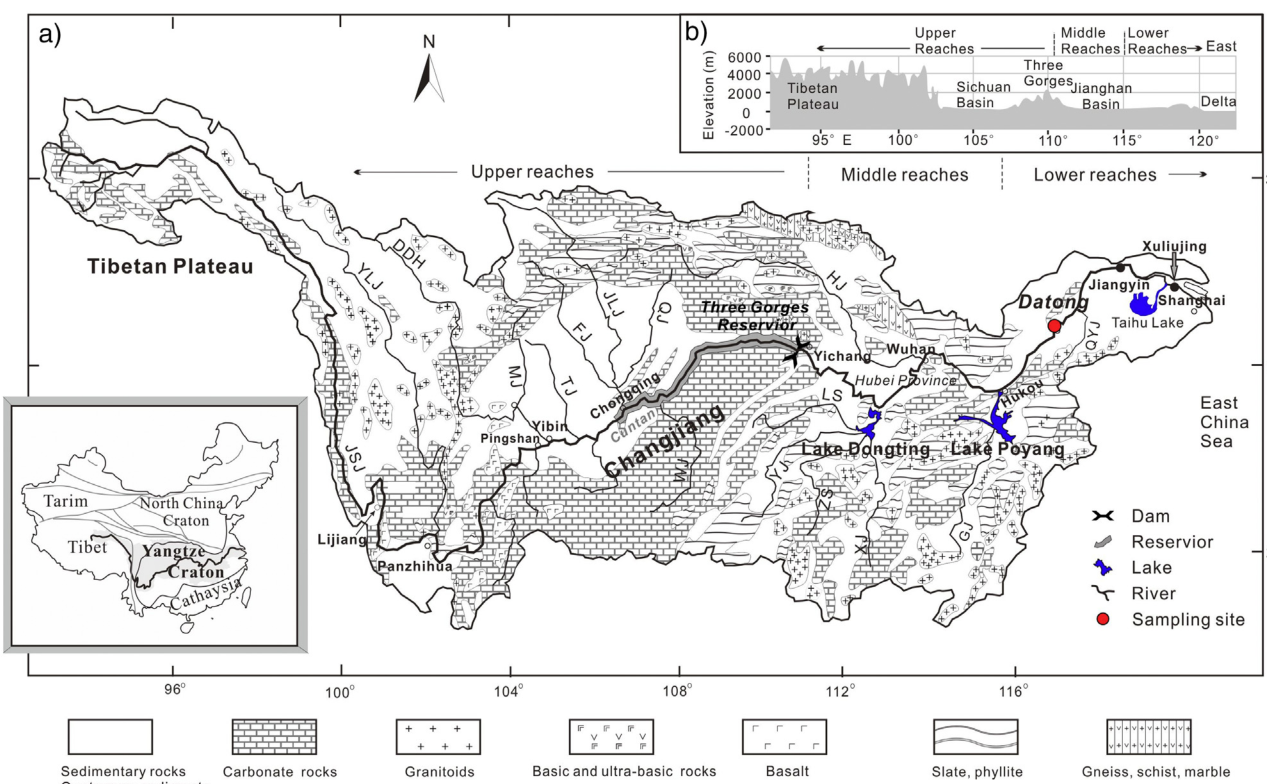

Fig. 1. (a) A schematic map showing the Changjiang catchment, major tributaries, sampling location, and major rock types. Modified after Geological Map of China (1:2,500,000, China Geological Survey, http://www.ngac.org.cn); (b) The topographic relief of the Changjiang drainage basin, from the Tibetan Plateau in the headwaters to the river mouth.