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Changes in water and sediment exchange between the Changjiang River and Poyang Lake under natural and anthropogenic conditions, China

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HIGHLIGHTS

- The river–lake interaction greatly changed after 2003.
- Climate change exerted greater influence on water exchange between river and lake.
- Human activities imposed more impact on sediment exchange between river and lake.
- The forcing of Changjiang River on Poyang Lake significantly weakened after 2003.
- The sediment contribution of Lake Poyang to Changjiang River greatly increased.

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ABSTRACT

To study the fluvial interaction between Changjiang River and Poyang Lake, we analyze the observed changes of riverine flux of the mid-upstream of Changjiang River catchment, the five river systems of Poyang Lake and Poyang Lake basin. Inter-annual and seasonal variations of the water discharge and sediment exchange processes between Changjiang River and Poyang Lake are systematically explored to determine the influence of climate change as well as human impact (especially the Three Gorges Dam (TGD)). Results indicate that climate variation for the Changjiang catchment and Poyang Lake watershed is the main factor determining the changes of water exchanges between Changjiang River and Poyang Lake. However, human activities (including the emplacement of the TGD) accelerated this rate of change. Relative to previous years (1956–1989), the water discharge outflow from Poyang Lake during the dry season towards the Changjiang catchment increased by 8.98 km^3 y^{-1} during 2003–2010. Evidently, the water discharge flowing into Poyang Lake during late April–late May decreased. As a consequence, water storage of Poyang Lake significantly reduced during late April–late May, resulting in frequent spring droughts after 2003. The freshwater flux of Changjiang River towards Poyang Lake is less during the flood season as well, significantly lowering the magnitude and frequency of the backflow of the Changjiang River during 2003–2010. Human activities, especially the emplacement and operation of the TGD and sand mining at Poyang Lake impose a major impact on the variation of sediment exchange between Changjiang main river and Poyang Lake. On average, sediments from Changjiang River deposited in Poyang Lake before 2000. After 2000, Changjiang River no longer supplied sediment to Poyang Lake. As a consequence, the sediment load of Changjiang River entering the sea increasingly exists of sediments from Lake Poyang during 2003–2010. As a result, Poyang Lake converted from a depositional to an erosional system, with a gross sediment loss of 120.19 Mt y^{-1} during 2001–2010, including sand mining.

1. Introduction

Changjiang catchment is one of the largest drainage basin in the world, its annual water discharge (9000×10^8 m^3 y^{-1}) and sediment load (4.78×10^8 t y^{-1}) are ranked as the fifth and fourth in the world, respectively (Milliman and Farnsworth, 2010). The Changjiang

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catchment has been undergoing significant changes caused by: natural environment changes and human activities like reservoir emplacement, inter-basin water transfer, sand mining, and the implementation of reforestation projects (Chen et al., 2001; Yang et al., 2002; Gao, 2006, 2007; Dai et al., 2008). Especially, the sediment load of Changjiang River entering the sea abruptly decreased after the emplacement of TGD (Gao et al., 2011; Yang et al., 2011), which imposed a profound impact on the estuary–coast–continental shelf system (Gao et al., 2011; Yang et al., 2011), and resulted in a series of eco-environmental problems (Gao and Wang, 2008).

After the emplacement of TGD in 2003, the mid-lower reach of Changjiang catchment underwent complex changes, including intensification of riverbed erosion (Dai and Liu, 2013) and changes in the interaction between the main river of Changjiang River (abbreviated below as "main river") and the lakes of the mid-lower reaches (Min et al., 2011; Guo et al., 2012; Lai et al., 2013). Of the ten most severe spring droughts that occurred for Poyang Lake during 1960–2010, four occurred after 2003 (in 2004, 2005, 2008 and 2009) (http://www.china.com.cn/news/txt/2011-05/26/content_22642355_4.htm). The coincide between frequent occurrence of spring droughts for Poyang Lake and the emplacement of the TGD, not only triggered a debate whether the TGD is responsible for these spring droughts, but also attracted attention towards the change of interaction of fluvial fluxes between Changjiang River and Poyang Lake (Ye et al., 2012). This exchange process is mainly influenced by the river–lake interaction, as well as by the morphologic evolution of the riverbed and the lake basin (Shankman and Liang, 2003; Guo et al., 2008; Lai et al., 2013). The alteration of the river–lake interaction cannot solely be due to the emplacement of the TGD, but ought to be the result of a complex interaction among a series of alterations under the impact of natural environment changes and human activities for Poyang Lake watershed, upper and middle reaches of Changjiang catchment and Poyang Lake basin (Guo et al., 2011a; Min et al., 2011; Ye et al., 2013). Therefore, in order to reveal the water and sediment exchange between Changjiang River and Poyang Lake, the following three conditions need to be better understood: a) the variations of inner- and inter-annual water discharge and sediment load of the Changjiang River and Poyang Lake watershed, given changes in climate and human activities (especially the TGD); b) the elevation variation of Poyang Lake basin and the main riverbed under the influence of human activities; and c) the inter-annual and seasonal variations of water discharge and sediment load exchange between Changjiang River and Poyang Lake.

Poyang Lake watershed is a major water and sediment source to the Changjiang River mainstream (Yang et al., 2007). Therefore, the alteration of water and sediment exchange between Changjiang River and Poyang Lake will have an impact on the water and sediment flux of Changjiang River towards the sea. As the largest freshwater lake in China, Poyang Lake is also an important wetland (Lei et al., 2011), and exerts important roles in flood-mitigation storage, regulation of the local climate and as protection of global biodiversity (Wu et al., 2011a; Nakayama and Shankman, 2013; Wang et al., 2013). Consequently, better understanding of the alteration of water and sediment exchange between Changjiang River and Poyang Lake induced under natural condition changes and human activities, will not only be helpful to explore the effect of the river–lake interaction change on the occurrence frequency and mechanism of drought and flood disasters of Poyang Lake and its surroundings, but also be beneficial for the prediction of the hydrodynamic variations of Poyang Lake, as well as for better understanding the ecological environment changes of the lake and its wetland and how these evolve in future.

In this study, we aim to: (1) analyze the inner- and inter-annual variations of water discharge and sediment load of Changjiang River mainstream, under the influence of climate change and human impact; (2) reveal the trend in variation of water discharge and sediment load of Poyang Lake entering the lake caused under natural condition changes and human activities; (3) estimate the contribution of water and sediment of Poyang Lake to the Changjiang River; (4) study the impacts of human activities and river–lake interaction changes on the sediment budget of Poyang Lake; and (5) as part of the above described analyzes, systematically explore the influences of catchment climate changes, TGD and other human activities on the water and sediment exchange variations between Changjiang River and Poyang Lake.

2. Physical setting

Poyang Lake is located at the junction of the south bank of the Changjiang River (Fig. 1). Its basin area is 16.2×10^4 km^2, accounting for 9% of the Changjiang River drainage area. The Poyang Lake watershed, with abundant rainfall, can be considered a subtropical humid monsoon climate zone, with an annual precipitation of 1632 mm (Xu and Qin, 1998). As for a monsoonal systems, the inner-annual precipitation is unevenly distributed: the flood season (April–June) consists of 44% of the annual rainfall whereas the rainfall during the dry season (October–February) accounts for only 22.4% (Ye et al., 2013). Consequently, the annual distribution of water discharge is also not uniform; during the flood period alone (from April to June) more than 50% of the annual flow is derived (Shankman et al., 2006). Poyang Lake watershed encompasses a varied and complex topography, including mountains, uplands and plains, which account for 36%, 42% and 22% of the area of Poyang Lake watershed, respectively (Liu et al., 2009).

The Poyang Lake, with an area of 3583 km^2 and a volume of 27.6 km^3, is about 173 km in length from north to south and 74 km width from east to west (Xu et al., 2001). The lake can be divided into two parts: the southern part which is characterized by a broad area with a shallow water depth; and the northern part with deeper waters which is long and narrow and thereby forming the watercourse for the Poyang Lake water that flows into Changjiang River mainstream (Poyang Lake–Changjiang River watercourse).

Poyang Lake is a throughput type of lake, mainly recharging freshwater from the five tributary rivers, the Gan River, Fu River, Xin River, Rao River and Xiu River, and discharging to the Changjiang River at Hukou (Table 1). The gross annual water discharge and sediment load of the five rivers account respectively for 85.4% and 87.2% of the total water discharge and sediment load entering Poyang Lake (Chen et al., 2002). The Gan River, 766 km in length is the largest contributing river to Poyang Lake watershed; and Xin River and Fu River are ranked respectively as the second and third largest rivers of the Poyang Lake watershed. However, the gross annual water discharge and sediment load of Gan River, Fu River combined and Xin River exceed respectively 89% and 90% of that of the five rivers (Sun et al., 2010). The Rao River system includes the Chang River and Lean River, and the Xiu River system is formed by the Xiu River itself and the Liao River branch.

Poyang Lake is regulated both by the five rivers and the Changjiang River, which results in its annual fluctuation of water level between the wet summer season and the relatively dry fall and winter (Zhao et al., 2011). During a typical year, Poyang Lake expands to a large water surface during the wet season, but shrinks to little more than a river during the dry season (Xu et al., 2001). The water discharges of the five rivers reach their peak between April and June, and sharply decrease from July to September. This distribution pattern is nearly reversed from that of the Changjiang River, which reaches its peak water discharge between July and September. As a result, freshwater from Poyang Lake flows into Changjiang River during April to June, which help to maintain the water discharge of Changjiang River during the dry season. During Changjiang River flood season (July–September) backflow from Changjiang River to Poyang Lake occurs, which is beneficial to mitigate peak flows of the Changjiang River, and retain water level at Poyang Lake as well (Wu et al., 2011a).

The water discharge and sediment load entering Poyang Lake greatly changed as human activities, especially land cover changes and reservoir emplacement, intensified (Sun et al., 2010). Deforestation became more devastating with rapid human population increase and economic