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Dynamic changes of sediment load in the middle reaches of the Yellow River basin, China and implications for eco-restoration

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ABSTRACT

Abrupt reduction of the sediment load in the middle reaches of the Yellow River has extracted much attention during the past several decades due to global climate changes and intensive human activities. This paper investigates the spatial and temporal variations of annual sediment load in the section between Hekouzhen and Longmen in the middle reaches of the Yellow River basin from 1962 to 2009 by using annual observations at 21 hydrological gauging stations (4 mainstream and 17 tributaries stations), by making use of Mann–Kendall test and simple linear regression for trend detection, and the sequential cluster analysis method and Student's *t* test for changing point detection. The results suggest that sediment load from both mainstream and tributaries show significant decreasing trends at confidence level of 0.01. Evident abrupt changing points are detected around 1970s for most stations, but for Toudaoguai station and Fugu station are found in the mid-1980s, which are mainly attributed to the operation of Longyangxia Dam. In addition, abrupt changes in the sediment series at some stations from the tributaries were found around the late 1990s, this situation may be resulted from the "Green for Grain" project launched in 1999. Sediment budget analysis indicates that the 17 tributaries contributes 70.60% sediment load to the whole research area, which suggests that the majority sediment load contribution to He-Long region is from these tributaries. The comparison among three mainstream sections implies that the sediment is mainly from Wubao–Longmen section. And contribution of tributaries in each mainstream section is mainly from Huangfuchuan River, Kuye River, Wuding River and Yan River. The reduction of the sediment load is mainly caused by human activities especially soil and water conservation projects (such as afforestation, terraces, reservoirs and dams). In summary, the results in this study provide a further evidence for a more exact sediment source region and implementing soil and water conservation measures more effectively in the middle reaches of the Yellow River basin, China.

1. Introduction

Rivers are the major pathways of water, sediment and other materials transfer from lands to oceans on the earth, and the cycling of these materials plays an important role in the delta and estuarine evolution (Walling and Fang 2003; Wang et al., 2011). Along with the global climate changes and anthropogenic activities, dramatic variations of runoff and sediment load in many large rivers have occurred all over the world (Walling 2006; Milliman et al., 2008; James and Kettner, 2011). Studies on the world large rivers (e.g., Mississippi River, Ebor River, Yangtze River, Yellow River) show that the sediment load changed significantly in response to the climate changes, constructions of hydraulic engineering (reservoirs and dams) and land use changes (Mikhailova 2003; Fu et al., 2005; Li et al., 2009; Xu and Milliman 2009; Meade and Moody 2010; Mu et al., 2012; Zhao et al., 2012a; Ouyang et al., 2013). Dams construction may cause far-reaching influence on hydrological regime and the river ecosystem (Konrad 2009; Benjankar et al., 2012; Egger et al., 2012; Ouyang et al., 2013; Li et al., 2014; Zhao et al., 2014). In recent decades, scholars as well as government and local decision makers pay considerable

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attention to the sediment problem, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) launched the International Sediment Initiative (ISI) in 2003 to increase awareness of sedimentation and erosion issues and to improve their ability to deal with the consequences of streamflow and sediment load variation on the basis of a complete understanding of the changes, which will be greatly helpful for management of soil and sediment resources, flood mitigation and water resources management.

The Yellow River is well-known in the world for its extremely high sediment load. The Yellow River basin accounts for approximately 6% of the sediment load globally (Miao et al., 2011). The statistic data 16×10^8 t (the observed data of Shaanxian county hydrological station from 1919–1960) released by Yellow River Conservancy Commission has been used for several years to state situation of the Yellow River sediment load, but actually sediment load of the Yellow river has reduced significantly in the recent 50 years (Mu et al., 2012). Numerous studies investigated the spatial and temporal variations of sediment load, and the potential influencing factors leading to the significant reduction of sediment load in the Yellow River basin (Wang et al., 2007; Liu et al., 2008; Gao et al., 2011; Miao et al., 2011; Mu et al., 2012; Wang et al., 2012; Zhao et al., 2013). Wang et al. (2007) analyzed sediment load variations along the Yellow River basin, and found that the gradual sediment decrease ascribed to reservoirs and dam constructions in the upper reaches, while soil and water conservation practices caused the decrease of sediment load in the middle reaches, and river sediment reduction owed to water abstraction in the lower reaches. Peng et al. stated that the decreasing sediment load at Huayuankou station was influenced by soil and water conservation, which accounted for 40% of the total amount of reduction, and sediment trapping by reservoirs (Sanmenxia and Xiaolangdi) in the upper reaches accounted for 30% of the total amount of reduction, human activities led to the 10% decrease and the precipitation decrease accounted for the remaining 20% decrease. Wang et al. (2012) detailed spatial and temporal variations of the suspended sediment deposition (SSD) based on the annual suspended sediment in the upper Yellow River. The changes in SSD are mainly influenced by human activities. Mu et al. (2012) analyzed the recent 90 years sediment discharge changes and influencing factors in the Yellow River based on the Shaanxian county hydrological station annual sediment discharge series, and concluded that the sediment reduction caused by human activities and rainfall is 81% and 19%, respectively.

The middle reaches of the Yellow River basin is the most serious soil loss region in China, particularly from Hekouzhen to Longmen (He-Long region) station. It has been reported that the He-Long region supplies nearly 90% of total sediment to Huayuankou station (Ran et al., 2007; Wang et al., 2007; Liu et al., 2008; Gao et al., 2011). Studies by Liu et al. (2008) showed that the annual sediment yield in the middle reaches is extremely higher than sediment yield in the upper and lower reaches. In the middle and lower reaches, sediment yield is dramatically influenced by human activities (such as reservoirs, and soil and water conservation programs). Gao et al. (2011) found that the human intervention (e.g., soil and water conservation measures) and climate changes (e.g., temperature and precipitation) were responsible for the dramatic decreasing streamflow and sediment load in the middle reaches of the Yellow River.

As mentioned above, all of these studies detailed changes in streamflow and sediment load of the Yellow River by using hydrological data with different temporal and spatial scale, and analyzed the potential impact factors (including rainfall, grain for green, warping dam, soil and water conservation measures, reservoir and agricultural irrigation projects, etc.). However, few studies investigated the runoff and sediment load for the whole Yellow River catchment by using both mainstream and tributary measurement data. Furthermore, studies on the relations of sediment between the mainstream and the tributary are very limited. Better understanding of the temporal changes and spatial contribution of sediment is greatly useful for soil and water conservation, eco-rehabilitation and river basin management in the middle reaches of the Yellow River basin.

Therefore, the objectives of this study are: (1) to statistically analyze both mainstream and tributaries' spatial and temporal variation of annual sediment load in the middle reaches of the Yellow River basin, (2) to detect the relations of sediment load between the mainstream and the tributaries of the He-Long region, and (3) to assess possible impact factors of sediment load changes detected in this study.

2. Materials and methods

2.1. Study area

The study area (Fig. 1) is located in the middle reaches of the Yellow River (MRYR) basin, from Hekouzhen (the gauging station is Toudaoguai, 110°02′ E,40°17′ N) to Longmen (the gauging station is Longmen, 108°02′ E,35°40′ N) region. The mainstream flows

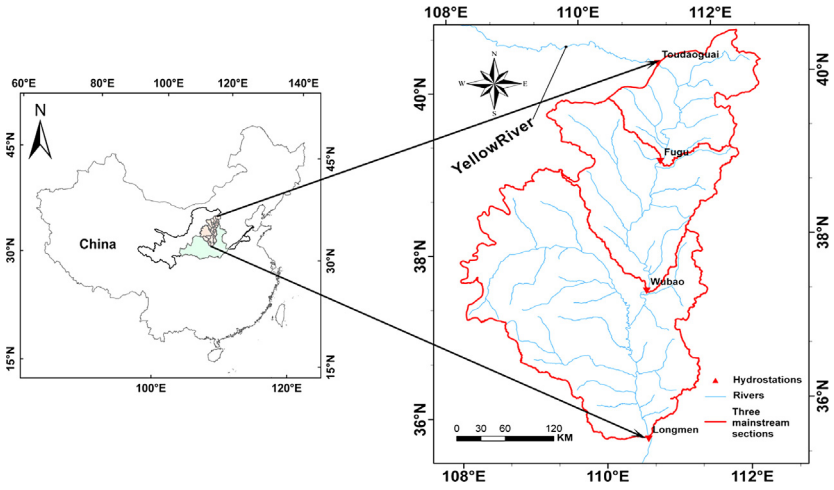

Fig. 1. Location of the study area in the middle reaches of the Yellow River basin.