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# Multi-temporal scale changes of streamflow and sediment discharge in the headwaters of Yellow River and Yangtze River on the Tibetan Plateau, China

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ABSTRACT

The changes of water and sediment discharges in the headwaters of large Asian rivers have increasingly become a hot issue. This study investigated the streamflow and sediment discharge changes in the headwaters of Yellow River Basin (YRB) and Yangtze River Basin (YARB) by using long-term hydro-meteorological data from 1956 to 2012. The nonparametric Mann–Kendall test, Pettitt test, cumulative anomaly curve (CAC), and double cumulative curve (DCC) were used to identify trends and change points of the hydro-meteorological variables and quantify the response of streamflow and sediment discharge to climate change and anthropogenic activities. The results are as follows. (1) Slightly decreasing trend in streamflow and increasing trend in sediment discharge were detected from 1956 to 2012 in the headwater of YRB. Meanwhile, both streamflow and sediment discharge in the headwater of YARB showed increasing trend. Change-point analyses further revealed that turning (transition) years existed and the abrupt decline in streamflow and sediment discharge began in 1989. (2) The specific sediment yield–runoff depth and sediment concentration–streamflow relationships in the two basins could be well fitted by the power function on the annual, flood season, and monthly scales. Sediment productive ability of runoff during the flood season was much greater than that over the full year. (3) The headwater of YRB contributed huge amount of water resources and very little sediment to the downstream, however, the headwater of YARB had little influence on downstream. (4) Compared with the baseline period (1956–1989), precipitation reduction played a major role in the streamflow and sediment discharge reductions in the post-baseline period (1990–2012). Given the scarcity of soil and water resources, anthropogenic and climatic impacts on streamflow and sediment discharge must be given more attention in the future.



## 1. Introduction

Water is the base of the life on earth and a major limiting factor for socio-economic development in the world (Miao and Ni, 2009). At the same time, sediment transport from continents to oceans via rivers is one of the most important processes regulating river-bank stabilization, soil formation, biogeochemical cycling of elements, crustal evolution and many other earth-related processes. The integrated consequences of climate change and diverse anthropogenic activities have led to the considerable global alterations of fluvial hydrological regimes during recent decades (Cohen et al., 2014; Jiang et al., 2015; Milly et al., 2005). Apparent decreasing and increasing trends in streamflow and sediment discharge have been reported in many basins around the world (Jiang et al., 2015; Milly et al., 2005; Walling and Fang, 2003). To effectively utilize water resources and reasonably manage river flows, it is essential to investigate the historical changes of streamflow and sediment discharge on different temporal and spatial scales, and to examine the reasons for the significant changes.

Large rivers around the world have experienced a significant reduction in streamflow and sediment discharge over the last decades (e.g., Jiang and Wang, 2016; Milliman et al., 2008; Walling and Fang, 2003). On the global scale, Milliman et al. (2008) found

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that approximately one-third of 137 world-representative rivers exhibited more than a 30% change in annual discharge, and they identified the climatic and anthropogenic factors affecting river discharge in the three distinct river types, i.e. normal, deficit and excess. Walling and Fang (2003) reported that nearly 50% of 145 major global rivers showed significant increasing or decreasing trends in sediment discharge. Panda et al. (2011) illustrated dramatic reductions in sediment discharge in tropical river basins: approximately 88% (62%) of 133 gauging stations showed declines in sediment discharge in the monsoon (non-monsoon) season. Salmoral et al. (2015) demonstrated that the upper Turia basin of Spain exhibited significant decreasing trend in streamflow. According to 10 gauging stations on 10 large rivers in China, there was little change in streamflow but a dramatic decrease in sediment discharge in the southern rivers, and both sediment discharge and streamflow showed significant reductions in the northern rivers (Jiang et al., 2015; Liu et al., 2008). Moreover, Xu et al. (2010) investigated the temporal trend of precipitation and streamflow in five major Chinese rivers during 1951–2000 and indicated the significantly different hydrological regime changes and anthropogenic activity roles in northern and southern rivers. Chu et al. (2009) estimated that dams and reservoirs, soil and water conservation, water consumption and in-channel sand mining accounted for 56%, 23%, 15% and 6% of the total sediment reduction by anthropogenic activities for nine major Chinese rivers during 1959–2007, respectively. The changes in streamflow and sediment discharge have intensified stresses on natural and human-management ecosystems.

The headwaters of the Yellow River Basin (YRB) and Yangtze River Basin (YARB) are located in the hinterland of the Tibetan Plateau, known as "China's water tower" and representing an important ecological barrier in China (Liu et al., 2013; Tong et al., 2014). The Tibetan Plateau, within which the headwaters, has high terrain, poor soil parent material, soil depletion, and a fragile ecosystem, so it is difficult to restore once degradation has occurred (Fan et al., 2010; Jiang and Zhang, 2015; Li et al., 2013). Over the last century, under the background of climate warming and intensified human activities, the region's eco-environment has changed significantly (Jiang et al., 2016a,b; Li et al., 2013). These changes, which directly threaten the ecological security of headwater regions, include glaciers recession, snow line lifting, lakes shrinking, rivers being cut off, soil loss, grassland degradation, and a sharp downturn of water conservation capacity (Jiang et al., 2016a,c; Tong et al., 2014). Glacier recession and lifting of the snow line directly affect the water recharge of plateau lakes and wetlands; hence, numerous lakes and wetland areas have shrunk or even become dry and swamp meadow vegetation and has been gradually replaced by moderately xeric plateau vegetation (Fang, 2012; Liu et al., 2013). Grassland degradation, worsening desertification, rampant grassland rodents, declining quality of wildlife habitats, and habitat fragmentation have reduced the regional biodiversity (Liu et al., 2013). The ecosystem of headwater is fragile, so it has long been a hot area for geographic and ecological studies, and it is also a key area for ecological conservation (Li et al., 2013; Liu et al., 2013; Sun et al., 2011).

Under the background of climate warming and intensified human activities, it is very necessary to examine how the water and sediment discharge have changed, and their response to climate change, human activities, and changing environment (Jiang and Zhang, 2016; Li et al., 2013). There have been many researches on the discussions of water discharge and sediment load in large rivers, especially in the YRB and YARB, China. However, the majority of previous studies focused on the variations of streamflow or sediment discharge in main sections or tributaries, fewer analyses have been conducted along the mainstream and headwater area. The previous studies focusing on the headwaters of YRB and YARB has been confined to the analysis of streamflow, but there has been little focus on sediment discharge, and the analyses are so coarse that the inter-annual variation, relationships between water and sediment, and response to the climate change and human activities have not been revealed sufficiently (Bing et al., 2011; Shao et al., 2013). Based on the above understandings, this study used streamflow and suspended sediment discharge records of 57 years in the headwaters of YRB and YARB to systematically investigate the inter-annual variations of streamflow and sediment discharge and their correlation in the headwaters. Then, the DCC method was used to quantify the relative contribution ratios of climate change and anthropogenic activities on water and sediment changes. In addition, nine gauging stations along the mainstream of the Yellow River and Yangtze River were applied to investigate the possible impacts of water and sediment changes in the headwater on midstream and downstream. The objectives of the study are to (1) identify the inter-annual variations of streamflow and sediment discharge and their correlation in the headwaters of YRB and YARB during 1956–2012, (2) investigate the possible impacts of water and sediment changes in the headwater on the midstream and downstream, (3) examine the main causes of the variations in streamflow and sediment discharge in the headwater and quantify the contribution ratios of anthropogenic activities and climate change. The results of this study will be helpful for understanding the detailed hydrological regime of streamflow and sediment discharge and to provide a reference for water resources planning and effective management in the YRB and YARB.

## 2. Research area description

The headwaters of YRB and YARB are located in the hinterland of the Tibetan Plateau, southern Qinghai Province. Its geographic position is 31°29′–36°12′ N latitude and 89°45′–102°23′ E longitude (Fig. 1). The climate is a typical plateau continental climate, showing alternating hot and cold seasons, obvious wet and dry seasons, small annual temperature range, long hours of sunshine, and strong radiation (Jiang et al., 2016a; Jiang and Zhang, 2015, 2016). The annual mean temperature ranges from −5.6 to −3.8 °C, and annual precipitation lies between 262.2 and 772.8 mm from west to southeast. Regarding water resources, the annual mean streamflow is $330.0 \times 10^8$ m$^3$ in total, which are $201.0 \times 10^8$ m$^3$ in YRB and $129.0 \times 10^8$ m$^3$ in YARB, respectively. The years' average sediment discharges are $1212.6 \times 10^4$ t in YRB and $949.5 \times 10^4$ t in YARB, respectively. The spatial distribution of soil has significantly vertical zonality from high to low altitude in the order of alpine cold desert soil, alpine meadow soil, gray brown soil, chestnut soil, and mountain forest soil, respectively (Fan et al., 2010; Liu et al., 2008a,b; Shao et al., 2009). Vegetation types include coniferous forest, broadleaf forest, theropencedrymion, shrubland, grassland, meadow, and some others, of which grassland and meadow occupy the largest areas (Fan et al., 2010). The headwater area is characterized by serious wind erosion (altitude zone higher than 5300 m), water erosion (altitude zone below 4500 m), and freeze-thaw erosion (altitude zone ranges between 4500 and 5300 m) (Pei et al., 2011; Shao et al., 2009; Sun et al., 2011). Bulletin of Soil and Water Conservation in Qinghai Province (Water Resources Bureau of Qinghai Province, 2010) reports that the soil loss area in the southern Qinghai Province is $11.48 \times 10^4$ km$^2$, of which water erosion, wind erosion, and freeze-thaw erosion account for $1.84 \times 10^4$ km$^2$, $1.16 \times 10^4$ km$^2$, and $8.48 \times 10^4$ km$^2$, respectively. Before the implementation of Three Rivers Headwater Region (TRHR) ecological restoration project in 2005, plateau meadow presented an overall degradation trend, and the area of moderately degraded grassland was as high as $0.12 \times 10^8$ hm$^2$, accounting for 58% of the available grassland (Liu et al., 2013; Shao et al., 2013). In addition, the rodent area in the headwater area was about $644.4 \times 10^4$ hm$^2$, accounting