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Changes in monthly flows in the Yangtze River, China – With special reference to the Three Gorges Dam

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SUMMARY

Much has been written on the hydrology of the Yangtze River in China, especially since the construction of the Three Gorges Dam. Given the range of views in the literature on the impacts of dams and other natural and anthropogenic activities in the catchment on monthly flows, we here set out to analyse the behavior of monthly flows over the period of record 1955–2014. In the literature, the Three Gorges dam has been singled out for particular comment, mostly adverse. In this paper we analyse trend in temperature, precipitation and discharge of the Yangtze River at the monthly time scale over a period that includes the 11 years since the Three Gorges Dam came into operation. The results show that for the upper basin, there has been a marked increase in discharge in the low flow months of January to March that began abruptly in 2003 and an abrupt decrease in flow in October at the same time. Similar changes are found for discharge from the lower basin but in that case the changes have occurred gradually over the period of record. These changes are the outcome of the operation of hydroelectric and flood control dams that have been built continuously in the lower basin since 1955 while in the upper basin the building of the Three Gorges Dam began a phase of rapid dam building not seen in the lower basin. The decreased flows in the late summer and autumn are not of sufficient magnitude to cause any problems for navigation or water supply. The enhanced flows in the winter low flow period are beneficial in that they reduce the likelihood of salt water intrusions in the estuary adversely affecting the supply of freshwater to Shanghai.

1. Introduction

The Yangtze River in China is the 5th largest river in the world in terms of annual discharge and its catchment has a population exceeding 400 million, some 35% of the population of China and produces 25% of its Gross Domestic Product. As such, it has attracted considerable attention in the literature. The construction of the Three Gorges Dam (TGD, Fig. 1) greatly intensified this attention in both the popular press and the scientific literature, with strong assertions and predictions of its effects, mainly adverse. However, the Yangtze has proved to be a resilient river, especially in hydrological terms, as reported by Chen et al. (2014) who concluded, after an analysis of the annual flow series for the Yangtze, that despite the intensive dam building, population growth and economic development in the catchment, annual discharge has not been affected in any significant way. This has been reported by many others researching the hydrology of the Yangtze, including, for example, Xu et al. (2008), Zhang (2014) and Zhang et al. (2008a,b).

Despite this resilience, the Yangtze is still discussed in terms of water stress. Nilsson et al. (2005) have classified the 292 large river systems of the world as 'unaffected', 'moderately affected' and 'strongly affected' based on criteria of number of biomes, fragmentation of the channels by dams, extent of regulation of the flow, area of the catchment under irrigation, and the value of economic production. They list the Yangtze as one of the 29 large river systems in Asia that are strongly affected. The World Wildlife Fund and the Nature Conservancy (2015) have mapped the stressed water catchments at the global scale on the basis of the ratio of water abstracted to total annual flow. The Yangtze is mapped as a stressed catchment. They also map consumptive water use and show the Yangtze as a river with high consumptive water use. These analyses were undertaken at the annual scale and they note that had they carried out a similar classification using seasonal data the stress levels would have been higher.

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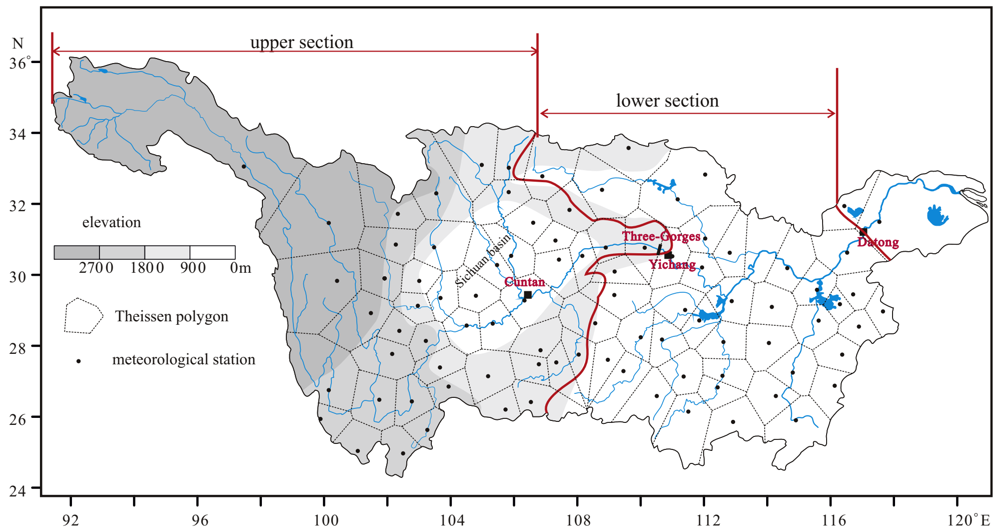

Fig. 1. The Yangtze basin. Two sub-basins are delimited by the gauging stations at Yichang (Upper) and Datong (Lower) and the upper section has the highest elevation. Black dots show the locations of the 91 meteorological stations used in this study. Boundaries of the Theissen polygons used for areally weighted mean calculations of precipitation and temperature are shown.

It is therefore possible that there are changes occurring to monthly or seasonal flows that were not detectable at the annual scale by Chen et al. (2014) and others. Jiang et al. (2008) analysed monthly trends in precipitation and discharge for the period 1961–2000 (prior to the operation of the Three Gorges Dam) and found significant upward trends in discharge from the upper catchment, as measured at Yichang hydrological station (Fig. 1), in February and July and from the whole catchment, as measured at Datong hydrological station (Fig. 1), in January, February, March, July, and August. Downward trends were seen at Yichang for May, October, and November and at Datong only in May. They explain these trends in monthly flows as being driven by equivalent changes in precipitation though in an earlier paper, using the same data, they ascribed these changes to climate warming (Jiang et al., 2007). Similar results have been reported in other studies based on data prior to the start of operation of the Three Gorges Dam (Gong and Ho, 2002; Hu et al., 2003; Zhang et al., 2008a,b).

The Three Gorges Dam began storing water in 2003. Once flow data for the Yangtze in the post Three Gorges Dam period became available, the tone of the discussions of trends in the monthly and seasonal data changed with a focus on the impacts of the Three Gorges Dam. The purposes for which the Three Gorges Dam was built are to generate hydroelectricity and assist in flood control so Yang et al. (2015) point out that the only way that it contributes to overall loss of water from the Yangtze is by evaporation, estimated to be $\sim$0.3 km^3/yr, and argue that the seasonal effects of impoundment and release affect short term discharge and not overall annual flow. Mei et al. (2015) contend that the hydrology of the Yangtze is mainly controlled by the Three Gorges Dam and that precipitation variability has little effect on the discharge. Like Guo et al. (2012) they point out that the effects diminish with distance downstream from the dam.

One of the problems with the present focus on the impact of the Three Gorges Dam is that it has only been in operation for a relatively short time so there is not yet a record of its performance across a representative range of hydrological conditions in the Yangtze catchment. This focus on the Three Gorges Dam also ignores the fact that it is but one of nearly 50,000 dams in the catchment and that since its completion an additional 76 dams have been built in the upper Yangtze catchment with a combined storage capacity more than twice that of the Three Gorges Dam (see Fig. 5). It is consistently stated that the Three Gorges Dam is the biggest dam in the world, but this is true only in terms of the size of the dam wall and its electricity generating capacity. In hydrological terms, the Three Gorges Dam is quite small, since it can store only 4% of the mean annual flow of the Yangtze and is therefore not capable of changing such significant hydrological characteristics as the seasonal flow regime, and it is located in a catchment where there are other dams that in total store around 32% of the mean annual flow. Major rivers elsewhere have experienced much greater impacts as a consequence of the construction of dams, including total reversal of the seasonal flow regime (see, for example, McMahon and Finlayson, 1995; Finlayson et al., 1994).

In this paper we analyse the hydrology of the Yangtze River at the monthly time scale using data that cover the period 1955–2014, thus including 11 years during which the Three Gorges Dam has been completed and brought into full operation. Our aim is to identify the changes that have occurred in that period in relation to temperature, precipitation, and the ongoing construction of dams, the Three Gorges Dam being the most prominent.

2. The Yangtze catchment

The Yangtze, the longest river in China, is 6300 km long. Its total catchment area is 1.8×10^6 km^2 though the total area used in this paper is 1.7×10^6 km^2 as the gauging station at Datong is located upstream of the river mouth to avoid tidal influence. Tidal flows into the estuary mainly cause backup of the flow of the river but during the low flow period (December to March) salt water can intrude into the estuary and affect the fresh water intakes for Shanghai's water supply system.

We here deal with the catchment in two sections, the upper and lower catchments, where the upper catchment is the area upstream of the Yichang gauging station, which is located just downstream of the Three Gorges Dam. The lower catchment is the area between the Yichang gauging station and the furthest downstream gauging station at Datong (Fig. 1). The upper catchment is influenced by the Indian Summer Monsoon and the lower catchment by the East Asian Summer Monsoon (Ding and Chan, 2005). The climate is classified as Köppen Cfa in the lower catchment and Cwa along the north and west. The climate becomes drier and colder at the western end of the upper catchment (Peel