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Variability and trend in the hydrology of the Yangtze River, China: Annual precipitation and runoff

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SUMMARY

The catchment of the Yangtze River in China has a long history of human occupation and the intensity of human impacts has increased markedly since economic reforms began in the late 1970s. In order to try to assess the impact of these changes on the hydrology of the river, we analyse both the annual flows of the Yangtze River and annual temperature and precipitation for the Yangtze catchment for the period 1955–2011 and for the three sections of the catchment, Upper, Middle and Lower as defined by the location of the gauging stations at Yichang, Hankou and Datong respectively. Mean annual temperature increases downstream from 12.7 °C in the Upper to 16.0 °C in the Lower section. A significant increasing trend in mean annual temperature is detected over the period 1955–2011 in the whole catchment and all sub-sections. Mean annual precipitation for the whole catchment is 1045 mm ranging from 859 mm in the elevated Upper section to 1528 mm in the Lower section. Precipitation variability is low by world standards with an annual Cv of 0.066. Using the Mann–Kendal and Rank Sums tests we do not find any trend in precipitation in the catchment. Mean annual runoff for the whole catchment is 515 mm ranging from 421 mm in the Upper Catchment to 838 mm in the Lower Catchment. Runoff variability is also low by world standards with an annual runoff Cv of 0.129. For the Middle Catchment we find a small but statistically significant increase in runoff and the runoff ratio over the period 1955–2011, possibly caused by change in the nature of the surface due to accelerated urbanization post 1980 and increased area of water storage. Overall, annual runoff in the Yangtze River shows little response to the major changes occurring in the basin. In a multiple correlation analysis of discharge, precipitation, dam volume, population and GDP, only precipitation is significantly correlated with discharge, explaining 80% of the variance. Widespread reporting of the impact of development on the annual water yield of the Yangtze, especially the impact of dams and notably the Three Gorges Dam, are not supported by this analysis.

1. Introduction

The Yangtze River basin in eastern and central China has a long history of human occupation and is probably the site of the beginning of wet rice cultivation some 8000 years BP (Zong et al., 2007). It is reasonable to speculate that this human occupation is reflected in the hydrology of the river, especially given the long history of water management associated with activities such as rice cultivation. The measurement of flow in the Yangtze did not begin until 1865 at Hankou in the Middle Yangtze (Fig. 1) and runoff from (almost) the whole basin has only been measured since 1950 at Datong (Fig. 1). It is also the case that the intensity of human activities in the Yangtze catchment has increased dramatically since the reforms and opening of the Chinese economy by Deng Xiao Ping, starting in 1978. A lot has been written describing a clear response to dam building in terms of sediment yield and its impact on estuarine and coastal regions during this later period (Chen et al., 2001; Yang et al., 2003, 2006, 2011; Zhang et al., 2006). However, no such response is evident in annual flow despite some claims that reduced discharge in the Yangtze due to dams has changed the whole circulation of the South China Sea (Lee et al., 2004; Yan et al., 2008). There has also been increasing concern about climate change as a driver of hydrological changes in the Yangtze (Zhang et al., 2007, 2008; Zhu et al., 2011). Discharge, temperature and precipitation data are available for the Yangtze catchment that

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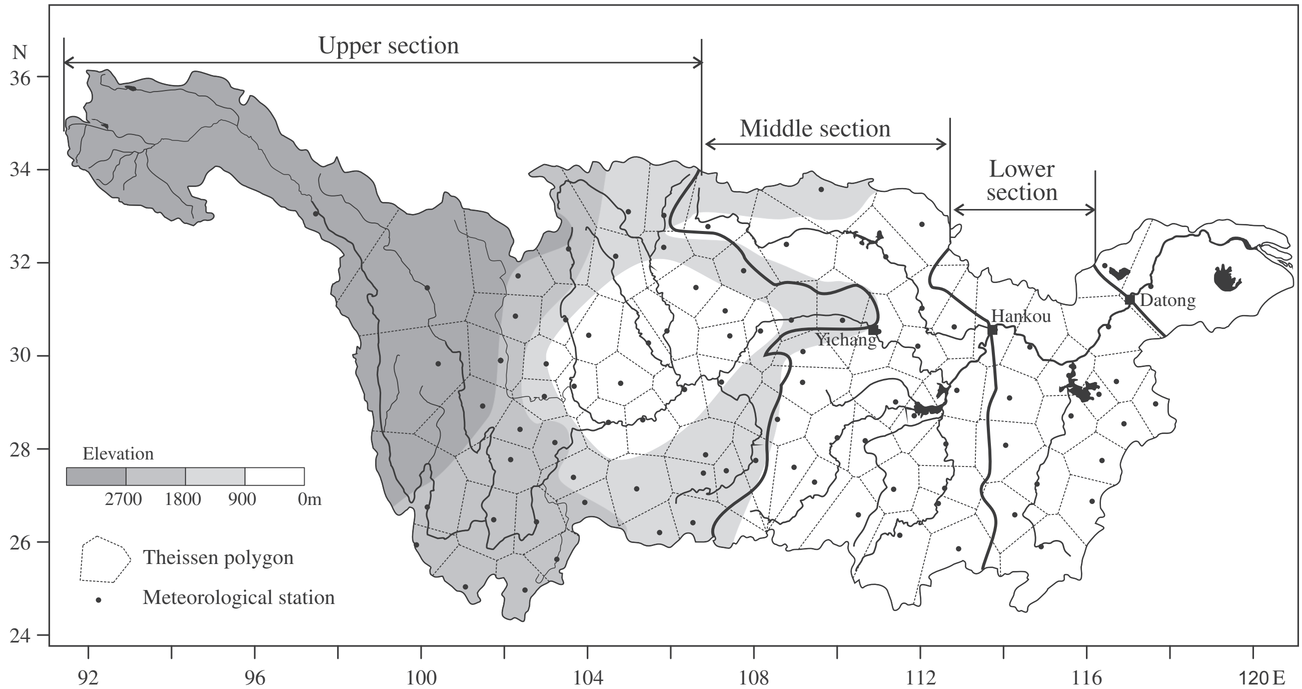

Fig. 1. Map of the Yangtze basin showing the three sub-catchments used in this study and the meteorological stations with their associated Thiessen polygons.

cover this period and permit the analysis of the impacts of these significant changes.

Some studies assume or predict that economic growth in a catchment will reduce water availability, such as that by Brown and Halwell (1998) who predicted that economic growth of 5% per year would drive huge increases in industrial water use throughout China (actual economic growth since then has been about twice this rate). Hubacek and Sun (2005), looking at future water availability in eight regions (not river basins) in China, suggest that per capita income growth and associated lifestyle changes will cause the biggest jump in demand for additional water. However, in the broader literature on river basins and changing water availability, there is no common assumption that economic growth will result in reduced water availability or reduced flows. Several drivers of changing demand are typically identified, and population growth is often seen as more important than economic growth. Alcamo et al. (2003, 2007) conclude that income growth is important in driving increases in water withdrawals in the future in developing countries, but they also recognise that agriculture remains by far the most important user. In China-specific studies (Shin, 1999; Onishi et al., 2009; Wu et al., 2011), aspects of economic growth are considered important in driving water demand, but the make-up of this growth, the continued dominance of agricultural use, population growth and changing flows as a result of the operation of dams are also recognised as being significant.

In the case of the Yangtze River basin, Vörösmarty et al. (2000) see a pattern of sensitivity where both climate change and population pressures increase water stress. They report no water stress in the Yangtze basin in 1985 but their scenario building indicates a deterioration of this situation by 2025, driven mainly by climate change and population increase. Alcamo et al. (2003) have also carried out a scenario development to 2025 that includes the Yangtze catchment. They report that in 1995 the Yangtze water stress was low, as measured by the ratio of water withdrawals to availability (wta) of 0.2. In their scenario to 2025 they do not consider climate change and assume that there will be no growth in the area of irrigated land. On this basis they argue that the Yangtze wta will remain below 0.4, the threshold for water stress.

In this paper we consider the period 1955–2011 during which there have been major changes occurring in the Yangtze basin in terms of economic development (as measured by GDP), urbanisation (as measured by the growth in the non-agricultural population), intensification of agriculture and the construction of dams. This period has also seen a steady increase in population. There are other land use changes that have the potential to affect runoff, such as changes to the forest cover and land degradation. We have not included them here as a previously published review of these issues indicates that they have no significant impacts at this stage (Finlayson et al., 2012).

The hydrology of the Yangtze catchment is described at the annual time step for the whole catchment and for each of the upper, middle and lower sections of the catchment (Fig. 1). The annual rainfall, runoff and temperature series are analysed for trend and we also examine changes in the relationship between rainfall and runoff at the whole of catchment scale. We analyse the annual rainfall in the Yangtze basin and runoff in the Yangtze River over this period in relation to the major relevant changes that have occurred in the catchment. Our purpose is to attempt to detect a hydrological response (as measured by annual water yield) to the significant changes that have taken place in the Yangtze catchment during this period.

2. The Yangtze catchment

The Yangtze River originates on the Tibetan Plateau and discharges into the East China Sea, 6300 km away. Total drainage area is 1.8×10^6 km^2 though the last gauging station on the river at Datong commands an area of only 1.7×10^6 km^2 since it is situated at the upstream limit of tidal influence. Here we subdivide the catchment into three sections, based on the location of gauging stations for which suitable data are available. The Upper Yangtze consists of the area upstream of Yichang; the Middle Yangtze is that part of the catchment between Yichang and Hankou; and the Lower Yangtze between Hankou and Datong. These sites are