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IDENTIFICATION FOR THE IMPACT OF CLIMATE CHANGE AND HUMAN ACTIVITIES ON STREAMFLOW IN XITIAOXI RIVER BASIN, CHINA

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ABSTRACT: As the crucial headwater of Taihu Lake basin, Xitiaoxi River basin was chosen as the study case. The hydrological time series was divided into two periods, the baseline period and the changed period. Two approaches (the hydrological sensitivity-based method and the decomposition method based on Budyko hypothesis) were used to quantitatively identify the impact of climate change and human activities on stream flow. The results obtained by using the two approaches were verified each other, and it showed that climate change attributed to 38%~42% and human activities 58%~62%. Human activities attribution is dominant and it is the most considerable cause for the variation of hydrological processes in the basin.

Key Words: climate change, human activities, change-point, Taihu Lake

1. INTRODUCTION

Along with the globe warming, the dual effects of climate change and human activities alter hydrological processes and water resources systems, as well as fields closely associated with hydrosphere (Ye *et al.*, 2003; Russell *et al.*, 2009). Climate change intensifies regional water cycle (Milly *et al.*, 2005; Huntington, 2006) and it may lead to streamflow instability in the future, such as the Mississippi (Jha *et al.*, 2004; Jha *et al.*, 2006; Kim *et al.*, 2013), the Rhine basin(Kwadijk and Rotmans, 1995), St. Lawrence tributaries (Boyer *et al.*, 2010), the Siurana catchment (Candela *et al.*, 2012) and the northern China (Guo *et al.*, 2002). And increasing anthropogenic activities emit greenhouse to change climate (Tett *et al.*, 2002; Gedney *et al.*, 2006) and on the other hand directly transform catchment characters to induce hydrological variation (Nakayama, 2012). River regimes altered in the Great Plains of the United States attributable to damming and impoundment (Costigan and Daniels, 2012). Also, human activities for grazing, cultivation and planting changed the hydrological regime in the Andean páramos (Buytaert *et al.*, 2006). And human activities in the northern area of China contain 4 large river basins contributed to nearly 20%~50% of the runoff decrease (Ren *et al.*, 2002).

At the changeable background, it complicates mechanisms of hydrological processes, disorders such hydrological extremes as floods and droughts, and increases the uncertainty of future hydrological regimes (Malmqvist and Rundle, 2002; Jung *et al.*, 2012; Ye *et al.*, 2013). Thus, it is necessary to detect and attribute the detailed driving forces for hydrological alteration and identify the impacts of climate change and anthropogenic activities on streamflow for specific approaches to attempt the balance of water resources supply and demand in a basin, as well as the balance of ecosystem and environment. Quantitative assessment of the main driving forces could help a visualized cognition and a better solution of water issues. A study indicated that 60% of the climate-related tendencies in the western United States on streamflow were human-induced, which predicted a future water supply crisis for the region (Barnett *et al.*, 2008). Climate change by precipitation and potential evaporation and human activities accounted for over 40% and 50% in Wei River basin (Du and Shi, 2012). Intensive human activities in many regions of China contributed over 50% to runoff variation, larger than the impacts of climate change (Miao *et al.*, 2011; Wu *et al.*, 2012; Ye *et al.*, 2013). Most of these assessments of climate change and human activities impacting on streamflow either major on the general contribution or focus on the influence of detailed driving factors (Bao *et al.*, 2012; Ye *et al.*, 2013) and apply statistical analysis based on hydro-meteorological observations or hydrological models to distinguish the synthesis effects (Hang *et al.*, 2011).

Taihu Lake basin surrounds the most economical developed regions in China. Within its special location and social demand, water resources encounter real challenges with increasingly aggravated human activities. Meantime, the basin is one of the most fragile climate areas in which hydrological processes and water resources system are easily influenced by climate change. As one vital headwater of Taihu Lake basin, Xitiaoxi River basin is disturbed by climate change and anthropogenic activities (Zhang *et al*., 2012). It is of value to probe into the driving force of streamflow variation and detect the changing role of hydrological processes in the Xitiaoxi River basin. The aim of the study is to quantitatively identify the impact of climate change and human activities on streamflow in the basin. Two methods, the hydrological sensitivity-based method and the decomposition method based on Budyko hypothesis, would be used to estimate the contribution of climate change or human activities to runoff variation, respectively. The estimation would provide the support to take practical measures for water resources management in the Xitiaoxi River basin.

2. MATERIALS

Xitiaoxi River is an important tributary in the upstream of Taihu Lake, originating from the main peak, Longwang Mountain, of Tianmu Mountain. The mainstream is 145 km long, flowing from southwest to northeast. With an area of 1 355 km^2, Xitiaoxi River basin has an average altitude of 266 m. The mean annual precipitation of the basin is 1 626 mm and its intra-annual distribution is uneven, majoring in from April to October. Hengtang hydrological station is the outlet of the basin and its mean annual runoff is 781 mm (Fig. 1).

Precipitation, evapotranspiration and runoff, are applied to identify for the effects of climate change and human activities on runoff in the basin. As actual evapotranspiration is difficult to obtain, potential evaporation is used instead. The time series is from 1972 to 2010. To get a general discernment over the study area, areal precipitation and potential evaporation was processed by inverse distance weighted method with observations in 21 rainfall stations and 12 evaporation stations.

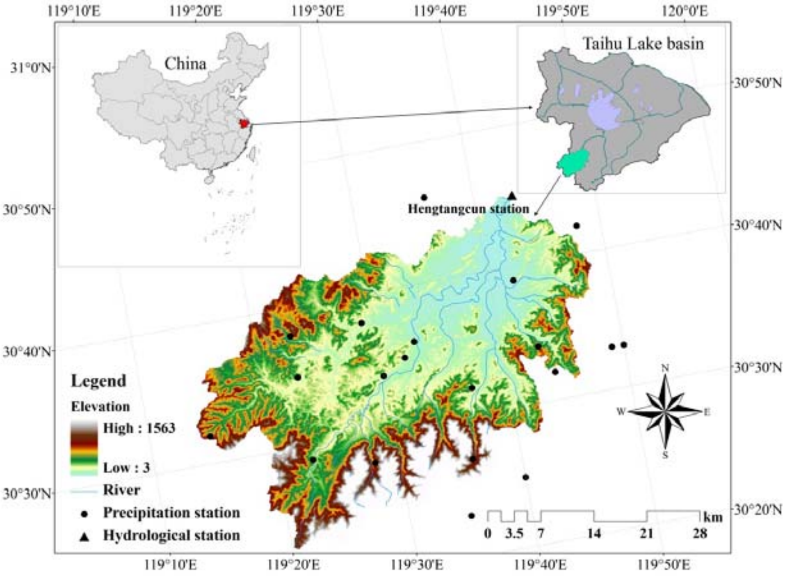

Fig.1 Topography of Xitiaoxi River basin

3. METHODS

To identify the respective impacts of climate change and human activities on streamflow, hydrological time series are divided into two periods (*i.e.* baseline period and changed period) by an identified change-point. Changes in the changed period are comparative to the baseline period. The following two methods discern the impact of climate change and human activities on streamflow based on the period division.

3.1 Hydrological Sensitivity-based Method

Hydrological sensitivity-based (HSB) method (Jones *et al.*, 2006) is actually a simple hydrological model based on water balance with responses to climate variability considering precipitation and potential evaporation. It is widely used to estimate the impacts of climate change and human activities on streamflow variation (Li *et al.*, 2007; Ye *et al.*, 2013). Generally, the water balance for a basin is as follows:

$$P = E + Q + \Delta S \tag{1}$$

where P, E and Q are precipitation, evapotranspiration and runoff, respectively, and ΔS represents the change of water storage in a catchment. For a long time over 10 years, ΔS can be defined as zero, and the relationship between precipitation and evapotranspiration is (Zhang *et al.*, 2001):

$$\frac{E}{P} = \frac{1 + w(E_0 / P)}{1 + w(E_0 / P) + (E_0 / P)^{-1}} \tag{2}$$

where E_0 is potential evaporation, w is a parameter relevant to vegetation type.

Runoff variation induced by precipitation and potential evaporation can be expressed as (Dooge *et al.*, 1999; Milly and Dunne, 2002):

$$\Delta Q^c = \beta \Delta P + \gamma \Delta E_0 \tag{3}$$

where ΔQ^c is the runoff variation caused by climate change; ΔP and ΔS are relative changes of precipitation and potential evaporation. β and γ are the sensitivity coefficients of precipitation and potential evaporation, which are calculated as:

$$\beta = \frac{1 + 2x + 3wx^2}{(1 + x + wx^2)^2} \tag{4}$$

$$\gamma = -\frac{1 + 2wx}{(1 + x + wx^2)^2} \tag{5}$$

where x is the dryness index which equals E_0/P.

If ΔQ is the total runoff variation caused by both climate change and human activities, then the runoff variation induced by human activities ΔQ^h can be calculated by

$$\Delta Q^h = \Delta Q - \Delta Q^c \tag{6}$$

3.2 Decomposition Method Based on Budyko Hypothesis

The decomposition method based on Budyko hypothesis (DMBH) (Wang and Hejazi, 2011) is based on Budyko hypothesis and water balance. Originally, natural catchments conform to the Budyko curve, *i.e.* the Budyko hypothesis (Budyko, 1974). Within the Budyko curve, change in the horizontal direction can represent the climate impacts as the index E_0/P is only influenced by climate change; while in the vertical direction, index E/P incorporates the effects of human activities and climate change. The Budyko hypothesis transforms if either one is disturbed. And it makes the change deviate the Budyko curve (see Fig. 2, with natural change, the change would be from A to C, while from A to B if basin conditions change). There are many functional forms to describe Budyko curve (Wang and Hejazi, 2011) and Eq. (2) was selected as the expression in the study. With the Budyko curve, A represents the natural state for the baseline period, C represents the ideal developed state without human activities and climate change for the changed period, and B is the real state within human interference and climate effects for the changed period. Assume A (E_{01}/P_1, E_1/P_1), B (E_{02}/P_2, E_2/P_2), and C (E_{02}/P_2, E'_2/P_2). The subscripts *1* and *2* are for the baseline period and the changed period. E_1 and E_2 are obtained by the water balance equation. And the rate E'_2/P_2 can be obtained by the Budyko function validated in the baseline period.

Climate change causes variation of both the horizontal and vertical components and human activities only induce variation of the vertical components. Thus, the change of human activities can be computed. For a long time period, the water balance can be expressed as

$$Q = P(1 - E/P) \tag{7}$$

And the anthropogenic contribution can be calculated by

$$\Delta Q^{\mathrm{h}} = P_2(E'_2/P_2 - E_2/P_2) \tag{8}$$

where ΔQ^h is the runoff variation caused by human activities.

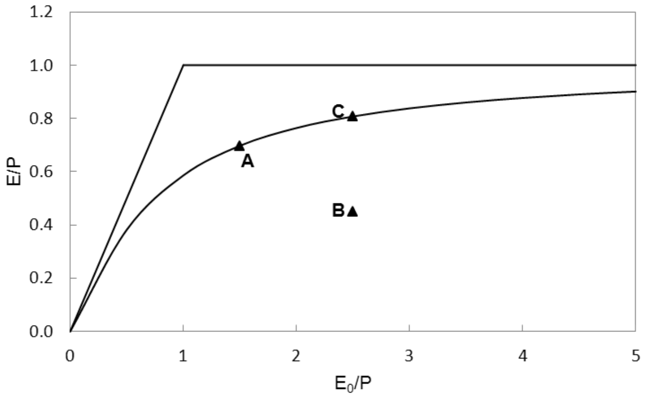

Fig. 2 The variation of the Budyko hypothesis (Wang and Hejazi, 2011)

4. RESULTS AND DISCUSSIONS

4.1 Variation of the Hydrological Time Series

The three time series, precipitation, potential evaporation and runoff, all demonstrated a decreasing linear trend in recent 40 years (see Fig. 3). The fluctuation of runoff was consistent with variation of precipitation and the lowest and highest values occurred in 1978 and 1999. Since 1999, all the three factors tended to decrease significantly. Qiu *et al.* (2013) has detected the change-point of precipitation and runoff sequence with validation during the study period in the basin and determined that both of the abrupt change occurred in 1999. Within analysis of the catchment conditions, the study introduced the change-point 1999 as the division of the baseline period (1972~1998) and the changed period (1999~2010). The division indicated that the basin in the changed period was interfered with notable anthropogenic activities and climate impacts; while in the baseline period, it kept a comparative natural state. Still, there were continuous human activities exemplifying as hydraulic engineering construction and urbanization and climate change as global warming during the baseline period. Also, their impact on hydrological processes might be delayed in the baseline period and presented remarkable reflections in the changed period. The quantitative assessments comparative to the natural state is underestimated.

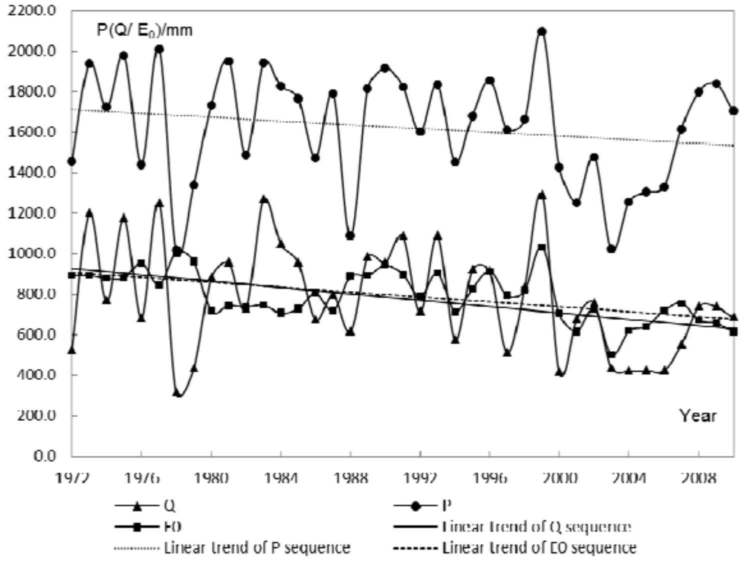

Fig. 3 Changing curves and linear trends of precipitation, potential evaporation and runoff time series

Compared to the baseline period, runoff, precipitation and potential evaporation in the changed period decreased 26%, 10% and 18%, respectively (see Table 1). However, actual evapotranspiration increased 52 mm and accordingly the ratio ET/P increased 18% while E_0/P decreased 9%. The decrease of precipitation and the increase of actual evapotranspiration are consistent with the decrease of runoff. Table 1 showed that the evapotranspiration ratio ET/P nearly equaled to the dryness index E_0/P in the baseline period. But ET/P was larger than E_0/P in the changed period. Variations of precipitation and potential evaporation were mainly caused by climate change; both of climate change and human disturbance aroused changes in runoff and actual evapotranspiration. The stability of E_0/P and the great fluctuation of ET/P indicated that anthropogenic effects on hydrological processes might be predominant.

Table 1 Variation of runoff, precipitation and potential evaporation during the baseline period and the changed period

	Q (mm)	P (mm)	E_0 (mm)	ET (mm)	E_0/P	ET/P
Baseline period	848	1677	839	830	0.50	0.49
Changed period	631	1513	690	882	0.46	0.58
Variation	-217	-164	-149	52	-0.04	0.09

4.2 Assessment of Climate Change and Human Activities Impacting on Runoff Variation by the HSB Method and DMBH

According to Table 1, the variation of runoff, precipitation and potential evaporation are -217 mm, -164 mm and -149 mm, respectively. In the baseline period, the parameter w was determined to be 2.0. Accordingly, β and γ are equaled to 1.23 and -0.74, respectively. Then the runoff variation induced by climate change calculated by the HSB method was -92 mm.

The quantitative contribution of climate change to runoff variation was 42% and 58% of human activities (see Table 2).

For the DMBH, point A, B and C were (0.50, 0.49), (0.46, 0.58), and (0.46, 0.49), respectively. The runoff variation induced by human activities was -135 mm and it contributed 62% while climate change contributed 38% (see Table 2).

The HSB method computed runoff variation by climate change with the value of 92 mm and the DMBH calculated by human activities with the value of 135 mm. The accumulation of the two driving forces by the two methods was 227 mm while the actual runoff variation was 217 mm. The error was 10 mm by a relative error of 4%, which was among the rational bias. Thus, the estimation by the two methods can be cross validated. And it concluded that the effects of climate change on runoff variation accounted for 38%~42% and human activities 58%~62%. The result was consistent with the outcome of Zhang *et al.* (2012). Furthermore, the study gave a more robust result by a changing interval for the identification and enriched the findings for the basin.

Table 2 Quantitative assessment of climate change and human activities impacting on runoff variation by the HSB method and the DMBH

	parameter		Baseline period		Changed period	
			ΔQ^c (mm)	$\frac{\Delta Q^c}{\Delta Q}$ (%)	ΔQ^h (mm)	$\frac{\Delta Q^h}{\Delta Q}$ (%)
HSB method	β	1.23	-92	42	-125	58
	γ	-0.74				
DMBH	ET'/P	0.49	-82	38	-135	62

The HSB method was used to quantitatively detect and attribute the impact of climate change and human activities on streamflow in different regions with different catchment conditions (*e.g.* Jiang *et al.*, 2011). And Patterson *et al.* (2012) applied the DMBH to take in quantitative estimation in the South Atlantic, USA. The two methods were commonly utilized in the identification for the two driving forces. Though the two methods were both based on water balance and the relationship of precipitation and evapotranspiration, the HSB method considered the impact of climate change and the DMBH considered the impact of human activities with a different perspective. Both of the methods analyzed the alteration of precipitation and potential evaporation. For a humid region as Xitiaoxi River basin that E_0/P and even ET/P were much smaller than 1.0, precipitation was the majored factor of climate change and the consideration for the two factors could almost contain the effect of climate change in the basin. But for the DMBH, the Budyko hypothesis might be not exactly correct and (E_0/P, ET/P) developed naturally would deviate the Budyko curve (Wang and Hejazi, 2011). Thus, it was uncertainty existing in its consequence of the assessment.

The results declared that human activities dominated to disturb hydrological processes with a percent larger than 50% in Xitiaoxi River basin. As an upstream and a headwater of Taihu Lake basin, which was highly developed and mostly intense with human activities, it was not so intensified by anthropogenic intervention. However, increasing human activities should attract attention to. In the Xitiaoxi River basin, land cover/land use change influenced storm runoff (Wan and Yang, 2007). And urbanization became one main factor to affect hydrological responses in the basin (Li *et al.*, 2009). Also, various water conservancy projects, deforestation and other human activities altered hydrological processes in the region *(Zhang et al.*, 2012). Following the rapid development in the region, human activities would be increasing. Other than human perturbation, climate change contributed largely to runoff variation. The basin belongs to a climate vulnerable area adjacent to ocean. Climate would easily be affected by globe warming. The two driving forces both greatly impact hydrological processes and water resources in the Xitiaoxi River basin. It is crucial to consider their effects for water resources management and take measures to reduce their negative effects to meet the demand of water resources in the basin.

5. CONCLUSIONS

In recent 40 years, climate change and human activities have attributed to streamflow reduction in Xitiaoxi River basin. The assessment of the HSB method and the DMBH demonstrated that the contribution of climate change to runoff variation accounted for 38%~42%, and human activities accounted for 58%~62% during the changed period comparative to the baseline period. Anthropogenic effects dominated the streamflow change and the impact of climate change was also one essential cause. Within the increasing human demand, it is vital to take measures for water resources management in the basin.

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