

The determinants of streamflow variability and variation in Three-River Source of China: climate change or ecological restoration?

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Abstract Exploring the determinant between climate change and ecological restoration for streamflow dynamics is a significant issue in global change research and is essential for restoration policy assessment and climate change adaptation. In this paper, the combination of elasticity method and Budyko framework was applied with the meteorological and hydrological data from 1980 to 2014. The variability and variation of streamflow were explained by individual elasticity coefficient and contribution of climate change and ecological restoration between 1980–1999 and 2000–2014. Results showed that streamflow was more sensitive to climate change in the Yellow River source (YER) than in the Yangtze River source (YZR). Ecological restoration was positively correlated with the variability of streamflow in YER with 7.38% relative change in elasticity coefficients, while it was opposite trend in YZR with a relative change of -7.41% . However, the impacts of climate change and ecological restoration on the variation of streamflow were not

consistent with the variability. In YER, ecological restoration dominated the streamflow reduction with a contribution of 82.43%, whereas, in YZR, climate change mainly contributed to the streamflow increase which could explain 123.72% and the precipitation was the major contributor. By analysis, the difference in two catchments might result from the spatial heterogeneity of precipitation conditions and land use/cover change, especially the conversion of grassland. The results suggest that the implementation of ecological recovery should consider the difference of streamflow change in response to ecological restoration and climate change for the sustainability of water resources.

Keywords Streamflow variability and variation · Climate change · Ecological restoration · Sensitivity and contribution analysis · Three-River Source of China

Introduction

Hydrological circulation process, especially for streamflow, is significantly influenced by climate change and anthropogenic interference (Gordon et al. 2005; Sterling et al. 2013). The streamflow change reflected the response of water cycle to the changing climate and underlying surface. Research indicated that climate change is driving the variation of streamflow through hydrological inputs and watershed characteristics while human activities are mainly through the latter (Jiang et al. 2015). Climate change affected the streamflow dominantly through precipitation and evapotranspiration (Li and Chen 2015; Touhami et al. 2015). Anthropogenic interference greatly altered the underlying surface and water resource reapportionment, which was ascribed by land use/cover change (LUCC),

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urbanized and industrialized extension, hydropower development and irrigation intensification (Leng et al. 2015a; Tomer and Schilling 2009; Zhang et al. 2008). Therefore, it is necessary to identify the determinant influencing streamflow, which is of importance to make a long-term sustainable water strategy.

Global warming and regional climate change were conspicuous over the past century (James and Makiko 2016; Spracklen 2016), which substantially affected the seasonal water supply (Immerzeel et al. 2010). Climate change exacerbated the uneven distribution of water resources through affecting hydrological process (Piao et al. 2010; Leng et al. 2015b), especially in the drought and warm years (Michelle et al. 2016;). Besides, the availability of water yield was impressionable to immoderate consumption. As a result of anthropogenic interference, major urban watersheds were influenced in USA (Velpuri and Senay 2013). Since the 1990s, aiming at the issues of water shortage and ecological degradation, Chinese government has initiated some ecological conservation projects and water allocation policies, such as the Natural Forest Conservation Program. Possible water effect of extensive ecological restoration is focused on simultaneously. Heavy investments of ecological conservation and restoration indicated that most of the ecosystem services were significantly improved from 2000 to 2010 (Ouyang et al. 2016) and it was very beneficial to ecological and socioeconomic effects (Liu et al. 2008). However, water consumption of recovered ecosystem was limited in the seasonally dry areas where streamflow was decreasing due to the feedback of these restoration projects (Csaba and Ge 2014; Feng et al. 2016). Under global climate change, how much human activity could influence the dynamic of streamflow remains unclear because of lacking comprehensive analysis on its variability and variation. The methods to evaluate the impacts of climate change and anthropogenic interference on streamflow are various, mainly including the elasticity method and hydrological modeling (Adam et al. 2007; Immerzeel et al. 2010; Wang and Hejazi 2011). Among these methods, the elasticity method integrated with the Budyko framework is an appropriate way to separate the sensitivity and contribution of anthropogenic interference and climate change to streamflow as brief, effective and practical (Li 2014; Roderick and Farquhar 2011; Yang and Yang 2011). In terms of climate change and anthropogenic interference, individual elasticity was used for the evaluation of streamflow variability and their contributions to explain the variation of streamflow. Climate factors were mainly consisted of precipitation and potential evapotranspiration, and the effect of ecological restoration on streamflow was reflected by landscape parameter in Budyko framework. It was found that, in the Danjiangkou Reservoir, the

dominant contributor to streamflow change was climate change (Liu et al. 2013), while, in the Yellow River Source, land use/cover change (LUCC) were the main causes of streamflow decrease (Zheng et al. 2009). Moreover, the mechanisms of streamflow variability and the vulnerability of water resources were explored using the Budyko framework method (Singh and Kumar 2015; Zhang et al. 2016a). Based on these methods, streamflow effect could be assessed.

Three-River Source region, the main hinterland of the Tibetan Plateau, is the headwater of the Yangtze River and Yellow River catchments. It plays a critical role in the water resources safety of China. Meanwhile, it is sensitive to climate change and human activities because of the unique geographic characteristics and climatic conditions (Zhang et al. 2011). Ecological restoration is a dominant anthropogenic interference with the prohibition of intensive human activities during recent decades, which affects the underlying surface in Three-River Source region (Guo et al. 2016).

The objectives of this paper are to: (1) investigate the trend of streamflow change from 1980 to 2014; (2) explore the sensitivity of streamflow to climate change and ecological restoration referred to precipitation, potential evapotranspiration and landscape change; and (3) quantify the contributions of climate change and ecological restoration to streamflow variation.

Data and methods

Study area

Three-River Source region (31°06'N–35°42'N, 90°36'E–103°24'E) is located in the Tibetan Plateau of China (Fig. 1) and experiences a typical plateau continental climate. Study area includes the Yangtze River source (YZR) and Yellow River source (YER) with the outlets of Zhimenda and Tangnaihai, respectively. YZR and YER separately supply 25 and 49% of water for their downstream regions. The YZR covers 1.4×10^5 km² and the YER covers 1.2×10^5 km². Annual streamflow depth ranges from 61.30 to 268.98 mm, annual precipitation is approximately 290.50 to 685.47 mm, and the potential evapotranspiration is between 770.85 and 955.89 mm.

Data

- (1) Hydrological data: The observed data of annual streamflow for the Zhimenda and Tangnaihai hydrological stations from 1980 to 2014 are acquired from the Hydrological Bureaus of the Tibet Autonomous Region. As ecological restoration is engaged

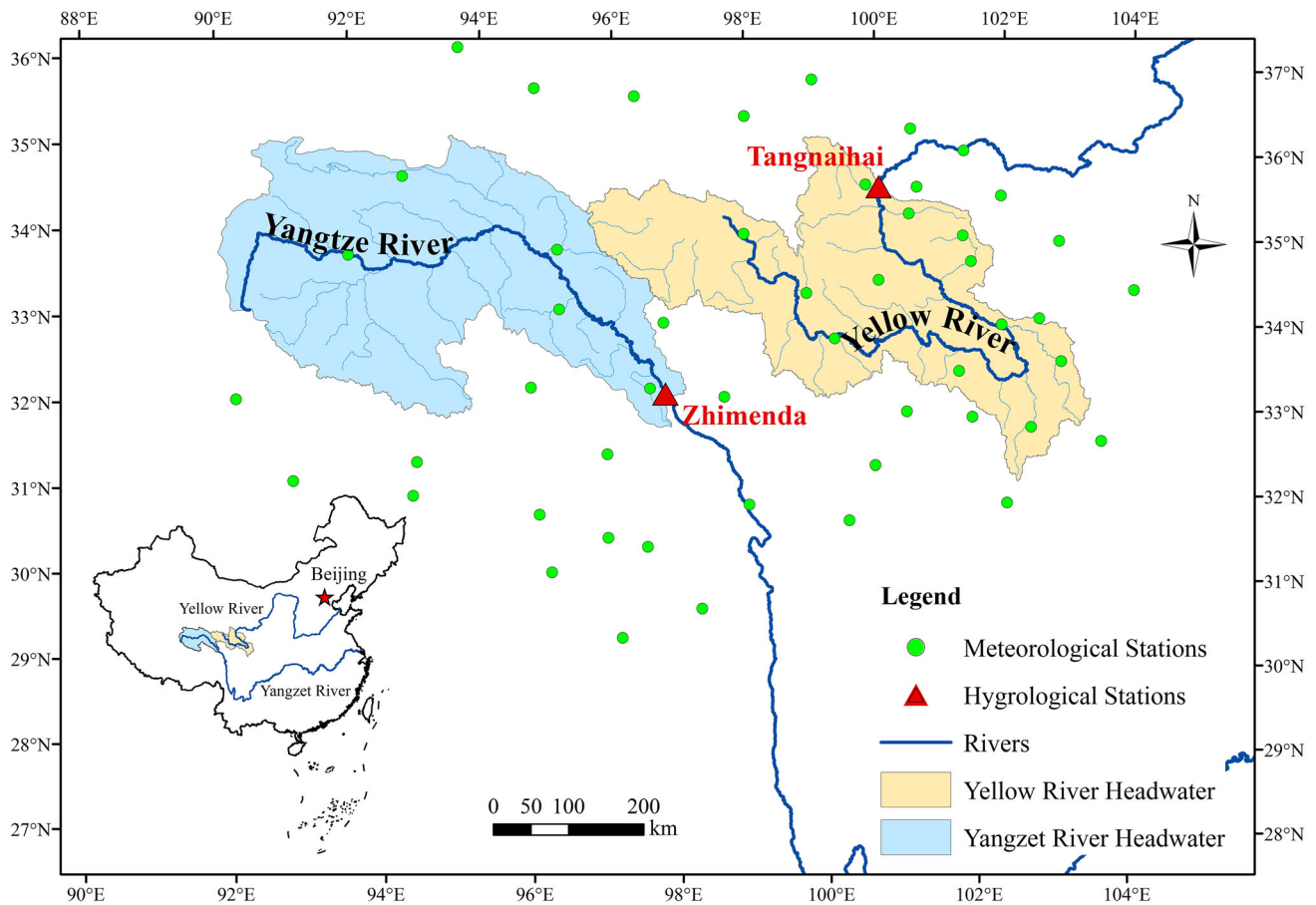


Fig. 1 Geographic information of the Yellow River and Yangtze River sources with outlet hydrological stations and main meteorological stations

since 1990s, the period is divided into period I (1980–1999) and period II (2000–2014).

- (2) Meteorological data: The daily meteorological records for 49 national meteorological stations are used from 1980 to 2014 (Fig. 1), which are obtained from the National Climatic Center of China Meteorological Administrator (<http://data.cma.cn/data/index/6d1b5efbdcfb9a58.html>) and include precipitation, temperature, solar radiation, vapor pressure and wind speed.
- (3) Land use/cover change (LUCC) data: The datasets of LUCC in 1995 and 2010 are obtained from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (<http://www.resdc.cn/data.aspx?DATAID=99>) with a spatial resolution of 1 km × 1 km (Liu et al. 2014). The LUCC data in 1995 represent for the situation of land use before the implement of ecological restoration, while the LUCC data in 2010 stand for the present situation since ecological policy.

Methods

Statistical methods

The significant trend for the interannual data of hydrological factors is detected by Mann–Kendall statistical test due to its robustness for non-normally distributed data (Fathian et al. 2016). According to the operation result, if $p \leq 0.01$, Mann–Kendall test indicates a significant trend at a level of $p = 0.01$; else if $0.05 \leq p < 0.01$, it indicates a significant trend at a level of $p = 0.05$.

Potential evapotranspiration (ET_0)

The daily ET_0 value of the Three-River Source is calculated by the Penman–Monteith method (Allen et al. 2006) using Eq. (1):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} u_2 VPD}{\Delta + \gamma(1 + 0.34u_2)}, \quad (1)$$

where R_n ($\text{MJ m}^{-2} \text{d}^{-1}$) is the net radiation flux density at the surface; G ($\text{MJ m}^{-2} \text{d}^{-1}$) is the sensible soil heat flux

density; T_a ($^{\circ}\text{C}$) and u_2 (m s^{-1}) are the mean daily air temperature and wind speed at a height of 2 m, respectively; VPD (kPa) is the vapor pressure deficit (the difference between the saturated and actual vapor pressures); Δ ($\text{kPa } ^{\circ}\text{C}^{-1}$) is the slope between the saturated vapor pressure and air temperature; and γ ($\text{kPa } ^{\circ}\text{C}^{-1}$) is the psychrometric constant. It is worth noting that R_n is a function of solar radiation (R_s), which is estimated as the difference between the net shortwave radiation (R_{ns}) and the net long-wave radiation (R_{nl}). R_s is expressed by Eq. (2):

$$R_s = \left(a_s + b_s \frac{M}{N} \right) R_a, \tag{2}$$

where M (hour, h) is the actual insolation duration, N (h) is the maximum possible duration of sunlight or daylight hours, M/N is the relative insolation duration and R_a ($\text{MJ m}^{-2} \text{d}^{-1}$) is the extraterrestrial radiation intensity. The coefficients of a_s and b_s are estimated by an optimized method for solar radiation (Fathian et al. 2016) and can improve the precision of the ET_0 estimation.

Attribution analysis of streamflow change

The impacts of climatic variation and human activities on streamflow are evaluated by the elasticity method which separate the contributions of climate from human activities quantitatively (Choudhury 1999). The elasticity coefficient E_x is expressed by Eq. (3):

$$E_x = \lim_{\Delta x/x \rightarrow 0} \left[\frac{\Delta Q/Q}{\Delta x/x} \right] = \frac{\partial Q}{\partial x} \times \frac{x}{Q}, \tag{3}$$

where Q is the streamflow (mm) and x is the impact factor of streamflow (e.g., precipitation and ET_0). A positive (negative) E_x of the x factor suggests that an increase (decrease) in the x variable will cause an increase (decrease) in streamflow. For instance, an E_x of 0.1 indicates that a 10% increase in the x factor may lead to a 1% increase in streamflow.

The climatic factors mainly include precipitation and evapotranspiration while the latter also reflects the temperature tendency. Ecological restoration is a dominated human interference with few other intensive activities in Three-River Source. The variation of streamflow can be expressed as Eq. (4):

$$\Delta Q_{\text{obs}} = \Delta Q_{\text{clim}} + \Delta Q_{\text{human}}, \tag{4}$$

where ΔQ_{obs} is the observed change in streamflow and ΔQ_{clim} and ΔQ_{human} are the changes in streamflow resulting from climate change and human activities, respectively. Moreover, ΔQ_{clim} can be estimated by Eq. (5) (Liu et al. 2012; Milly and Dunne 2002):

$$\Delta Q_{\text{clim}} = \Delta Q_P + \Delta Q_{ET_0}, \tag{5}$$

where ΔQ_P and ΔQ_{ET_0} are the contributions of precipitation and ET_0 to the change in Q , respectively.

For the Three-River Source area, actual evapotranspiration can be calculated by water balance. For a long temporal scale in the Three-River Source area, the average annual change in water storage can be assumed to be negligible (namely $\Delta S \approx 0$) (Destouni et al. 2013; Levi et al. 2015). Using available data of precipitation and streamflow, ET_a can be computed by Eq. (7):

$$ET_a = P - Q - \Delta S. \tag{6}$$

When $\Delta S \approx 0$,

$$ET_a = P - Q. \tag{7}$$

Based on Budyko, ET_a can be estimated (Budyko 1963), and one of proposed equations, the Choudhury–Yang Equation, is expressed as Eq. (8). Climate-driven change is combined precipitation with ET_0 , as shown in Eq. (5), while human-driven change is reflected by the landscape parameter n which is very related to vegetation in Three-River Source region (Zhang et al. 2016b). Precipitation, ET_0 and n are associated with Eq. (8):

$$ET_a = \frac{P \cdot ET_0}{(P^n + ET_0^n)^{1/n}}. \tag{8}$$

Therefore, streamflow change is connected to climate-driven and human-driven changes by Eqs. (7) and (8). Combining Eqs. (4) to (8), the observed streamflow change can be expressed by differential Eq. (9):

$$\begin{aligned} dQ &= \frac{\partial f}{\partial P} dP + \frac{\partial f}{\partial ET_0} dET_0 + \frac{\partial f}{\partial n} dn \\ &= \varepsilon_P \frac{dP}{P} Q + \varepsilon_{ET_0} \frac{dET_0}{ET_0} Q + \varepsilon_n \frac{dn}{n} Q, \end{aligned} \tag{9}$$

where ε_P , ε_{ET_0} and ε_n are the elasticity coefficients of precipitation, potential evapotranspiration and landscape parameter n , respectively. The aridity index (AI) $\varphi = ET_0/P$, and the elasticity coefficients can be expressed by Eqs. (10) to (12):

$$\varepsilon_P = \frac{(1 + \varphi^n)^{1/n+1} - \varphi^{n+1}}{(1 + \varphi^n) \left[(1 + \varphi^n)^{1/n} - \varphi \right]}, \tag{10}$$

$$\varepsilon_{ET_0} = \frac{1}{(1 + \varphi^n) \left[1 - (1 + \varphi^{-n})^{1/n} \right]} \tag{11}$$

and

$$\varepsilon_n = \frac{\ln(1 + \varphi^n) + \varphi^n \ln(1 + \varphi^{-n})}{n \left[(1 + \varphi^n) - (1 + \varphi^n)^{1/n+1} \right]} \tag{12}$$

Results

Interannual variation in hydrological factors

The hydrological characteristics of the Three-River Source are presented in Fig. 2 and Table 1. Figure 2 shows the interannual variations in precipitation (a), potential evapotranspiration (b), streamflow (c), aridity index (d) and streamflow coefficient (e), and Table 1 lists their trend significance. From 1980 to 2014, streamflow, precipitation and streamflow coefficient show upward trends but aridity index is a significant decrease in YZR; however, streamflow and streamflow coefficient display a downward trend following the remarkable increase in potential evapotranspiration in YER.

In terms of the trend change between the two periods (period I: 1980–1999, period II: 2000–2014), hydrological factors in YER are consistent with those in YZR. Precipitation, streamflow and streamflow coefficient present downtrends in period I, whereas they exhibit significant upward trends in period II for YER and YZR. The

increasing slopes of potential evapotranspiration in period II are remarkable as contrasted with those in period I. For aridity index, the trend is increasing in period I but decreasing in period II. However, the change in the average values of these factors is not identical in YER and YZR. In YER, the average value of precipitation, potential evapotranspiration and aridity index is higher in period II than in period I as well as the average values of streamflow and streamflow coefficient are reduced by 9.61 and 10.56%, respectively. The results indicate that, in YER, the increase in average potential evapotranspiration is greater than the increase in precipitation; thus, the streamflow yield shows a downtrend. For the YZR, the average aridity index is decreased in period II, even though both the average precipitation and potential evapotranspiration increased. The streamflow and streamflow coefficient are enhanced by 22.62 and 4.35%, respectively, in period II than that in period I. The increase in streamflow is attributed to the result that the increase in precipitation is more significant than the increase in evapotranspiration.

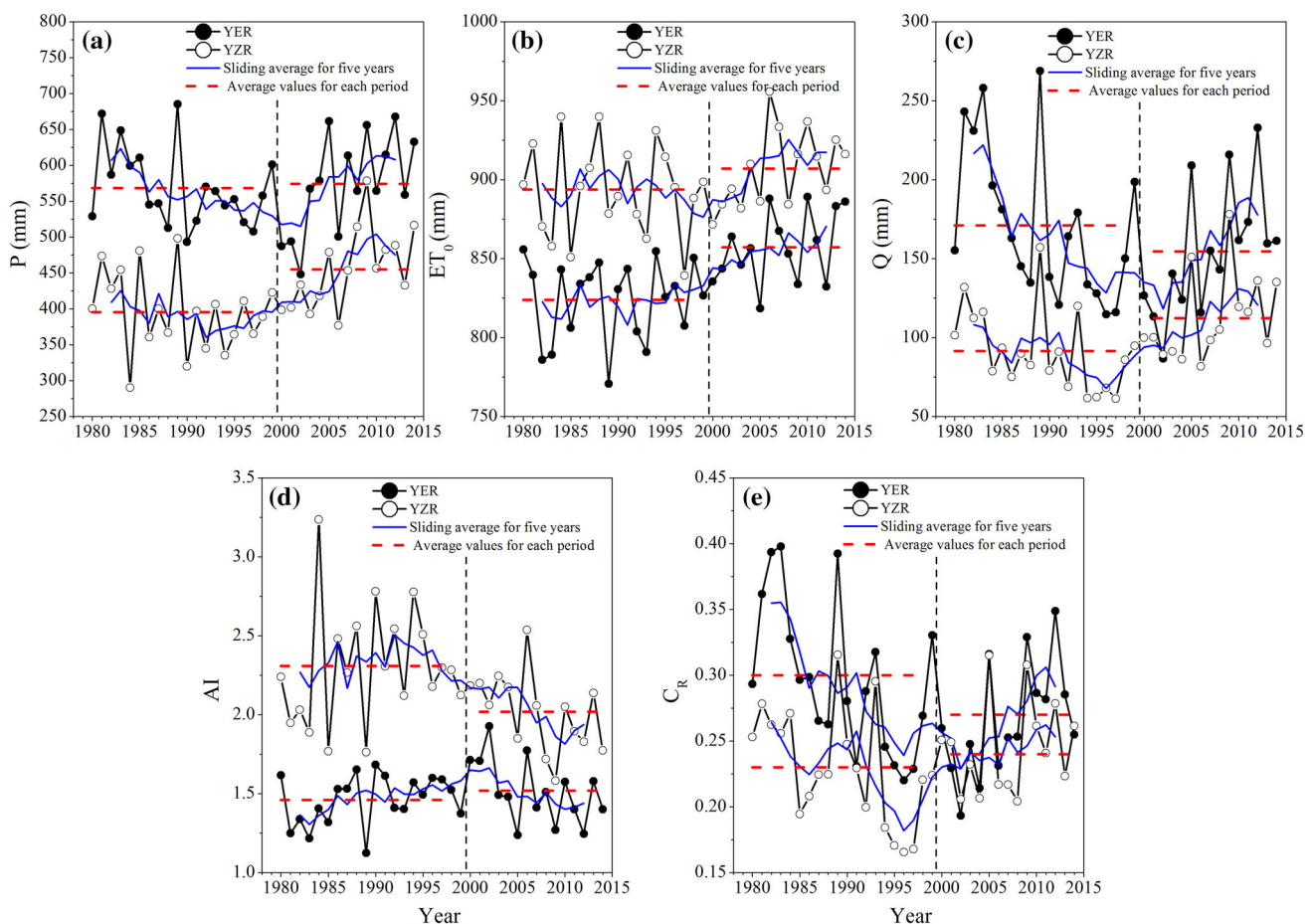


Fig. 2 Interannual variation in precipitation (P) (a), potential evapotranspiration (ET_0) (b), streamflow (Q) (c), aridity index ($AI = ET_0/P$) (d) and streamflow coefficient ($C_R = Q/P$) (e) from 1980 to 2014

in the Three-River Source region. The blue lines show the sliding averages for 5 years, and the red horizontal dashed lines are the average values for each period

Table 1 Trend significance test results for streamflow and climatic factors in different periods (period I: 1980–1999; period II: 2000–2014)

Period	Headwater	<i>P</i>	<i>ET₀</i>	<i>Q</i>	<i>AI</i>	<i>Q/P</i>
1980–2014	Yellow River	0.36	1.62**	− 1.03	0.19	− 0.19
	Yangtze River	2.65**	0.70	0.71	− 1.25*	0.01
Period I	Yellow River	− 3.35	0.25	− 4.12*	0.83	− 0.54**
	Yangtze River	− 2.31	− 0.4	− 1.96*	0.87	− 0.37*
Period II	Yellow River	9.66*	2.1	5.49**	− 2.37	0.53*
	Yangtze River	7.48*	2.69*	2.62	− 2.69*	0.16

* and ** are the significance levels at *p* = 0.05 and 0.01, respectively

Elasticity of streamflow to climate change and ecological restoration

Based on the elasticity analysis, the relationships between streamflow and its influencing factors are provided in Table 2. The absolute values of elasticity coefficient for precipitation are the largest, which indicates that streamflow in the Three-River Source area is most sensitive to the precipitation among the influential factors. However, the absolute value of the elasticity coefficient for landscape parameter *n* is larger than the climate elasticity of streamflow. It implies that anthropogenic factor is more significant than climate change.

By contrast, it has a change in elasticity of streamflow from period I to period II. Elasticity coefficients of precipitation, potential evapotranspiration and landscape parameter *n* for YER increased by 5.21, 11.12 and 7.38%, respectively. Increases in the elasticity coefficients of precipitation and potential evapotranspiration are 0.23 and 0.48%, respectively, in YZR, but lower than those observed in YER. Moreover, the elasticity coefficient of landscape parameter *n* is reduced by 7.41% in period II than in period I for YZR.

Quantifying the contributions of climate change and ecological restoration to streamflow

ΔQ is identified as the variation of streamflow between periods II and I. The observed ΔQ decreased by 16.43 mm for YER and increased by 20.72 mm for YZR. Based on Eqs. (8) and (9), the individual contribution of impact factors related to climate change and ecological restoration is estimated (Fig. 3). The relative errors of both the total contribution (con_Δ*Q*) of streamflow change and observed streamflow change (observed Δ*Q*) for the YER and YZR

are within the scope of ± 5%, which indicates that the quantitative method to assess the contribution amounts of streamflow change is feasible.

The impact of climate change and ecological restoration on streamflow presents a difference between YER and YZR. In YER, the contribution of precipitation, potential evapotranspiration and ecological restoration to streamflow is 3.11, − 6.12 and − 14.11 mm, which account for − 18.19, 35.76 and 82.43% of the streamflow decrease, respectively. By contrast, in YZR, these three influence parameters (Pre, *ET₀*, *n*) contribute to streamflow increase by 26.21, − 1.23 and − 4.79 mm, which account for 129.83, − 6.11 and 23.72% of the streamflow increase, respectively. Climate change that is integrated precipitation with potential evapotranspiration accounted for 123.72% of the change in streamflow in YZR while only approximately 18% in YER. Ecological restoration is responsible for more than 80% of the decrease in streamflow in YER and approximately 24% of the decrease in streamflow in YZR. Therefore, the main driving factor of streamflow variation is ecological restoration in YER, while it is climate change in YZR.

Discussion

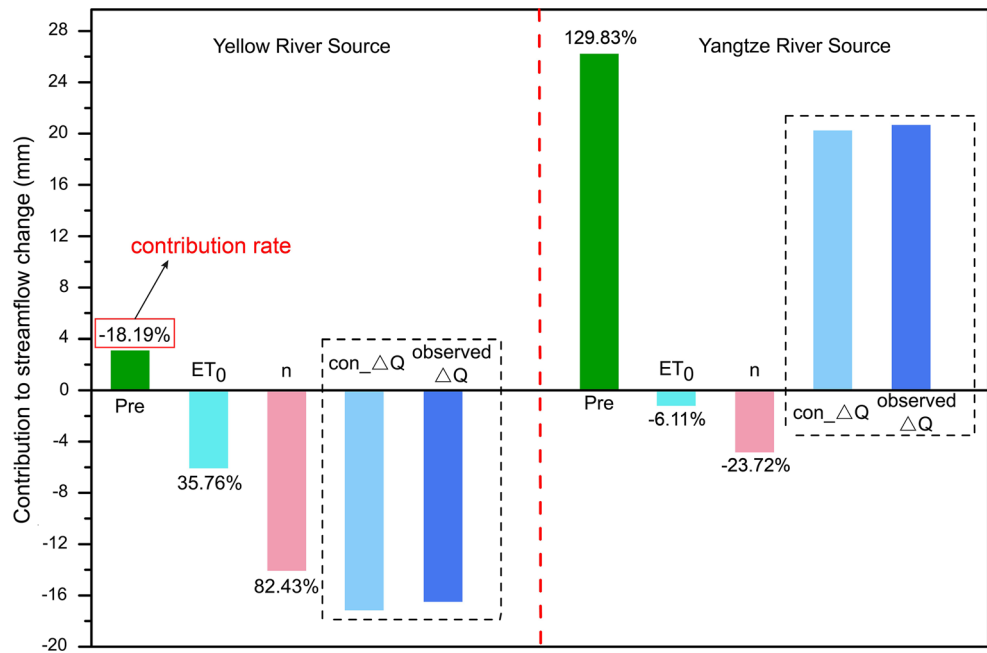
Possible mechanisms of the streamflow response to climate change and ecological restoration

This study explains the possible mechanism of streamflow variability and variation. Climate change and ecological restoration lead to water repartition. Global assessment shows that streamflow change from climate-driven is often overshadowed by human-driven in the twentieth century (Jaramillo and Destouni 2014). Future changes in

Table 2 Elasticity coefficients of streamflow with respect to precipitation (*P*), potential evapotranspiration (*ET₀*) and landscape parameter (*n*) in period I and period II

Headwater	Period I			Period II			Relative change (%)		
	ε_P	ε_{ET_0}	ε_n	ε_P	ε_{ET_0}	ε_n	ε_P	ε_{ET_0}	ε_n
Yellow River	1.88	− 0.88	− 1.16	1.98	− 0.98	− 1.24	5.21	11.12	7.38
Yangtze River	1.90	− 0.90	− 1.61	1.91	− 0.91	− 1.49	0.23	0.48	− 7.41

Fig. 3 Contributions of climate change and ecological restoration to streamflow change. The percentages at the heads of columns are the contribution rates of individual factors to streamflow change. The estimated total contributions (con_ΔQ) and observed streamflow changes (observed ΔQ) are shown in dashed boxes



precipitation and vegetation are to challenge the security of water resources (Guimberteau et al. 2013; Ukkola et al. 2016). Climate change affects aridity index and streamflow coefficient. According to this study, combined aridity index increase and streamflow coefficient decrease in YER, climate factors perform a strong sensitivity to streamflow reduction, which was consistent with the findings of Zhang et al. (2011). As shown in Table 3, the values of *n* for the YER and YZR are increased by 7.12% (from 1.33 to 1.43) and 3.25% (from 1.21 to 1.25) comparing period I with II, respectively. Ecological restoration mainly contributes to the streamflow decrease in YER and partly irritates the streamflow variability of YZR. There also is an increase in the values of landscape parameter *n* for Loess Plateau region (Li et al. 2016; Liang et al. 2015). It can be seen that ecological restoration plays a crucial function on streamflow.

To explore the cause of the changes in landscape parameter, LUCC data for 1995 and 2010 (Table 4) are investigated. Areas of forest and high-coverage and median-coverage grasslands are significantly increasing, while the area of low-coverage grassland is narrowing. Especially for the high-coverage grassland, its region is increased by 3448 and 2292 km² in YER and YZR, respectively. The

Table 3 Comparison of the landscape parameter *n* values between period I and period II

Headwater	Period I	Period II	Relative change rate (%)
Yellow River	1.33	1.43	7.12
Yangtze River	1.21	1.25	3.25

results indicate that land cover is converted from low-coverage to high-coverage grasslands due to the implementation of ecological restoration. In terms of main vegetation coverage, the greater increase in forest and high-coverage grassland for YER explains the larger change in landscape parameter *n* in YER.

Some improvements exist in the attribution analysis. First, the interaction of vegetation and climatic factors such as precipitation is not involved in this study for the complicated process. It is simplified that the change in vegetation is caused by human factors. The interaction mechanism can be explored by hydrological model and land surface model to reveal the impact of vegetation and climatic factors on streamflow. Second, the impact of glacier change on streamflow should be further studied in next work although this part can be ignored through verification using the Gravity Recovery and Climate Experiment (GRACE) data (Xue et al. 2013).

Risk analysis of water resources and strategy suggestions

Effects of climate change and ecological restoration on water resources show the spatial heterogeneity for different catchments. The Yellow River flows through arid and semiarid regions with low precipitation and serves as the main water supply for downstream regions. A reduction in streamflow for YER puts water resources at risk. Water demand for agriculture, industry and domestic consumption may not be met the water demand of downstream regions. Under climate change, the possibility of drought occurrence is greater and less water storage could be

Table 4 Land use/cover change (LUCC) in 1995 and 2010 for the Three-River Source region

Headwater	Land use	1995	2010	Change	Change (%)	
Yellow River	Residential	49	50	1	2.04	
	Cultivated	509	500	- 9	- 1.77	
	Forest	8568	8721	153	1.79	
	Grassland					
	High coverage	19,469	22,917	3448	17.71	
	Median coverage	38,716	40,756	2040	5.27	
	Low coverage	36,042	28,118	- 7924	- 21.99	
	Glacier	173	157	- 16	- 9.25	
	Water	2258	2407	149	6.60	
	Unused	16,704	18,859	2155	12.90	
	Yangtze River	Residential	30	33	3	10.00
		Cultivated	91	103	12	13.19
		Forest	602	705	103	17.11
Grassland						
High coverage		1950	4242	2292	117.54	
Median coverage		25,320	27,800	2480	9.79	
Low coverage		78,683	64,878	- 13,805	- 17.55	
Glacier		1290	1301	11	0.85	
Water		5348	6679	1331	24.89	
Unused		28,915	36,469	7554	26.12	

adjustable (Liu et al. 2015). Therefore, some hydrological regimes are emerged to cope with the future warming (Leng et al. 2016). Streamflow increase in YZR also implies a water security problem. Unlike Yellow River, the Yangtze River flows through a humid region with abundant rainfall (more than 1000 mm annually). High-intensity rainfall and low vegetation coverage may give rise to the flood peak, which enhances the probability of flood occurrence (Sang and Yang 2016). For instance, the entire drainage of the Yangtze River Basin suffered tremendous flooding in 1998 on account of vegetation destruction and land reclamation (Yin and Li 2001). Therefore, water resource conservation and ecological restoration should be formulated based on local conditions and integrated impact factors such as hydrology, meteorology topography and human activities. It suggests that the implementation of recovery strategies should be appropriate in case of insufficient and excessive operation.

Conclusion

The impacts of ecological restoration and climate change on the variability and variation of streamflow are quantitatively assessed. Results indicate that streamflow reduction in YER is determined by ecological restoration which explains more than 80%, while it was more sensitive to climate change in terms of the variability of streamflow. In YZR, climate change dominates the streamflow increase

with an explanation of nearly 120% while the increase in streamflow is more susceptible to ecological restoration. Our findings illustrated that the response of streamflow to the ecological conservation projects is different for the two vital catchments and suggested that regional adaptive measures should be made.

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