Hydrological recovery in two large forested watersheds of Southeastern China: importance of watershed property in determining hydrological responses to reforestation

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Abstract. Understanding hydrological responses to reforestation is an important subject in watershed management, particularly in large forested watersheds (>1000 km^2). In this study, we selected two large forested watersheds (Pingjiang and Xiangshui) located in the upper reach of the Poyang Lake watershed, Southeastern China (with an area of 3261.4 and 1458 km^2, respectively), along with long-term data on climate and hydrology (1954-2006) to assess the effects of large-scale reforestation on streamflow. Both watersheds have similar climate and experienced comparable and dramatic forest changes during the past decades, but with different watershed properties (e.g., the topography is much steeper in Xiangshui than in Pingjiang), which provides us with a unique opportunity to compare the differences in hydrological recovery in two contrasted watersheds. Streamflow at different percentiles (e.g., 5%, 10%, 50% and 95%) were compared using a combination of statistical analysis with year-wise method for each watershed. The results showed that forest recovery had no significant effects on median flows ($Q_{50\%}$) in both watersheds. However, reforestation significantly reduced high flows in Pingjiang, but had limited influence in Xiangshui. Similarly, reforestation had significant and positive effects on low flows ($Q_{95\%}$) in Pingjiang, while it did not significantly change low flows in Xiangshui. Thus, hydrological recovery is limited and slower in the steeper Xiangshui watershed, highlighting that watershed property is also important for determining hydrological responses to reforestation. This finding has important implications for designing reforestation and watershed management strategies in the context of hydrological recovery.

Key words: large watersheds, reforestation, streamflow changes, streamflow at different percentiles

1. Introduction

Water quantity is of utmost importance for ecosystem functions, and economic and social development. In forested watersheds, forests play an important role in hydrological processes and their associated ecological functions. Numerous studies have indicated that forest changes (e.g., reforestation or deforestation) can significantly affect hydrological processes (Jackson et al., 2005; Clinton, 2011; Ford et al., 2011; Iroumé and Palacios, 2013; Liu et al., 2015a). However, there are large variations in hydrological responses to forest changes, probably depending on climate and watershed characteristics. Understanding those variations can greatly improve our understanding of the possible mechanisms responsible for hydrological responses and support our management decisions on water and watershed protections.

In large forested watersheds, various factors including climate, land cover or forest changes and watershed properties can influence streamflow (Anderson and Kneale, 1982). While previous research mainly focused on how climate and forest cover change affect hydrology, limited research has been conducted to examine the role of watershed property in hydrological responses. However, watershed property can be an important factor in determining hydrological responses (Allan, 2004; Poff et al., 2006a; Poff et al., 2006b; Price et al., 2011; Troch et al., 2013; Zhou et al., 2015). For example, Zhang et al. (2014) studied two neighboring watersheds (3420 km^2) and Willow (2860 km^2) in British Columbia, Canada, and found that their contrasted hydrological responses to forest harvesting are mainly related to the difference in their topography and landform complexities. Zhou et al (2015) also found that watershed characteristics such as watershed slope and size play an important role in hydrological responses in their meta-data analysis from 168 global studied large forested watersheds. Clearly, more case studies are needed to assess how watershed properties affect hydrological responses in the context of the other key drivers (e.g., climate and forest changes).

Poyang Lake of Jiangxi Province which directly flows into Yangtze River is the largest freshwater lake (3500 km^2) in China. It is fed by five rivers including Gan, Xin, Xiu, Rao and Fu. Poyang Lake provides significant water resources, wildlife habitats (especially for migratory birds) and economic values (Guo et al., 2008; Huang et al., 2012; Schmalz et al., 2014). However, Poyang Lake basin experienced severe forest disturbance from 1960s to 1980s. Such intense land use changes resulted in severe environmental degradation. To restore degraded environment, several ecological restoration and protection programs (e.g., large-scale reforestation) have been implemented since 1980s (Wei et al., 2008). As a result, the forest coverage has increased significantly in the past a few decades. Because Poyang lake basin plays a strategic significance in environmental protection and economic development in the province as well as in the lower reach of Yantze River basin, assessing the ecological effects of those large-scale stewardship programs would be crucial for determining the effectiveness of ecological recovery and for guiding future program design. To our knowledge, several studies had been conducted to assess how large-scale reforestation programs might affect soil erosion and forest carbon processes, but no research has been conducted to assess hydrological recovery under those large-scale stewardship programs.

Two large neighboring watersheds including Pingjiang watershed (2689.20 km^2) and Xiangshui watershed (1758 km^2) with similar forest change levels but different watershed properties in the upper reach of the Poyang Lake watershed were chosen for the study. Hydrological variables such as streamflow at different percentiles (e.g., high flows and low flows) were examined for each watershed, and their differences were then compared. The objectives of this study were: (1) to assess how stream flows (high and low flows) respond to forest changes at each watershed; (2) to compare their hydrological responses between two different watersheds; and (3) to discuss implications for watershed management.

2. Watershed descriptions and data

2.1. Watershed characteristics

The Pingjiang and Xiangshui watersheds feed into Gan River, the largest tributary of the Poyang Lake watershed (Fig. 1). The drainage areas of the two watersheds are 2689 km^2 and 1758 km^2, respectively. The two watersheds are located in the hilly region of Jiangxi Province, China. The Xiangshui watershed is characterized with a steeper topography than the Pingjiang watershed with the former having 23.9% of the watershed area being higher slopes (from 30° to 50°) while the latter having only 4.6% for the same slope class (Table 1). Soils are mountain red soil and yellow-red soil with sandy loam texture in both watersheds. The main characteristics of two watersheds are presented in Table 2.

Figure 1. The location of the Pingjiang and Xiangshui watersheds

Table 1. Averaged slopes in two studied watersheds (Pingjiang and Xiangshui)

Table 2. A summary of watershed characteristics for Pingjiang and Xiangshui watersheds

The two studied watersheds are within the subtropical monsoon zone and have a similar precipitation regime. The average annual precipitations are 1575 mm and 1611 mm in Piangjiang and Xiangshui watersheds, respectively, of which most fall from April to June (the wet season, about 50%) and less from September to November (the dry season, about 12%). The average annual temperatures are 18.9 °C and 19.2 °C, respectively. The maximum temperature in summer and the minimum temperature in winter are 37 °C and 0 °C, respectively (Fig. 2).

Figure 2. Average monthly precipitation, streamflow, maximum temperature and minimum temperature from 1957 to 2006 for the Pingjiang watershed (a) and the Xiangshui watershed (b)

The majority of annual peak flows correspond to rainfall events in two watersheds. In Pingjiang watershed, annual peak flows are between 137 and 870 m^3/s per $1000km^2$, while between 108 and 728 m^3/s per $1000km^2$ in Xiangshui watershed. Annual minimum flows range from 2.0 to 11.6 m^3/s per $1000km^2$ in Pingjiang watershed and are 0.9 to 11.4 m^3/s per $1000km^2$ in the Xiangshui watershed. Average annual mean flows are 848 and 858 m^3/s, respectively.

The major land cover types include forests, agriculture, grass, and urban and construction land. Subtropical evergreen broad-leaved forest is the major climax vegetation type in the studied watersheds, including *Castanopsis fabri*, *Castanopsis sclerophylla*, *Schima superba*, *Sassafras tzumu* and *Castanopsis fissa*. In contrast, major plantation forests are *Pinus massoniana*, *Cunninghamia lanceolata*, *Camellia oleifera* Abel and *moso bamboo*.

2.2. Data

Stream flow data area available from 1957 to 2006 for both watersheds. The hydrometric stations for data collection are part of the Chinese National Hydrometric Network (Fig. 1). Climate data are also available for the same length (1957-2014) for each watershed (5 climate stations for Pingjiang and 3 for Xiangshui), and include the records of daily maximum, mean, and minimum temperatures and daily precipitation. The averaged watershed-based precipitation estimates were derived by the Thiessen polygon method.

3. Methods

3.1. Leaf area index (LAI) and forest coverage

The Global Land Surface Satellite (GLASS) LAI data were used as the proxy of forest coverage in the studied watersheds. The GLASS LAI product provides the global LAI at the spatial resolution of 0.05 degree and temporal resolution of 8-day for the period of 1981 to 2014 (http://www.bnu-datacenter.com/). The GLSS LAI data has been validated through the field measurements to ensure data quality for long term studies in vegetation changes (Liang and Xiao, 2012; Xiao et al., 2014). The growing season LAI values were based on the LAI values from April to October for each year. The watershed-based LAI values were derived by averaging the LAI data for the pixels where more than 50% of their pixel areas falls inside the watershed boundaries.

Forest change is the main type of land use changes in our studied watersheds. Because the complete records of annual deforestation and reforestation areas are unavailable, forest coverage and LAI data were used to indicate historic forest changes during the study period (1957-2006). As shown in Figure 2, forest cover was greatly reduced in 1965-1984 due to large-scale forest disturbance (e.g. deforestation). Since then, forest cover was significantly increased from about 30% in the 1980s to 70% in 2006 in both watersheds due to implementation of the reforestation projects (1990-2006) (Figure 3). Thus, the entire study period was divided into the forest disturbance period (1957-1985) and the forest recovery period (1990-2006).

Figure 3. Forest coverage (%) from 1950 to 2006 in the Pingjiang and Xiangshui watersheds (a) and (b) Leaf Area Index (LAI) for the Pingjiang and Xiangshui watersheds

3.2. Median, high and low flows

In this study, FDCs (flow-duration curves) were applied to define high, median and low flows. FDCs represent the percent of time streamflow for any given value exceeded or equaled in a period of record (Vogel and Fennessey, 1994). In this study, median flows are defined as the flows that exceed or are equal to $Q_{50\%}$. High flows are defined as the flows that exceed or are equal to $Q_{5\%}$ and $Q_{10\%}$ ($Q_{5\%}$: flows exceeded at 5% of the time in a given year and $Q_{10\%}$: flows exceeded at 10% of the time in a given year), while low flows are defined as the flows that are equal to or less than $Q_{95\%}$ ($Q_{95\%}$: flows exceeded at 95% of the time in a given year) (Zhang et al., 2014b; Liu et al., 2015b).

In order to assess the impacts of forest changes on high, median and low flows, the effect of climate variability must be eliminated. For a single watershed, pair-wise comparisons can be used to address this issue (Levy, 1975; Broomell et al., 2011; Zhang et al., 2014b; Liu et al., 2015b; Eastwood et al., 2016). Because high flows are mainly caused by some rainfall events, we can find some similar and comparable rainfall events between the reforestation and deforestation periods with similar $R_{5\%}$ and $R_{10\%}$, respectively ($R_{5\%}$: rainfall exceeded at 5% of the time in a given year and R10%: rainfall exceeded at 10% of the time in a given year). However, low and median flows are significantly correlated with annual rainfall, annual maximum temperature and annual mean temperature (Tables 3 and 4). Therefore, paired years between the reforestation and deforestation periods were selected for analysis of low and median flows (Tables S1 and S2). More details about this method can be found in Zhang and Wei (2014a) and Liu et al. (2015b).

Table 3. Correlation analyses between low flows and climatic variables in the Pingjiang and Xiangshui watersheds

Table 4. Canonical correlation analyses between climate variables and hydrological variables (low and median flows) in the Pingjiang and Xiangshui watersheds

Table S1. Selected pairs for high flows (5% and 10%) in the Pingjiang and Xiangshui watersheds

Table S2. Selected pairs for median and low flows in the Pingjiang and Xiangshui watersheds

3.3. Estimation of recession constants

Recession constant is a useful indicator reflecting the characteristics of the study basin (Barnes and Bertram, 1939; Ge et al., 2014). For a watershed, the difference in recession constants of streamflow with similar climate conditions between different periods can be ascribed to the effect of land cover change, while the difference in recession constants of streamflow between the two studied watersheds under similar climate conditions can be ascribed to the effect of different water properties on streamflow.

In this paper, the classical recession curve based on Genetic Algorithm (GA) was adopted to study and analyze the daily runoff (Equations 1 and 2).

$$Q_t = Q_0\, e^{-\beta t} \qquad (1)$$

$$\beta = (\ln Q_0 - \ln Q_t)/t \qquad (2)$$

Here, Q_0 is the initial discharge (t = 0), Q_t is the discharge at a later time / (usually in days), and β is the recession constant.

The paired-wise approach was also used to assess the effects of forest changes on recession constants. Because high flows are mainly caused by rainfall events (e.g., storm events) in the study area, we can select similar and comparable rainfall events between the reforestation and the disturbance periods (Table S3).

Table S3. Selected pairs for recession constant in the Pingjiang and Xiangshui watersheds

4. Results

4.1. High flows response to forest changes

As shown in Figure 4a, the average magnitude of high flows ($Q_{5\%}$) in the reforestation period (327.7 m^3/s) was significantly lower ($p < 0.01$) than that in the deforestation period (534.9 m^3/s) in the Pingjiang watershed. Similarly, the average magnitude of high flows ($Q_{10\%}$) in the reforestation period (164.4 m^3/s) was also significantly lower ($p < 0.01$) than that in the deforestation period (198.7 m^3/s) in the Pingjiang watershed (Fig. 4c).

For the Xiangshui watershed, the average magnitude of high flows ($Q_{5\%}$) in the reforestation period (233.0 m^3/s) was lower than that in the deforestation period (251.4 m^3/s) (Fig. 4b), but their difference was not statistically significant (p=0.46). The average magnitude of high flows ($Q_{10\%}$) in the reforestation period (118.0 m^3/s) was significantly lower ($p < 0.05$) than that in the deforestation period (127.9 m^3/s) (Fig. 4d). Thus, reforestation significantly decreased high flows in the Pingjiang watershed, while such an effect is relatively limited in the Xiangshui watershed.

Figure 4. High flows and median flows for the selected pairs in the reforestation and deforestation periods: (a) high flows (5%) for the Pingjiang watershed; (b) high flows (5%) for the Xiangshui watershed; (c) high flows (10%) for the Pingjiang watershed; (d) high flows (10%) for the Xiangshui watershed; (e) Median flows (50%) for the Pingjiang watershed; and (f) Median flows (50%) for the Xiangshui watershed

4.2. Median flows response to forest changes

As shown in Figures 4e and 4f, the averaged magnitudes of median flows in the reforestation period (43.1 and 41.5 m^3/s, respectively) were found no significant difference (p=0.21 and 0.27, respectively) than those in the deforestation period (40.3 and 38.4 m^3/s) in Pingjiang and Xiangshui watersheds, respectively, indicating that reforestation had no significant effects on median flows ($Q_{50\%}$) in both watersheds.

4.3. Low flows response to forest changes

As shown in Figure 5a, the average magnitude of low flows in the reforestation period (12.3 m^3/s) was significantly higher ($p < 0.01$) than that in the deforestation period (8.7 m^3/s) in the Pingjiang watershed. In contrast, the average magnitude of low flows in the deforestation period did not significantly differ from that in the reforestation period (Figure 5b) in the Xiangshui watershed. Thus, reforestation significantly increased low flows in the Pingxiang watershed but not in the Xiangshui watershed.

Figure 5. Low flows and recession constants of streamflow for the selected pairs in the reforestation and deforestation periods: (a) low flows for the Pingjiang watershed; (b) low flows for the Xiangshui watershed; (c) recession constants for the Pingjiang watershed; and (d) recession constants for the Xiangshui watershed

4.4. Responses of recession constants to forest changes

As shown in Figures 5c and 5d, the averaged recession constant of streamflow in the reforestation period was significantly lower (p=0.049) than that in the deforestation period in the Pingjiang watershed, while the difference was not significant (p=0.52) in the Xiangshui watershed, suggesting that hydrological responses to reforestation is more sensitive in the Pingjiang watershed than in the Xiangshui watershed.

5. Discussion

Although the effects of reforestation on peak flows are still controversial (Gafur et al., 2003; Nadal-Romero et al., 2016; Liu et al., 2015a), a general conclusion is that increased forest coverage through reforestation can reduce high flows (Llorens et al., 1997; Gebrehiwot et al., 2010; Nadal-Romero et al., 2016). Our study found that reforestation can significantly decrease high flows, which can thereby reduce flood risks. Thus, our results are consistent with the general conclusion conducted in other regions (e.g., Gafur et al., 2003; Bahremand et al., 2007; Tran et al., 2010). Our results are also supported by another study in a neighboring watershed (Meijiang) of the same region (Liu et al., 2015b) where the historic forest change is similar to those in our study. The common reason for reducing high flows after reforestation is that reforestation increases forest coverage and slowly improves soil conditions, and consequently enhances soil infiltration capacity and reduces high flows.

Our study showed that reforestation significantly increased low flows in the Pingjiang watershed. Although not statistically significant (p=0.084), the low flows after reforestation in the Xiangshui watershed was also improved (Figure 5b). Thus, reforestation had a positive role in low flows in the study watersheds. Our results are consistent with various reforestation studies, particularly in higher humidity environment (Buttle, 2011; Yao et al., 2012; Liu et al., 2015b). For example, Zhou et al. (2010, WRR) studied the effects of large-scale reforestation on hydrology in the whole Guangdong province, and found that increasing of 30% forest cover played a positive role in redistributing water from the wet season to the dry season and, consequently, in increasing water yield in the dry season. The main reason for enhancing low flows from reforestation is that reforestation improves vegetation and soil conditions, and consequently improves soil infiltration and groundwater recharging, which have positive effects on low flows.

The responses of low flows to reforestation are inconsistent across different climate regimes. Lu et al. (2016) firstly estimated effects of reforestation on groundwater resource using seven evapotranspiration models and suggested that China's unprecedented reforestation program would result in greatly decreased depth of groundwater in the arid and semiarid areas of northern China. A similar study conducted in the Loess Plateau of China also found that a statistically significant ($p < 0.1$) reductions of 0.03 mm of groundwater per year from 1955 to 2010 due to implementation of large-scale reforestation projects (Gao et al., 2015). The results from a paired watershed experiment in South Africa showed that low flows were reduced by half due to reforestation

(Smith and Scott, 1992). A study analyzing the responses of streamflow to forest plantation expansion in six large river watersheds (from 94 to 1545 km^2) of Central-Southern Chile indicated that reforestation had less effects on low water flows ($Q_{80\%}$ to $Q_{90\%}$) in relatively drier soils (Iroumé and Palacios, 2013). However, in humid region, increases in vegetation cover often lead to greater infiltration of rainfall into the soil, and as a result, increase water storages and low flows (Zhou et al., 2010). More case studies are needed before a general conclusion between reforestation and low flows can be developed.

Although reforestation generally played a positive role in streamflow in our study area, there are large differences in the hydrological responses between the two study watersheds. As shown above, there are more significant effects on both high and low flows in Pingjiang watershed than in Xiangshui watershed. Since both watersheds have the similar historic forest change and climate, we believe that the difference in their responses of high and low flows was mainly due to the difference in their watershed properties. A close examination on their watershed properties shows that their main differences in watershed property are on watershed slopes and sizes. Many studies show that watershed size can be an important factor affecting hydrological responses to land cover changes (Buttle and Metcalfe, 2000; Blöschl et al., 2007; Zhang and Wei, 2014a; Zhou et al., 2015). A smaller sized watershed often has less buffering capacity as it may contain fewer heterogeneous landscape components (e.g., wetlands, lakes) and complexities, and as a result, is more sensitive to land cover changes. In our study watersheds, Xiangshui watershed is much smaller than Pingjiang watershed so a quicker hydrological response should be expected in Xiangshui watershed. The limited and slower hydrological response in Xiangshui watershed after reforestation as compared with Pingjiang watershed suggests that the factor other than watershed size came into play. Thus, we reasonably judge that the difference in watershed slope between two watersheds is the major factor determining the variations of their hydrological responses. The Xiangshui watershed has a much larger area percentage (23.9%) with the slope class (30%-50%) as compared to that (4.6%) in the Pingjiang watershed (Table 1). In Southern China where a monsoon climate is dominant, a steeper watershed often has more severe soil erosion if deforestation occurs, and consequently it would take much longer time to recover through reforestation process once severe soil erosion occurred (Chen et al., 2002; Zheng et al., 2015).

The importance of watershed property in hydrological responses to land cover or forest changes is gradually recognized in scientific communities. This is particularly relevant for larger watersheds (e.g., >1000km^2) where there are more landforms (e.g., wetlands, lakes), more land cover types and thus more interactions and complexities of various watershed properties. Several studies on forest changes and hydrology in large forested watersheds in British Columbia, Canada conclude that the effects of forest changes on water are likely watershed specific (Lin and Wei, 2008; Zhang and Wei, 2014b) which clearly demonstrates the importance of watershed property in determining the relationship between forest changes and water. However, assessing how watershed property affects hydrological responses among other key drivers such as forest change and climate is a challenging subject. Some studies have applied integrative indicators such as topographic index (Woods et al., 1997; Hjerdt et al., 2004; Liu et al., 2012) or flow paths and transit time (McGuire and McDonnell, 2006; Soulsby et al., 2009) to assess watershed behaviors or functions while other studies used a landscape approach (Poff et al., 2006a; Poff et al., 2006b; Price et al., 2011) Nevertheless, more case studies are needed in this direction.

Our results from this study have important management implications. The Pingjiang and Xiangshui watersheds are very important headwater systems to Poyang Lake, the largest freshwater lake in China, where is crucial to sustain aquatic ecological functions (Guo et al., 2008). Many studies had demonstrated alteration of flow regimes (especially for low and high flows) may be one of the most serious and ongoing threats to the integrity of river ecosystems (Ward et al., 1999; Bunn and Arthington, 2002; Poff and Zimmerman, 2010; Liu et al., 2015b). Therefore, it is highly important to manage flow regimes for sustainable watershed ecosystems in Poyang Lake Bain.

Our results demonstrate a positive effect of reforestation on high and low flows in both Pingjiang and Xiangshui watersheds. This confirms that our reforestation programs implemented over the last decades provide important benefits to restoration of watershed functions in terms of hydrology. More importantly, our study found that hydrological recovery of a steeper watershed likely takes much longer time once it is deforested or damaged, suggesting that we must take extra care when we design management strategies in more sensitive watersheds.

6. Conclusion

We found that reforestation decreased high flows, but increased low flows in our studied watersheds, which is beneficial to maintenance of aquatic functions and water supply. We also found that there are large variations in hydrological responses to similar reforestation levels likely due to the difference in watershed property (e.g., watershed slope). Thus, we conclude that hydrological recovery through reforestation is largely dependant on watershed property when forest change and climate are similar and comparable.

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Table captions

Table 1 Averaged slopes in two studied watersheds (Pingjiang and Xiangshui)

Watershed	Percentage of watershed area (%)					
	Slop > 35°	25°-35°	15°-25°	8°-15°	3°-8°	< 3°
Pingjiang	4.60	52.82	2.40	29.44	6.63	4.11
Xiangshui	23.85	26.99	9.20	33.05	6.17	6.91

Table 2 A summary of watershed characteristics for the Pingjiang and Xiangshui watersheds

Metrics	Pingjiang	Xiangshui
Drainage area (km^2)	2689.20	1758
Average elevation (m)	298	429
Soil type	Mountain red soil and Yellow-red soil	Mountain red soil and Yellow-red soil
Annual mean precipitation (mm)	1575	1611
Annual mean Temperature (°C)	18.9	19.2
Annual mean ET(mm)	879.2	936.8
Annual mean flow(mm)	848	858
Runoff Coefficient	0.54	0.53
Maximum flow(m^3/s)	1530	1280
Minimum flow(m^3/s)	5.5	2.3
BioGeoClimatic zone	Subtropic monsoon	Subtropic monsoon
Forest type	Subtriopical everygreen boradleaf forest and conifer forest	Subtriopical everygreen boradleaf forest and conifer forest
Dominant Disturbance Type	Logging	Logging
Hydrometric station	Hanlinqiao	Mazhou

Table 3 Correlation analyses between low flows and climatic variables in the Pingjiang and Xiangshui watersheds

Watersheds	Precipitation		Tmax		Tmin		Tave		Wind speed	
	Manna-Kendall	Spearman	Manna-Kendall	Spearman	Manna-Kendall	Spearman	Manna-Kendall	Spearman	Manna-Kendall	Spearman
Pingjiang	0.48**	0.68**	-0.34**	-0.48**	0.14	0.18	-0.21*	-0.32*	-0.12	-0.21
Xiangshui	0.57**	0.39**	-0.44**	-0.61**	0.04	0.04	-0.23*	-0.05	-0.07	-0.11

Tave, Tmax and Tmin refer to annual mean, maximum and minimum temperatures, respectively.

**Statistical difference at p<0.01.

*Statistical difference at p<0.05.

Table 4 Canonical correlation analyses between hydrological variables (median and low flows) and climatic variables in the Pingjiang and Xiangshui watersheds

Watersheds	Canonical correlation analysis	Canonical R	Significant
Pingjiang	Precipitation, Tave and Tmax	0.88	$p<0.01$
Xiangshui		0.89	$p<0.01$

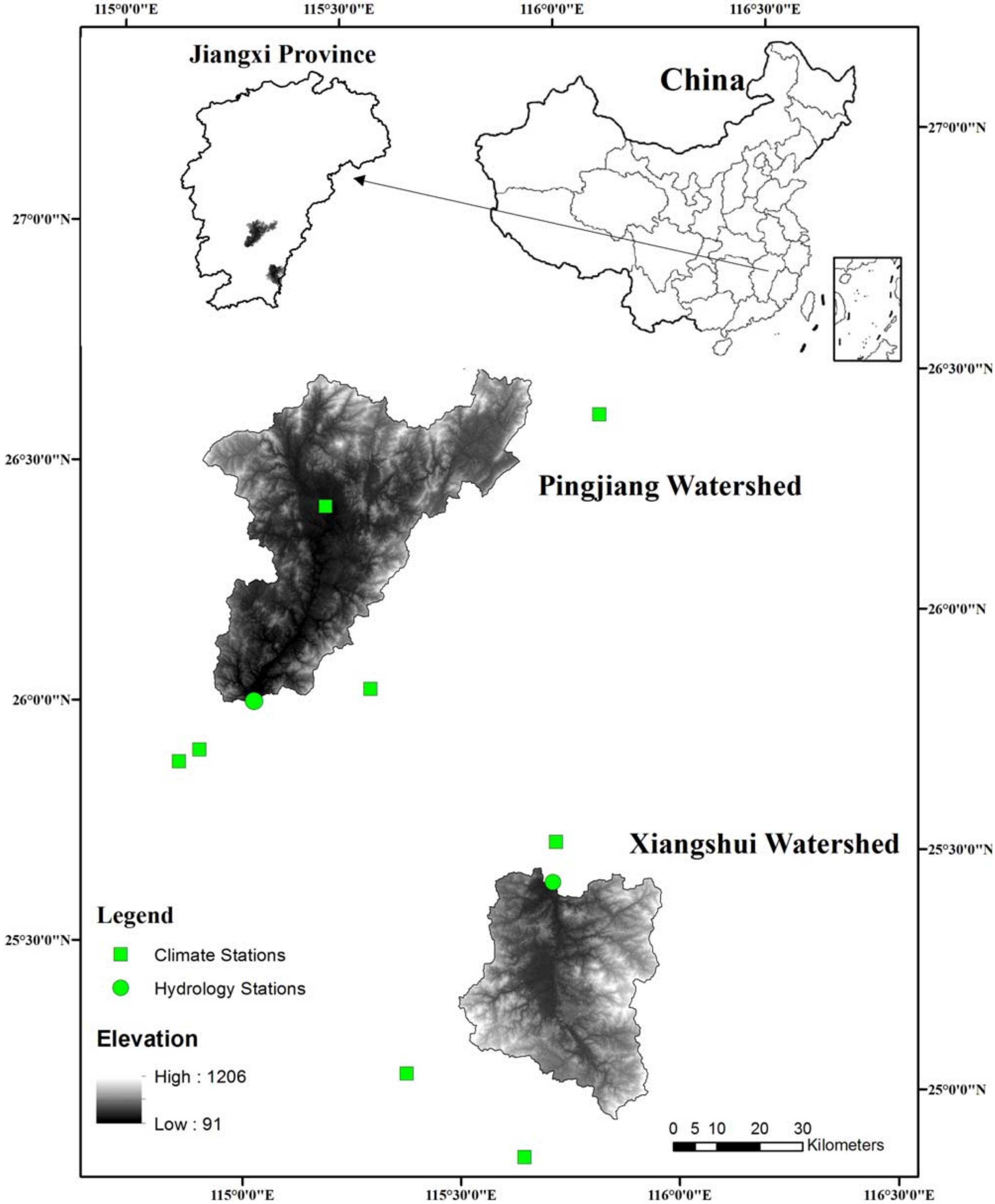

Figure 1. The location of the Pingjiang and Xiangshui watersheds

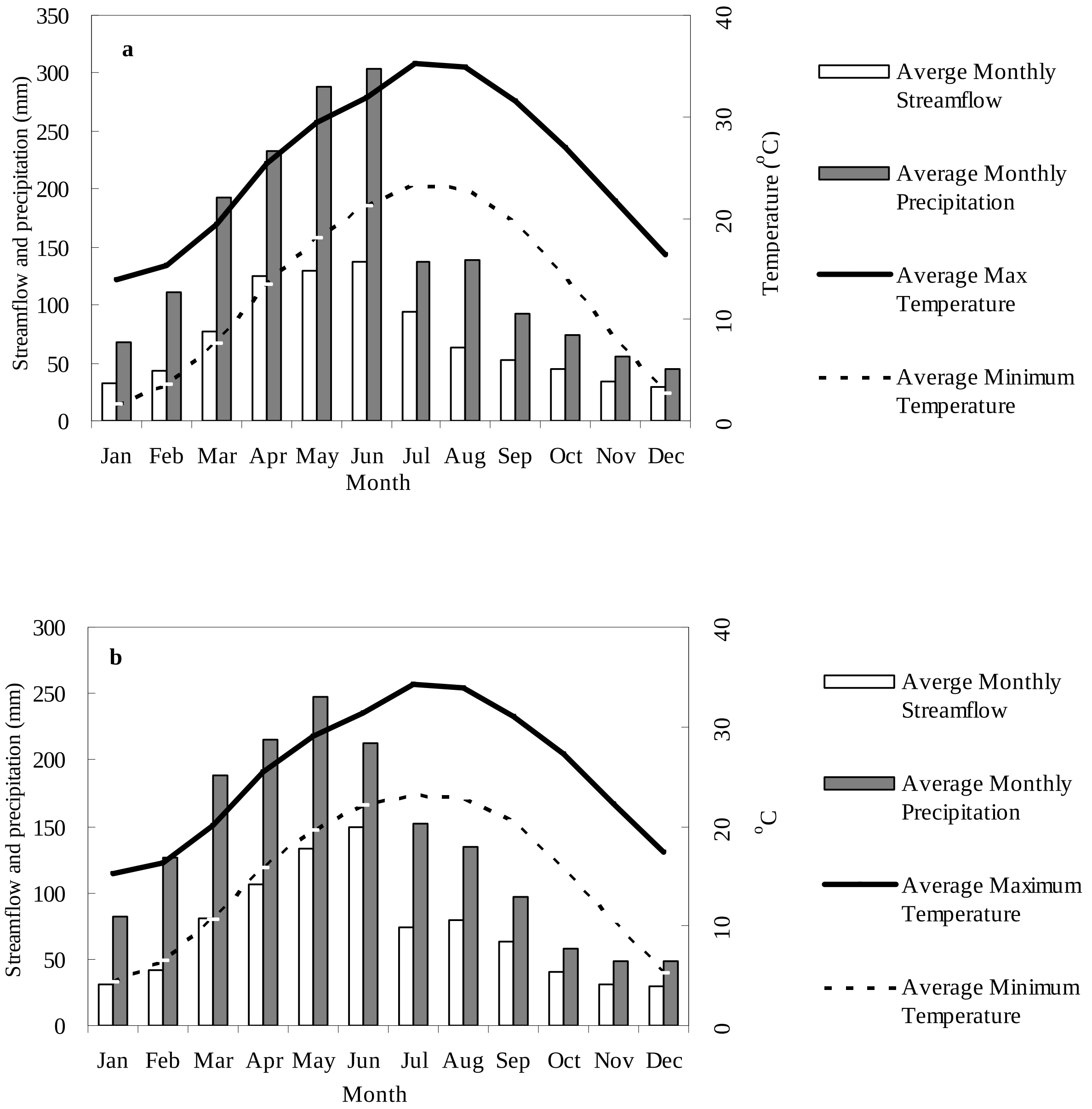

Figure 2 Average monthly streamflow, precipitation, minimum temperature and maximum temperature from 1957 to 2006 for the Pingjiang watershed (a) and the Xiangshui watershed (b)

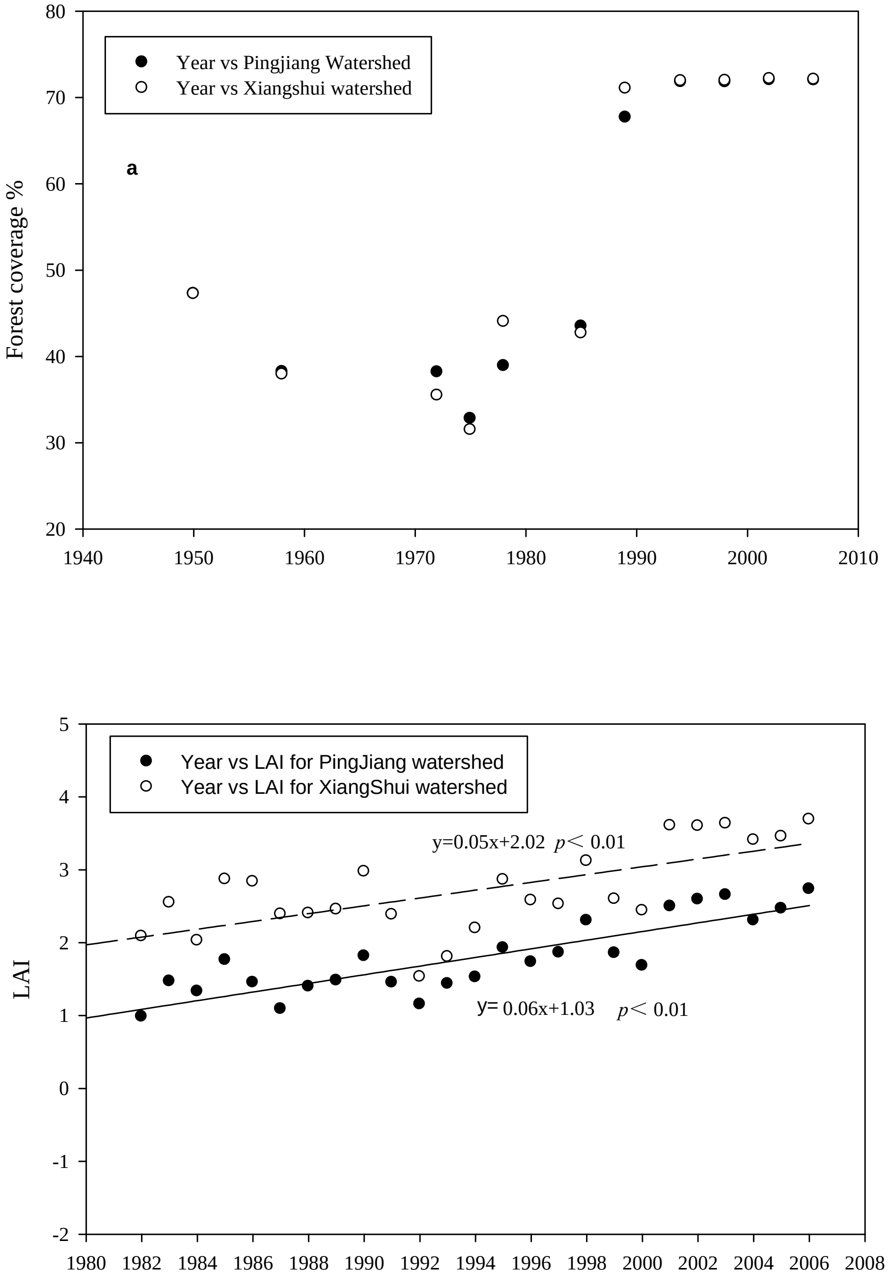

Figure 3 Forest cover (%) (a) and Leaf Area Index (LAI) (b) from 1982 to 2006 in the Pingjiang and Xiangshui watersheda

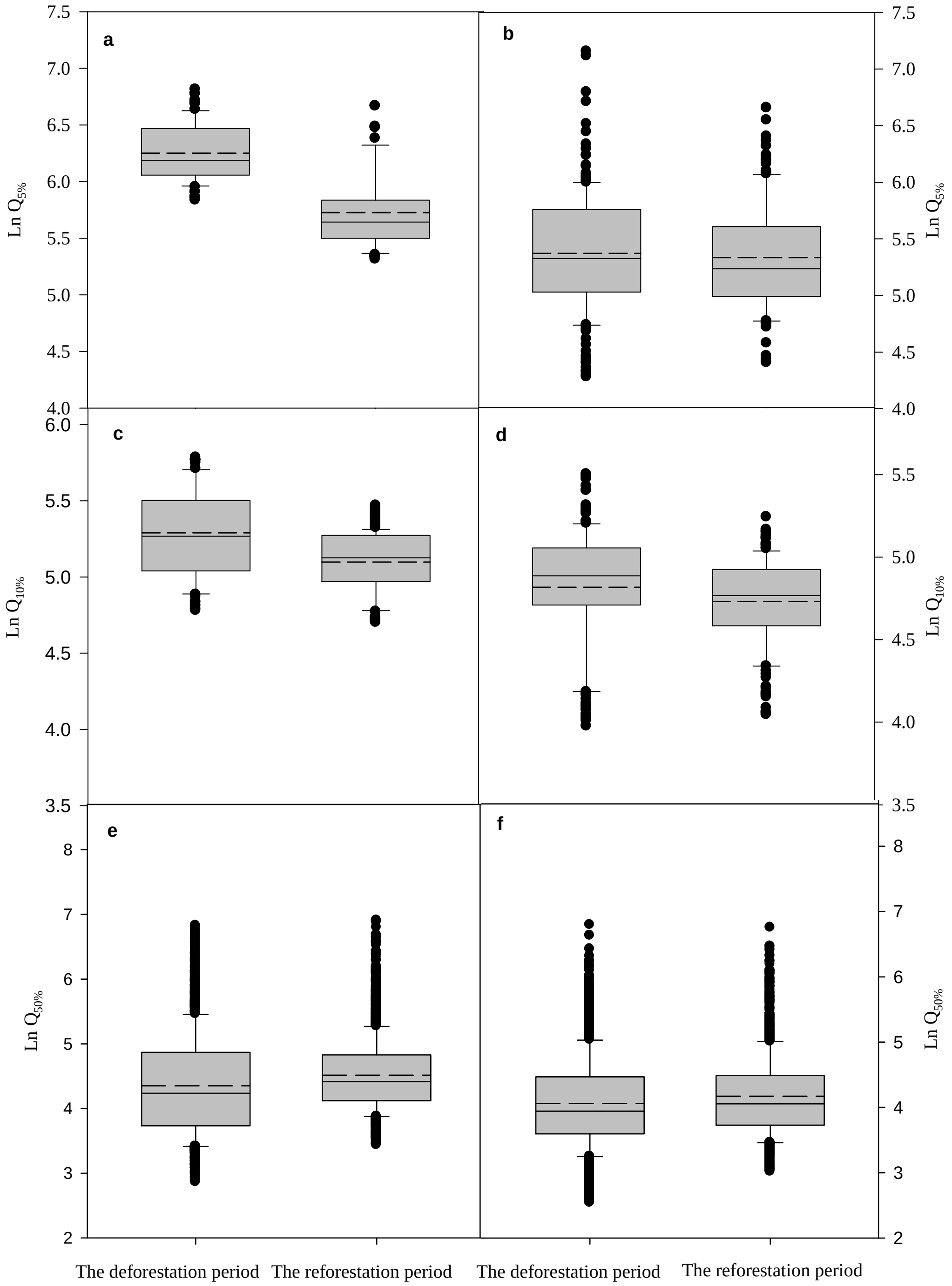

Figure 4 High flows and median flows for the selected pairs in the deforestation and reforestation periods: (a) high flows ($Q_{5\%}$) for the Pingjiang watershed; (b) high flows ($Q_{5\%}$) for the Xiangshui watershed; (c) high flows ($Q_{10\%}$) for the Pingjiang watershed; (d) high flows ($Q_{10\%}$) for the Xiangshui watershed; (e) Median flows ($Q_{50\%}$) for the Pingjiang watershed; and (f) Median flows ($Q_{50\%}$) for the Xiangshui watershed

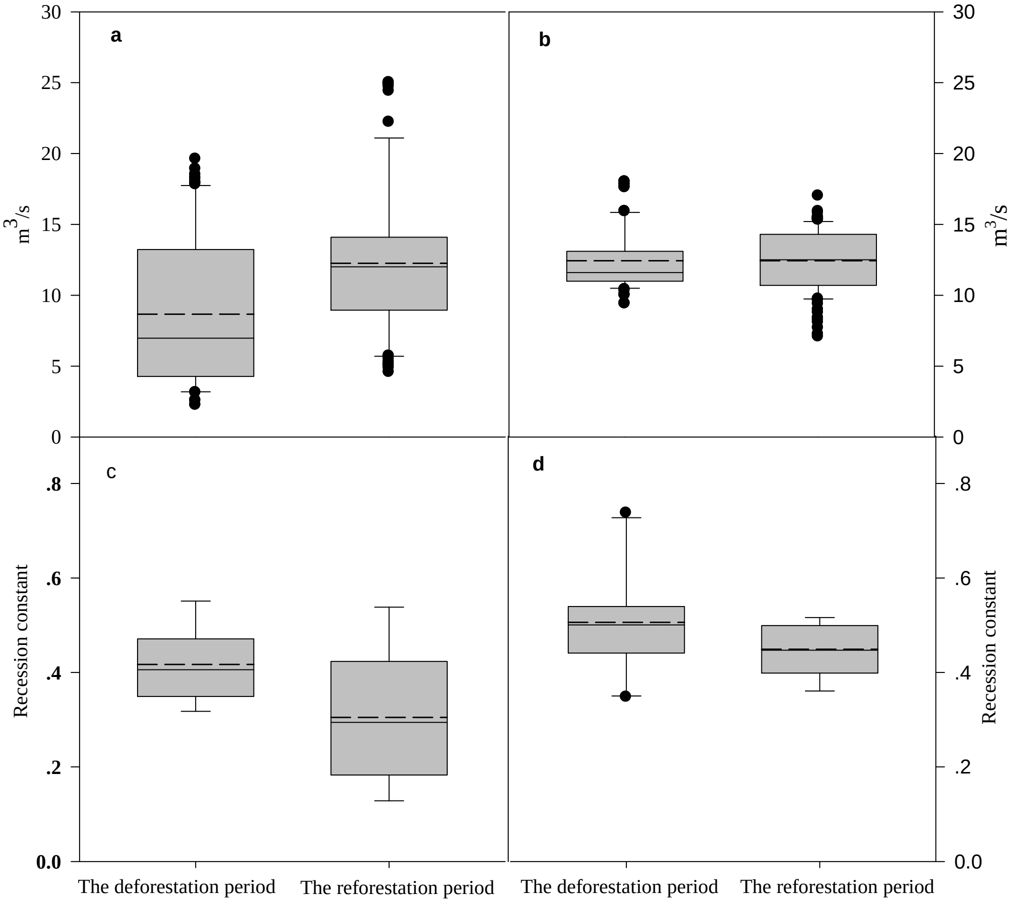

Figure 5. Low flows and recession constants of streamflow for the selected pairs in the deforestation and reforestation periods: (a) low flows for the Pingjiang watershed; (b) low flows for the Xiangshui watershed; (c) recession constants for the Pingjiang watershed; and (d) recession constants for the Xiangshui watershed