Characteristics and Attribution Analysis of Baseflow Variation in the Ganjiang River Basin from 1980 to 2019

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Abstract. This study delineates the baseflow processes in the Ganjiang River Basin using daily streamflow data from 1980 to 2019, and analyzes the variations in baseflow depth and the Baseflow Index (BFI) over the past 40 years. The trends, abrupt changes, and persistence of these parameters were examined. The contribution rates of climate change and human activities to baseflow variations were identified using the elasticity coefficient method. The results indicate that the baseflow processes separated by the three-digital filter method align well with the actual daily baseflow dynamics in the Ganjiang River Basin. Over the past four decades, both baseflow depth and BFI exhibited an insignificantly increasing trend with persistence. The baseflow depth is unevenly distributed within the year, predominantly in spring and summer, while BFI is higher in autumn and winter. The years of abrupt change for baseflow depth and BFI differ, with the former occurring earlier than the latter. Compared to the period of 1980-1991, human activities had a greater impact on baseflow depth during 1992-2019, while the influence of climate factors decreased. The average annual baseflow depth increased by 65.31 mm from 1992 to 2019 compared to the period of 1980-1991, with climate change being the primary contributing factor, accounting for 65.14% of the increase. Among climate factors, precipitation was the main contributor. Human activities contributed to a baseflow depth change of 22.77 mm, accounting for 34.86% of the total increase.

Keywords: Baseflow, Climate Change, Human Activities, Ganjiang River Basin, Contribution Rate

1. Introduction

Under the combined influence of climate change and human activities, the hydrological processes in river basins are undergoing complex and profound transformations [1, 2]. Baseflow, as a significant component of basin runoff, plays a crucial role in maintaining the water balance [3], preserving the health of river ecosystems [4], and sustaining riverbed depth [5]. The drivers of baseflow changes primarily include climate and human activities, encompassing factors such as precipitation, evapotranspiration, temperature, land use [6], reservoir construction [7], and agricultural irrigation [8]. A thorough understanding of the characteristics of baseflow changes and their driving factors is essential for comprehending the hydrological cycle, rational exploitation and utilization of water resources, and protection of the aquatic environment in river basins.

Baseflow separation methods typically isolate baseflow from total runoff, including graphical methods, hydrological modeling, environmental isotopes and hydrochemistry, and numerical simulation [7]. The digital filter method within numerical simulation is widely applied in baseflow process studies [9]. Methods such as the elasticity coefficient [10], multiple linear regression, and double mass curve [11] are commonly used in baseflow change attribution analysis.

The Ganjiang River Basin is sensitive to global climate change, and significant changes in vegetation cover have occurred within the basin, with cultivated land decreasing and becoming more dispersed from 1990 to 2015 [12]. It is necessary to further investigate the characteristics of baseflow changes and their influencing factors in the Ganjiang River Basin, based on studies of runoff variation patterns and their causes [13, 14], to achieve a comprehensive understanding of the evolution of the basin's water cycle. This paper employs the elasticity coefficient method to quantify the contributions of climate change and human activities to baseflow variations in the basin, providing a scientific basis for the rational planning and efficient management of water resources in the Ganjiang River Basin.

2. Data and Methods

2.1. Study Area

The Ganjiang River Basin, located in the central-southern part of Jiangxi Province, between 113°34′~116°38′E and 24°31′~28°45′N (Figure 1), is the largest tributary of the Poyang Lake Basin. The basin's average annual inflow to the lake is 68.6 billion m³, accounting for approximately 40.4% of the total inflow to the Poyang Lake Basin [15]. The Ganjiang River Basin covers an area of 81,800 km², constituting 50% of the total area of the Poyang Lake Basin. The basin is characterized by a subtropical monsoon climate, with an average annual temperature of 17.8°C and average annual precipitation of 1,600 mm. The spatial and temporal distribution of precipitation in the Ganjiang River Basin is uneven, with 4~6 months accounting for 50% of the annual total, and a pattern of higher precipitation in the east and mountains compared to the plains. Land use types within the basin include cultivated land, forest, grassland, water bodies, urban and rural construction land, and unused land, with forest and cultivated land dominating, accounting for over 90%, and forest covering more than 65%.

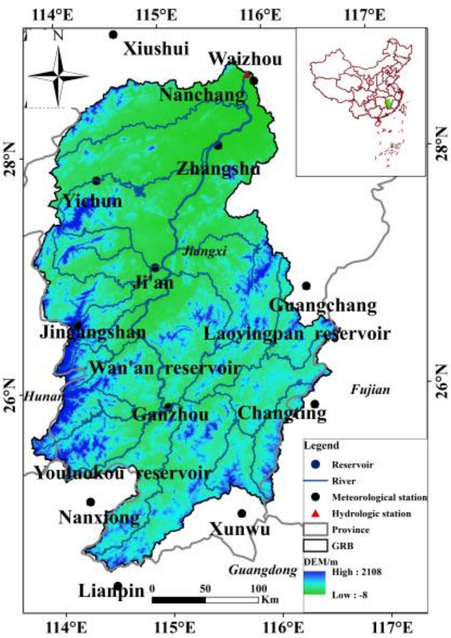

Figure 1. Sketch map of Poyang Lake Basin

2.2. Data Sources

Baseflow analysis utilized daily runoff data from the Wanzhou hydrological station in the Ganjiang River Basin from 1980 to 2019, sourced from hydrological annals. Basin topographic data with a spatial resolution of 30 m were obtained from the Geospatial Data Cloud. Meteorological data from 12 meteorological stations in the Ganjiang River Basin, covering the period from 1980 to 2019, were sourced from the National Meteorological Data Center(Figure 1). Annual precipitation in the basin was calculated using the Thiessen polygon method, and potential evapotranspiration was estimated using the FAO-modified Penman-Monteith formula.

2.3. Analysis Methods

This study employed the digital filter method, specifically the three-time digital filter, to separate baseflow from daily runoff data at the Wanzhou station from 1980 to 2019 [16]. Baseflow depth and

Baseflow Index (BFI) were used as analysis indicators, and the Mann-Kendall (M-K) trend test [17] was applied to analyze the temporal variation characteristics of the series. The Pettitt abrupt change test [18] was combined with the M-K test to identify the years of abrupt changes in the series.

Based on the Budyko hypothesis [19], the comprehensive impact of underlying surface characteristics on basin water balance was analyzed. The specific basin water-heat coupling balance equation is:

$$E = \frac{P \times ET_0}{\left(P^n + ET_0^n\right)^{1/n}} \tag{1}$$

Where P is the average precipitation (mm), R is the average runoff depth (mm), ET_0 is the potential evapotranspiration (mm), and n is the underlying surface parameter, which can comprehensively reflect changes in underlying surface characteristics such as topography, vegetation, and land use [20] on basin water balance. An increase of n indicates an increase in vegetation area and a decrease in impervious surface area, exerting a greater influence on runoff [21]. The elasticity coefficient method [22] was used to quantify the contribution rates of climate change and human activities to baseflow changes, which can be expressed as:

$$\varepsilon = \frac{\partial Q_b / Q_b}{\partial X / X} \tag{2}$$

Where is $\mathcal{E}$ elasticity coefficient, Q_b is baseflow, X is potential evapotranspiration or runoff. The least-squares method is employed to estimate the elasticity coefficients of climatic factors. By incorporating the impacts of climatic variables on baseflow, the resulting baseflow change under climate influence can be expressed as:

$$\Delta Q_b^{\overline{climate\ change}} = \left(\varepsilon_{ET_0}\frac{\Delta ET_0}{ET_0} + \varepsilon_P\frac{\Delta P}{P}\right)Q_b \tag{3}$$

3. Results and Analysis

3.1. Baseflow Variation Characteristics

The average runoff depth at the Wanzhou station from 1980 to 2019 ranged from 479.11 to 1,401.01 mm, increasing at a rate of 1.64 mm/year (Figure 2). The baseflow depth ranged from 297.43 to 837.35 mm, with a multi-year average of 503.40 mm, increasing at a rate of 1.31 mm/year. The annual average BFI fluctuated within a range of 0.50-0.70, showing an overall insignificantly increasing trend from 1980 to 2019.

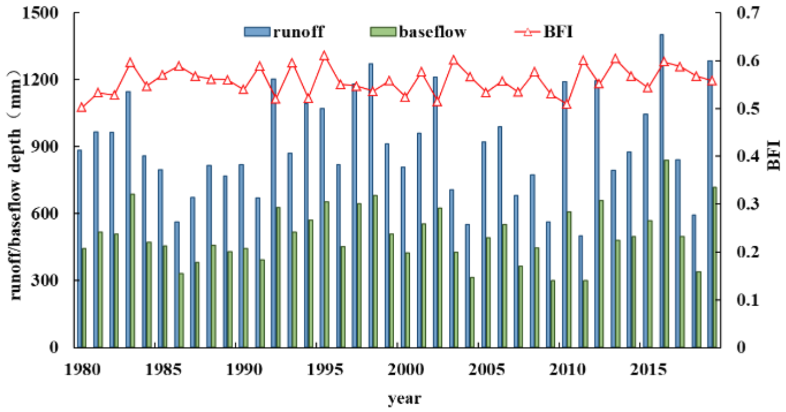

Figure 2. Annual runoff, baseflow and BFI of Ganjing Basin

The baseflow depth is unevenly distributed throughout the year, exhibiting a distinct "single-peak" distribution. Baseflow is mainly concentrated from March to August, accounting for 70.27% of the total annual volume. The variation range of baseflow depth in autumn and winter is smaller than that in spring and summer, indicating greater stability of baseflow depth in autumn and winter. The maximum multi-year average BFI occurs in October (0.78), and the minimum in January (0.52). The BFI is relatively low in spring and summer and higher in autumn and winter, serving as the main source of streamflow during the dry season.

The combination of M-K abrupt change test and Pettitt test determined that the year of abrupt change for baseflow depth was 1991, and for BFI, it was 2010. The onset of abrupt change in baseflow depth preceded that of BFI. The average annual baseflow depth from 1980 to 1991 was 459.00 mm, increasing to 524.31 mm from 1992 to 2019; the average BFI from 1980 to 2010 was 0.56, increasing to 0.58 from 2011 to 2019.

3.2. Correlation between Baseflow Variation and Climate and Human Activities

The relationship between climate factors, represented by precipitation and potential evapotranspiration, and baseflow variation was analyzed (Figure 3). The annual average values of precipitation and potential evapotranspiration from 1980 to 2019 were 1,768.52 mm and 1,023.76 mm, respectively. The linear slopes of their changes were 6.8 mm/10 years and -9.04 mm/10 years, respectively. Precipitation showed an insignificantly increasing trend from 1980 to 2019, while potential evapotranspiration exhibited a significantly decreasing trend during this period.

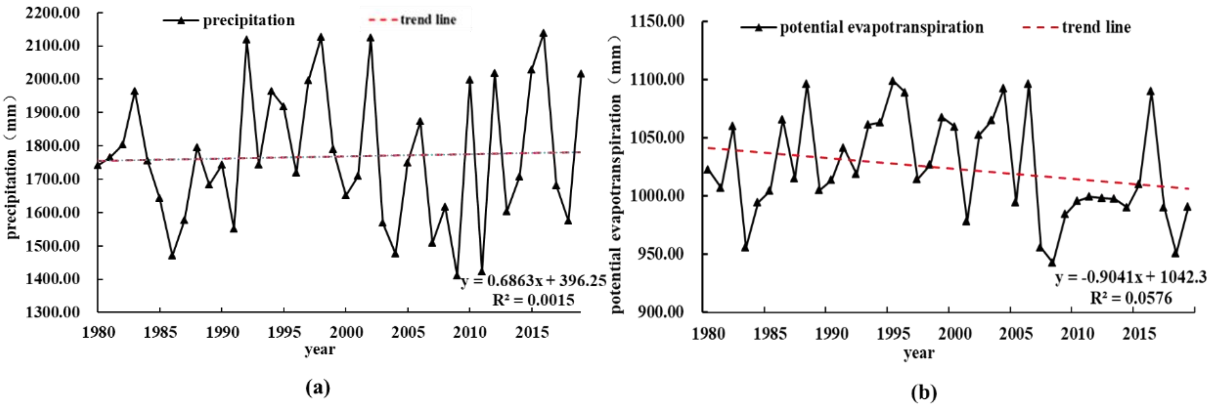

Figure 3. Variation of annual (a) P and (b) ET0 in Ganjiang River Basin

Spearman rank correlation test was used to analyze the correlation between precipitation, potential evapotranspiration, baseflow depth, and BFI, indicating a significant correlation between precipitation and baseflow depth, with a correlation coefficient of 0.913, and a correlation coefficient of 0.353 with BFI. Potential evapotranspiration was negatively correlated with baseflow and BFI, with correlation coefficients of -0.04 and -0.019, respectively.

Human activities influence hydrological processes by altering underlying surface conditions. The average n value in the Ganjiang River Basin from 1980 to 2019 was 1.89, showing a decreasing trend. Correlation analysis found that baseflow depth was significantly negatively correlated with n (correlation coefficient -0.734), while BFI showed an insignificant positive correlation with n. This suggests that a decrease in vegetation area and an increase in impervious surface area within the basin lead to an increase in baseflow depth. Moreover, since the impact of n on runoff is greater than that on baseflow, the rate of change in runoff is greater than that in baseflow, which may lead to an increase in BFI.

3.3. Attribution Analysis of Baseflow Variation

Based on the results of the abrupt change test, the year of abrupt change for baseflow depth was 1991. The baseline period for baseflow depth was 1980-1991, and the change period was 1992-2019. The potential evapotranspiration and precipitation during the change period increased by 0.06% and 5.09%, respectively, compared to the baseline period (Table 1). The slight increase in potential evapotranspiration and the greater increase in precipitation indicate that the basin was more humid during the change period than the baseline period.

Table 1. Hydro-Meteorological Index and Baseflow Ɛ In the Ganjiang River Basin

period	ET_0 (mm)	P (mm)	n	P (mm)	Baseflow (mm)	Elasticity Coefficients		
						ε_{ET0}	ε_p	ε_n
1980-1991	1023.36	1707.67	2.11	1707.67	459.00	-2.91	2.26	-0.68
1992-2019	1023.93	1794.60	1.80	1794.60	524.31	0.86	1.64	-1.07

The elasticity coefficients of baseflow depth to potential evapotranspiration and precipitation during the baseline and change periods were -2.91 and 2.26, respectively, indicating that baseflow depth increased with increasing precipitation and decreasing potential evapotranspiration during the baseline period. During the change period, the elasticity coefficients were 0.86 and 1.64, respectively, with the absolute values of both elasticity coefficients being smaller than those in the baseline period, and the absolute value of the elasticity coefficient for precipitation being greater than that for potential evapotranspiration, indicating that baseflow depth is more sensitive to changes in precipitation. This aligns with the overall understanding from the correlation analysis. Additionally, the absolute value of the elasticity coefficient of baseflow to n during the change period was greater than that during the baseline period, indicating that the impact of human activities on baseflow depth increased, while the impact of climate change on baseflow depth decreased.

The main factor influencing the increase in baseflow depth during the change period was climate change, with precipitation being the primary climate factor, accounting for 63.82% of the total contribution, and the overall contribution of climate factors being 65.14% (Table 2). Among climate factors, the changes in potential evapotranspiration and precipitation led to baseflow changes of 0.86 mm and 41.68 mm, respectively. Human activities contributed to a baseflow depth change of 22.77 mm, accounting for 34.86% of the total increase.

Table 2. Attribution of Baseflow Depth Changes in the Ganjiang River Basin

ΔR (mm)	ΔR_{ET0} (mm)	ΔR_P (mm)	ΔR_{CC} (mm)	ΔR_{Hu} (mm)	C_{CC} (%)	C_{Hu} (%)
65.31	0.86	41.68	42.54	22.77	65.14%	34.86%

4. Discussion

Human activities in the Ganjiang River Basin primarily involve changes in land use patterns and the construction of water conservancy facilities. Land use changes at the beginning and end of the study period (1980 and 2019) were investigated using land use data. From 1980 to 2019, urban and rural construction land, grassland, and water bodies increased by 1,282 km², 301 km², and 108 km², respectively, with urban and rural construction land experiencing the largest increase, at a dynamic rate of 2.46%. Human activities in the Ganjiang River Basin have significantly intensified during the study period, with an increase in urban and rural construction land leading to changes in underlying surface conditions. Forest, cultivated land, and unused land areas have decreased, with reductions of 1,078 km², 523 km², and 53 km², respectively. Specifically, the area of forest converted was the largest, totaling 11,057 km². The area of cultivated land also decreased significantly over the 40 years, totaling 10,541 km². Although the area of construction land within the basin increased, the area of construction land only accounts for 3.1% of the basin area, and the increase in grassland and water bodies led to an increase in baseflow.

In addition, several large reservoirs have been built in the Ganjiang River Basin since the 1980s. Examples include the Baiyunshan Reservoir, which was completed in 1980, the Youluokou Reservoir in 1981, and the Laoyingtan Reservoir in 1983, all of which are large-scale reservoirs with total storage capacities exceeding 100 million m³ [23]. For example, the Wan'an Reservoir, the largest in the Ganjiang River Basin, is located in the middle reaches of the Ganjiang River and began operations in 1990 [24], with a total storage capacity of 2.216 billion m³. Since the 1990s, several floods with peak flows exceeding 10,000 m³/s have occurred in the upper reaches of the Ganjiang River, and the Wan'an Reservoir has played a role in flood regulation, reducing peak flows and compensating for deficits. The abrupt change in baseflow depth in the Ganjiang River Basin in 1991 is closely related to the series of reservoirs built in the upper reaches of the Ganjiang River.

5. Conclusions

(1) Over the past 40 years, both baseflow depth and BFI in the Ganjiang River Basin have shown an increasing trend with persistence, and the persistence of baseflow depth is stronger than that of BFI. The baseflow depth is unevenly distributed throughout the year, exhibiting a distinct "single-peak" distribution. The BFI is relatively low in spring and summer and higher in autumn and winter.

(2) The years of abrupt change for baseflow depth and BFI differ, with the former preceding the latter. Based on the absolute values of the elasticity coefficients of baseflow depth to climate factors during the baseline and change periods, it is evident that the impact of human activities on baseflow has increased, while the impact of climate change on baseflow has decreased.

(3) The main factor influencing the increase in baseflow during the change period was climate change, with precipitation being the primary climate factor, contributing 63.82% to the total increase, and the overall contribution of climate factors being 65.14%. Human activities contributed 34.86% to the increase in baseflow.

Acknowledgments

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