Analysis of baseflow variation characteristics in the middle reach of Wei River Basin

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Abstract

Baseflow is the main component of streamflow in dry periods, especially in arid and semi-arid areas. Based on the observed discharge of Xianyang station in the middle reach of Wei River Basin during 1970 to 2005, daily streamflow was separated into direct runoff and baseflow by Recursive Digital Filter method. M-K test method was used to test the variation trend of baseflow series. Results showed that annual baseflow had a significant decreasing trend. Furthermore, breakpoint of annual baseflow was occurred in 1993. The corresponding mean annual baseflow reduced from 2.98 104m3/s in the period of 1970-1992 to 1.47 104m3/s in the period of 1993-2005. Average annual BFI value was 0.63, indicating that more than 60% of streamflow was contributed by baseflow in the study area. Variations in baseflow can be attributed by the changes of precipitation, evaporation, temperature and buried depth of groundwater level. Overall, analyzing on variations of baseflow in the middle reach of Wei River Basin would be helpful for understanding the effects of climate change and human activities on baseflow.

Keywords

Recursive Digital Filter Method, Baseflow Index, Trend Test, Attribution Analysis.

1. Introduction

Baseflow is the component of streamflow that includes groundwater flow and flow from other delayed sources [1]. It is noted that the real baseflow contribution is unknown. There are all kinds of baseflow separation methods. However, the selection of baseflow separation methods seems to be subjective [2]. With the effect of climate change and human activities, variations in baseflow had been reported in previous studies [3-6].

Based on observed daily streamflow data (1970-2005) in Xianyang station, Recursive Digital Filter method was employed to separate streamflow into direct runoff and baseflow. The aim of this study is (1) to investigate the temporal variation of baseflow; (2) to conduct the attribution analysis of baseflow changes.

2. Methods

2.1 Recursive Digital Filter Method

Recursive Digital Filter method was proposed by Eckhardt based on one parameter digital filter method [7]. The expression of Recursive Digital Filter method was represented as

$$b_t = \frac{(1-BFI_{\max})\times a\times b_{t-1} + (1-a\times BFI_{\max}\times Q_t)}{1-a\times BFI_{\max}} \tag{1}$$

Where b_t and b_{t-1} are baseflow at the time steps of t and t-1, m^3/s; Q_t is the total streamflow at the time step of t, m^3/s; a is filter parameter. BFI_{max} is the maximum of BFI.

There are two parameters in the Recursive Digital Filter method, that is, a and BFI_{max}. In this study, the default value of 0.98 was assigned to filter parameter. Wei River Basin is belonged to perennial rivers of porous aquifers, so BFI_{max} value of 0.80 was used.

2.2 Mann-Kendall Non-parameter Test Method

Mann-Kedall non-parametric test method (M-K method) was applied to analyze the trend variation and abrupt point of baseflow time series in Xianyang station. The specific calculation steps for M-K method were described as follows [8-10]:

Firstly, mathematical formula for a statistic was expressed as:

$$S=\sum_{i=1}^{n-1}\sum_{j=n+1}^{n} sgn\left(x_j - x_i\right) \tag{2}$$

$$sgn\left(x_j - x_i\right)=\begin{cases}1 & x_j > x_i\\ 0 & x_j = x_i\\ -1 & x_j < x_i\end{cases} \tag{3}$$

Where S is a statistic; *sgn* is sign function; x_i and x_j is target variables of the *ith* and *jth*, respectively; n is sample number.

When n is greater than 8, S will approximately obey the normal distribution with the mean of zero and variance of $Var(S)$.

$$E(S)=0 \tag{4}$$

$$Var(S)=\frac{n(n-1)(2n+5)}{18} \tag{5}$$

Where $E(S)$ is the mean of S; $Var(S)$ is the variance of S.

Then the test statistic of M-K method was represented as:

$$Z=\begin{cases}\dfrac{S-1}{\sqrt{Var(S)}} & S>0\\ 0 & S=0\\ \dfrac{S-1}{\sqrt{Var(S)}} & S<0\end{cases} \tag{6}$$

Where Z is the test statistic; $Z > 0$ shows that the corresponding time series has an increasing trend; On the contrary, $Z < 0$ shows that the time series has an decreasing trend.

3. Results and Discussion

3.1 Variations of Annual Baseflow and BFI

Annual baseflow varied from $0.36\times10^4 m^3/s$ to $5.73\times10^4 m^3/s$ during 1970 to 2005 in Xianyang station (Fig. 1). Coefficient of variation and skewness of annual baseflow were 0.59 and 0.68, respectively, suggesting that interannual change of baseflow was not large and the asymmetry of baseflow distribution was not obvious. Annual baseflow had a decreasing trend. M-K test result indicated that the decreasing trend of annual baseflow was significant (Z=-2.38). Huang et al. (2014) pointed out reduced streamflow was mainly caused by climate and human activity, and the human activities were the main driving factor. The abrupt point of annual baseflow in Xianyang station occurred in 1993 (Fig. 2). Huang et al. (2014) found 1970 and 1994 at Xianyang Station when 1960-2006 daily runoff data were used. Hence, the whole study period was separated to two stages, that is, natural period (1970-1992) and variation period (1993-2005). Mean annual baseflow reduced from $2.98\times10^4 m^3/s$ in the natural period to $1.47\times10^4 m^3/s$ in the variation period. However, BFI values of two periods were the same (BFI=0.63), demonstrating that more than 60% of streamflow was contributed by baseflow both in natural and variation periods. As is shown in Fig. 3, BFI values were between 0.56 and 0.73 during 1970-2005, also with the mean value of 0.63.

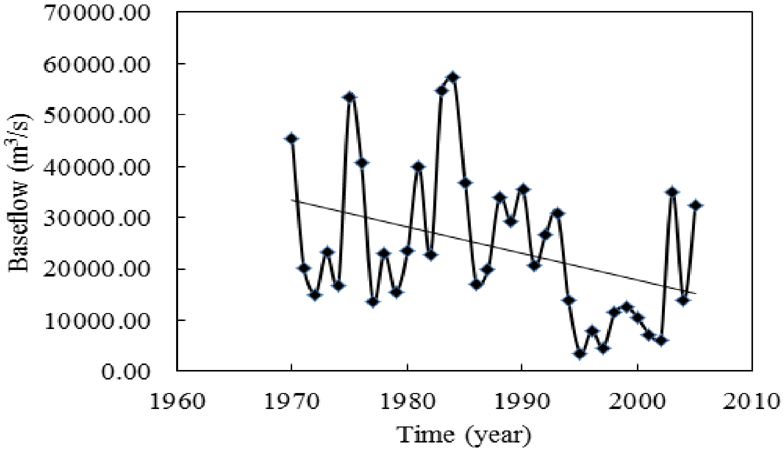


Fig. 1 Variation of annual baseflow during 1970-2005 in Xianyang station

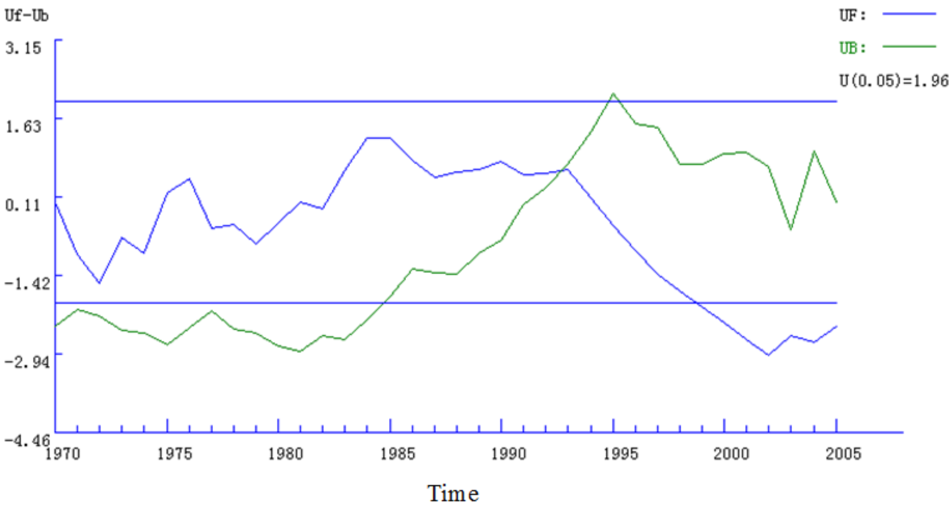


Fig. 2 Abrupt point test of annual baseflow in Xianyang station

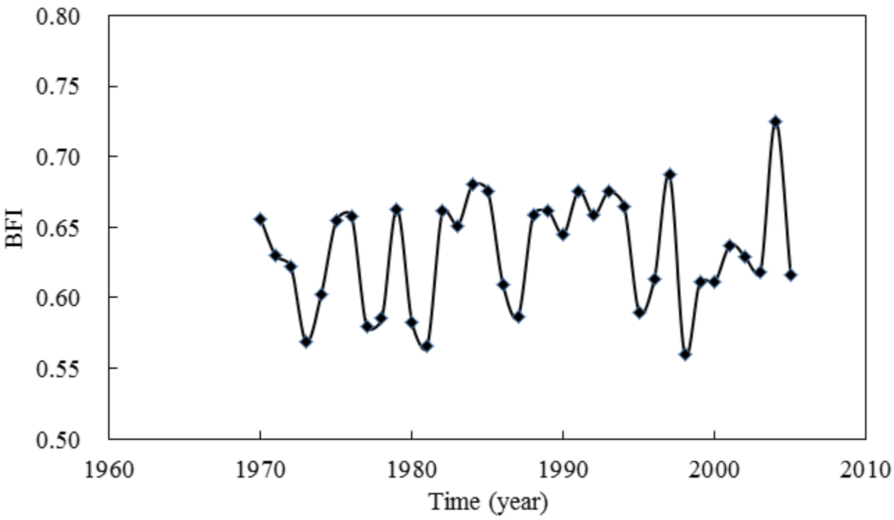


Fig.3 Variation of BFI during 1970-2005 in Xianyang station

3.2 Attribution analysis of variation in baseflow

In this study, several factors such as precipitation, evaporation, temperature, groundwater table were considered to analyze the impact of them on baseflow variation.

3.2.1 Precipitation

Precipitation is the main recharge source of streamflow. As is shown in Fig. 4, annual precipitation fluctuated in Xianyang during 1970-2005. Annual precipitation was lowest in 1977, with the value of 255.8mm. The corresponding baseflow volume was $1.37\times10^4 m^3/s$, which was a local minimum value. The maximum precipitation occurred in 1983, with the value of 855.3mm. Baseflow volumn was $5.49\times10^4 m^3/s$ in the same year, which was close to the highest baseflow volume in 1984. It may be attributed by the delay of precipitation recharge.

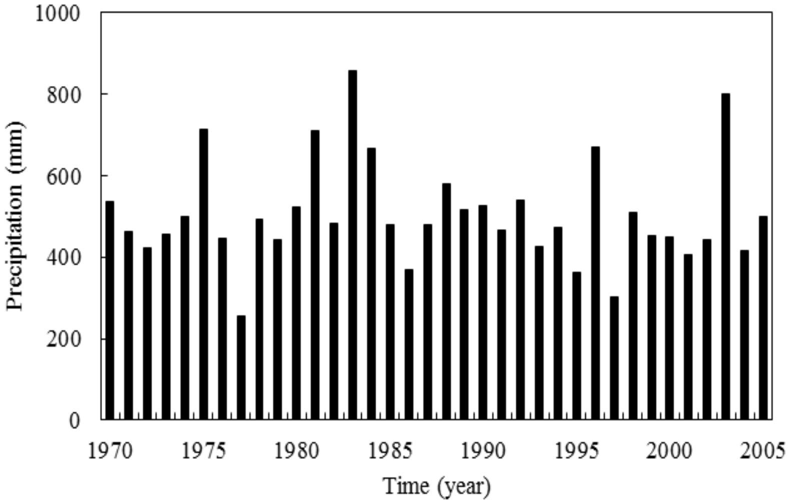


Fig. 4 Interannual variation trend of precipitation in Xianyang (1970-2005)

3.2.2 Evaporation and Temperature

Limited to the length of data, variation of annual evaporation during 1980 to 2001 in Xianyang was analyzed. Annual evaporation ranged from 1107.3mm to 1823.5mm, with an average of 1461.0mm. Annual evaporation series tended to increase from 1980 to 2001 (Fig. 5). From the perspective of water balance, change of water storage would reduce when precipitation was constant and evaporation increased. Annual mean air temperature of Xianyang was between 12.0℃ to 14.7℃from 1981 to 2004 (Fig. 6). As a whole, temperature had an increasing trend during 1981 to 2004. Both evapotranspiration and temperature changes may result in baseflow decreasing from 1980s to 2000s.

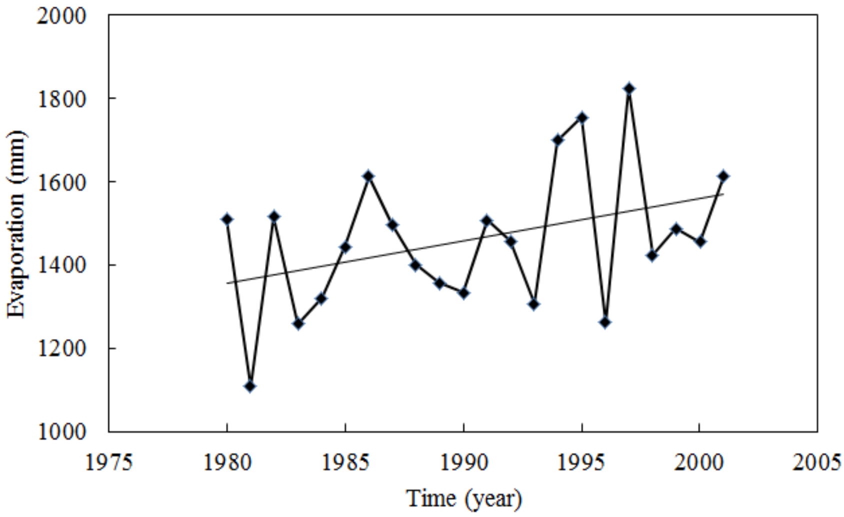


Fig. 5 Interannual variation trend of precipitation in Xianyang (1980-2001)

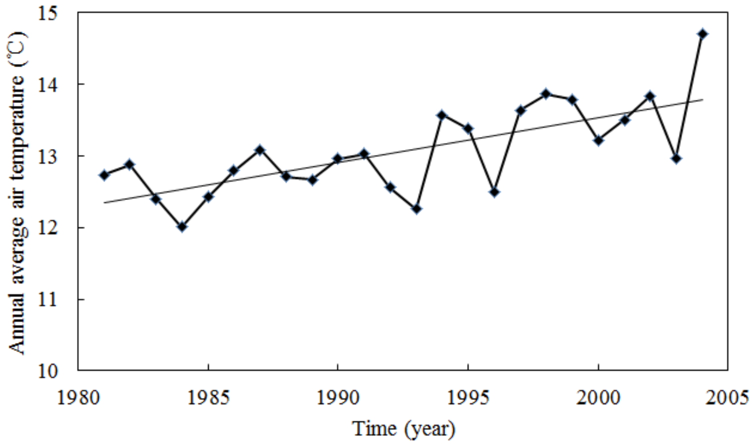


Fig. 6 Interannual variation trend of temperature in Xianyang (1981-2004)

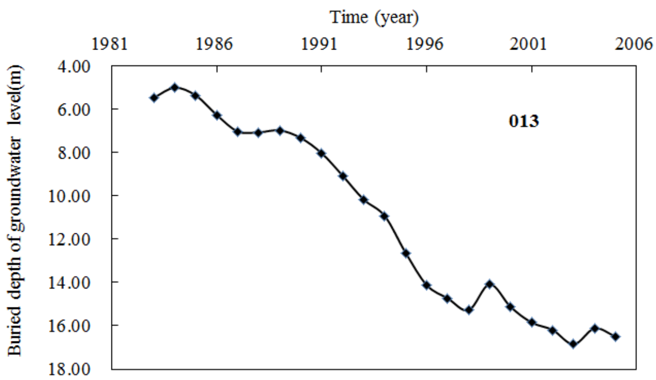
3.2.3 Groundwater table

Two wells (No. 013 and 059) in Xianyang city were selected to investigate the changes of groundwater table. The basic information of two wells was shown in Table 1. It can be seen from Fig. 7, groundwater table had a decreasing trend during 1983 to 2005. Buried depth of groundwater levels varied from 5.46m to 16.50m for well 013 and 10.65m to 20.39m for well 059 during 1983 to 2005, respectively. Mean annual groundwater level reduced 0.48m per year for well 013 and 0.42m per year for well 059. From this perspective, groundwater discharge may decrease within 1983-2005, which is consistent with the change of baseflow. It is noted that annual baseflow decreased significantly from 1983 to 2005 (Z=-2.91).

The main recharge source of regional groundwater is originated from precipitation and irrigated water in the study area. Due to the rise of annual temperature and evaporation, groundwater recharge may reduce from the aspect of water balance. Besides, groundwater exploitation is another primary factor which causes the decrease of groundwater. Thus, the amount of groundwater discharging to streamflow may decrease. As a whole, factors such as precipitation, evapotranspiration, temperature and buried depth of groundwater level all changed during the study period, indicating that baseflow variation may be attributed by influencing factor considered above. However, driving factors may not only be limited to those. In addition, the correlation between baseflow and influencing factors was not analyzed in this study, so it is an ongoing work.

Table 1 Basic information of observed wells in Xianyang

Well No.	Coordinate		Groundwater type	Elevation (m)
013	108°45′11″E	34°19′19″N	Phreatic water	385.95
059	108°33′13″E	34°18′37″N	Phreatic water	408.00



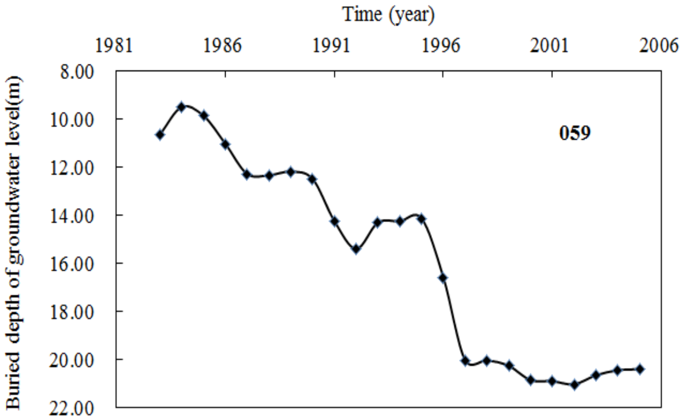


Fig.7 Variations of buried depth of groundwater levels

4. Conclusions

Recursive Digital Filter method was used to separate baseflow from daily streamflow at Xianyang station during 1970 to 2005. Then M-K non-parameter test method was employed to conduct the variation trend of annual baseflow. Results indicated that annual baseflow decreased significantly with Z value of -2.38. The abrupt point of annual baseflow in Xianyang station occurred in 1993. The corresponding mean annual baseflow reduced from $2.98\times10^4 m^3/s$ during 1970-1992 to $1.47\times10^4 m^3/s$ in period of 1993-2005. Average annual BFI value was 0.63, suggesting that over 60% of streamflow was contributed by baseflow in the study area. Variations in baseflow can be attributed by the changes of precipitation, evaporation, temperature and buried depth of groundwater level.

Acknowledgements

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