Identification of impacts of climate change and direct human activities on streamflow in Weihe River Basin in Northwest China

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Abstract: Climate change and human activities make major influences on hydrology, which are known to have important impacts on streamflow variation. Therefore, it is critically important to identify how climate change and human activities will impact streamflow variation. Thus, the goal of this study is to identify the impacts of climate change and direct human activities on annual streamflow at four hydrologic stations in the Weihe River basin of China, with the estimation of evaporation based on the Budyko hypothesis. The Mann-Kendall test was employed to detect the break points of the four stations. According to the occurrence time of break points, the data series were divided into two periods: pre-change period (1960-1984) and post-change (1985-2010) period. The parameter of one-parameter Budyko-type model was calibrated with observed data during the pre-change period, with the R^2 values ranged from 0.95 to 0.97 and the NSE values ranged from 0.80 to 0.94, and the high R^2 and Nash-Sutcliffe Efficiency coefficient shows the model has good performance. The contribution ratios of climate change impacts on decreasing streamflow were 37%, 23%, 57% and 43%, and those of the impacts of direct human activities were 63%, 77%, 43% and 57% for the Linjiacun, Xianyang, Lintong and Huaxian station, respectively. Both the climate change and direct human activities have positive impacts on streamflow decrease at all of the four stations, and the direct human activities are the main factor causing the decrease of annual streamflow.

Keywords: streamflow, climate change; human activities; evaporation, hydrological cycle, watershed, Budyko hypothesis, Weihe River basin

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1 Introduction

Complex interactions occur regarding the impacts of climate change and human activities on the hydrological cycle and water resources system[1,2]. Shifts in climate characteristics, such as changes in precipitation, temperature and evapotranspiration, can alter the streamflow[3]. Human activities can alter streamflow by directly affecting climate conditions and influencing the hydrological cycle[3]. Direct human activity effects include land use and land cover change, reservoir construction, irrigation area management and soil conservation practice[4-7].

The effects of climate change and human activities on streamflow have been investigated by many researchers through a series of studies in many regions[8,9]. For example, Schilling et al.[10] identified the effect of land use/ land cover impacts in the Mississipi River, while Wang et al.[11] investigated the climate change and human impacts in the Yellow River. Extensive investigations have been performed with linking climate change

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projections and/or land use change scenarios with ecohydrological models, including dozens of studies that have been performed using the Soil and Water Assessment Tool (SWAT) model[12,13]; e.g., see review studies compiled by Gassman et al.[14] and Krysanova and White[15].

Zuo et al.[16] quantified a noticeable decrease in the monthly streamflow of the Weihe River, located in central China, by using a water balance model that was executed on the basis of measurements obtained at 13 hydrological gauging sites during the period of 1960 to 2009. The results indicated that the main driving factors that resulted in decreased streamflow in the Weihe River Linjiacun, Xianyang and Zhangjiashan subwatersheds resulted from human activities. By developing an improved climate elasticity method, Zhan et al.[17] used streamflow data of Weihe River basin to determine the effects of climate change and human activities on the streamflow change, and they found that 71%-78% of the contributions to the decreasing runoff were due to human activities. Wang et al.[18] used a distributed time-variant gain model to identify the effects of climate change and human impact on streamflow change of the Yellow River basin in China. At the Laohahe Basin, Jiang et al.[19] quantified the two effects on streamflow by using the VIC-3L model. In all of these studies, hydrological models have been used to assess the effects of climate change and human activities on streamflow change, however, these hydrological models had significant uncertainty which caused by the parameter setting, most of them have 2, 3 or even more parameters, as known to all, different parameters control different functions of models, and its deviation will cause complex uncertainty of the system.

The Weihe River is the largest tributary of the Yellow River in China and supplies approximately 85% of the water supply to over 22 million people in Xi'an, Baoji, Xianyang and other cities[20]. It is the major water resource for the Guanzhong Plain (Central Shaanxi Plain) region, which is also a key political, cultural, and economic center in western China. The Guanzhong Plain region comprised 64%, 56% and 72% of the overall Shaanxi province population, arable land and irrigated area, respectively, in 2006. However, the total production of water in Shaanxi Province was only 6.369 billion m^3, which is equivalent to just 25.5% and 29.4% of the per capita consumption at the province level, which is far below the internationally recognized per capita consumption water level. The region lies mainly in arid and semi-arid ecoregions, where water resources are limited. Due to the water resources shortage problem, the government has invested human and financial resources to the water transfer project from south to north, i.e. from Hanjiang River to Weihe River in Shaanxi Province[21]. In addition, studies have indicated that the streamflow during the 20th century in the Weihe River basin has been decreasing significantly[22-24]. Therefore, it is important to quantify the effects of climate change and human activities on streamflow variation, and to determine the main influences of streamflow decrease, for the Weihe River.

Recently, on the basis of Budyko-type equations[25-27], which consider the hydrological processes during long period both the water and energy constraints, are widely used in quantifying the impacts of climate change and human activities on streamflow change[28,29]. According to the Budyko hypothesis equation, which was proposed by Fu[30], and SVM-based model, Huang et al.[31] analyzed the attribution of runoff changes to climate change and human activities in Weihe River. Jiang et al.[32] employed four single-parameter Budyko-type equations to assess the impacts of climate change and human activities on streamflow change in Weihe River basin. Wang et al.[33] discussed the Budyko framework processes effects on water balance and the Budyko curve type changes under climate change. Yuan et al.[34] used the Budyko-type equation (Budyko)[25] to estimate climate variability and human activities impacts on streamflow change in Dongting Lake. In aiming to identify the impacts of climate change and human activities on runoff change, it is generally to obtain a change point to divide the long-term series into two or more periods, by choosing the first period as baseline (pre-change period), and choosing the other ones as impact periods (post-change period), then used some models to separate the changes between the two periods into the two impacts[35]. The non-parametric method Mann-Kendall method, which was developed early in 1945[36,37], was widely applied in detecting the change points in hydrological area. Mann-Kendall test was used to detect the change points of streamflow for choosing the baseline and impact periods reasonably. Fan et al.[38] used Mann-kendall test find the change point on annual runoff series in Weihe River. Guo et al.[39] detected the change point on discharge of Weihe River using Mann-kendall test. Li et al.[40] applied Mann-Kendall test to assess the change point on annual temperature in Shangqiu City, China.

In this study, the main objectives are to: (1) identify the change points on annual streamflow across four hydrological stations in the Weihe River basin, and separate the long-term streamflow series into pre-change and post-change period; (2) assess the impacts of climate change and human activities on streamflow change by using the one-parameter Budyko-type equation; (3) discuss the contributions of climate change and human activities to streamflow. The existence of these results has profound implications to understand the changes of water balance and the water management in the study region and the similar regions.

2 Study area and observations

The Weihe River is the largest tributary of the Yellow River in China and is the main river of Shaanxi Province, Ningxia Hui Autonomous Region and Gansu Province (Figure 1). The catchment drains an area of 135 000 km^2 and the main stream is 818 km long. The mean annual natural runoff is 10.04 billion m^3, mean annual precipitation is 610 mm and the mean annual temperature ranges from 7.8°C to 13.5°C across the whole basin.

The impacts of human activities and climate change on streamflow were studied at four hydrological stations and 22 rain gauges in the Weihe River basin which have measured streamflow, precipitation and evaporation data. The four stations (Linjiacun, Xianyang, Lintong and Huaxian) are located on the main stream of the Weihe River (Figure 1 and Table 1). The 22 rain gauges are distributed all over the whole Weihe River basin (Figure 1). The daily data from 1960 to 2010 include streamflow data observed at hydrological stations, and daily precipitation data recorded at the rain gauges in controlled catchment[20]. The area precipitation was gathered from the 22 rain gauges in the catchment.

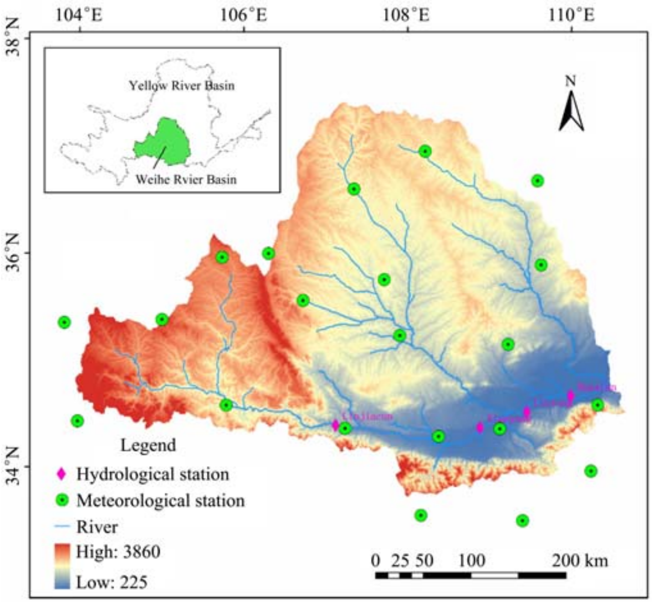


Figure 1 Location of study stations four hydrologic stations and 22 rainfall gauges within the Weihe River basin

Table 1 Locations and catchment of four stations in the Weihe River basin in China

Name	Station	Longitude I	Latitude/N	Catchment/km^2
1	Linjiacun	107.05	34.38	30.611
2	Xianyang	108.70	34.32	46.827
3	Lintong	109.12	34.26	97.299
4	Huaxian	109.77	34.58	106.498

3 Methods

3.1 One-parameter Budyko model

Based on the Proportionality Hypothesis, Wang and Tang[25] proposed a Budyko-type equation with only one parameter, Huang et al.[31] used the original equation, and Jiang et al.[32] applied a four parameter equation. The one-parameter Budyko equation was used in this study. Wang and Tang[25] implemented a model to clarify the precipitation decomposing into three parts, i.e. effective precipitation, continuing evaporation and runoff in a long period time, where the soil water storage change can be ignored. Wang and Tang[41] denoted the evaporation E_o as initial evaporation, which has no relation with runoff. Savenije[42] defined initial evaporation as evaporation that originates from leaf interception, forest floor and the temporary storage in pools. The other part, P-E_o, is denoted as effective precipitation, which is related with runoff, and then decomposed into runoff (Q) and continuing evaporation (E_c). The total evaporation is the sum of E_o and E_c. Potential evaporation is denoted as E_p, and the values of E_p–E_o is denoted as effective potential evaporation. The value for runoff can be computed as P–E_o. The relation can be explained as follows:

$$\frac{E-E_o}{E_p-E_o}=\frac{P-E}{P-E_o} \tag{1}$$

$$P=\begin{cases} E_o \\ P-E_o=\begin{cases} E_c & E_p-E_o \\ Q & P-E_o \end{cases} \end{cases} \tag{2}$$

Based on the Equation (1), According to Wang and Tang[41], the one-parameter Budyko-type equation can be expressed as follows:

$$\frac{E}{P}=\frac{1+E_p/P-\sqrt{(1+E_p/P)^2-4\varepsilon(2-\varepsilon)E_p/P}}{2\varepsilon(2-\varepsilon)} \tag{3}$$

where, ε is the ratio ($\varepsilon=\frac{\gamma}{H}$) of initial evaporation ratio ($\gamma=\frac{E_o}{W}$, W is soil wetting) to the Horton index ($H=\frac{E}{W}$, see H details in Troch et al.[43]). And ε can be interpreted as $\varepsilon=\frac{E_o}{E}$ and ranges from 0 to 1. The one-parameter Budyko-type Equation can satisfy the Budyko Curve essential boundary condition: $\frac{E}{P}\to 0$, as $\frac{E_p}{P}\to 0$ and $\frac{E}{P}\to 1$, as $\frac{E_p}{P}\to\infty$, and it also satisfies the Thomas's "*abcd*" model[44] for monthly scale. The one-parameter Budyko-type Equation interpreted the relationship of the generalized Proportionality Hypothesis to the Budyko Curve well.

3.2 Decomposing method for quantifying the climate change and direct human activities impacts

Wang and Hejazi[45] proposed a simple method to categorize long-term annual streamflow change into two partitions: climate-induced and direct human-induced. The climate-induced part is caused by changes in precipitation and evaporation, and the direct human-induced streamflow change is caused by the changes of precipitation portioning into runoff and evaporation, Figure 2 shows the decomposing method proposed by Wang and Hejazi[45] to quantify the impacts of climate change and direct human activities on streamflow, based on the original Budyko Curve[25].

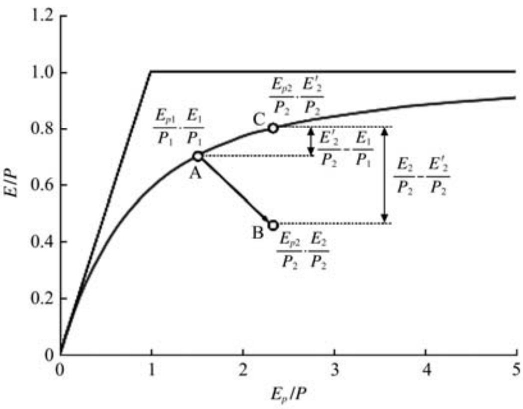


Figure 2 Decomposing method to quantify the climate and human activities impacts

The hypothesis is based on the relationship that as the impacts of climate change and direct human activities change in a watershed, the resulting effects could shift point A (pre-change period) to point B (post-change period) over time (Figure 2). The dryness index and the evaporation ratio would also change from E_{p1}/P_1 and E_1/P_1 in the pre-change period to E_{p2}/P_2 and E_2/P_2 in the post-change period, respectively. However, Point A would shift along the original Budyko-type Curve to point C (with dryness index), and the evaporation ratio would change from E_{p1}/P_1 and E_1/P_1 to E_{p2}/P_2 and E'_2/P_2, respectively, if climate is the only factor changing in the watershed (Figure2). The climate change effects are the same between point B and point C because the vertical values for both points are the same (Figure 2). So the precipitation value at point C is still equal to P_2. Only climate change will cause the shift from point A to point C (Figure 2) in both the horizontal and vertical directions, i.e., from E_{p1}/P_1 to E_{p2}/P_2 (horizontal) and E_1/P_1 to E'_2/P_2 (vertical). From point B to point C, only direct human activities will influence the changes in the vertical direction; i.e., from E_2/P_2 to E'_2/P_2; There is no horizontal change because the horizontal values of the two points are the same (E_{p2}/P_2). Finally, the vertical change from point A to B (E_1/P_1 to E_2/P_2) occurs due to both direct human activities and climate change impacts (Figure 2).

The climate change impacts will affect both the horizontal and vertical components, but changes in direct human activities will only impact vertical components. Therefore, the first step is to compute the impacts of direct human activities. In addition, the soil water storage change can be ignored during the long-term period, hence, the streamflow can be explained as follows:

$$Q = P(1 - E / P) \tag{4}$$

Similarly, the contribution of direct human and climate change on streamflow change can be computed as:

$$\Delta Q^h = P_2\left(\frac{E_2'}{P_2} - \frac{E_2}{P_2}\right) \tag{5}$$

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

$$\Delta Q = Q_2 - Q_1 \tag{7}$$

where, ΔQ^h and ΔQ^c are the streamflow changes caused by direct human activities and climate change impacts, respectively. Q_1 and Q_2 are the observed streamflow during the pre-change period and post-change periods, respectively. The values of ΔQ^h (or ΔQ^c) can be positive or negative, which reflects positive or negative effects on streamflow, respectively, due to direct human activities.

The percentage of the contribution of climate change (C) and direct human activities (H) can be estimated using the climate sensitivity method[41]:

$$C = 100(\Delta Q^c / \Delta Q) \tag{8}$$

$$H = 100(\Delta Q^h / \Delta Q) \tag{9}$$

3.3 Mann-Kendall test

The Mann-Kendall test[34,35] is a non-parametric statistical test method, which is widely used to detect the break points of time series. It can be applied in the context of non-normality and censoring data, is simple to compute and is high efficiencent[46,47]. The test statistic (UF_k) is computed as follows:

$$UF_k = \frac{S_k - E(S_k)}{\sqrt{var(S_k)}}, \quad (k=1,2, \ldots,n) \tag{10}$$

$$S_k = \sum_{i=1}^{k} r_i \quad (k=2,3, \ldots,n) \tag{11}$$

$$r_i = \begin{cases} +1, \; while \; x_i > x_j \\ 0, \; while \; x_i \le x_j \end{cases} \quad (j=1, 2, \ldots,n) \tag{12}$$

$$\begin{cases} E(S_k) = \dfrac{k(k-1)}{4} \\ var(S_k) = \dfrac{k(k-1)(2k+5)}{72} \end{cases} \quad (k=2, 3, \ldots,n) \tag{13}$$

where, x_i is the variable of a time series X (x_1, x_2, …, x_{n-1}). N is the number of the series. R_i is the ranks of the observation x_i. As shown in Equation (11), the test statistic depends on the rank of the observations and no relating with the real values. $E(S_k)$ and $var(S_k)$ are the mean and variance values of S_k, respectively.

In the Mann-Kendall test, $UB_k = UF'_k$, UF'_k is computed by using Equation (10) with the inverse time series (x_n, x_{n-1}, …, x_1). α is the significance level for the test, and $U_{(\alpha/2)}$ is the standard normal deviates. After got the UF_k and UB_k series, in this research, set α=0.05, $U_{\alpha/2}$= ±1.96, plot all the UF_k, UB_k, +1.96 and –1.96 in one coordinate system. If the intersection point located in the limits of the significance level, a significant change point exists, and the series is separate into two segments by the change point. Otherwise, it indicating no change point exists.

3.4 Nash-Sutcliffe Efficiency coefficient

The Nash-Sutcliffe Efficiency (NSE) coefficient[48] is computed as follows:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs}^i - Q_{est}^i)^2}{\sum_{i=1}^{n}(Q_{obs}^i - Q_{ave}^i)^2} \tag{14}$$

where, Q_{obs} is the measured runoff; Q_{est} is the estimated runoff; and Q_{ave} is the mean value of the measured runoff. The NSE can range from –∞ to 1. Values between 0.0 to 1.0 is assumed to indicate satisfactory model performance, the model performance is satisfactory based on previously suggested model evaluation criteria, and values≤0.0 indicates unacceptable performance[49,50].

Table 2 The NSE values distribution based on Moriasi

Temporal scale	Very good	Good	Satisfactory	Not satisfactory
annual	>0.75	0.60≤NSE≤0.75	0.50<NSE<0.60	≤0.50
monthly	>0.85	0.70≤NSE≤0.85	0.55<NSE<0.7	≤0.55
daily	>0.80	0.70≤NSE≤0.80	0.50<NSE<0.7	≤0.50

4 Results and discussion

4.1 Streamflow trend and break point detection

The results of the Mann-Kendall test are shown in Figure 3 based on using observed annual streamflow for the four stations (Linjiacun, Xianyang, Lintong and Huaxian) during the entire study period of 1960 to 2010. The test results exhibited a significant decreasing trend in annual streamflow for all four stations (Figure 3), with a significance level of α=0.05. And the break points for the streamflow at Linjiacun, Xianyang, Lintong and Huaxian were 1990, 1985, 1986 and 1987, respectively. Generally, the results in this study are consistent with previous investigations for the Weihe River basin; i.e., that the break points were detected in the 1990s[11,12].

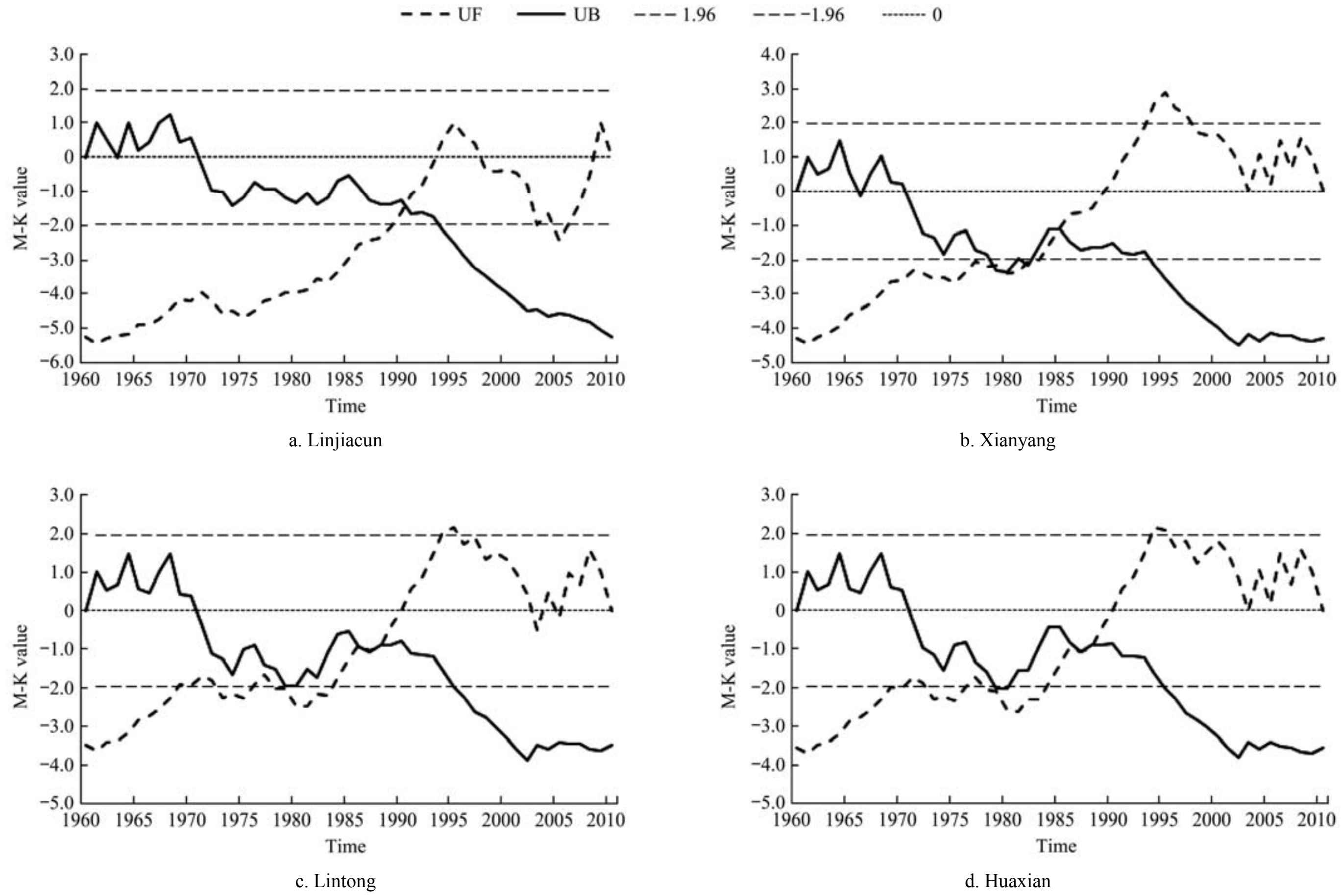


Figure 3 Variation detected by Mann-Kendall test results for mean annual streamflow at four stations across the Weihe River basin

According to the test results, the break points began in 1985 indicating that the pre-change point period occurred during 1960 to 1984. Thus, this period is used as the baseline period for the calibration and validation of the model parameters, and the post-change period after 1985 is used as the runoff changed period.

4.2 Model developed

The one-parameter Budyko-type model was used to estimate streamflow for the Weihe River basin at annual scale. The model has only one parameter (ε) which needs to be calibrated with the optimization objective function, which is defined as the minimization of the sum of squares of the difference between the modelled ($Q_{mod,i}$) and recorded ($Q_{rec,i}$) annual streamflow:

$$\mathrm{OBJ} = \sum_{i=1}^{N} (Q_{rec,i} - Q_{mod,i})^2 \tag{15}$$

where, $Q_{mod,i}$ and $Q_{rec,i}$ are the values of modelled and recorded annual streamflow, respectively, and N is the number of the series.

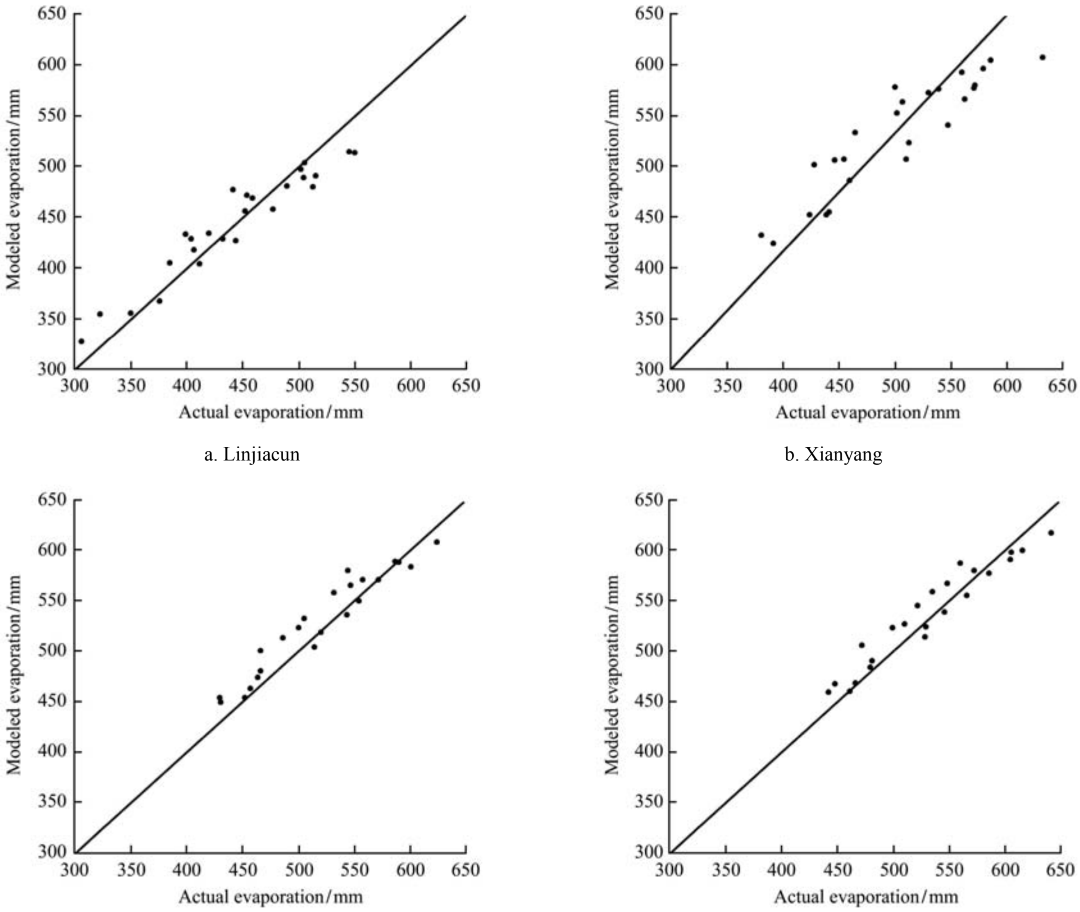
The values of the model parameter (ε) are estimated based on the observed data from 1960 to 1979 to develop a satisfactory model for each of the four stations. A calibration period of 20 years was selected (1960 to 1979), which is 80% of the baseline period and is intended to minimize the uncertainty of limited data during the pre-change period (1960-1984). The remaining five years (1980-1984) were selected as the validation period.

The fitted parameter values for all four Weihe River stations are listed in Table 2. As shown in Table 2, all four estimated values of ε are between 0-1, and thus are acceptable values. The value of ε indicates a strong spatial change, which gradually increase from the minimum value 0.61 at the upstream location (Linjiacun station) to the maximum value of 0.75 at the downstream location controlled by Huaxian station.

Table 2 Parameters of one-parameter Budyko-type models ε over the four stations

Site	Mean runoff/mm	Mean E_p/mm	Mean P /mm	Mean E_p/P	ε
Linjiacun	73.84	780.12	513.22	1.57	0.61
Xianyang	80.68	795.59	579.91	1.42	0.65
Lintong	66.10	822.31	582.30	1.46	0.74
Huaxian	60.67	824.80	589.35	1.45	0.75

Figure 4 shows the comparison between modeled and observed evaporation values for the four stations during 1960 to 1985. The data points are clustered around the 1:1 slope lines for all of the stations, indicating that the modeled evaporation levels were consistent with the measured evaporation values. The R^2 and NSE values are calculated during the validation period 1980-1984, and shown in Table 3. The R^2 values ranged from 0.95 to 0.97, and the NSE values ranged from 0.80 to 0.94. The high R^2 and NSE values indicate strong model performance for all four stations. The application results show that the one-parameter Budyko-type model were acceptable for annual streamflow estimation.



a. Linjiacun b. Xianyang

c. Lintong d. Huaxian

Figure 4 Comparison of estimated and observed values of evaporation at all the four stations

Table 3 The R^2 and Nash-Sutcliffe efficiency coefficient for the one-parameter Budyko-type models based on the validation data from 1980 to 1984 at each station during Weihe River basin

Station	R^2	NSE
Linjiacun	0.97	0.94
Xianyang	0.95	0.80
Lintong	0.96	0.90
Huaxian	0.96	0.89

4.3 Impacts of climate change and direct human activities on streamflow

The decomposing method based on the Budyko Hypothesis[25] is adopted here to quantify the impacts of climate change and direct human activities on decreasing Weihe River streamflow. The computed differences between the modeled streamflow and the pre-change period streamflow indicate that the Weihe River streamflow has been decreasing due to climate change and direct human activities. The impacts of climate change and direct human activities on decreased streamflow during the post-change period are listed in Table 4.

Table 4 Impacts of climate change and human activities based on the variation period point 1985 across Weihe River basin

Site	Period	Observed runoff /mm	Simulated runoff /mm	Total change /mm	Human impact		Climate change	
					mm	%	mm	%
Linjiacun	1960-1984	99.58	98.36					
	1985-2010	49.09	80.85	50.50	31.76	63	18.74	37
Xianyang	1960-1984	102.63	108.35					
	1985-2010	49.32	90.62	53.31	41.29	77	12.02	23
Lintong	1960-1984	78.84	74.23					
	1985-2010	47.89	61.23	30.95	13.33	43	17.61	57
Huaxian	1960-1984	73.47	73.84					
	1985-2010	42.38	60.07	31.09	17.69	57	13.40	43

The impacts of climate change on decreasing streamflow are relatively weak for the Linjiacun, Xianyang and Huaxian stations, as evidenced by overall streamflow contributions of 37%, 23% and 43%, respectively. In contrast, stronger climate change impacts were predicted for the Lintong station with a contribution of 57% (Table 4). Compared with the impacts of climate change, strong impacts of direct human activities on streamflow were estimated for the Linjiacun, Xianyang and Huaxian stations with contributions of 63%, 77% and 57%, respectively, but the direct human activities effects are relatively weak for the Lintong station (contribution of 43%). These results confirm that both components have positive effects and result in decreased Weihe River streamflow, but the impacts of direct human activities are stronger than climate change.

4.4 Discussion

Assessment of direct human activities and climate change on Weihe River streamflow in this study showed that both factors had a significant effect. The streamflow and climate change comparison results between the post-change period (1985-2010) and the pre-change period (1960-1984) for all four Weihe River hydrological stations are summarized in Table 5. From Table 5, annual streamflow in the post-change period obviously decreased, with predicted decreases of 51%, 49%, 36% and 39% at the Linjiacun, Xianyang, Lintong and Huaxian stations, respectively, as compared to pre-change period streamflow. The analysis showed that annual actual evaporation has slightly decreased during the post-change period, with percentage decreases ranging from 1% to 5% (Table 5). Annual precipitation during the post-change period was also estimated to have decreased by about 10% at all four stations (Table 5).

Table 5 Changes of streamflow, actual evaporation and precipitation in post-change period compared with that of values in pre-change period

Station	Streamflow		Actual evaporation		Precipitation	
	Change /mm	Percentage /%	Change /mm	Percentage /%	Change /mm	Percentage /%
Linjiacun	50.50	51	5.61	1	56.14	10
Xianyang	52.59	49	7.66	2	58.19	10
Lintong	29.56	36	25.68	5	58.08	9
Huaxian	29.93	39	26.81	5	58.85	10

Direct human activities, such as hyper-irrigation and water and soil conservation projects, have increased significantly in the Shaanxi Province region. There are now 9 hyper-irrigation areas covering about 5924 km^2, 14 reservoirs, almost 1200 pump stations and channels extending a total length of 3571 m[20] in the province, due to growing population and food production requirements. At the same time, effective precipitation for streamflow generation has declined and other land use changes have occurred, such as terracing of cropland landscapes which results in surface runoff reductions of up to 65% compared to sloping cultivated land[51]. All of these factors result in direct human activities having a greater impact on Weihe River streamflow change as compared to the effects of climate change, during the post-change period.

Huang et al.[31] investigated the attributions to climate change and human activities on streamflow changes in 1970-2008 in Weihe River basin by using Budyko hypothesis and SVM-based model. Huang et al.[31] found that the relative contributions of human activities at Linjiacun and Huaxian Stations are 57.8%, 69.8% and 54.7%, 65.3%, respectively, which is very similar with our findings in these two stations. Based on the sensitivity-based method and dynamic water balance model, Zuo et al.[16] also separated the impacts of climate change and human activities on streamflow change in 1960-2009 in Weihe River, they found that the contributions of human activities on streamflow in Linjiacun, Xianyang, Lintong, and Huaxian stations are 65%, 55%, 33% and 43%, respectively, which are slightly lower than our results. Difference in method, models and time period caused the slight different quantitative inter-comparison with our findings. Nevertheless, the impacts of human activities on streamflow change higher than climate change are consistent with our study.

5 Conclusions

Climate change and direct human activities are the major factors that impact hydrological systems and are known to have impacts on streamflow change. We computed the streamflow for a pre-change period (1960-1984) for the Weihe River in central China using a one-parameter Budyko model with an assumption of no direct human activities. The differences between the modeled streamflow and the pre-change period streamflow showed that Weihe River streamflow has been decreasing due to climate change effects. And the differences between the modeled streamflow and the observed streamflow in post-change period further indicated that the decreasing streamflow trends are also being caused by direct human activities. The main conclusions are shown as follows:

(1) A Mann-Kendall test was used to detect the streamflow break points for all four stations, which were determined to be 1990, 1985, 1986 and 1987 for the Linjiacun, Xianyang, Lintong and Huaxian stations, respectively. The Mann-Kendall test results also showed that the observed annual streamflow has declined significantly during the study period. The high R^2 and NSE statistics confirm that the one-parameter Budyko-type model performed well. In addition, the computed ε parameter values show a strong spatial pattern between the four hydrological stations.

(2) The contribution ratios of climate change impacts on decreasing streamflow were 37%, 23%, 57% and 43% for the Linjiacun, Xianyang, Lintong and Huaxian stations, respectively. In comparison, the contribution ratios of impacts of direct human activities were 63%, 77%, 43% and 57% for the Linjiacun, Xianyang, Lintong and Huaxian stations, respectively. These results reveal that direct human activities have overall greater impacts on the decreasing streamflow trends as compared to climate change.

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