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# Quantitative estimation of the impact of precipitation and human activities on runoff change of the Huangfuchuan River Basin

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**Abstract:** The runoff of some rivers in the world especially in the arid and semi-arid areas has decreased remarkably with global or regional climate change and enhanced human activities. The runoff decrease in the arid and semi-arid areas of northern China has brought severe problems in livelihoods and ecology. To reveal the variation characteristics, trends of runoff and their influencing factors have been important scientific issues for drainage basin management. The objective of this study was to analyze the variation trends of the runoff and quantitatively assess the contributions of precipitation and human activities to the runoff change in the Huangfuchuan River Basin based on the measured data in 1960–2008. Two inflection points (turning years) of 1979 and 1998 for the accumulative runoff change, and one inflection point of 1979 for the accumulative precipitation change were identified using the methods of accumulative anomaly analysis. The linear relationships between year and accumulative runoff in 1960–1979, 1980–1997 and 1998–2008 and between year and accumulative precipitation in 1960–1979 and 1980–2008 were fitted. A new method of slope change ratio of accumulative quantity (SCRAQ) was put forward and used in this study to calculate the contributions of different factors to the runoff change. Taking 1960–1979 as the base period, the contribution rate of the precipitation and human activities to the decreased runoff was 36.43% and 63.57% in 1980–1997, and 16.81% and 83.19% in 1998–2008, respectively. The results will play an important role in the drainage basin management. Moreover, the new method of SCRAQ can be applied in the quantitative evaluation of runoff change and impacts by different factors in the river basin of arid and semi-arid areas.

**Keywords: runoff; precipitation; variation trend; human activities; contribution rate; Huangfuchuan River Basin**

## 1 Introduction

The runoff of some rivers in the world especially in the arid and semi-arid areas has decreased remarkably with global or regional climate change as well as intensified human activities in the last decades. The runoff decrease in the arid and semi-arid areas of northern

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China has brought severe problems in livelihoods and ecology. It has been an important scientific issue in hydrology to reveal the characteristics and trends of runoff change and their influencing factors. The study focusing this aspect will be helpful in drainage basin management.

Much research has been done on the runoff variations of different river basins across the world in the past few years. According to the period of time, six aspects of studies on runoff changes can be divided: 1) Daily change of runoff, such as, the study on the daily runoff change of the 48 river drainage basins in Switzerland which were not disturbed by human activities (Marius-Victor *et al*., 2005); 2) Monthly change, as Kahya and Kalayc (2004) studied the changing trend of the 26 river drainage basins in Turkey; 3) Seasonal change, for example, Omar *et al*. (2006) analyzed the winterly and estival runoff change of the Mackenzie River; 4) Yearly change, for instance, the annual change of the Yangtze River flow (Zhang *et al*., 2006; Jiang *et al*., 2007) and of the lower Yellow River discharge (Wang and Li, 2011); 5) Decadal change, it is reported many researches were focusing on runoff change in different decades for different rivers; 6) Stepwise analysis of runoff change for a long time series, for example, the runoff stepwise analysis of the Yellow River reported by Wang *et al*. (2009). According to climate characteristics, four aspects of studies on runoff changes can be identified: 1) Upland cold region, for instance, natural runoff stage analysis controlled by the least duration of each stage of the Buha and Shaliu rivers (Li *et al*., 2010); 2) Arid region, e.g., analysis of runoff variation trend of the Tarim River (Tang, 1992); 3) Semi-arid region: a series of studies focused on the runoff change in this region were reported (e.g., Jing and Zheng, 2004; Liu and Zhang, 2004; Xu, 2004; Yang *et al*., 2005; Zhang *et al*., 2009; Wang *et al*., 2012); 4) Humid region, for example, the studies on the runoff change of the Pearl River (Zhujiang) in southern China (Chen and Chen, 2002; Wang *et al*., 2004). According to methods, those studies could be divided into four types: 1) Time sequencing analysis; 2) Moving average analysis in different step lengths; 3) Inflexion analysis, such as accumulative anomaly, Mann-Kendall rank analysis method, and so on; 4) Factor analysis, e.g., Xu (2011) studied variation in annual runoff of the Wuding River and its quantitative influences of climate change and human activity by multivariate statistical methods. However, it is often difficult to ascertain the quantitative contributions of natural factors and human activities to runoff changes. Although using multivariate statistical methods some studies reported have obtained contribution rate of natural and non-natural factors to runoff change in certain river basins, some results may not be authentic because weight of each factor is subjective.

The present study focuses on the runoff variation characteristics and trend of the Huangfuchuan River Basin during the period 1960–2008. The turning year in the runoff change or precipitation variation was obtained by accumulative anomaly of runoff or precipitation, respectively. This method of accumulative anomaly is effective in comparison with double-accumulative curve of runoff and precipitation. Each fitted linear relationship between year and accumulative quantity in different periods divided by the turning year has a very high correlation coefficient. In this study a method in terms of slope change ratio of accumulative quantity (SCRAQ) was put forward which could be used to estimate the contributions of precipitation, evapotranspiration and human activities to runoff change. This method could be applied in the study on runoff changes in arid and semi-arid river basins and the results could be used as a reference in Huangfuchuan River Basin management.

## 2 Regional setting

As a first-order tributary of the middle Yellow River, the Huangfuchuan River originates from the eastern part of the Ordos Plateau, flows through the transitional zone of the Loess Plateau and hungriness grassland, and empties into the main stream of the Yellow River in Fugu County of Shaanxi Province (Figure 1). The Huangfuchuan River Basin covers an area of 3246 km$^2$ with a relief of 649 m (Han *et al*., 2002). It is mainly composed of Nalin and Changchuan tributaries. The maximum and minimum elevations in the basin are 1482 m and 833 m, respectively, and the main stream is 137 km long. The Huangfuchuan station located at the river outlet was established in 1954 (Figure 1). The basin area above the station is 3175 km$^2$. The Huangfuchuan River Basin is located in the transitional belt of warm temperate and mesothermal zones, belonging to southeast monsoon influencing range, and characterized by semi-arid continental climate.

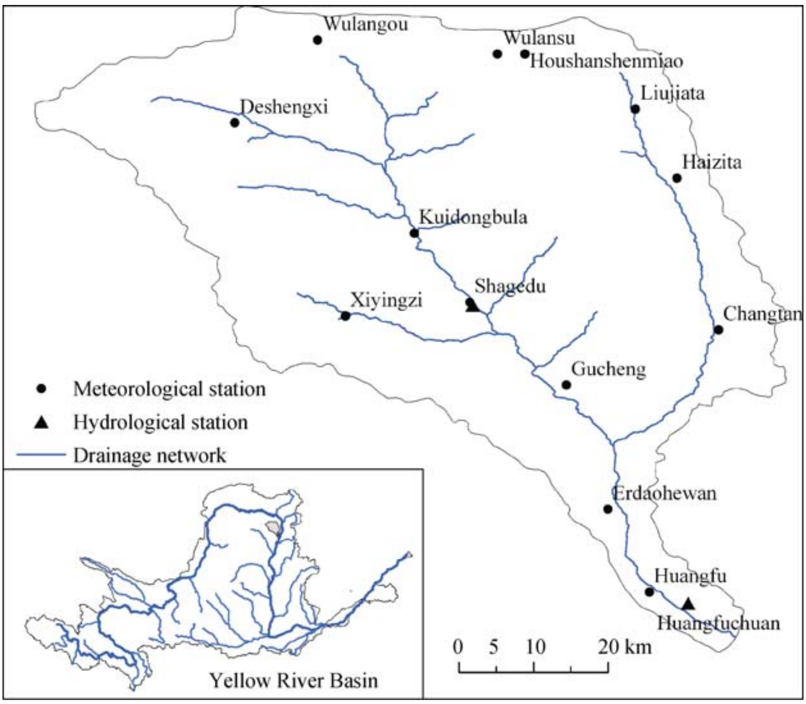


**Figure 1** The locations of the Huangfuchuan River Basin and the meteorological and hydrological stations

The soil matrix in the river basin is mainly weathering sandstone, loess and desert sand. The land surface material is sand and silty loess with coarser particles. According to soil erosion type the basin can be divided into three subregions: 1) loess hilly-gully region, located in the eastern and southwestern parts of the river basin with an area of 918.3 km$^2$, gully density of 5–9 km/km$^2$, and a vegetation coverage about 20%; 2) sandy loess hilly-gully region, located between Nalin and Changchuan tributaries and southern edge of the Hobq Desert with an area of 546.1 km$^2$, gully density of 4.2 km/km$^2$, and a vegetation coverage about 15%; 3) sandstone weathering hilly-gully region, located in the northwestern part of the river basin with an area of 1781.6 km$^2$, gully density of 7.42 km/km$^2$, and a very low vegetation coverage. Here the bedrock is widely exposed (Han *et al.*, 2002).

# 3 Data sources and methodology

The Huangfuchuan gauging station established in 1956 was selected to examine the annual runoff variations of the Huangfuchuan River Basin in the period 1960–2008. The hydrological data at the station used in this study were collected from *Annual Report on Yellow River Water and Sediment* (YRCC, 1956–1989) during the period 1960–1989, from the reference reported by Han *et al*. (2002) in the period 1990–1997. The runoff data after 1997 were provided by the Ministry of Water Resources of the People's Republic of China (MWR) (1998–2008). There are 13 meteorological stations in the river basin at present. The annual precipitation data during the period 1960–2008 for the Huangfu station established in 1953 were collected inextenso and were provided by China Meteorological Administration (http://www.cma.gov.cn/english/). The meteorological stations in the river basin increased from 7 in 1966 to 13 in 1977 (Figure 1). The annual precipitation data of these stations in the period 1966–1989 were collected from the *Annual Report on Yellow River Water and Sediment* (YRCC, 1956–1989) but were not available after 1989.

The mean annual precipitation data for the river basin in the period 1966–1989 were interpolated by the Kriging method using ArcGIS with annual precipitation data of the meteorological stations in the river basin together with those from the neighbouring stations outside it. The annual mean precipitation data before 1966 could not be obtained by this method because of sparse meteorological stations. Accordingly, it needs to fit a relationship between the annual precipitation ($x$, mm/a) at the Huangfu station and the mean annual precipitation ($y$, mm/a) for the river basin in the period 1966–1989. The best relation is expressed below:

$$y = 120.52 + 0.64x \tag{1}$$

This regression has a much higher correlation coefficient ($R$) of 0.92 and significant level ($P$) of <0.0001. Then the annual precipitation data for the river basin during the periods of 1960–1965 and 1990–2008 could be calculated by formula (1) via replacing $x$ by the annual precipitation data at the Huangfu station in the corresponding periods. Thus we obtained the full series of mean annual precipitation data for the river basin during the period 1960–2008.

The methods used in this study is mainly the accumulative anomaly (Ran *et al*., 2010) which was used to reveal the turning year in the changes of runoff or precipitation. Another important method in terms of slope change ratio of accumulative quantity (SCRAQ) was put forward in this study and can be used to calculate quantificationally the contributions of precipitation to and other influences on the runoff change.

The accumulative anomaly is an index to distinguish the changing tendency of discrete data. For a discrete series $x_i$, the accumulative anomaly ($X_t$) for data point $x_t$ can be expressed as:

$$\hat{X}_t = \sum_{i=1}^{t}(x_i - \bar{x}), \quad t = 1, 2, \ldots, n, \qquad \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{2}$$

where $\bar{x}$ is the mean value of the series $x_i$, and $n$ is the number of discrete points. As the equation suggests, the accumulative anomaly can be used to analyze the fluctuation magnitude of a series of discrete data. Specifically, a positive accumulative anomaly indicates that the corresponding data point is higher than the average, otherwise lower than the average (Ran *et al*., 2010). If the relation curve is composed at least of the two parts mentioned above, then the turning year could be identified. In this study, the variable $x$ represents annual runoff, or mean annual precipitation. The detailed intro of the SCRAQ will be in next section.

The main natural factors influencing runoff change are precipitation and temperature. The precipitation variation influences the runoff change directly, while the temperature variation can influence evaporation firstly, and then lead to runoff change indirectly. As reported by Xu (2011), there is no evident relation between annual mean temperature and annual runoff in the drainage basins on the Loess Plateau at least during the last 50 years. Therefore, it is without regard to the temperature change in the multiple factor regression analysis of runoff changes in the study area. Hereby, in this study we took the precipitation as the climatic factor, while human activities were regarded as the non-natural factors. Human activities include water diversion, construction of reservoirs and check dams, water and soil conservation. It is difficult to calculate the contributions of each measure to the runoff change in the river basin, because the annual data of each measurement can not be collected completely. Accordingly, we only calculate the compound influence of all kinds of human activities on the runoff change.

# 4 Results

## 4.1 Variations of the annual runoff and precipitation

The annual runoff variation and the 5-point moving average runoff of the Huangfuchuan River Basin are illustrated in Figures 2a and 2b, respectively. The larger fluctuations appear in the 1960s and 1970s and have no clear changing trends. But since the late 1990s they have a remarkable decreasing trend.

The annual variation of precipitation at the Huangfuchuan station is illustrated in Figure 3a. The fluctuation is more remarkable in the 1960s, but insignicant generally hereafter than that later on. The 5-point moving average precipitation (Figure 3b) shows that the value

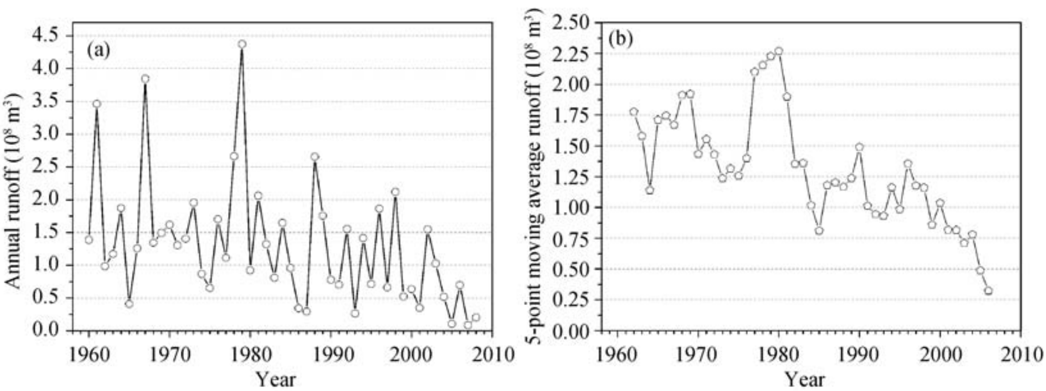


**Figure 2** Runoff variation of the Huangfuchuan River Basin during 1960–2008 for annual runoff (a), and 5-point moving average runoff (b)

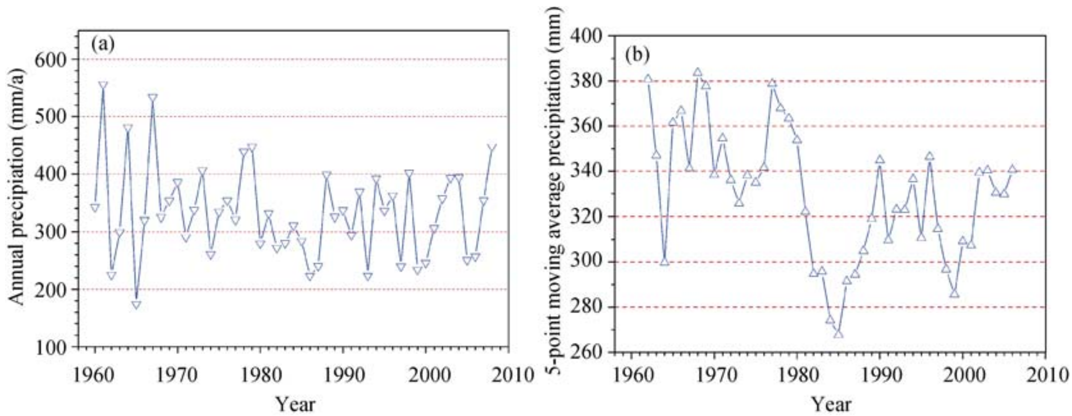


**Figure 3** Precipitation variation of the Huangfuchuan River Basin during 1960–2008 for annual precipitation (a), and 5-point moving average precipitation (b)

of precipitation has been smaller since around 1980 than that previously.

## 4.2 The inflexion points of the runoff and precipitation change

### 4.2.1 The limitations of the double-accumulative curve method

In recent years the double-accumulative curve of the runoff or precipitation has been widely used in the studies on hydrology, water resources and fluvial geomorphology. But up to the present few of researchers has reported the limitations of these curves in estimation of inflexion point for runoff or precipitation. Figure 4 shows the double-accumulative curve of the runoff and precipitation in the Huangfuchuan River Basin and the two inflexion points obtained according to the curve. Though the inflexion points are distinct and the relationships between the accumulative precipitation and runoff in different intervals separated by the points are significant, to a great extent these points did not reflect the real inflexion points for both runoff and precipitation. For instance, suppose the runoff in a river basin was only influenced by precipitation, if the runoff and precipitation increased or decreased

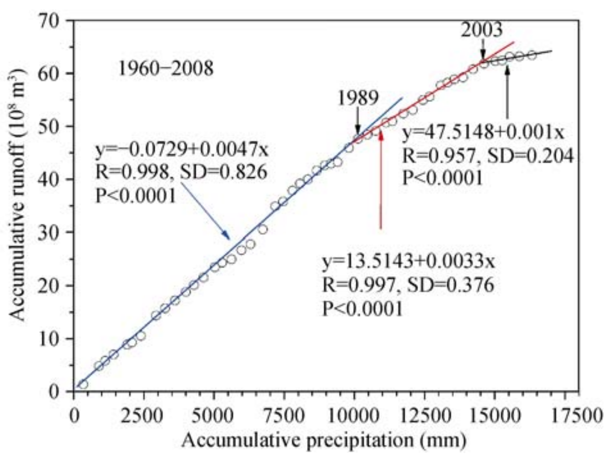


**Figure 4** Variation trend of the double-accumulative curve of precipitation and runoff and inflexion points of the Huangfuchuan River Basin

synchronously by the same proportion, we couldn't get the inflexion points using the double-accumulative curve, while the truth is there should have. It is obvious that use this method of the double-accumulative curve to determine the inflexion points in changes of precipitation and runoff has a serious limitation. Otherwise, in determining the inflexion points with this method, subjective could not be avoided because of visual partition. So, the inflexion points in Figure 4 could not always reflect the real changing trend for both runoff and precipitation in the study river basin. The more effective method should be used.

#### 4.2.2 The inflexion points based on accumulative anomaly method

The accumulative anomaly of annual runoff of the Huangfuchuan River Basin in 1960–2008 calculated by formula (2) is illustrated in Figure 5a. It is shown that there is an increasing trend prior to 1979, and a decreasing trend after 1979. The inflexion point of the runoff change in this time period is 1979. For the period 1979–2008, the accumulative anomaly of annual runoff (Figure 5b) also shows an increasing and a decreasing trend respectively before and after 1998. The inflexion point in this period is 1998.

The accumulative anomaly of annual precipitation of the Huangfuchuan River Basin in 1960–2008 calculated based on formula (2) is illustrated in Figure 6a. It is shown an increasing trend prior to 1979, and a decreasing trend after 1979. The inflexion point is 1979

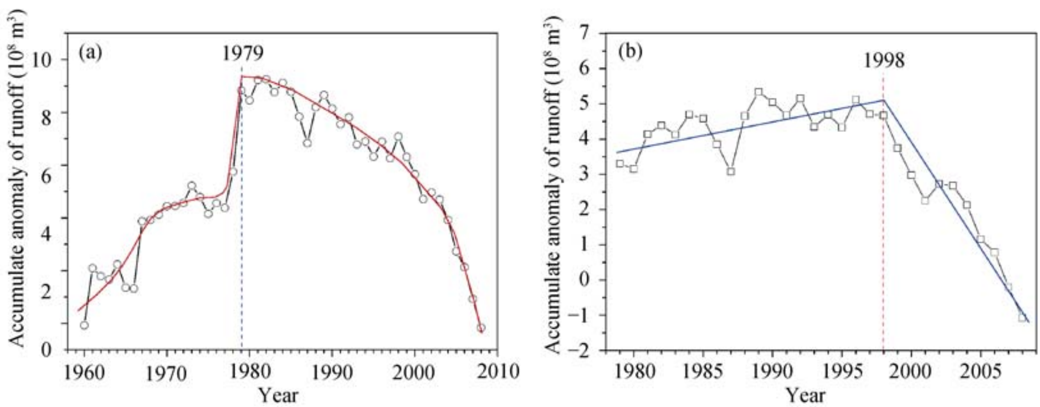


**Figure 5** Variations of the accumulative runoff anomaly of the Huangfuchuan River Basin in 1960–2008 (a), and 1979–2008 (b)

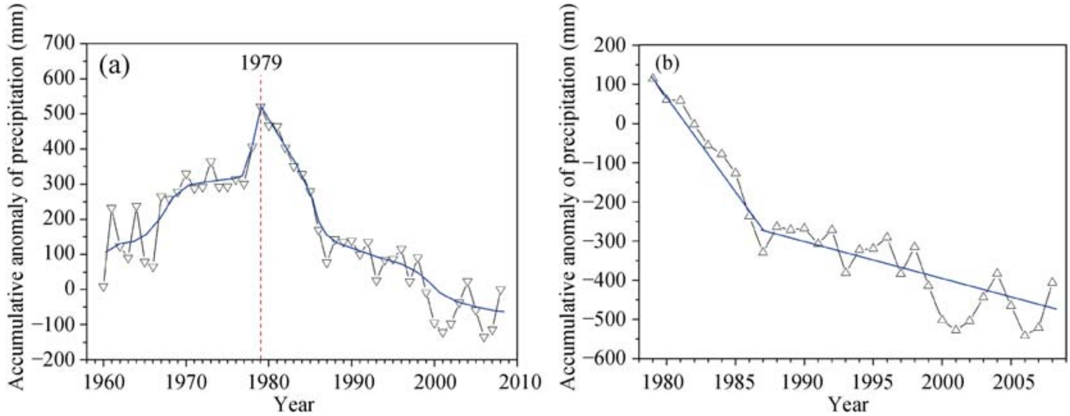


**Figure 6** Variations of the accumulative precipitation anomaly of the Huangfuchuan River Basin in 1960–2008 (a), and 1979–2008 (b)

which is the same as that of the runoff in this period. But the accumulative anomaly of annual precipitation in 1979–2008 (Figure 6b) shows a decreasing trend as a whole. It is not same to the changing trend of the runoff in 1979–2008.

There are two inflexion points, 1979 and 1998, for the runoff change, and only one point, 1979, for the precipitation variation in 1960–2008. In the Huangfuchuan River Basin the runoff change before 1979 had been mainly influenced by the precipitation change, because human activities had been weak in this time period. Since 1979, except the influence of precipitation on runoff change, human activities have gradually intensified and have influenced on the runoff change to a certain extent. In order to calculate the contribution of precipitation and human activities to the runoff change, we took the period 1960–1979 as the base period, and took the periods of 1979–1998 and 1998–2008 as two different measurement periods.

### 4.3 Relationships between year and runoff, and between year and precipitation during the three periods

The two inflexion points (1979 and 1998) of the runoff change in the Huangfuchuan River Basin could divide its runoff change into three periods, 1960–1979 ($A_R$), 1980–1997 ($B_R$) and 1998–2008 ($C_R$). The fitted linear relationships between year and accumulative runoff during the three periods are shown in Figure 7a and by formulas (3)–(5), in which, $x$ is year and y is accumulative runoff ($10^8$ $m^3$), the subscript expresses time period.

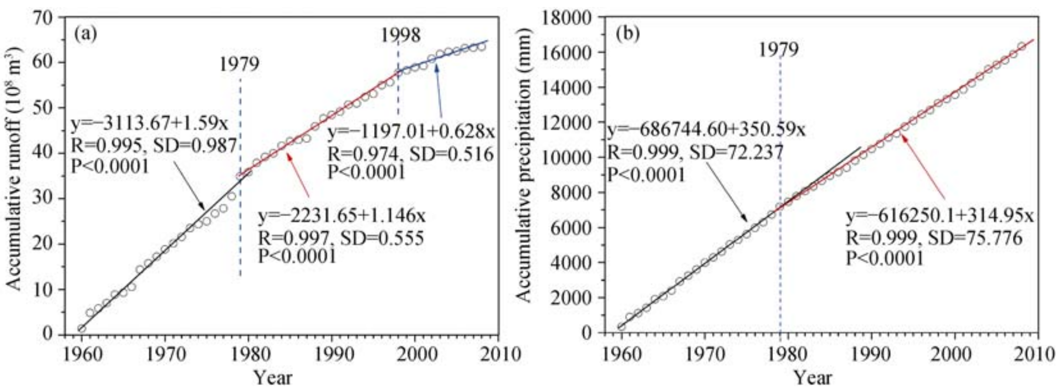


**Figure 7** The relationships between year and accumulative runoff (a), and between year and accumulative precipitation (b) of the Huangfuchuan River Basin

$$Y_{A_R} = -3113.67 + 1.59 x_{A_R} \tag{3}$$

where $R$=0.995, $SD$=0.987, $P$<0.0001.

$$Y_{B_R} = -2231.65 + 1.146 x_{B_R} \tag{4}$$

where $R$=0.997, $SD$=0.555, $P$<0.0001.

$$Y_{C_R} = -1197.01 + 0.628 x_{C_R} \tag{5}$$

where $R$=0.974, $SD$=0.516, $P$<0.0001.

The whole time period is divided into two different periods by the inflexion point (1979) of the precipitation change in the Huangfuchuan River Basin as: 1960–1979 (Ap) and 1980–2008 (Bp). The fitted linear relationships between year and accumulative precipitation during the two periods are shown in Figure 7b and formulas (6) and (7), in which, $x$ is year and $Y$ is accumulative precipitation (mm), the subscript expresses time period.

$$Y_{Ap} = -686744.60 + 350.59 x_{Ap} \tag{6}$$

where $R$=0.999, $SD$=72.237, $P$<0.0001.

$$Y_{Bp} = -616250.1 + 314.95 x_{Ap} \tag{7}$$

where $R$=0.999, $SD$=75.776, $P$<0.0001.

Four of the correlation coefficients exceed 0.99 and only one is 0.974. All the $P$ values are < 0.0001.

### 4.4 Contribution rate of the human activities and precipitation to the runoff change

To analyze quantificationally the influence of climate and human activities on runoff change, the multiple regression method is used widely. In many situations, the results got by the method might be different by different researches, because the weight of each factor has a different value. To calculate more accurately the contributions of the precipitation and human activities to runoff change, a new method in terms of SCRAQ is put forward.

On the assumption that the slope of the linear relation between year and accumulative runoff before and after a inflexion point is $S_{Rb}$ and $S_{Ra}$ (both units are $10^8 m^3/a$), respectively, and the slope of the linear relation between year and accumulative precipitation before and after the inflexion point is $S_{Pb}$ and $S_{Pa}$ (both unit is mm/a), the slope change rate of the accumulative runoff ($R_{SR}$, unit is %) can be expressed as below:

$$R_{SR} = 100 \times (S_{Ra} - S_{Rb})/S_{Rb} = 100 \times (S_{Ra}/S_{Rb} - 1) \tag{8}$$

The slope change rate of the accumulative precipitation ($R_{SP}$, unit is %) can be expressed as below:

$$R_{SP} = 100 \times (S_{Pa} - S_{Pb})/S_{Pb} = 100 \times (S_{Pa}/S_{Pb} - 1) \tag{9}$$

When $R_{SR}$ or $R_{SP}$ is positive, the slope is increase, and when they are negative, the slope is decrease. Well then, the contribution rate ($C_P$, unit: %) of precipitation to runoff change can be expressed as below:

$$C_P = 100 \times R_{SP}/R_{SR} = 100 \times (S_{Pa}/S_{Pb} - 1)/(S_{Ra}/S_{Rb} - 1) \tag{10}$$

As the variation of mean annual air temperature leads to the evapotranspiration change and finally influences on the runoff change, the contribution of the evapotranspiration must be calculated. On condition that the slope change ratio of the linear relation between year and accumulative evapotranspiration in a river basin is $C_{ET}$ (unit: %), then the contribution of human activities ($C_H$, %) to the runoff change can be expressed as below:

$$C_H = 100 - C_P - C_{ET} \tag{11}$$

Briefly, the three periods, 1960–1979, 1980–1997 and 1998–2008, intersected by the two inflexion points in the accumulative runoff curve (1979 and 1998) are expressed as $A_R$, $B_R$ and $C_R$, respectively, where $A_R$ is regarded as a base period because of limited impact of human activities.

In comparison of the time period $B_R$ with $A_R$, the slope of the linear relation of the accumulative runoff decreased by $0.444 \times 10^8$ m$^3$/a, at a rate of 27.92% (Table 1). Synchronously, the slope of the linear relation of the accumulative precipitation decreased by 35.64 mm/a, the decrease rate was 10.17% (Table 2). Compared the measure period of $B_R$ with the base period of $A_R$, the slope change rates for both accumulative runoff and precipitation could be

**Table 1** The slopes of the linear relation between year and accumulative runoff and their change rates of the Huangfuchuan River Basin

| Time period | The slope of the relation between year and accumulative runoff ($10^8$ $m^3$/a) | Comparison of the slope with that in $A_R$ | | Comparison of the slope with that in $B_R$ | |
|---|---|---|---|---|---|
| | | Change quantity ($10^8$ $m^3$/a) | Change rate (%) | Change quantity ($10^8 m^3$/a) | Change rate (%) |
| $A_R$: 1960–1979 | 1.590 | – | – | – | – |
| $B_R$: 1980–1997 | 1.146 | –0.444 | –27.92 | – | – |
| $C_R$: 1998–2008 | 0.628 | –0.962 | –60.50 | –0.518 | –45.20 |

**Table 2** The slopes of the linear relation between year and accumulative precipitation and their change rates of the Huangfuchuan River Basin

| Time period | The slope of the relation between year and accumulative precipitation (mm/a) | Comparison of the slope with that in $A_R$ | | Comparison of the slope with that in $B_R$ | |
|---|---|---|---|---|---|
| | | Change quantity (mm/a) | Change rate (%) | Change quantity (mm/a) | Change rate (%) |
| $A_R$: 1960–1979 | 350.59 | – | – | – | – |
| $B_R$: 1980–1997 | 314.95 | –35.64 | –10.17 | – | – |
| $C_R$: 1998–2008 | 314.95 | –35.64 | –10.17 | 0 | 0 |

equal for both $B_R$ and $A_R$ if the precipitation is only the influencing factor on the runoff change. Thus, the calculated $C_P$ according to formula (10) could be 100%. Actually, the calculated $C_P$ using formula (10) is 36.43%, while $C_H$ using formula (11) is 63.57%. That means the contribution of the decreased precipitation and the intensified human activities to the decreased runoff is 36.43% and 63.57% in the time period $B_R$, respectively.

In comparison of the time period $C_R$ with $A_R$, the slope of the linear relation of the accumulative runoff decreased by $0.962\times10^8$ $m^3$/a, the decrease rate was 60.5% (Table 1). Synchronously, the decrease rate of the slope for the linear relation of the accumulative precipitation was still 10.17% (Table 2). So, the calculated $C_P$ is 16.81%, while $C_H$ is 83.19%, using formulas (10) and (11), respectively. Namely, the contribution of the decreased precipitation and the intensified human activities to the decreased runoff is 19.3% and 80.7% in the time period $C_R$ compared with $A_R$, respectively.

In comparison of the time period $C_R$ with $B_R$, the slope of the linear relation of the accumulative runoff decreased by $0.518\times10^8$ $m^3$/a, the decrease ratio was 45.2% (Table 1), while the slope for the linear relation of the accumulative precipitation was still the same (Table 2). So, the calculated $C_P$ is 0, while $C_H$ is 100%, using formulas (10) and (11), respectively. Namely, the contribution of precipitation and human activities to the runoff change is 0 and 100% in the time period $C_R$ compared with $B_R$, respectively.

# 5 Discussion

The turning year of runoff change for some tributaries in the Loess Plateau was reported by predecessors. We will compare the study results of some references with that of this study to discuss the spatial differences of runoff change among different tributaries in the plateau. The applied prospect of SCRAQ method will be also discussed in this section.

### 5.1 The significance of the two turning years in the runoff change

Based on the comparison of decadal runoff change in the Huangfuchuan River Basin, Han *et al*. (2002) concluded that the mean annual runoff was $1.2678\times10^8$ $m^3$/a in the 1980s, which decreased by $0.4903\times10^8$ $m^3$/a compared with that of the 1970s. The contributions of the precipitation and other factors to the runoff change were 51.6% and 48.4%, respectively. It was $0.9806\times10^8$ $m^3$/a in the 1990s which decreased by $0.7778\times10^8$ $m^3$/a compared with that of the 1970s. The contributions of precipitation and other factors were 40.7% and 59.3%, respectively. It is shown that the influence of precipitation on the runoff change has a decreasing trend, contrarily, the contributions of other factors have an increasing trend. The contribution rate of precipitation may not be correct because of the absence of accurate turning years and the shorter series of data. In our study, the series of runoff and precipitation data is in a longer period of 1960–2008, and the two turning years, 1979 and 1998, are detected. Results of the runoff change and contributions of different influencing factors in different periods divided by the turning years would be more accurate.

The turning years of runoff change of the right-bank tributaries of the Hekouzhen-Longmen reach of the Yellow River are different for different tributaries. The result reported by Xu (2011) showed that the turning year of runoff change for the Wuding River was 1971 in the period 1956–1996. The contributions of precipitation and human activities to the runoff change in the period 1972–1996 were 50.8% and 49.2%, respectively. The turning year of runoff change of the Kuyehe River during the period 1954–1993 was 1973 (Zhao *et al*., 2010). As mentioned above, there were two turning years, 1979 and 1998, in the runoff change of the Huangfuchuan River Basin during the period 1960–2008. Obviously, the turning year in runoff change showed a delayed tendency from south to north in the right-bank tributaries of the middle Yellow River. The phenomenon might be caused by different intensities of human activities, i.e., the different densities of population and different beginning years of water and soil conservation.

Why there is only one turning year in runoff change of Wuding and Kuye tributaries? The end year data for the Huangfuchuan River Basin is 2008 while for Wuding and Kuye tributaries, the end year of data is 1996. If the data could be extended to 2008 for the Wuding and Kuye tributaries, the second turning year in runoff change for the two tributaries could be detected. However, the two turning years in the runoff change of the Huangfuchuan River Basin indicate that the influencing intensity of precipitation on runoff change is decreasing, while that of the human activities is increasing.

### 5.2 The theoretical basis and application prospect of SCRAQ method

Multiple regression method was used to calculate the contributions of natural factors and human activities previously. There is an evident difference among the results obtained by different researchers using this method because the weight values of each factor in the method have certain subjectivity. On the other hand, the results are generally imprecise, because the multiple correlation coefficients for each factor in the method are generally low. In the method of SCRAQ, the independent variable is year which is objective, and the dependent variable is accumulative runoff or accumulative precipitation which could eliminate the effect of fluctuations of annual data. Consequently, the linear relationships between year and accumulative quantity usually have higher correlation coefficients which provide the condition for quantitative analysis using the SCRAQ method. The presupposition of the SCRAQ method is that, supposing the runoff change in a river basin in a time period is only influenced by the precipitation, then the slope change ratio of the linear relationship between year and the accumulative runoff is equal to that between year and the accumulative precipitation, thus, the contribution of precipitation to the runoff change is 100%; if the slope of the linear relationship between year and the accumulative runoff changes but the slope between year and the accumulative precipitation is constant, the contribution of precipitation to the runoff change is 0. The contribution of precipitation to the runoff change is always equal to the rate of the slope of linear relationship of the accumulative precipitation divided by the slope of linear relationship between year and the accumulative runoff if regardless other factors.

After we calculate the contribution of precipitation to runoff change using the SCRAQ method, the contributions of other factors could be analyzed further. If temperature changes have influenced on evapotranspiration change in a river basin, we could use the formula proposed by Zhang *et al*. (2001) to calculate the annual evapotranspiration, and could further obtain the contribution of accumulative evapotranspiration to runoff change using the SCRAQ method. Finally, the contribution of human activities to runoff change is the difference from 1 minus the sum of contributions of precipitation and evapotranspiration. An inference is that the contributions of each single activity of human could be calculated using this method if the annual data for the single activity can be obtained. The method could be applied in quantitative evaluation of the runoff change and impacts by different factors in arid to semi-arid river basins.

# 6 Conclusions

(1) There are two turning years, 1979 and 1998, in the runoff change and one turning year of 1979 in the precipitation change of the Huangfuchuan River Basin during the period 1960–2008. The correlation coefficients of the linear relationships between year and accumulative runoff in the three different periods (1960–1979, 1980–1997 and 1998–2008) are 0.995, 0.997 and 0.974 while both they are 0.999 for the linear relationships between year and accumulative precipitation in the periods of 1960–1979 and 1980–2008.

(2) To calculate more accurately the contributions of the precipitation and human activities, a new method, SCRAQ, was put forward and used in this study. Taking the period 1960–1979 as a base period (the influence of human activities is gentle and neglectful), the contribution rates of precipitation and human activities to the runoff change in the Huangfuchuan River Basin are 36.43% and 63.57% during the period 1980–1997, and 16.81% and 83.19% during the period 1998–2008, respectively (the evapotranspiration change is small and neglectful).

(3) The present study revealed the runoff changing trend and the contributions of main factors in the runoff change of the Huangfuchuan River Basin. The results could be used in the water resources management in the river basin. Moreover, the SCRAQ method could be applied in quantitative evaluation of the runoff change and impacts by different factors in arid and semi-arid river basins.

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