Impact of Climate Change and Human Activity on the runoff in the Upper Reaches of the Shiyang River, Northwest China

Peng Li, Jianhua Xu, Zhongsheng Chen, Benfu Zhao

Based on the hydrological and meteorological data of the upper reaches of Shiyang River basin in Northwest China from 1960 to 2009, this paper analyzed the change in runoff and its related climatic factors, and estimated the contribution of climate change and human activity to runoff change by using the moving T test, cumulative analysis of anomalies and multiple regression analysis. The results showed that temperature revealed a significant increasing trend, and potential evaporation capacity decreased significantly, while precipitation increased insignificantly in the past recent 50 years. Although there were three mutations in 1975, 1990 and 2002 respectively, runoff presented a slight decreasing trend in the whole period. The contributions of climate change and human activity to runoff change during the period of 1976-2009 were 45% and 55% respectively.

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1. Introduction

Global air temperature has risen by 0.74℃ in the last 100 years, increasing water circulation ,spatial-temporal reallocation of water resources, flood and drought hazards(National Climate Centre, 2007), Global warming is bound to cause changes in evaporation and precipitation, which affects the change of catchment hydrology(Ma et al., 2003). Study of impacts of climate change or climate variability on hydrological processes and water resources has been an important area of research in hydrology (Chen et al.,2012;Mo et al.,2007;Shen et al.,2007).In addition to climate change, increasingly enhancement of human activities such as irrigation, cultivation, deforestation, afforestation and urban construction has also introduced changes to flow regime, and with the advancement of science and technology, the intervention of human activity in the hydrological cycle is becoming more intensive (Dong et al.,2012). With global climate change and the human water resources development and utilization in large scale, the variation of surface or sub-surface runoff is changing. Not climate change in general sense, but the combined effects of climate change and human activity affect runoff variation. Therefore, it has grown up to be a new scientific issue to explore the impact of the natural variations and human activity on the evolution of water resources.

In the arid region of Northwest China, continental runoff is mainly from precipitation, ice and snow melting water, in which hydrological systems are more vulnerable. The studies have proved effects of climate change and human activity on the runoff are significantly sensitive in the arid region of Northwest China, and these effects have resulted in severe environmental degradation and water crises (He, Zhang&Sun, 2012; Luan et al., 2007; Hou et al., 2007).The arid area of Northwest China has become one of the regions which respond most strongly to climate change and human activity. Shiyang River Basin is a typical inland river basin. Its surface runoff is primarily recharged by precipitation, along with ice and snow melting water, which is the lifeline of Shiyang River Basin Oasis. In the last 50 years, the surface runoff out of the mountains has reduced (Wang, 2007). Shortage of water resources not only influences the development of national economy, but also results in a series of serious ecological and environmental problems (Bakalowicz, 2005). Thus, exploring the driving factors of water

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resources change in the Shiyang River Basin has become an important research subject.

In recent years, understanding the influence and relative importance of climate change and human activity on hydrology and water resources has drawn considerable concerns (Xu&Ai, 1989a; Xu&Ai, 1989b; Xu&Ai, 1990; Wang, 2011a; Xu, 2007; Zhang,2012;Chen, 2009; Xu, 1995).Many studies on runoff trends and their attribution have appeared. However, many of these studies remain in the analysis of the runoff and the qualitative analysis of effect of climate change and human activity (Guo&Wang, 2009; Ding&Ma, 2007;Sun et al., 2010),the relative contribution of climate change and human activity to runoff in the Shiyang River has not been well investigated. Based on this, we selected the upper reaches of Shiyang River Basin as a study area, and analyzed the climate and hydrological change trend of the basin. Meanwhile, the change points of annual runoff were also dectected, and then the time series runoff data were divided into two study periods-"natural baseline period" and "changing period" (Wang, 2006).By establishing the linear regression model in natural baseline period, the effects of climate change and human activity on streamflow can be estimated in the changing period. The aim is to provide a scientific basis for the establishment of water management policy. At the same time, it is also expected to provide a reference for the related research in the arid region of northwest China.

2. Study area and data

2.1 Study area

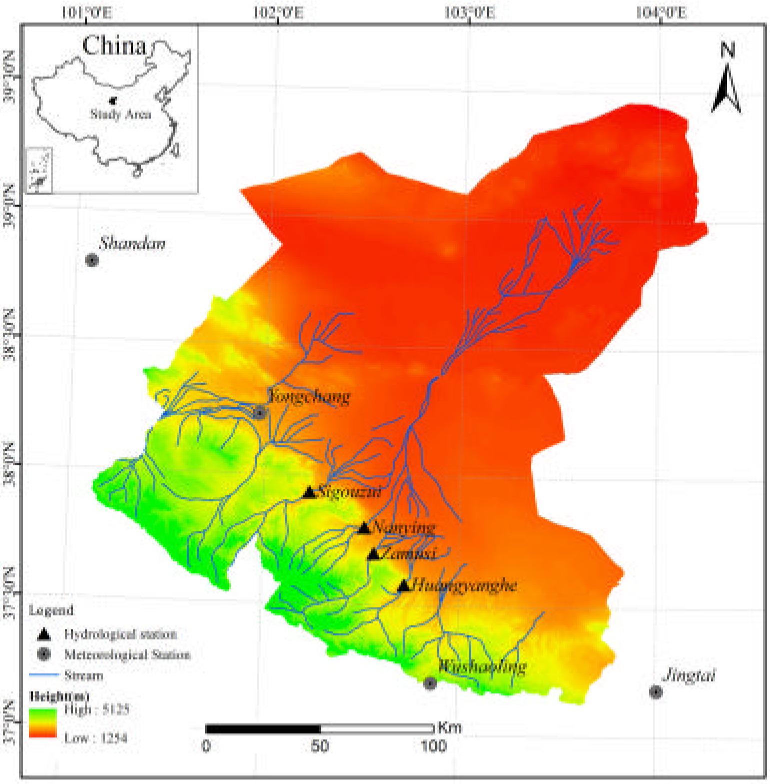

Fig.1 Shiyang River Basin

The Shiyang River basin, one of three continental rivers in the Hexi corridor, is located in the

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eastern portion of the corridor in Gansu province of northwest China. The basin encompasses an area of $4.16 \times 10^4 km^2$ with a population of 2.27 million and covers the area between 101°41'—104°16'E and 36°29'—39°27'N(**Fig.1**). The basin is situated in the inland with dry climate, scarce precipitation, intensive evaporation, water shortage, and extremely fragile ecological environment. The basin spans three climatic zones from south to north, which includes the southern cold semiaridand and semihumid zone at the highland of Qilian Mountain(altitude2000– 5000 m) with an annual precipitation of 300–600 mm and potential evaporation of 700 –1200 mm; the middle cool arid zone at the flatland of the Hexi Corridor (altitude 1500–2000 m) with an annual precipitation of 150–300 mm and potential evaporation of 1200–2000 mm; the northern temperate arid zone (altitude1300–1500 m) with an annual precipitation of 150 mm and potential evaporation of more than 2000 mm.

The basin originates from the southern part of the Qilian Mountain, and ends at the Minqin Oasis. The river includes eight tributaries, but only four tributaries, the Huangyang, Zamu, Jinta and Xiying, converge as Shiyang River in the outlet of the Qilian Mountains, The four tributaries are mainly fed by rainfall, glacier melt and snowmelt from the Qilian Mountains. It is well known that the ecological environment in north-west China is vulnerable to water shortages(Xu&Li, 2007).For Shiyang River Basin, it has become an area with the largest population and the most overdevelopment of water resources in Hexi corridor, The conflict between ecological protection and economic development has become more prevalent as a result of increased utilization of water resources, and the sustainable development of the regional economy is severely constrained by water shortages (Dong et al,2010).

2.2 Data

In this study, temperature , precipitation and potential evaporation are selected as climatic factors, the temperature and precipitation data were from Shandan, Yongchang, Wuqiaoling and Jingtai meteorological station , For lack of long-term evaporation observations, potential evapotranspiration was estimated using the Penman-Monteith method recommended by FAO (Allen *et al*., 1998) based on the four meteorological data and the areal evapotranspiration was estimated as the centroidal value interpolated by inverse square distance method. The runoff data for the four tributaries (e.g. Huangyang, Zamu, Jinta, Xiying) is from observation stations at mountain outlets. The quality control of the data has been done by the hydrological and meteorological agencies of the government.

Long-term climate changes can alter the runoff production pattern, the frequency and severity of floods, especially in arid or semi-arid regions. Therefore, a small change in meteorological condition may result in marked changes in runoff (Gan, 2000). To investigate effect of climate change and human activity on streamflow, this study used the time series data of annual runoff, annual average temperature, annual precipitation and annual potential evapotranspiration from 1960 to 2009.

3 Methodology

3.1 Detection of hydrologic changes

To detect the long-time change in climate factors and the runoff, the widely used linear regression method was invoked for trend detection(Zhang&Wang,2007) ,and the moving t-test was used to determine the abrupt change. In addition to the long-term changes of annual runoff, departure accumulation was also investigated to show the changes of the runoff.

3.2 impact assessment

To estimate the impact of climatic variation on the runoff, the multiple linear regression model is carried out using the scenario of a changing runoff and climate condition as observed in the natural baseline period, and the fixed model parameters as calibrated in the changing period.

This paper takes 1975 as the boundary, 1960 ~ 1975 as the basin natural period, 1976~2009 as the changing period. The segmentation methods are as follows.

$$\Delta W_H = |W_{HR} - W_{HN}| \tag{1}$$

$$\Delta W_C = |W_{HN} - W_B| \tag{2}$$

$$\Delta W_T = \Delta W_H + \Delta W_C \tag{3}$$

$$\eta_T = \frac{\Delta W_H}{\Delta W_T} \times 100\% \tag{4}$$

$$\eta_C = \frac{\Delta W_C}{\Delta W_T} \times 100\% \tag{5}$$

$\triangle W_T$ represents runoff change amount ,$\triangle W_H$ represents the runoff change amount for influence of Human Activity ,$\triangle W_C$ represents runoff change amount for influence of climate change. W_B represents the runoff of natural period ,W_{HR} represents actual runoff of period affected by human activity, W_{HN} represents natural runoff of period affected by human activity, η_T and η_c represent the contribution of the human activity and climate change respectively(Wang, 2008).

4 Results

4.1 Changes in catchment climate

Because the long-term trend in hydrological processes is potentially affected by climate change and natural variability is considered to be an important factor for the river discharge (Shi et al., 1995). Examining the historical trend of these of variables may help to reveal the effect of climate change on water resources systems (Chen et al., 2006).

4.1.1 Temperature trend analysis

The temperature change is the most direct reflection of the performance for the characteristics of climatic variation basin (Wang, 2011b). By the influence of the global warming, Shiyang River upstream region climate for fifty years, on the whole, has undergone a significantly rising trend at 0.01 significance level, and tendency rate is 0.34℃/10a(**Fig.2 (a)**). But in different time intervals, temperature variation is different. The variation in temperature is small in the 1970s and 1960s, the average temperature is 0.2 ℃ higher in the 80 s than in the 70s,the growth of temperature has been increasing gradually since 1990s.Meanwhile, the annual mean temperature was 0.4 ℃ higher in the past ten years of this century than it was in the 1990s. The research showed that, it was the warmest in 1998 during fifty years, with the temperature reaching 6.5℃.In addition ,1987, 1990, 1994, 2006, 2009 witnessed warmer weather. While in 1967, 1970, 1984 the temperature is lower. From this it can be seen that, since 1960, Shiyang River upstream region experienced the transition from the cold period to warming periods. From 1960 to 1985 it was the cold period, while it turned to warming spells after 1985.which is generally consistent with the global and Chinese warming period (Chu, 2010). Compared with other regions in the world, the temperature has obvious influence on runoff characteristics in arid areas. As the heat index, the temperature influencing runoff can be shown as follows: glaciers melting, evapotranspiration variation and alpine precipitation patterns altering. Moreover, temperature difference between in watershed land surface and in near-surface layer can be enlarged, so as to form the basin climate (Cao, 2003).

4.1.2 Precipitation trend analysis

The runoff is the composition of precipitation evaporation and other ingredients of water cycle, which can well reflect the influence of the climate change and human activity[(Wang et al.,2012).Rainfall in Shiyang River upstream areas shows slightly increasing trend, with the growth rate of 6.6mm/10a (**Fig.2(b)**). In the 1960s average rainfall (230mm) was lower, by contrast, from 2000 to 2009 it was 258mm. While it showed little change in the 1970s ,1980s and 1990s, and striking changes happened during the past 50 years, precipitation reached 324mm as the maximum in the 2007 and 149mm as the minimum in 1962.There were several local peak in 1961 .1971.1983 and 1993, rather, local valley values appeared in the 1965,1972 and 1991.

Compared with other continental river basins in arid areas in northwest China, increasing tendency in the precipitation is not obvious in the upper reaches of Shiyang River, which is not conducive to the formation of rainfall runoff, affecting the water resources quantity to some extent.

4.1.3 potential evaporation change

The potential evaporation exhibited a large variation with the decreasing rate of -22.5mm/10a from 1960 to 2009 in the upper reaches of Shiyang River, which passed the test under the significant levels 0.01(Fig.2(c)). It can be seen that the potential evaporation fluctuated dramatically in the nearly last 50 years. In 1969, it jumped to the highest level for the entire study period, which is 1113mm.Then it decreased, and didn't arrive the lowest until 1985 (866 mm),the linear decrement rate reached up to 150mm/10a from 1969 to 1985, The potential evaporation changed smoothly during 1980s and 1990s,while it has begun to increased significantly since 2004 ,then, it returned to the level it was in the 1960s.For the fragile ecosystem of Shiyang River, it should be a notable phenomenon that the potential evaporation increased recently.

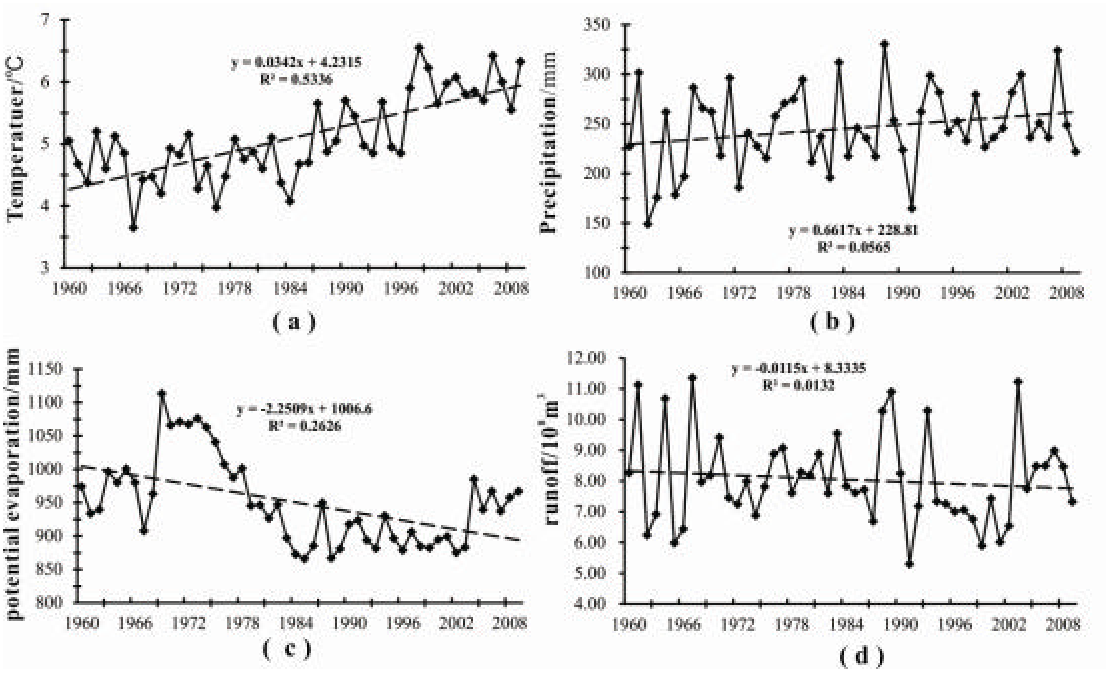

Fig.2 Changing trends of temperature (a),precipitation(b),potential evaporation(c)and runoff in the upper reaches of Shiyang River Basin

4.2 The runoff trend and mutation analysis

4.2.1 The interannual variability of runoff

As can be seen from the Fig.2(d) annual runoff volume takes on a slightly reduced tendency in the upstream of Shiyang River from 1960 to 2009 with the rate of $-0.115\times 108m^3$／10a (**Fig.2(d)**), reaching the maximum for $11.35\times 10^8m^3$ in 1967 and the minimum for $5.30\times 108m^3$ in 1991. The annual runoff in 1960s is $8.31\times 10^8m^3$,which is more than the 1970s' and 1990s' by $0.26\times 10^8m^3$, $1.08\times 10^8m^3$ respectively, however, it is $0.21\times 10^8m^3$ less than 1980s',the mean annual runoff from 2000 to 2009 is less than the 1960s' by $0.24\times 10^8m^3$ .Throughout the study period, the runoff fluctuation shows greatly instable.

4.2.2 Runoff mutation characteristics

Accumulated deviation and sliding T test are often used to detect whether there is a mutation point for time-series data. The accumulation of anomalies for the runoff from 1960 to 1975 was basically in a steady state. Which was on the rise from 1976 to 1990 and declined from 1991 to 2002, while from 2003 to 2009 was rising. On this account, it can be judged that the Shiyang River showed a statistically significant change points in runoff in 1975, 1990 and

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2002(**Fig.3**).The mutation years measured through sliding T test method is the roughly same as that through accumulated deviation method. Thus, it can be concluded that it did exist three mutations in the time series of the runoff in past 50 years. which is in 1975,1990 and 2002.Runoff is basically in stable state before 1975,while it began to change drastically after 1975,it is not hard to find, that the impact of climate change and human activity on runoff change significantly enhanced after 1975. So this paper selects 1960-1975 as the natural period, we assumes that runoff was less exposed from human activity before 1975, 1976 ~ 2009 is selected as changing period, when runoff has been effected by both climate change and human activity.

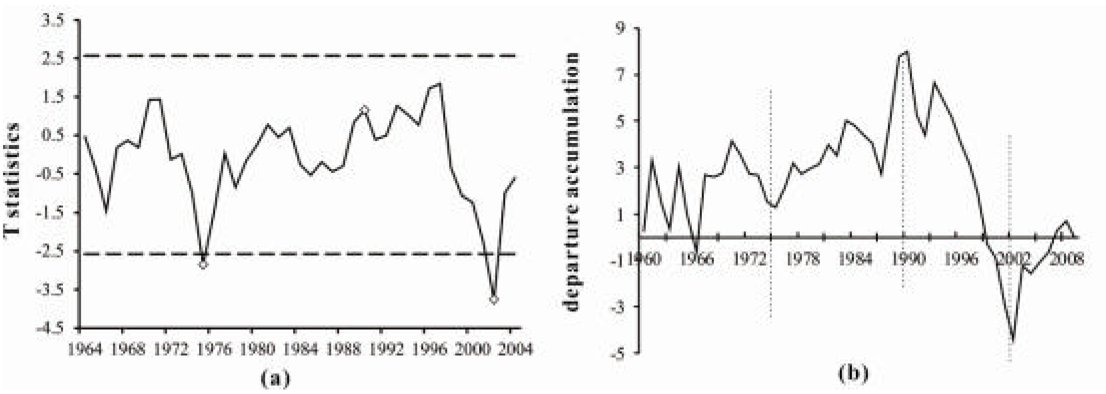

Fig. 3 T Statistic graphs（a） and the departure accumulation graphs (b) for the runoff in the upper reaches of Shiyang River Basin

4.3 The impact of climate change and human activity on the runoff

The basic ideas for analyzing climate change and human activity on the runoff in upper reaches of Shiyang River: According to the data before mutation point, multivariable regression was used to explore associations between runoff and precipitation, temperature and potential evaporation. Then, according to the multiple regression model, the annual runoff after mutation point can be calculated, the difference between the data from calculation and measured data is the amount of runoff produced by human activity, and the difference between the runoff after the mutation point and the average runoff before the mutation is the amount of runoff effected by climate change.

Shiyang River mainly comes from the precipitation on its upper reaches and the thaw on high mountains, due to rising temperatures, increased precipitation and weakly weakening potential evaporation, surface runoff of Shiyang River shows weakly decreasing trend in the recent 50 years. Correlative analysis of the main impact factors is made with DPS7.05 software, the correlations between runoff and precipitation, temperature and potential evaporation are 0.72($p<0.01$),-0.49($p<0.05$) and -0.33($p<0.05$) respectively. The results show that there is a high correlation between runoff and precipitation, temperature and potential evaporation. Among them, the correlation between runoff and precipitation was the highest, which indicates the precipitation had the strongest impact on the runoff in the Shiyang River Basin.

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According to the runoff and climate data from 1960 to 1975, the multiple linear regression model is made, as follows.

$$Y=0.0236X_1- 0.9640X_2-0.0068X_3+14.081$$

X_1 represents precipitation, X_2 represents temperature, X_3 represents potential evaporation, Y represents runoff. F = 7.8, alpha = 0.0037, which indicate that the regression equation passed the significance test at 0.01 level.

According to mutation point, the entire time is divided into three periods, which are 1976~1990、1990~2002 and 2003~2009,the impact of human activity and climate change on runoff flow changes are separately calculated .

Tab.1 Contributions from climate change and human activity to the runoff in the upper reaches of Shiyang River

Year	Simulation of runoff in nature ($10^8m^3/a$)	Measured runoff ($10^8m^3/a$)	Impact of climate change		Impact of human activity	
			Variation ($10^8m^3/a$)	Contribution rate (%)	Variation ($10^8m^3/a$)	Contribution rate (%)
1976~1990	9.098	8.487	0.979	62	-0.611	38
1991~2002	8.504	7.003	0.385	20	-1.501	80
2003~2009	8.023	8.672	-0.097	13	0.650	87
1976~2009	8.667	8.001	0.548	45	-0.666	55

Using the formula (4) and (5), it can be obtained that from 1976 to 2009 contribution rate from the climate change and human activity to the runoff are 45% and 55% respectively, In 1976 ~ 1990, 1991 ~ 2002 and 2003 ~ 2009, the contribution rate from climate change are 62%, 20% and 13%.while from human activity is 38%, 80%and 87%(**Tab.1**). Therefore, it is clear that the human activity, as well as the changes of climate, contributed to the trend of runoff detected in this study. The contribution rate from human activity to runoff is obviously increasing. Since the 1990s, the contribution from human activity is greater than that from climate change; human activity is the leading factor to the decrease of runoff.

Contribution rate from human activity is relative to the effects of climate change, the contribution rate does not represent the influence quantity from human activity on runoff. In the 1990s, the influence of human activity on runoff is the most, which lies in three respects: (1) the water is diverted directly from the river, which would reduce the surface runoff; (2) the human activities may affect the natural runoff production by forcing climate change; (3)with population growth, water demand increasing and over-exploitation of groundwater, the ground water level declines, coupled with deforesting and overgrazing, resulting in the contabescence of natural vegetation, it effects formation of rainfall runoff.

In 2003 ~ 2009, the effect of human activity on Shiyang River runoff is less, the reason is that the shifts of hydro-climatic regimes could potentially result in many eco-environmental changes in the extremely arid environment such as the Shiyang River Basin. The Development of Western China was carried out, at the same time; Gansu Province has also introduced a series

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of management planning regulations and policies for water resources in Shiyang River Basin. Especially, The State Council approved the planning of comprehensive regulation for the Shiyang River Basin in 2007, After years of comprehensive harnessing, proportion of ecological environment water supply increased year by year, which can help restore the level of groundwater and ecological environment in the Shiyang River Basin (Xu, 2010).

With the highest-intensity development of water resources and the most serious environmental and ecological problems, Shiyang River Basin is inland River Basin where water resources are the strongest constrains for socio-economic development in Hexi Corridor in Gansu Province (Qi, 2006) .With the increase of population and exploitation of water resources, the impact of human activity on the runoff should be constantly changing.

5. Discussion

Human activity in this paper is a relatively broad concept, including such water conservancy activities with a purpose as the transformation of watershed land surface, soil conservation and water conservancy projects which have a direct impact on runoff, and other human activity with non-water conservancy purposes, such as socio-economic structure adjustment (Wang, 2008). In this study, the generalized human activity and climate change are taken as independent variables, to evaluate the influences of the two variables on the runoff quantitatively and separately may not be accurate. This is because the impact of human activity and climate change on the runoff is not actually independent. There are essentially three parts which determine the runoff, climate change or fluctuation, human activity and the basic geographical features. There are a lot of uncertainties in the simulation of the impact of human activity and climate change on the runoff process. (1) The choice of the model. There is no mature model at present, so the author mainly chose specific model according to their own situation. (2)The selection of data .Errors are inevitable when people are measuring data, meteorological data is only used for point data, at the same time, the different number of selected stations can also cause different results.(3)The effect of Basic geographical characteristics on runoff is difficult to quantify.(4) Human activity and climate change are not independent variables. With the reasons above, how to build a reasonable model for accurate separation of the impact of human activity and climate change on runoff is a major challenge for the relevant researchers, which needs further study.

6. Conclusions

In the recent 50 years, the temperature in upper reaches of Shiyang River is rising with linear change rate of 0.34℃/10a, and has passed the significance test with a=0.01, Precipitation does show insignificant increasing trend, while potential evaporation shows significant decline, with the linear change rate reaching 22.5 mm / 10a. The results show that the climate in this district is changing from warming-drying type to warming-wetting type, which is consistent with the results by Shi (Shi et al., 2003). Because the Shiyang River Basin is located in the cold region, the contribution of glacier and snow melting to runoff is significant. The significantly increasing temperature during the last 50 years would led to the increase of water from glacier and snow melting, which should result in the increase of runoff. But from 1960 to 2009, the runoff has showed a trend of slight reduction in this region and linear change rate is about $-0.115\times 10^8 m^3/10a$, which indicates the changes of runoff of Shiyang River are affected not only by climate change but also by human activity.

This paper shows that the runoff in the upper reaches of Shiyang River had change points in 1975, 1990 and 2005, so this study selects 1960-1975 as baseline period of the runoff change and 1976-2009 as changing period. By establishing a linear regression model of runoff and temperature, precipitation and potential evaporation in the baseline period, it quantitatively estimates the contribution rate of climate change and human activity on runoff during 1976-2009. The contribution rates of human activity to runoff during 1976-1990, 1991-2002 and 2003-2009 are 38%, 80%and 87% respectively. While the contribution rate of climate change to runoff is 62%, 20%and13%.The ratio of the impact of human activity on stream flow showed an increasing trend, making it the dominant factor affecting runoff.

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