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Study on the Climate Change of Shiyang River Basin in Chinese Arid Inland Area

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This paper selects indexes such as climate inclination rate, anomaly, cumulative anomaly and 5 a moving average to study the climate change of Shiyang River from 1951 to 2005. It discusses the characteristics and laws of the variation of meteorological factors. The results show that in the past 50 years, the overall performance rainfall in the basin is a downward trend. 1962 was a turning point for the reduction of the rainfall in the upstream. But there was a significant increase in the midstream and the downstream since the 1990s. The region has a warmer temperature since 1987, 1997 and 1987 respectively for the upstream, the midstream and the downstream. The temperature surged in particular in 2000. The wind velocity in the upstream significantly increased in the 20th century. That in the midstream registered a fluctuation for every decade. 1984 marked the decrease of wind velocity in the downstream. As for the humidity, the mid-1950s to mid-1960s were the period with the most obvious reduction, while in the late 1990s, the humidity significantly reduced in the midstream. The humidity remained low between 1999 and 2005. With the construction of Shiyang River Protection Project in recent years, the drought has been eased in the midstream and the downstream and the situation is expected to improve gradually.

1. Introduction

Climate change has always been a hot concern to all countries in the world. Zhao, Wang, Xu et al. (2005) pointed out in his study that over the past 50 years China's annual average temperature was rising at a rate of 0.02-0.08^{o}C per ten-year. Climate change generates impact on regional ecology, society and economy, especially lays burdens on the fragile ecological environment and is detrimental to those areas with poor ability to adapt (Houghton, Jenkins and Ephraums (2010); Franziska and Philipp M. (2015); Wu, Wang, Li et al. (2014)). Shiyang River is located at the east of the Hexi (Gansu) Corridor, occupying an area of 4.16×104km^2. It has a temperate continental typical arid climate, with large temperature gap and evaporation but little rainfall. From 1950s to 1960s, in the upstream and midstream basin nearly 30 reservoirs were built. Harassed by climate change and an excessive demand of water as a result of the large population and more arable land, water shortage, soil erosion, shrinking glaciers, rivers drying up and other problems sprang up. Land salinization and desertification in the downstream Minqin region has grown ever since. Currently, Shiyang River is one of the inland rivers that inflicted by environmental problems. Water resources allocation, runoff variation and other relevant problems have attracted wide attention (Kang, Su, Tong et al. (2004); Ma, Shi, Shen et al. (2003); Han, Wang and Zhang (2008); Wang, Cheng and Shen (2002). Some researchers studied the relationship among the temperature, the rainfall and the runoff, how water resources influenced the climate change as well as dry and wet conditions of the climate (Xu, Li and Shi (2007); Zhang, Wang, Li et al. (2011); Liu (2006); Fu, Zhao, Wang et al. (2012)). However, these researches are limited to some meteorological factors and fail to reflect the climate change in Shiyang River Region. In comparison, this paper, through the analysis of four key meteorological factors over the fifty years including temperature, rainfall, wind velocity and humidity, provides a fundamental support for the evaluation of the social, economical and ecological effects of the Shiyang River dam construction.

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2. Source of data and research methodology

2.1 Source of data and the selection of meteorological stations

In order to fully reflect how the dam construction is impacted by the climate change, 3 meteorological stations (Fig.1) in the upstream Wushao Mountain region, the midstream Wuwei region and the downstream Minqin region which have the observation records of monthly temperature, rainfall, wind velocity, humidity and other data are selected. Weather data from Wuqiaoling meteorological station were recorded from 1951 to 2005 and that from Minqin meteorological station were recorded from 1953 to 2005. Data are from China Western Environmental and Ecological Science Data Center of Chinese National Natural Science Foundation (http://westdc.westgis.ac.ca) and China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn /home.do).

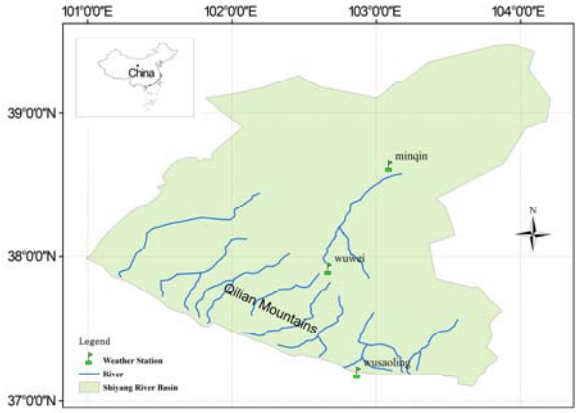

Figure 1: The location of the Shiyang River and the distribution of meteorological stations

2.2 Research methods

Compute the average value, decadal average value and 5a moving average value of each meteorological factor (Liu Meng, Qi and Yuan (2010); Andreas, Andrea and Geert (2015)). The linear regression equation is introduced to express the climate inclination rate and the linear variation, namely,

$x = a + bt, t = 1, 2, 3, ..., n$ (year), b>0 means that the value follows an upward trend with time; b〈0 means that the value follows an downward trend with time; with 10a as the unit, describe the variation rate of the factor; Use $S_n = \sum_{i=1}^{n} (x_i - \bar{x})$ to compute the cumulative anomaly, in which $\bar{x}$ refers to the average value, x_i refers to the average of year i and i=1, 2, …, n (year).

3. Result and analysis

3.1 The variation of the rainfall

Fig.2 shows the annual precipitation anomaly and cumulative anomaly from 1951 to 2005 in Shiyang River. And it can been seen, from 1951 to 2005, the average annual rainfall in the upstream Wushao Mountain region was 410.32mm with the highest at 555.2mm in 1961 and the lowest at 231.3mm in 1962. Over the past 50 years, the rainfall decreased at a rate of 6.2mm per ten-year. Inter-decadal average rainfall was 476.63mm, 355.29mm, 401.77mm, 412.66mm and 399.32mm respectively. From 2001 to 2005, the annual average rainfall was 422.18mm. The variation can be divided into three phases: 1951-1961 was in a fluctuating state and the anomaly was substantially greater than 0 with the average at 483.76mm; 1962 was a turning point with a rapid decline and 1962-1975 the anomaly was less than 0, with the average at 345.7mm. From 1976, the rainfall started to rise, and fluctuated near the perennial average value with a average increase of 413.54mm.

From 1951 to 2005, the average annual rainfall in the midstream Wushao Mountain region was 65.36mm with the highest value of 251.3mm in 1993 and the lowest of 91mm in 1962. Over the past 50 years the rainfall decreased at a rate of 6.3mm per ten-year. Inter-decadal average rainfall was 146.05mm, 174.39mm, 154.55mm, 162.75mm and 180.25mm respectively. From 2001 to 2005, the annual average rainfall was 182.94mm. The variation can be divided into three phases: 1951-1961 was in a fluctuating state and the anomaly was substantially less than 0 with the average at 141.92mm which was lower the average over the fifty years; 1964 was a turning point with a rapid increase and 1964-1973 the anomaly was more than 0 with the average at 184.11mm which was higher the average over the fifty years. From 1974-1992, it went down

first, then went up and the anomaly was basically less than 0; 1993 marked an apparent turning point. From 1993 to so far, the anomaly was basically greater than 0 and averaged at 188.71mm.

From 1953 to 2005, the average annual rainfall in the downstream Wushao Mountain region was 112.64mm with the highest at 202mm in 1994 and the lowest at 38.6mm in 1959. Over the past 50 years the rainfall increased at a rate of 1.3mm per ten-year, though not significantly. Inter-decadal average rainfall was 110.84 mm, 109.33 mm, 123.29 mm, 99.11 mm and 116.68 mm respectively. From 2001 to 2005, the annual average rainfall was 119.82mm. The variation can be divided into four phases: 1951-1965 marked a decrease at the rate of 27mm per ten-year and averaged at 102.03mm which was lower the average over the fifty years; 1966 was a turning point with a gradual increase and 1966-1979 the anomaly became more than 0 with the average at 127.46mm which was higher the average over the fifty years. From 1979-1991, it again went down at the rate of 20.4mm per ten-year averaging 100.64mm which was the lowest over the fifty years; it climbed up in 1992 and averaged at 120.46 mm, though with large fluctuation.

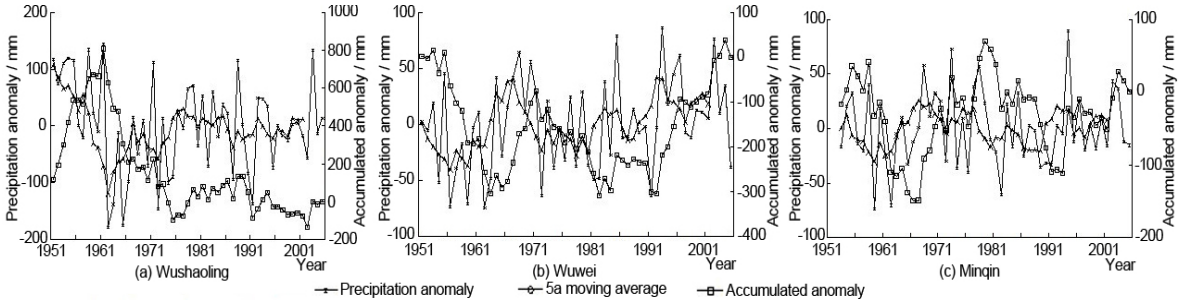

Figure 2: Annual precipitation anomaly and cumulative anomaly from 1951 to 2005 in Shiyang River

3.2 The variation of the temperature

Fig.3 is the annual mean air temperature anomaly and cumulative anomaly from 1951 to 2005 in Shiyang River.

From 1951 to 2005, the average temperature in the upstream Wushao Mountain region was -0.05^{o}C with the highest at 1.46^{o}C in 1998 and the lowest at -1.13^{o}C in 1967. Over the past 50 years the temperature increased at a rate of 0.17^{o}C per ten-year. Inter-decadal average rainfall was -0.21^{o}C, -0.32^{o}C, -0.31^{o}C, -0.19^{o}C and 0.39^{o}C respectively. From 2001 to 2005, the annual average rainfall was 0.71^{o}C. The variation can be divided into two phases: 1951-1986, the temperature fluctuated between -1.13-0.38^{o}C and the anomaly was basically less than 0 and became stable. The climate inclination rate was 0.07^{o}C per ten-year; 1987-2005, the temperature fluctuated between -0.3-1.46^{o}C with the anomaly basically greater than 0. And 1987 was a turning point with the climate inclination rate at 0.39^{o}C per ten-year. It surged in particular since 2000.

From 1951 to 2005, the average temperature in the midstream Wushao Mountain region was 7.93 ^{o}C with the highest at 9.6^{o}C in 2004 and the lowest at 6.4 ^{o}C in 1952 and the climate inclination rate was 0.29 ^{o}C per ten-year. Over the past 50 years the temperature increased at a rate of 0.17 ^{o}C per ten-year. Inter-decadal average rainfall was 7.45^{o}C, 7.69^{o}C, 7.64^{o}C, 7.84^{o}C and 8.29^{o}C respectively. From 2001 to 2005, the annual average rainfall was 9.39^{o}C. The variation can be divided into two phases: 1951-1996, the temperature fluctuated between 6.4-8.46^{o}C and the anomaly was basically less than 0 without much change. The climate inclination rate was 0.09^{o}C per ten-year; 1997-2005, the temperature fluctuated between 8.36-9.6^{o}C with the anomaly basically greater than 0. And 1997 was a turning point with the climate inclination rate at 0.62^{o}C/10 a.

From 1953 to 2005, the average temperature in the downstream Wushao Mountain region was 8.21^{o}C with the highest at 9.98^{o}C in 1998 and the lowest at 6.45^{o}C in 1967 and the climate inclination rate was 0.32^{o}C per ten-year. Over the past 50 years the temperature increased at a rate of 0.17^{o}C per ten-year. Inter-decadal average rainfall was 7.84^{o}C, 7.66^{o}C, 7.87^{o}C, 8.28^{o}C and 8.86^{o}C respectively. From 2001 to 2005, the annual average rainfall was 9.2^{o}C. The variation can be divided into two phases: 1951-1986, the temperature fluctuated between 6.5-8.64^{o}C and the anomaly was basically less than 0 without much change. The climate inclination rate was 0.05^{o}C per ten-year; 1987-2005, the temperature fluctuated between 8.15-9.98^{o}C with the anomaly basically greater than 0. And 1987 was a turning point with the climate inclination rate at 0.45^{o}C per ten-year.

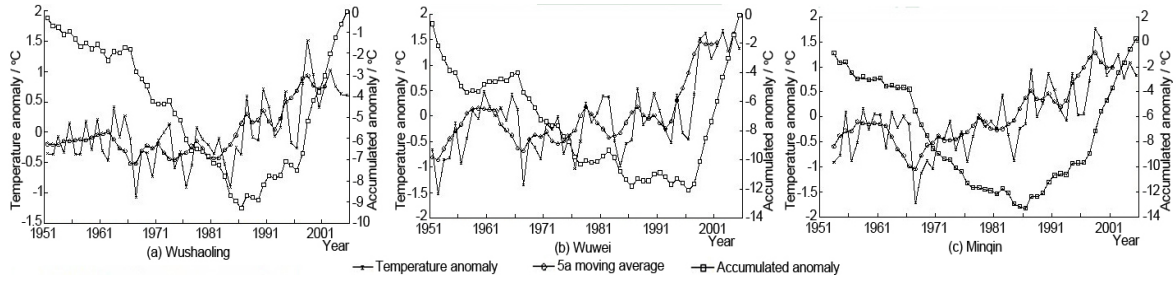

Figure 3: Annual mean air temperature anomaly and cumulative anomaly from 1951 to 2005 in Shiyang River

3.3 The variation of the wind velocity

The annual wind velocity anomaly and cumulative anomaly from 1951 to 2005 in Shiyang River are shown in Fig.4.

Between 1951 and 2005, average wind velocity in the upstream Wushao Mountain region was 4.8m/s, with the highest at 5.6 m/s in 1987 and the lowest at 3.63 m/s in 1951. It increased at 0.17 m/s per ten-year over the past 50 years. The average inter-decadal wind velocity was 4.27 m/s, 4.38 m/s, 5.28 m/s, 4.95 m/s, and 5.04 m/s respectively. The average wind velocity between 2001 and 2005 was 5.01 m/s. The variation can be divided into two phases: 1951-1968, the wind velocity showed a downward trend and the anomaly was basically less than 0. The decline rate was 0.08 m/s per ten-year; since 1969, it increased rapidly to a stable state and 1982 was a mark year. From 1969 till today, the anomaly was greater than 0 and averaged at 5.10 m/s.

Between 1955 and 2005, average wind velocity in the midstream Wushao Mountain region was 1.81m/s, with the highest at 2.43 m/s in 1973 and the lowest at 1.09 m/s in 1993. It went down over the past 50 years at 0.11 m/s per ten-year. The average inter-decadal wind velocity was 2.25 m/s, 1.76 m/s, 2.09 m/s, 1.64 m/s and 1.52 m/s respectively. The average wind velocity between 2001 and 2005 was 1.77 m/s. The variation can be divided into four phases: 1955-1962, the wind velocity fluctuated between 2.03-2.36 m/s and was quite stable. The anomaly was basically greater than 0. Since 1963, it decreased rapidly and the anomaly was greater than 0 averaging 2.04 m/s; 1984 suggested another downturn, though 1995 climbed up a little. From 1984 till today, the anomaly was less than 0 and averaged at 1.58 m/s.

Between 1955 and 2005, average wind velocity in the downstream Wushao Mountain region was 2.67m/s, with the highest at 3.03 m/s in 1958 and the lowest at 2.16 m/s in 2002. It decreased at 0.08 m/s per ten-year over the past 50 years. The average inter-decadal wind velocity was 2.82 m/s, 2.81m/s, 2.79 m/s, 2.87 m/s and 2.61m/s respectively. The average wind velocity between 2001 and 2005 was 2.36m/s. The variation can be divided into two phases: 1955-1983, the wind velocity showed a stable trend and the anomaly was basically greater than 0 averaging 2.80 m/s. 1984-2005 it declined and the anomaly was less than 0 averaged at 2.5m/s. Year 2000 experienced the decline in particular. The average wind velocity from 2000-2005 was 2.34 m/s.

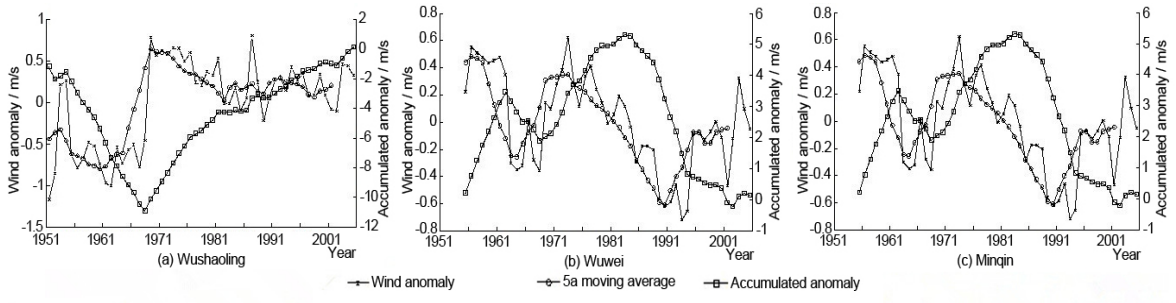

Figure 4: Annual wind velocity anomaly and cumulative anomaly from 1951 to 2005 in Shiyang River

3.4 The variation of the humidity

Fig.5 is the annual humidity anomaly and cumulative anomaly from 1951 to 2005 in Shiyang River.

From 1951 to 2005, the average relative humidity in the upstream Wushao Mountain region was 58.06% with the highest at 67.42% in 1953 and the lowest at 53% in 1997. Over the past 50 years the humidity decreased at a rate of 0.4% per ten-year. Inter-decadal average humidity was 459.84%, 57.53 %, 57.29%, 58.08 % and 57.78 % respectively. From 2001 to 2005, the annual relative humidity was 57.57%. The variation can be divided into three phases: 1951 -1954 registered the highest humidity over the fifty years, averaged at 65.27%

and the anomaly was substantially greater than 0; 1955-1966 it went down with fluctuation and the average was only 56.13% with the anomaly less than 0. From 1967 to so far, the humidity continued to fluctuating and the average 57.91% which was close to the average value over the fifty years.

From 1951 to 2005, the average relative humidity in the midstream Wushao Mountain region was 52.31% with the highest at 61.56%, in 1952 and the lowest at 44.67% in 2005. Over the past 50 years the humidity decreased at a rate of 0.44% per ten-year. Inter-decadal average humidity was 51.47%, 53.86 %, 53.03%, 52.26% and 53.26 % respectively. From 2001 to 2005, the annual relative humidity was 47.67 %. The variation can be divided into four phases: 1951 -1954 registered the highest humidity over the fifty years, averaged at 58.01% and the anomaly was substantially greater than 0; 1955-1962 it went down with fluctuation and the average was only 48.11% with the anomaly less than 0. From 1963 to 1998, the humidity continued to fluctuating and the average 53.51% which was close to the average value over the fifty years. Since 1998, it declined substantially. The anomaly was less than 0, averaging 47.68% which reached the lowest over the past 50 years.

From 1953 to 2005, the average relative humidity in the downstream Wushao Mountain region was 44.83% with the highest at 57.58%, in 1953 and the lowest at 39.33% in 1965. Over the past 50 years the humidity decreased at a rate of 0.3% per ten-year. Inter-decadal average humidity was 45.21%, 45.65%, 45.38%, 44.10 % and 44.02% respectively. From 2001 to 2005, the annual relative humidity was 44.57%. The variation can be divided into four phases: 1953-1955 registered the highest humidity over the fifty years, averaged at 49.44% and the anomaly was substantially greater than 0; 1956-1966 it went down with fluctuation and the average was only 43.45% with the anomaly less than 0. From 1967 to 1979, the humidity continued to fluctuating and the average 46.39%. Since 1980, it moved around the average at 44.10%.

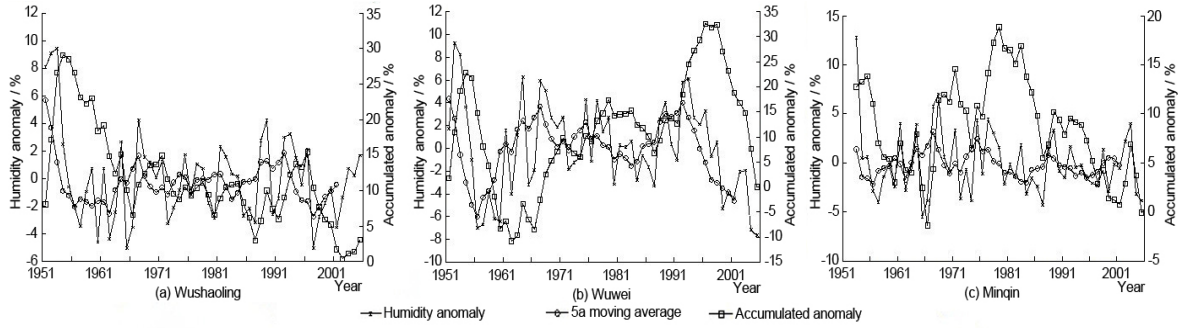

Figure 5: Annual Humidity anomaly and cumulative anomaly from 1951 to 2005 in Shiyang River

4. Discussion and conclusions

(1) It was found that there was much to follow in the temperature variation of Shiyang River, which kept on rising. The temperature in the midstream and the downstream experienced a substantial increase in 1987. This finding was in accordance with the study on the northwest of China. Under a high temperature, there is more evaporation.

(2) The rainfall in the upstream Wushao Mountain region in 1960s and 1970s witnessed a remarkable downward trend, with the reduction apparently from 1951 to 2005. However, the rainfall in the upstream was higher than that in the midstream and the downstream put together. Even though there was increasingly rainfall in the midstream and the downstream, the overall rainfall in this region was declining over fifty years. What's more, the growth of rainfall was smaller than that of the temperature, which means the increase of the rainfall lagged behind the increase of the temperature.

(3) The variation of the rainfall was adverse to that of the wind velocity. When the rainfall in the upstream was reduced, the wind velocity was higher. When the rainfall in the midstream and the downstream increased, the wind velocity was lower. Zhou, Shi, Shi(2012) pointed out in their research that rainfall and wind velocity were two main meteorological factors that influenced the extreme weather in Shiyang River Region. Thus, over the past 50 years, the arid situation wasn't improved much. As the rainfall lagging behind the temperature variation generated more effect, the wind velocity was expected to reduce. The drought might be eased to some extent. There could exist some errors due to the limitation of the observation time. Thus, the interpolation method is suggested to make up for the flaws.

Acknowledgments

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