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Long-term trends in climate and hydrology in Jinghe River Basin

L H Meng[1] and M F Zhang[1,*]

[1] School of Resource and Environment, University of Electronic Science and Technology of China, Xiyuan Avenue 2006, Chengdu, China 611731
*Email: mingfangzhang@uestc.edu.cn

Abstract. The Jinghe River Basin lies in the centre of the Loess Plateau in China which is located in the subtropical climate zone. The watershed suffers serious soil erosion, as well as droughts. It is one of the regions with the most severe soil erosion and the most vulnerable ecological environment not only in China but also in the whole world. Linear regression analysis, Mann-Kendall trends and breakpoint analysis were used to detect the changing dynamics of climatic variables and runoff in the basin. The result shows that the temperature and precipitation in the Jinghe River basin have a uniform spatial distribution from 1960 to 2005, and the mean average temperature has shown a significant upward tendency over the years. The average annual rainfall is relatively stable, showing a decreasing trend since the 1970s. Annual runoff over 1973-2003 was a decline with a breakpoint occurred in the 1990s. Understanding the long-term trend in climate and hydrology are crucial for water resource management in semi-arid regions such as the Loess Plateau.

1. Introduction

Water resources have become an economic resource and an integral part of the national economy. However, with the continuous increase in the population and the rapid economic growth, human demand for water resources has increased significantly. The existing water resources are insufficient to support social development. Therefore, water resources have evolved into contemporary problems and are directly related to economic development.

Climate change in the world is a common and widespread fact in the international community. The IPCC Assessment Report 5 (AR5) has pointed out that there is no doubt that global warming has exerted a significant impact for the past century. From 1880-2012, the ground temperature in increased by approximately 0.85°C. With the increase of climate change and human activities in the world, the lack of water resources and the deterioration of the environment have become a worldwide problem, especially in the Jinghe River Basin [1]. As a link connecting the atmosphere, the biosphere, and the earth, the water cycle is the main breakthrough point in exploring the impact of climate change on water resources. As an important part of the changing environment, the role of climate change in water resources has long been recognized by the international community and has become a hot topic in water science research in the 21st century [2-4]. Therefore, from the point of view of sustainable development, the use of statistical methods to analyse the temporal variations and trends of the climatic and hydrological factors is of great significance to the rational use and management of water resources in the Jinghe River Basins. On this basis, the effective use of water resources, the promotion of harmonious coexistence between man and nature, resources, provide a reference for the unified management of water resources in the Jinghe River Basin.

2. Study Area And Data Sets

2.1. Study Area

The Jinghe River is the largest tributary of the Weihe River, a primary tributary of the Yellow River. Located in the centre of the Loess Plateau, the Jinghe River runs between Liupanshan and Ziwuling, with a drainage area of 45421 km2 [5]. The average annual temperature of the basin is 9°C, and the annual precipitation is between 350 and 650mm, mainly in the summer. However, it is one of the regions with the most severe soil erosion and the most vulnerable ecological environment not only in China but also in the whole world which lead to the serious disasters every year.

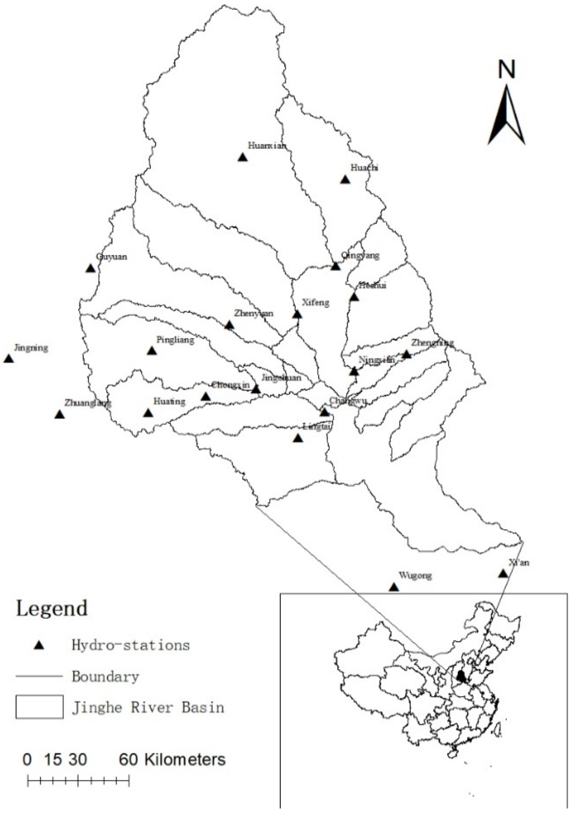

Figure 1. Hydro-stations and distribution in the Jinghe River Basin.

2.2. Data Stets

19 meteorological stations in the Jinghe River Basin were selected. The data mainly includes: the maximum and the minimum temperatures; monthly, seasonal, and annual average temperatures and precipitation from 1960 to 2005; and depth of runoff from 1973 to 2003. These are actual measured temperature, precipitation, and runoff data at the rainfall stations and weather stations, some of which are supplemented by the provincial hydrological bureaus. All the data are collected at the China Meteorological Data Service Centre and have passed quality inspection to ensure the accuracy.

3. Methodology

3.1. Linear Regression Analysis

Linear Regression is a regression analysis of the relationship between one or more independent variables and dependent variables using a least-squares function called a linear regression equation [6] which is represented by the form of $y=bx+a$ by finding its equation using the least squares method.

3.2. Mann-Kendall Test

The Mann-Kendall (MK) method is a non-parametric statistical test method, also called a non-distribution test. The advantage is that the sample distribution can be unknown. This test is also insensitive to outliers. It is suitable for type variables and sequence variables because of the simple calculation [6].

4. Result and Discussion

4.1. Temperature

The average annual temperature of the basin is 9 °C. Figure 2 shows the annual average, maximum, and minimum temperature of Jinghe River Basin in 1960-2005. According to the linear regression analysis, the annual average temperature during the period was averagely increased by 0.28°C/10a, and the maximum temperature and minimum temperature were 0.18°C/10a and 0.36°C/10a, respectively. Though all the three variables showed an upward trend, among which the consistent rising tendency of annual average temperature was greatest, and the other two showed larger fluctuations. In addition, a Mann-Kendall trend analysis was also conducted on each variable, dividing the time series into full-period (1960-2005), PDO warm phase (1977-1999), and PDO cold phase (1960-1976; 2000-2005). The results are shown in Table 1.

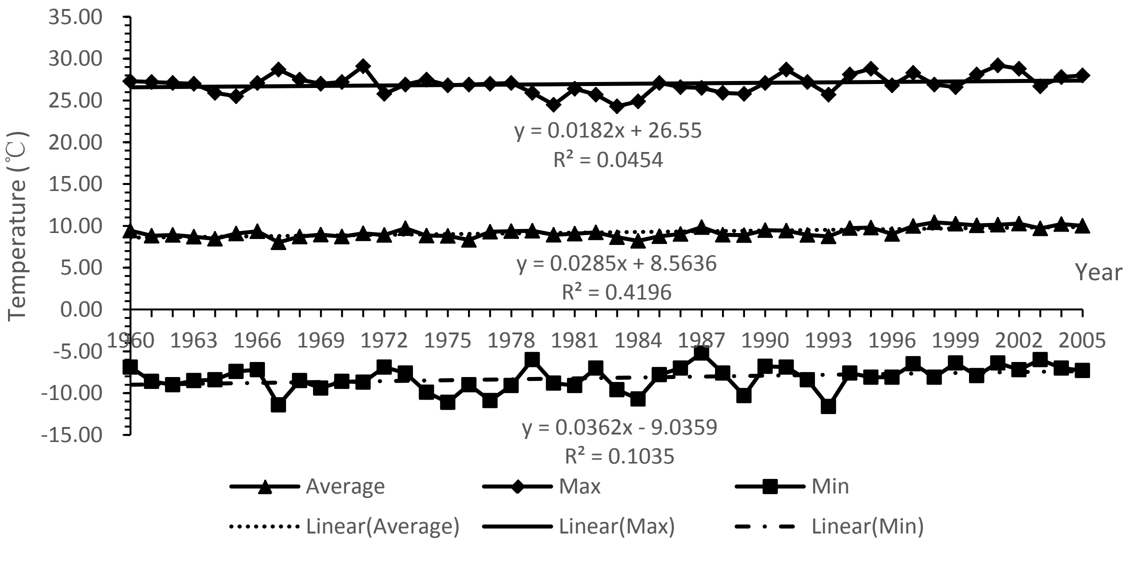

Figure 2. Average, minimum and maximum temperatures in the Jinghe River Basin.

The result in table 1 shows that during the whole period of 1960-2005, an obvious increasing trend was detected in most of the variables (ɑ=0.01) except for the summer average and maximum temperature. In addition, according to the pattern of large-scale climatic oscillations, in a cold phase of PDO (1960 to 1977), the annual minimum temperature of the basin had a significant decreasing trend. Correspondingly, in the warm phase of PDO (1977-1999), the annual maximum temperature showed a significant upward trend. Besides, the annual and summer average temperature also showed significant upward trend in the warm phase which means the warm phase of PDO exerted a greater impact on the summer average temperature and thus, influencing in annual scale of the basin. Relevant studies have shown that in typical warm phase of PDO, most parts of China, especially in North China, are relatively dry and warm [7,8], which to a certain extent explains the decrease in precipitation and runoff. In 2000-2005, insignificant trend was detected because of the limited data.

Figure 3 shows the Mann-Kendall break point test of the annual average temperature. As can be seen, the annual average temperature of the basin showed a slight downward trend before 1977 in the cold phase of PDO and then began to increase. The breakpoint occurred in 1994 after which the annual average temperature showed a significant upward trend.

Table 1. Mann-Kendall trend analysis of temperatures in the Jinghe River Basin.

variables	1960-2005	1960-1976	1977-1999	2000-2005
Annual average	**0.468**(p=0.000)**	0.034(p=0.875)	**0.317*(p=0.039)**	-0.20(p=0.817)
Spring	**0.347**(p=0.001)**	0.150(p=0.450)	0.191(p=0.215)	0.20(p=0.817)
Summer	0.170(p=0.100)	0.209(p=0.260)	**0.312*(p=0.042)**	-0.40(p=0.483)
Fall	**0.352**(p=0.001)**	0.008(p=0.964)	0.286(p=0.063)	0.20(p=0.817)
Winter	**0.421**(p=0.000)**	-0.033(p=0.894)	0.260(p=0.091)	-0.20(p=0.817)
Maximum	0.107(p=0.308)	-0.060(p=0.751)	**0.347*(p=0.026)**	-0.40(p=0.483)
Minimum	**0.277**(p=0.008)**	**-0.377*(p=0.043)**	0.127(p=0.412)	-0.40(p=0.483)

* significant at α=0.05; ** significant at α=0.01

4.2. Precipitation

The average annual precipitation in the Jinghe River basin is 528.6mm with limited spatial variation, basically decreasing from the southeast part of the basin to the northern part. Chronologically, the overall interannual variation is dramatic. The annual precipitation in the Jinghe River Basin reached the highest value (800.18mm) in 1964; the minimum value was 376 mm in 1995 which is less than half of the maximum. The precipitation within the year has an uneven distribution that is concentrated in summer of June, July, and August accounting for over 60% of the annual precipitation.

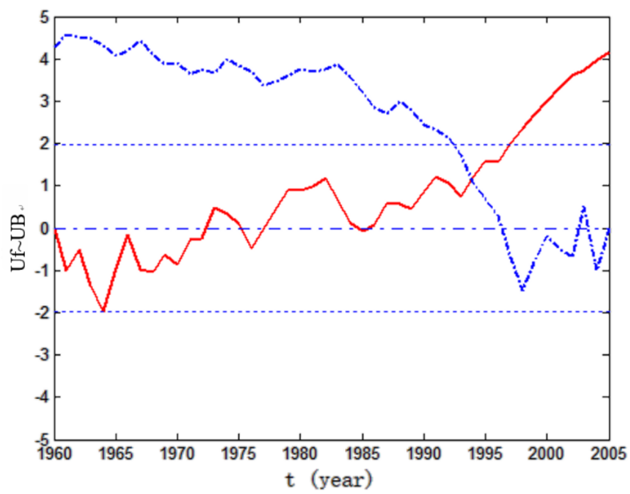

Figure 3. Mann-Kendall test of annual average temperature in Jinghe River Basin

The average precipitation fluctuates with time in the whole period, alternating between wet and dry years, and continuing with low values in the 1990s, as shown in the Figure 4. In 1995, severe drought lasted for 45 days resulting in drying-up of rivers. In the early 20th century, after a high value of 758.7mm in 2003, annual precipitation suddenly decreased to 467.9mm in the second year, only 60% of the previous year. According to the linear regression analysis of precipitation in the basin, the overall precipitation has a decreasing tendency. The climate change tendency was insignificant with a change rate of -16 mm/10a, with the R2 value of 0.0472.

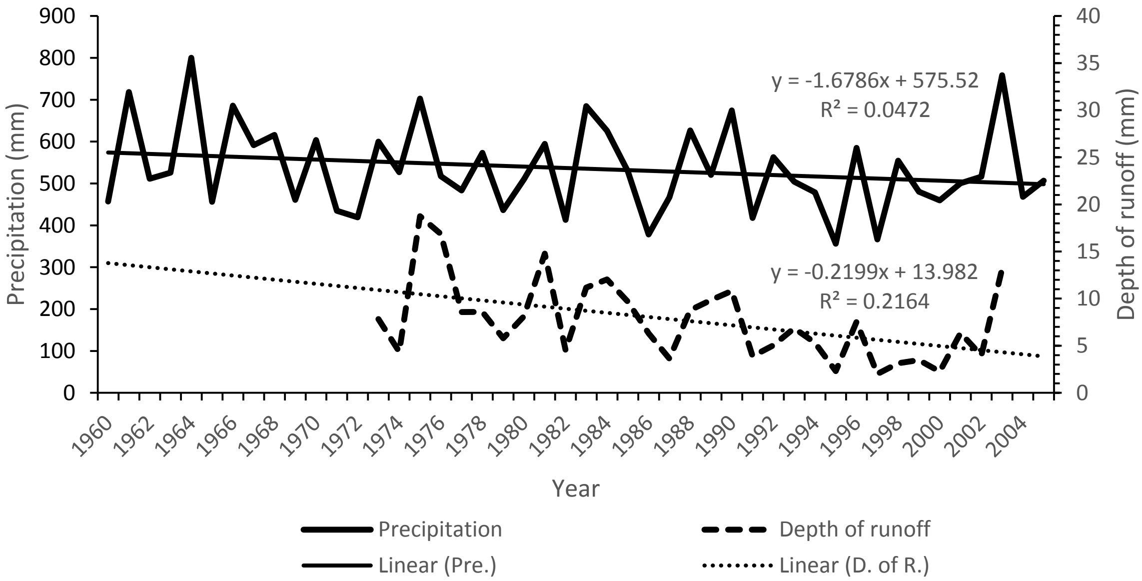

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Figure 4. Average annual precipitation and depth of runoff in the Jinghe River Basin.

Figure 5 shows the Mann-Kendall test of annual average precipitation. In the 1960s, the precipitation Uf value fluctuated from 0-1 suggesting a slight upward trend. The intersections occurred several times in the 1970s, however the change of trend is insignificant and thus cannot be regarded as breakpoints. Since 1990, the decrease has become more pronounced. On the whole the precipitation of the Jinghe River Basin has experienced drastic reduction especially after 1990s, which requires more focus and attention for further optimal watershed and water resource management strategies.

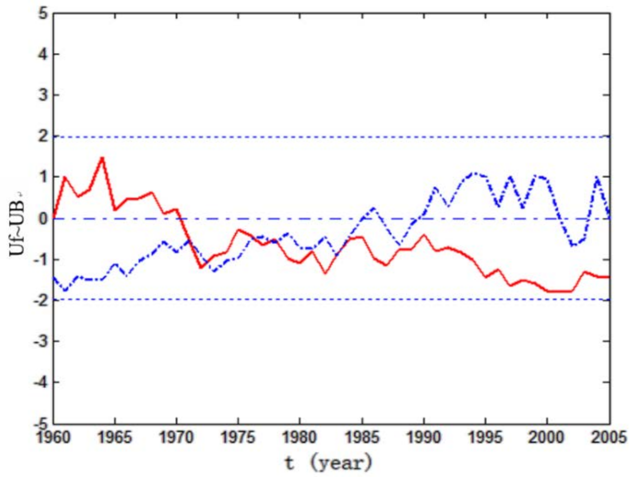

Figure 5. Mann-Kendall test of precipitation in the Jinghe River Basin

4.3. Runoff

The depth of runoff can represent the runoff variation in the Jinghe River Basin in response to precipitation. Data during 1973-2003 was selected for analysis. The average depth of runoff in Jinghe River Basin from 1973-2003 was 7.60mm. The linear correlation analysis (Figure 4) of the average annual depth of runoff according to the division of the hydrological year indicates that the runoff in the Jinghe River Basin during the whole period showed a reduction trend with a reduction rate of (2.2mm)/10a. The average value of 1970s, 1980s, and 1990s are 9.86mm, 8.89mm, and 5.03mm, respectively. A drastic reduction appeared in the 1990s which dropped by nearly average annual 50% compared to the 1970s. Besides, the shape of the runoff line and precipitation line have a fairly high consistency, which suggest that rainfall is the main source of the runoff in the basin and the runoff had a similar temporal pattern with the precipitation.

According to the Mann-Kendall test (Figure 6), the runoff before 1985 is relatively stable, with slight fluctuations. The breakpoint occurred in 1990 and then runoff of the Jinghe River Basin began to show a continuous downward tendency. After 1995 this tendency became significant. Relevant studies have clarified that in the 1990s, the Jinghe River Basin entered a dry period. During this period, a large-scale project of Grains for Green program in China was implemented. In particular, a large number of machine-building terraces were converted into terraced fields [9]. These measures had a better control of soil erosion in the basin however, have also caused a significant impact on runoff generation, leading to a substantial reduction in runoff.

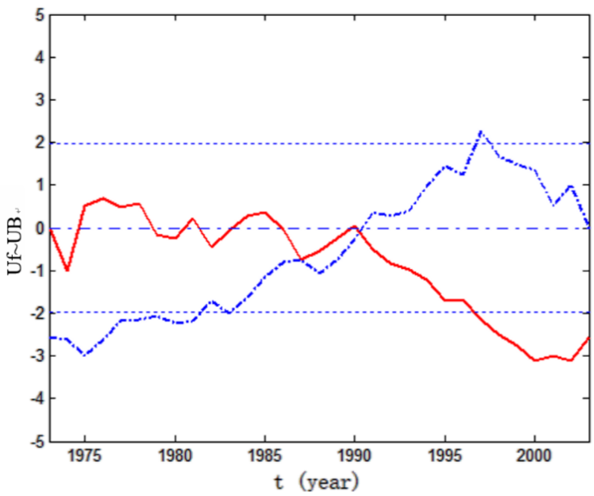

Figure 6. Mann-Kendall test of average annual depth of runoff in the Jinghe River Basin

5. Conclusions

(1) The average annual, minimum, and maximum temperatures of the Jinghe River Basin show an upward trend, with the average annual temperature increasing most significantly, at a rate of 0.28°C/10a. The upward trend became more pronounced after the breakpoint occurred in the early 1990s. The temperature pattern of the basin is in a accordance with the PDO, showing that the temperature change in the Jinghe River Basin is mainly affected by large-scale climate oscillation PDO.

(2) The overall trend of precipitation in the basin was insignificant but with obvious fluctuations. Within a year, the precipitation shows an uneven distribution, mainly in June-August, and summer precipitation accounted for more than 60% of annual precipitation.

(3) The runoff of the Jinghe River Basin shows a more significant decrease during the whole period, basically corresponding to the precipitation change. The rate of decline in the depth of runoff is (2.2mm)/10a. The average annual runoff has gradually decreased from the 1970s to the 1990s. After a sudden change in the early 1990s, there has been a significant reduction.

(4) With rising temperature and gradually decreasing precipitation, the runoff was on a significant decline. The shortage of water resources will intensifies the contradiction between supply and demand of local water resources. Therefore, the water resources protection, management and planning in the Jinghe River Basin must be further optimal. Such work will speed up the pace of building a water-saving society, implement the most stringent water resources management system, and scientifically and rationally develop and efficiency of utilize of water resources.

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