BCAS Vol.26 No.1 2012

# Climate Change and its Impact on Water Resources in the Huai River Basin

ZUO Qiting, CHEN Yaobin & TAO Jie

Center for Water Science Research, Zhengzhou University, Zhengzhou, Henan 450001, China

**Abstract** Rainfall and air temperature data from six meteorological stations above the Bengbu Sluice and hydrological and water resources evaluation data from the Bengbu Hydrological Station in the Huai River Basin from 1961 to 2008 are used to analyze the impact of changes in climatic factors on the amount of water resources in the Basin. There was a general trend of rise in its average annual air temperature, with the highest increase of 0.289°C/10a recorded at Bengbu in Anhui Province. Rising rainfall was mainly observed in the western part of the study area, while rainfall actually declined in the eastern part, *i.e*. the middle reaches of the Huai River. The Average rainfall in the study area was in a vaguely declining trend. In other words, the rainfall in the Basin is still much affected by natural fluctuations. On the whole, there was a trend of gradual decrease in the quantity of the Basin's water resources for the period under study. Water resources quantity is found to fall with decreasing rainfall and rising air temperature. Regression analysis is used to establish a mathematical model between water resources quantity and climatic factors (*i.e*. air temperature and rainfall) in order to explore the impact of climate change on water resources in the Basin. Moreover, various scenarios are set to quantitatively analyze the response of water resources to climate change. Sensitivity analysis shows that changes in rainfall have a much bigger impact on its water resources quantity than changes in its air temperature.

**Keywords** climate change, Huai River, water resources, R/S analysis

Dr. ZUO Qiting, born in 1967, is a leading and senior professor in hydrology & water resources and director of the Center for Water Science Research, Zhengzhou University. He holds the concurrent post of the Secretary-General of the Water Resources Commission, China Society of Natural Resources (CSNR), and Committee Member of the Water Resources Commission, Chinese Hydraulic Engineering Society (CHES). He has received many honors, including the Baogang Excellent Teacher, specialist of science and technology of Henan Province, excellent young and middle-aged key teacher of Henan Province for his outstanding teaching and research contributions. He has led and chaired 42 projects supported by the National Natural Science Fund of China, National Social Science Fund, National Science and Technology Support Program Topic, and Henan Provincial Science Fund for Distinguished Young Scholars and other national or provincial scientific programs. Dr. Zuo has published 10 monographs and 206 papers. His main research interests are human-water relationship and harmony theory, water resources planning and management, hydrological system and water system.
E-mail: zuoqt@zzu.edu.cn; zuoqiting@163.com

## 1. Introduction

Climate change is now exerting a growing impact on water resources in China. In June 2007, the Chinese government released *China's National Climate Change Program*, making water resources a key target area for the country to address the climate change challenge. Countermeasures and goals were also specified in the document. Global climate change is also a potential factor which directly affects China's future national security and sustainable social, economic and ecological development (Huang *et al*. 2006). Situated in a subtropical monsoon zone, the Huai River Basin is a transitional belt from a humid region to a semi-arid one. Though fairly abundant, its rainfall is mainly concentrated in the flood season and varies significantly from year to year. Natural disasters such as droughts and flooding are frequent occurrences. Uneven spatial and temporal distribution of water resources and deteriorating water quality have caused a huge impact on people's life and industrial and agricultural production in the region (Gao *et al*. 2008). The possible impact of climate change on the Basin is therefore an urgent issue for study. In their research on climate change in the Huai River Basin for the 1956-2002 period, Chen *et al.* (2008) found a marked rise in air temperature but a fall in rainfall. Based on an analysis of measured runoff data for almost 50 years, Zhang Jianyun *et al.* also spotted a slight falling trend of runoff in the Basin. This, coupled with social, economic and other external factors, is believed to have led to worsening water supply shortages in the region (Zhang *et al*. 2001). In addition, the Basin is also a major water supply source and the planned passing route for the eastern line of China's South-North Water Transfer Project. Climate change in the region will therefore affect the scheduling and allocation of water in the whole water transfer project.

This paper starts from analyzing the impact of changes in climatic factors on water resources quantity in the Basin. Data from six meteorological stations above the Bengbu Sluice and water resources evaluation data from the Bengbu (Wujiadu) Hydrological Station for a period of 48 years from 1961 to 2008 are used to study the pattern of changes in climatic factors and water resources quantity in the river basin. Building on existing research by Chinese and foreign scholars and in relation to the specific situation in this region, bivariate regression has been used to establish a linear statistical model for the relationship between water resources quantity and climatic factors so as to quantitatively examine the impact of climatic factors on water resources in the Huai River Basin.

The Bengbu Sluice down the Huai River.

## 2. The study area and research methodology

### 2.1 The study area

The Huai River Basin is situated in Eastern China and caught between the Yellow and Yangtze River basins. Covering the area between 30°55′~36°36′N and 111°55′~121°25′E, it is approximately 700km long from west to east and 400km wide from south to north, with a total area of around 270,000km$^2$. Originating from Tongbai and Funiu mountains in the west, the Basin adjoins the Yellow Sea in the east, the Yangtze River Basin in the south, and the South Dykes of the Yellow River and the Yimeng Mountain Range in the north, spanning the five provinces of Henan, Hubei, Anhui, Shandong and Jiangsu. Its terrain is high in the northwest but low in the southeast. From northwest to southeast, various tributaries join the main trunk of the Huai River, which flows into the sea below Hongze Lake (Xia *et al*. 2009; Ning *et al*. 2003). Local climate features a strong seasonality. In the climate regionalization scheme, with the Huai River and the North Jiangsu Irrigation Canal as the dividing line, the northern part of the Basin belongs to a warm-temperate, semi-humid region, while the southern part is a subtropical humid zone. Various weather systems affect the region. These include westerly troughs and cold vortexes from North China, typhoons and easterly waves from the tropics and the Jianghuai Shear Line, and locally-originated cyclone waves. These weather systems interact to give rise to diversified climate patterns and drastic weather changes in the river basin. With a favorable geographical location, the Basin occupies a strategic position in China’s national economy (Ning *et al*. 2003). The current study is concerned with the part of the Basin above Bengbu in Anhui Province, specifically, the area that is situated between 110°~115°E and 30°~35°N.

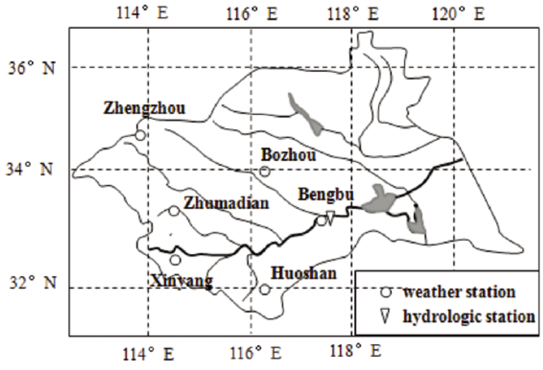

Figure 1 The Huai River Basin and distribution of its meteorological and hydrological stations.

### 2.2 Data sources and analytical methods

**(1) Data sources**

Monthly average air temperature and rainfall data of the China International Ground Exchange Station for the 1961-2008 period (including six stations in the Huai River Basin above Bengbu) provided by the National Meteorological Information Centre (China Meteorological Data Sharing Service System, http://cdc.cm.gov.cn/) are adopted to examine changes in the historical temperature and rainfall series in the Basin. Water flow data are collected for the Basin above the Bengbu Sluice. All the meteorological, water quality and quantity data are properly classified and sorted.

**(2) Data processing and analytical methods**

For the sake of data continuity, meteorological data from the China International Ground Exchange Station are used in this paper. All the data have passed strict quality checks. Some missing data have been interpolated using the mean values of the measured data for the same period of the nearest 30 years.

1) Change trend and trend rate. Let the following time series denote the sequential data of a certain factor:

$$X(t) = a_0 + a_1 t + a_2 t^2 \cdots a_n t^n$$

Wherein: $X(t)$ is the factor under study; $t$ is time; $a_1$ is linear trend rate; and $a_2$, $a_3 \ldots a_n$ can be determined by the least squares method or orthogonal polynomial (Qu *et al*. 2008).

2) R/S method. Use the Hurst Index to forecast a future trend.

The rescaled range (R/S) analysis method was first put forward by the British scientist H. E. Hurst and was subsequently supplemented and improved by Mandelbrot and Wallis, who developed it into a fractal theory for time series research (Mandelbrot and Wallis, 1969). Its basic principle and method are as follows:

Let $\{\xi(t)\}, t=1,2,3\cdots n$ be a time series. For any positive integer $\tau \geq 1$, define the mean sequence of the series as:

$$\langle \xi \rangle_\tau = \frac{1}{\tau}\sum_{t=1}^{\tau} \xi(t), \tau = 1,2,3\cdots,n$$

Use $X(t)$ to denote the cumulative deviation:

$$X(t,\tau) = \sum_{t=1}^{\tau}[\xi(t) - \langle \xi \rangle_t], 1 \le t \le \tau$$

The deviation range, R, is defined as:

$$R(\tau) = \max_{1\le t\ge\tau} X(t,\tau) - \min_{1\le t\ge\tau} X(t,\tau), 1 \le t \le \tau$$

The standard derivation is defined as:

$$S(\tau)=\left\{\frac{1}{\tau}\sum_{t=1}^{\tau}[\,\xi(t)-\langle\xi\rangle_{\tau}\,]^{2}\right\}^{0.5},\tau=1,2,\cdots n$$

If there is a relationship of $R(\tau)\ /\ S(\tau)\propto\tau^{H}$ in the analyzed time series $\{\xi(t)\},t=1,2,3\cdots n$, it suggests the existence of a Hurst phenomenon. The value (H) of the Hurst Index is the slope of the straight line in the double logarithmic coordinates (1nτ, ln (R/S)), obtained from a least squares fit. Different H values (0<H<1) represent different intensities of persistence in the time series, as shown in Table 1. H =0.5 shows that changes in the time series are completely independent and random. It can be seen that the Hurst Index can well reveal trendy components in a time series and its value can be used to judge the intensity of persistence or reverse persistence of the trendy components (Zhang and Cha, 2008; Feng *et al.*, 2007).

3) Regression analysis. Correlation analysis is used to establish an annual runoff computation formula for the Bengbu Station to quantitatively analyze the impact of climate change on water resources in the study area.

Table 1 The Hurst Index classification list (Zhang and Cha, 2008)

| Level | H Value Range | Persistence Intensity | Level | H Value Range | Reverse Persistence Intensity |
|---|---|---|---|---|---|
| 1 | 0. 50 < H ≤0. 55 | Very weak | -1 | 0. 45 ≤H < 0. 50 | Very weak |
| 2 | 0. 55 < H ≤0. 65 | Fairly weak | -2 | 0. 35 ≤H < 0. 45 | Fairly weak |
| 3 | 0. 65 < H ≤0. 75 | Fairly strong | -3 | 0. 25 ≤H < 0. 35 | Fairly strong |
| 4 | 0. 75 < H ≤0. 80 | Strong | -4 | 0. 20 ≤H < 0. 25 | Strong |
| 5 | 0. 80 < H < 1. 00 | Very strong | -5 | 0. 00 < H < 0. 20 | Very strong |

## 3. Characteristics of climate change

### 3.1 Characteristics of rainfall change

Linear regression analysis is performed on the annual rainfall data observed over 48 years at the six stations in the study area, and the values of Trend Rate a1 are obtained. The results show that over the 48 years only the Zhengzhou Station in Henan Province was in a declining trend, at a rate of 1.84mm/10a ($r^2$=0.0003). However, the magnitude of decrease was small and could not pass significance test. The rainfall recorded by the other stations was on a rising trend. The Bengbu Station had the most notable rising trend, reaching a rate of 31.17mm/10a ($r^2$=0.0422), followed by Zhumadian, with 16.94 mm/10a ($r^2$=0.0062); Huoshan, with 13.35mm/10a ($r^2$=0.0044); Bozhou, with 5.91mm/10a ($r^2$= 0.0015); and Xinyang, with 4.26mm/10a ($r^2$= 0.0005). In terms of trend rate alone, rainfall decreased in the northwestern part of the Basin but notably increased in the southwestern part. But the correlation coefficients were very small in all the cases and failed significance level test. R/S analysis results show that Zhumadian, Zhengzhou, Xinyang and Bozhou all registered a certain trend of rainfall rise, but with a fairly weak or very weak intensity of persistence. The other stations, however, showed a falling trend. In the study area, average rainfall had an H value of 0.4403, indicating a fairly weak persistence. The falling trend was not noticeable, and rainfall was much affected by natural fluctuations in climate.

### 3.2 Characteristics of temperature change

For the 48 years under study, the annual average air temperature at the all six stations was on a rising trend, with

Table 2 Annual rainfall change rates and correlation coefficients at the 6 stations

| Province | Henan | | | Anhui | | |
|---|---|---|---|---|---|---|
| Station | Zhengzhou | Zhumadian | Xinyang | Bozhou | Bengbu | Huoshan |
| Trend rate $a_1$ (mm/a) | -0.1842 | 1.6938 | 0.4256 | 0.5910 | 3.1170 | 1.3348 |
| Correlation coefficient R | 0.0169 | 0.0788 | 0.0229 | 0.0382 | 0.2055 | 0.0665 |
| Hurst index | 0.5289 | 0.6250 | 0.5044 | 0.4930 | 0.5010 | 0.4677 |

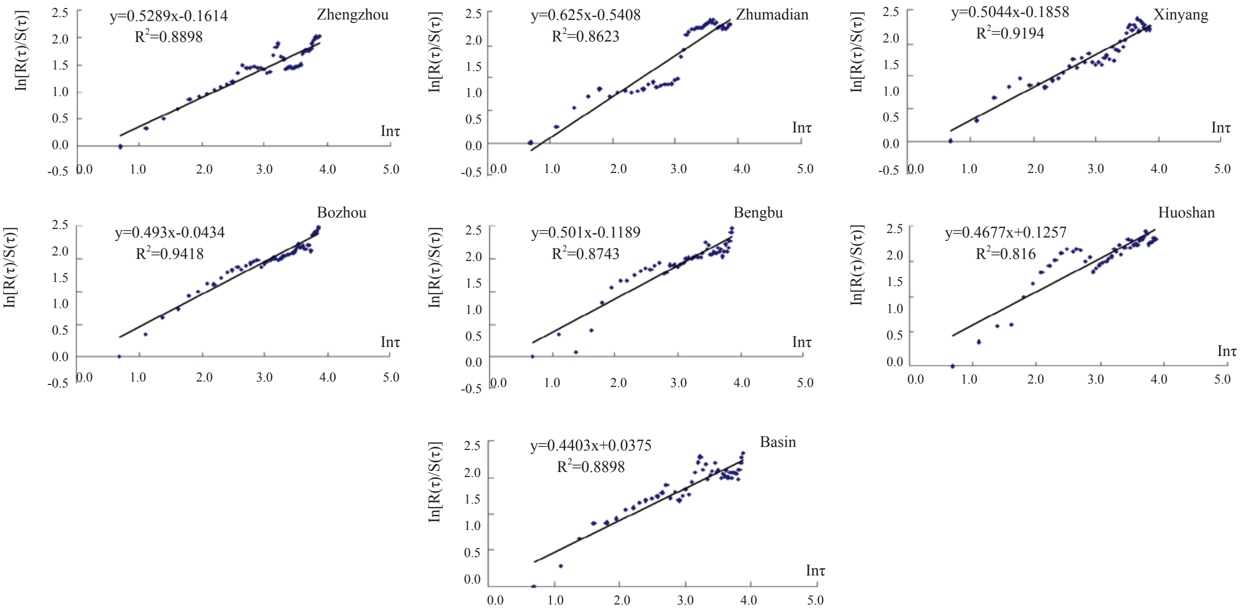

Figure 2 R/S analysis results of rainfall in the study area.

the fastest rise recorded in Zhengzhou, Bozhou and Bengbu and in the northwestern and southeastern parts of the study area. Specific changes in average annual air temperature were as follows: Zhengzhou, with 0.270°C/10a ($r^2$=0.345); Zhumadian, with 0.199°C/10a ($r^2$=0.198); Xinyang, with 0.189°C/10a, ($r^2$=0.247); Bozhou, with 0.264°C/10a ($r^2$=0.292); Bengbu, with 0.289°C/10a ($r^2$=0.412); and, Huoshan, with 0.198°C/10a ($r^2$=0.247). All the correlation coefficients passed significance test at the 0.01 confidence level. An H value of 0.9265 at Huoshan shows that the air temperature in the study area will continue a notably rising trend in the next few years. Against a background of global warming, the average air temperature in the whole study area will be on a rising trend. This is basically consistent with the warming trend in the Jianghuai region (Tian *et al*, 2005; Lu *et al*, 2010).

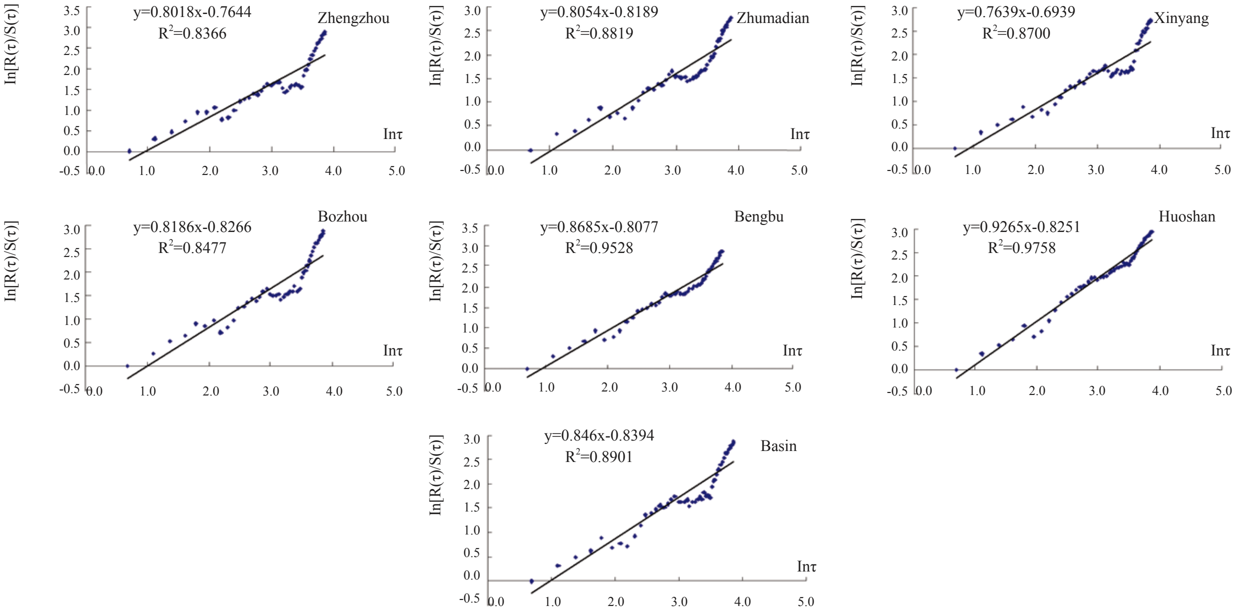

Figure 3 R/S analysis results of air temperature in the study area.

Table 3 Average annual air temperature change rates and correlation coefficients at the six stations

| Province | Henan | | | Anhui | | |
|---|---|---|---|---|---|---|
| Station | Zhengzhou | Zhumadian | Xinyang | Bozhou | Bengbu | Huoshan |
| Trend rate $a_1$ (°C/a) | 0.0270 | 0.0199 | 0.0189 | 0.0264 | 0.0289 | 0.0198 |
| Correlation coefficient R | 0.5871 | 0.4449 | 0.4968 | 0.5399 | 0.6408 | 0.4973 |
| Hurst index | 0.8018 | 0.8054 | 0.7639 | 0.8186 | 0.8685 | 0.9265 |

## 4. Characteristics of runoff change

Figure 4 shows the curve of natural runoff changes at the Bengbu Station. No clear trend of change can be detected from the curve, and the linear correlation coefficient involved is very small. Preliminary 5-year moving average fit reveals a wet and dry cycle of around 20 years at Bengbu. Annual runoff trend analysis only results in an H value of 0.4743 (Figure 5). This indicates a gradual falling trend, but the intensity of persistence is rather weak.

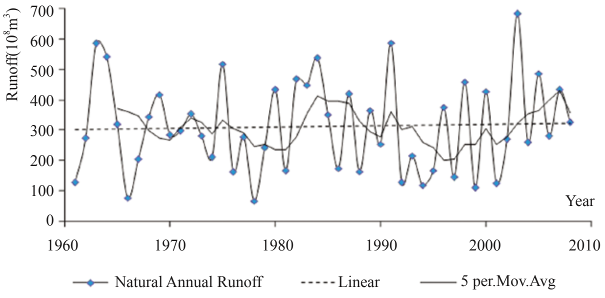

Figure 4 Natural annual runoff process and its change trend at the Bengbu Station.

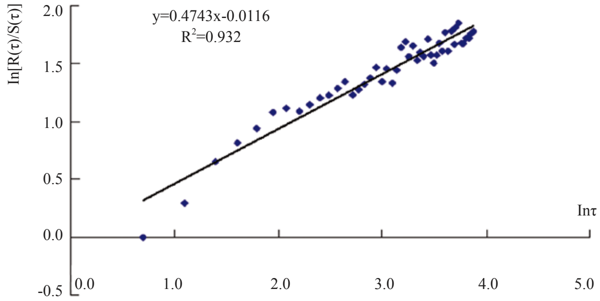

Figure 5 R/S analysis results of runoff at the Bengbu Station.

## 5. Impact of climate change on water resources

### 5.1 Model building

Climate change has a complicated impact on regional water resources. However, establishing statistical models to explore and simulate the prototype is still a rational and effective approach (Yuan, 1993). The current study uses bitivariate linear regression to establish a mathematical model between annual runoff (W) and annual rainfall (P) and average annual air temperature (T) to quantitatively analyze the impact of climate change on water resources. The following mathematical model is established:

$$W=C+aP+bT$$

Wherein: W is annual runoff; P is annual average rainfall; and, T is average annual air temperature.

For a bivariate linear regression model, the least squares method can be used to compute the constant C and coefficients a and b.

In the model, T and P are respectively the mean values weighted according to the station-controlled area/study area ratio. The calculation formula is as follows:

$$X(t)=\frac{1}{F}\sum_{t=1}^{n}[X_i(t)F_i]$$

Wherein: X is the mean of a climatic factor (*i.e.* T and P) in the study area; t is time; Xi and Fi are respectively the observed value of the climatic factor at Station i and the area controlled by Station i; and F is the area of the whole study area.

Using data for the 1961~2008 period, the natural annual runoff process at the Bengbu Station and its average annual air temperature and rainfall series can be established. The following model is obtained:

$$W=-45.972+0.762P-23.652T$$

Wherein: R=0.772, F=76.063, and Sig.F=0.000. It is very obvious that the correlation coefficient R is rather high, F is far greater than Sig.F, and Sig.F is less than 0.01. Significance level test shows a very good regression

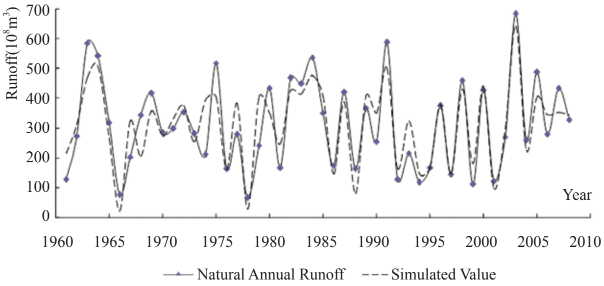

Figure 6 Comparison between observed and simulated annual runoff at the Bengbu Station.

result. Figure 6 compares the natural runoff process and the model-simulated result at the Bengbu Station.

### 5.2 Climate change impact analysis

To explore the impact of climate change on water resources in the Basin, this paper sets the following scenarios and uses the established water resources system model to quantitatively analyze how water resources respond to climate change. Table 4 shows that its annual runoff increases with rainfall but decreases with average annual air temperature. Assuming that air temperature does not change, when rainfall changes by 20%, runoff will change by 45.9%. Assuming that rainfall does not change, a 10% increase in rainfall will result in a rise of 22.95% in average natural runoff at the Bengbu Station, while a 20% increase in rainfall will increase mean average runoff by 45.90%. When rainfall is kept unchanged, a rise of 1°C in average annual air temperature will lead to a fall of 7.56% in annual natural runoff, while a 2°C increase will cause a runoff decrease by 15.12% at the Bengbu Station. Table 4 also shows that the annual runoff at the Bengbu Station is much more sensitive to rainfall changes than to air temperature changes.

Table 4 Annual runoff responses to various climate change scenarios at the Bengbu Station Units: %, °C

| Rainfall Change Rate (%) | Air Temperature Change (°C) | | | | |
|---|---|---|---|---|---|
| | -2 | -1 | 0 | 1 | 2 |
| -20 | -30.78 | -38.34 | -45.90 | -53.47 | -61.03 |
| -10 | -7.83 | -15.39 | -22.95 | -30.51 | -38.08 |
| 0 | 15.12 | 7.56 | 0.00 | -7.56 | -15.12 |
| 10 | 38.08 | 30.51 | 22.95 | 15.39 | 7.83 |
| 20 | 61.03 | 53.47 | 45.90 | 38.34 | 30.78 |

Note: Data in the middle of the table are annual runoff change rates (%).

## 6. Conclusions

The following preliminary conclusions can be drawn from the above analysis of climate change characteristics (mainly air temperature and rainfall) in the Basin (above Bengbu Station) and annual runoff changes at Bengbu Station:

(1) All the six stations in the study area showed a clear trend of rise in average annual air temperature from 1961 to 2008. All stations had a Hurst Index value of over 0.75, showing high persistence. Meanwhile, the high H value also indicates that air temperature will continue to rise for some time in the future. This is also a main reflection of climate warming in the river basin. Rainfall is unevenly distributed in space across the river basin. For the 1961-2008 period, rising rainfall was mainly observed in the western part of the study area, while rainfall actually fell in the eastern part, i.e. the middle reaches of the Huai River. The average rainfall in the study area was in a vaguely falling trend. In other words, rainfall in the river basin is still much affected by natural fluctuations.

Researchers collecting water samples in the Huai River.

(2) The annual runoff in the study area had an H value of 0.4743 for the studied period, showing a falling trend, though with weak persistence intensity. This is because runoff is more sensitive to rainfall than to average annual air temperature in the region.

Based on almost 50 years of water resources quantity, air temperature and rainfall data, the current research has developed a mathematical model and set different climatic scenarios to examine the future responses of water resources quantity to changes in climatic factors in the Basin above Bengbu. However, given the much generalized impact of social, economic and ecosystem changes, the conclusions reached here should be only considered as preliminary and can only reflect the impact of air temperature and rainfall changes on water resources quantity under the current conditions. It is still necessary to strengthen research on the joint impact of climate change and human activities on water resources in the Basin.

**Acknowledgements**

This research is supported by the National Natural Sciences Foundation of China (Project Nos. 51079132 and 50679075), the Special Research Fund Project of the Chinese Ministry of Water Resources (Grant No. 200801001), the Research Fund for the Doctoral Program of Higher Education of China (Grant No. 20094101110002), the National Key Scientific and Technological Project on Water Pollution Control and Treatment of China (Project No. 2009ZX07210-006).

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