Research on the Impacts of Warming Rate on Drought-flood in Huang-huai-hai River Basin of China

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Abstract. In this study, the sequential Mann-Kendall and Yamamoto test analysis are used to determine abrupt changes in temperature in Huang-huai-hai River Basin, while time series analysis via the traditional Mann-Kendall test and linear regression analysis for the different period is used to identify the basic trend of temperature. The results suggest that the temperature data can be divided into three periods: 1961-1985, 1986-1995 and 1996-2011. The slope of annual temperature during 1961-1985, 1986-1995 and 1996-2011 were -0.07°C(10yr)−1, 0.40°C(10yr)−1 and 0.04°C(10yr)−1 respectively. These three stages were defined as follows: Stage A (low temperature with no significant change), Stage B (sharp increase of temperature) and Stage C (stagnation of temperature increase). The drought/wet magnitude was assessed based on China-Z index and the area of drought/wet was calculated. The relationship between drought/wet area and temperature during the three stages was then analyzed and compared. The results showed that: during Stage A (low temperature with no significant change), flood area is comparatively big and drought area is small, but with acute interannual variation; during Stage B (sharp increase of temperature), flood area decreased but the drought area still increased; during Stage C (stagnation of temperature increase), flood area and drought area both had big interannual variation.

1. Introduction
Climate change has become one of the toughest issues of our times which has attracted the attention of many scholars. The annual mean surface warming since the 20th century has reversed long-term cooling trends of the past 5,000 years in mid-to-high latitudes of the Northern Hemisphere. For average annual temperature in northern hemisphere, the period during 1983-2012 was very likely the warmest 30-year of the last 800 years and was likely the warmest 30-year of the last 1400 years [1]. China is the world’s most populous country and is a major emitter of greenhouse gases. China has also been experiencing climate warming with no exception. Annual mean surface air temperature in China has increased significantly, with a changing rate of 0.22°C (10 yr)−1 for the period 1951-2001 and 0.08°C (10yr)−1 for the period 1905-2001[2]. Annual mean temperature in China now is 1.23°C higher than that in the 1950s. This is concluded from the ongoing measurements of 156 meteorological stations [3]. The average temperature has increased by 0.035°C /year, 0.03°C/year, 0.018°C/year and 0.02°C/year in the Northwest, Northeast, Southwest and Southeast parts of China in the past 60 years respectively [4-7]. In the context of climate change, the frequency and severity of extreme weather
events such as waterlog and drought are increasing sharply and a considerable number of countries have been suffering from weather-related disasters [8]. As one of the developing countries which are vulnerable to climate change, China is threatened by relentless waterlog and drought due to the negative influence on the natural ecosystems and socio-economic systems brought by these events. Over the past several decades, China has already experienced some devastating climate extremes [9], especially in Huang-huai-hai River Basin. According to statistics from other studies, the drought occurs almost twice every three years in Huang-Huai-Hai River Basin [10]. Haihe River Basin is a typical drought-prone area [11] while Huaihe River Basin often suffers from flood and waterlog [12]. Global change characterized by warming leads to the acceleration of hydrological cycle and then reduces the stability of hydrological system which may cause the extreme events. But the temperature rising rate is not stable and it varies during different periods. Thus the characteristics of waterlog and drought are different in different stages.

In this study, the China-Z index was chosen to assess drought/wet magnitude in Huang-Huai-Hai River Basin. Based on the observed annual temperature and time series analysis, the abrupt changes in temperature were determined which divided the temperature data into three periods. The relationship between drought/wet area and temperature for the three periods was then analyzed and compared.

2. Materials and methods

2.1. Study area

The Huang-Huai-Hai River Basin (HHH) situated between 110° and 120°E and between 32° and 42°N, is the area investigated in this study. The total area is 14.45×10^5 km^2, accounting for 15.0% of total area of China. The elevation of the study area varies from -7 to 6,188 m, dropping off from west to east. The Annual mean precipitation and evaporation of HHH are about 556.0 mm and 1699.5 mm respectively [13]. The population in HHH accounts for 35% of the total amount of China, and the GDP makes up 32% of that in the whole nation [14-15]. Covering the whole country’s 20.4% farmland and providing 23.6% grain production of the nation, the plain area in the basin plays a key role in Chinese agriculture production [16].

![Figure. 1 Location of Huang-Huai-Hai River Basin](image)

Table 1 the Area of Sub-River Basin and the Characteristic of Precipitation (1961-2010)

| River Basin               | Area /10^5km^2 | Annual Precipitation          |
|---------------------------|----------------|------------------------------|
|                           |                | Average/mm | Coefficient of Variation   |
| Haihe River Basin         | 3.20           | 538.1       | 0.18                        |
| Yellow(Huanghe) River Basin | 7.95           | 439.9       | 0.14                        |
2.2. Data
Mean daily precipitation for the period of 1961-2011 from 982 meteorological stations which are located in HHH were chosen in this study. Years that include missing data for a particular meteorological station are deleted prior to analysis. If the missing data reaches up to 80% of the total record for a certain meteorological station, data from this meteorological station is excluded from the analysis. The distribution of meteorological stations used in this research are shown in Figure 2.

| River Basin                  | Mean Daily Precipitation | Annual Precipitation | Skewness |
|------------------------------|--------------------------|----------------------|----------|
| Huaihe River Basin           | 3.30                     | 854.2                | 0.16     |
| Huang-Huai-Hai River Basin   | 14.45                    | 556.0                | 0.12     |

2.3. Assessment of drought/wet magnitude
IDW (Inversed Distance Weighted) method was applied to create continuous grid surfaces (5km×5km) for rainfall with the seasonal/annual precipitation data because the set of stations was dense enough to capture the extent of Huang-Huai-Hai River Basin surface variation [17]. The drought/waterlog magnitude of each grid at 12-month time scale (year scale) were evaluated by China-Z index (CIZ) [18] which was introduced to the National Meteorological Centre of China (NMCC) in the early 1990s [19].

Based on the assumption that precipitation data obeys the Pearson Type III distribution, the CZI is calculated as

\[
Z_i = \frac{6}{C_i} \left( \frac{C_s \phi_i + 1}{2} \right)^{1/3} - \frac{6}{C_i} + \frac{C_s}{6}
\]

Where, \(Z_i\) is the CZI, \(i\) is the current season (year), \(C_i\) is coefficient of skewness and \(\phi_i\) is standardized variate. The \(C_s\) and \(\phi_i\) can be calculated as

\[
C_s = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n \sigma^2}
\]

\[
\phi_i = \frac{x_i - \bar{x}}{\sigma}
\]

In Equation (2) and Equation (3),
\[ \sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2} \]  
(4)

\[ \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \]  
(5)

Where, \( x_i \) is seasonal (yearly) precipitation and \( n \) is the total number of years in the record.

With the standard listed in table 2 [18], the drought/waterlog magnitude of each grid can be evaluated.

| Level | CZI     | Magnitude          |
|-------|---------|--------------------|
| 1     | \( Z \geq 1.645 \) | Severely Waterlog  |
| 2     | 1.037 \( \leq Z < 1.645 \) | Moderately Waterlog |
| 3     | 0.842 \( \leq Z < 1.037 \) | Slightly Waterlog  |
| 4     | -0.842 \( < Z < 0.842 \) | Normal             |
| 5     | -1.037 \( < Z \leq -0.842 \) | Slightly Drought   |
| 6     | -1.645 \( < Z \leq -1.037 \) | Moderately Drought |
| 7     | \( Z < -1.645 \) | Severely Drought   |

### 2.4. Analysis of climatic drought/wet variation

A trend analysis of the annual drought/wet area variation was performed by applying the Mann-Kendall statistical test method, which is a non-parametric test that has been widely used for the long-term change analysis of climate and ecological process at regional scale [20]. The test statistic, Kendall’s S, is calculated as follows [21-22]:

\[ s = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \]  
(6)

Where, \( x \) are the data values at times \( i \) and \( j \), \( n \) is the length of the dataset and

\[
\text{sgn}(x_j - x_i) = \begin{cases} 
1 & \text{if } (x_j - x_i) > 0 \\
0 & \text{if } (x_j - x_i) = 0 \\
-1 & \text{if } (x_j - x_i) < 0
\end{cases}
\]  
(7)

Under the null hypothesis that \( x_i \) is independent and randomly ordered, \( S \) is approximately normally distributed when \( n > 8 \), with zero mean and a variance of

\[ \text{Var}(S) = \frac{n(n+1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \]  
(8)

The standardized test statistic \( Z \) is computed by the following formula:

\[
Z = \begin{cases} 
\frac{S - 1}{\sqrt{\text{Var}(S)}} & S > 0 \\
0 & S > 0 \\
\frac{S + 1}{\sqrt{\text{Var}(S)}} & S < 0
\end{cases}
\]  
(9)
The statistic $Z$ follows the standard normal distribution with a mean of zero and a variance of one under the null hypothesis of no trend in the series. At a chosen level of significance $\alpha = 0.05$, if $|Z| > 1.96$, then the trend of the series is significant.

3. Results

3.1. Changes of temperature in Huang-huai-hai River Basin

The observed annual temperature over Huang-huai-hai River Basin from 1961 to 2011 is presented in Figure 3. Average annual temperature for the study area is 8.42°C. Temperature is not stable, with an increase of 1.05°C from 1960s to 2000s. Based on the Mann-Kendall analysis, annual trend of temperature is positive. The trend is statistically significant with $Z$-value of 4.47 ($Z > 1.96$, $\alpha = 0.05$).

The sequential Mann–Kendall test and Yamamoto method were used to graphically illustrate the forward, middle and backward trends of annual temperature for the Huang-huai-hai River Basin for the period 1961-2011 (Figure 4). The slope of annual temperature during 1961-1985, 1986-1995 and 1996-2011 are $-0.07°C(10\text{yr})^{-1}$, $0.40°C(10\text{yr})^{-1}$ and $0.04°C(10\text{yr})^{-1}$ respectively. According to this, we define 1961-1985 is Stage A (low temperature with no significant change); 1986-1995 is Stage B (sharp increase of temperature); 1996-2011 is Stage C (stagnation of temperature increase).

Figure 3 Variation in annual temperature (1961-2011)

Figure 4 Sequential Mann–Kendall and Yamamoto test for annual temperature

Figure 5 is the spatial distribution of annual temperature slope of different periods in Huang-huai-hai region. Generally speaking, during 1961-1985 annual temperature in Huang-huai-hai region decreased slightly except the Yellow River source and Hetao plain where temperature increased slightly. During 1986-1995, temperature in Huang-huai-hai region increased widely (middle and lower reaches of the Yellow River, Haihe River Basin and Huaihe River Basin), especially in plain area of Haihe River Basin and Huaihe River Basin, where the temperature slope is more than $0.5°C/10\text{year}$. During 1996-2011, the warming feature is diametrically opposite to that during 1986-1995: except the Yellow River source where temperature increased quickly, all the other areas showed a decreasing trend.
3.2. Changes of drought and waterlog areas in Huang-huai-hai River Basin

Figure 6 illustrated the annual drought/wet areas in Huang-huai-hai River Basin from 1961 to 2011. Table 3 listed the average drought/wet areas in different magnitude. By comprehensively analyzing Figure 6 and Table 3, we can conclude that: ① In the recent 50 years, total area of drought in Huang-huai-hai region has increased while that of wetness has decreased. The changing rate slope are 0.14%(10yr)$^{-1}$ and 2.80%(10yr)$^{-1}$ respectively. The decreasing trend of wetness area has past significance test at $\alpha=0.05$; ② Drought and flood issues in Huang-huai-hai region has been relieved to some degree in the recent 50 years on the whole. For drought, although the total drought area increased, the trend is not statistical significant. Besides, area of moderate drought and severe drought has decreased. For waterlog, the area of different classes all have a decreasing trend, in which the decreasing area of severe wet has past the significance test at $\alpha=0.05$. 

![Figure 5: The slope of annual temperature during 1961-1985, 1986-1995 and 1996-2011](image-url)
Figure 6 Area of drought/waterlog in Huang-Huai-Hai River Basin from 1961 to 2011

Table 3 Area of drought in different magnitude

| Magnitude  | Drought       | Wet          |
|------------|---------------|--------------|
|            | Z-value | Area(10^4 km^2) | Z-value | Area(10^4 km^2) |
| Slightly   | 1.02    | 7.4           | -1.08   | 7.2            |
| Moderately | -0.20   | 15.5          | -1.88   | 14.0           |
| Severely   | -0.35   | 6.9           | -2.28*  | 7.5            |
| Total      | 0.32    | 29.7          | -2.07*  | 28.7           |

3.3. Impacts of temperature changes on drought and waterlog in Huang-huai-hai River Basin

Figure 7 and Figure 8 showed the impacts of temperature on drought and waterlog (here we focus on the area change of moderate and severe drought/waterlog). Table 4 and Table 5 show the statistical characteristic of drought/waterlog area with different warming rates.

① Impacts of different warming rates on drought area

From Figure 7 and Table 4 it can be seen that during Stage A (1961-1985, low temperature with no significant change), area of moderate drought and severe drought of Huang-huai-hai region was about 20.94×10^4 km^2 which was 14.5% of the whole study area. Besides, the drought area has big inter-annual variation. During Stage B (1986-1995, sharp increase of temperature), area of moderate drought and severe drought of Huang-huai-hai region was about 23.36×10^4 km^2 which has increased by about 11.6% compared to that during 1961-1985. But the inter-annual variation of drought area during Stage B is comparatively small. During Stage C (1996-2011, stagnation of temperature increase), area of moderate drought and severe drought of Huang-huai-hai region was about 23.85×10^4 km^2 which only increased a little (2.1%) compared with that during 1986-1995. And the inter-annual variation of drought area during Stage C increased to some degree compared to Stage B.

② Impacts of different warming rates on waterlog

It can be seen from Figure 8 and Table 5 that during Stage A (1961-1985, low temperature with no significant change), area of moderate waterlog and severe waterlog of Huang-huai-hai region was about 26.48×10^4 km^2 which was 18.3% of the whole study area. Besides, the waterlog area has big
inter-annual variation. During Stage B (1986-1995, sharp increase of temperature), area of moderate waterlog and severe waterlog of Huang-huai-hai region decreased sharply which has decreased by about 42.0% compared to that during 1961-1985. And the inter-annual variation was also the smallest. During Stage C (1996-2011, stagnation of temperature increase), area of moderate waterlog and severe waterlog of Huang-huai-hai has increased by 12.95% compared to that of 1986-1995. And the inter-annual variation also increased sharply.

Table 4 Statistical characteristic of drought area with different warming rates

| Index        | Unit | 1961-1985 | 1986-1995 | 1996-2011 |
|--------------|------|-----------|-----------|-----------|
| Temperature  | Average | ℃     | 8.03 | 8.39 | 9.04 |
|              | Slope   | °C/10a  | -0.07 | 0.40 | 0.04 |
|              | Cv      | /       | 0.041 | 0.040 | 0.042 |
| Drought area | Average | 10⁴km² | 20.94 | 23.36 | 23.85 |
| (Z<-1.037)  | Cv      | /       | 0.898 | 0.755 | 0.858 |

Table 5 Statistical characteristic of waterlog area with different warming rates

| Index        | Unit | 1961-1985 | 1986-1995 | 1996-2011 |
|--------------|------|-----------|-----------|-----------|
| Temperature  | Average | ℃     | 8.03 | 8.39 | 9.04 |
|              | Slope   | °C/10a  | -0.07 | 0.40 | 0.04 |
Cv / 0.041 0.040 0.042
Wet area Average \(10^4\) km\(^2\) 26.48 15.37 17.36
Cv / 0.915 0.758 1.122

4. Conclusion
During 1961-2011, annual mean temperature in Huang-huai-hai region showed a significantly increasing trend on the whole with the slope of 0.27°C (10yr\(^{-1}\)). The annual mean temperature in the 2000s increases by about 1.05°C compared with that in the 1960s. Two breaking points of the annual mean temperature change were detected via Sequential Mann–Kendall test and Yamamoto test, which are 1985 and 1995. Annual mean temperature has different changing features during 1961-1985, 1986-1995 and 1996-2011 respectively. During 1961-1985, the temperature of Huang-huai-hai region was comparatively low with no significant change. Temperature in most of the study area decrease slightly. During 1986-1995, temperature in Huang-huai-hai region increased sharply, which is especially significant in plain area of Haihe River Basin and Huaihe River Basin. During 1996-2011, temperature increase in Huang-huai-hai region stagnated on the whole; temperature only increased significantly in the source regions of the Yellow River.

During 1961-2011, total drought area of Huang-huai-hai region showed an insignificantly increasing trend while the total wet area had a statistic significant trend. Drought/wet area had different features in different warming stages. In Stage A (low temperature with no significant change), drought/wet area had big inter-annual variation but the drought area was smaller than the wet area. In Stage B (sharp increase of temperature), drought/wet area had small inter-annual variation but the drought area increased sharply while the wet area decreased sharply. In Stage C (stagnation of temperature increase), the mean value and inter-annual variation of drought/wet area both increased to some degree compared with those in Stage B, but the increasing magnitude of drought area was smaller than that of the wet area.

Acknowledgments
Acknowledgements. This research was funded by [National Key Research and Development Project] grant number [2017YFC1502404]; [National Natural Science Foundation of China] grant number [51709008,51779013]; National Public Research Institutes for Basic R&D Operating Expenses Special Project (no. CKSF2017061/SZ).

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