Long-term variation of water vapor content and precipitation in the Haihe river basin
Chun Chang, Ping Feng, Fawen Li and Yunming Gao

ABSTRACT

Based on the Haihe river basin National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis data from 1948 to 2010 and the precipitation data of 53 hydrological stations during 1957–2010, this study analyzed the variation of water vapor content and precipitation, and investigated the correlation between them using several statistical methods. The results showed that the annual water vapor content decreased drastically from 1948 to 2010. It was comparatively high from the late 1940s to the late 1960s and depreciated from the early 1970s. From the southeast to the northwest of the Haihe river basin, there was a decrease in water vapor content. For vertical distribution, water vapor content from the ground to 700 hPa pressure level accounted for 72.9% of the whole atmospheric layer, which indicated that the water vapor of the Haihe river basin was mainly in the air close to the ground. The precipitation in the Haihe river basin during 1957–2010 decreased very slightly. According to the correlation analysis, the precipitation and water vapor content changes showed statistically positive correlation, in addition, their break points were both in the 1970s. Furthermore, the high consistency between the precipitation efficiency and precipitation demonstrates that water vapor content is one of the important factors in the formation of precipitation.

Key words | correlation analysis, precipitation, variation characteristics, water vapor content

INTRODUCTION

China is a country that lacks water resources, which has become a major critical challenge for social and economic development. In the Haihe river basin, the amount of water resources per capita is only 305 m³ per year, representing 1/7 of the average in China and 1/27 of the average in the world (Bao et al. 2012; Liu et al. 2013). The water resources exploitation and utilization ratio in the Haihe river basin is generally over 100%, for surface water it is 67%, exceeding the internationally recognized reasonable limit of 40% (Li 2012). Not only is the contradiction between supply and demand for water sharpening, but also the problems of water pollution, groundwater over-exploitation and aquatic ecological degradation are getting worse. As a kind of latent water resource, the water vapor content and its transportation plays an important role in the water cycle and is closely related to water resources problems. So the effective management of water resources in the air has been one of the effective ways to solve regional water resources shortage problems (Zhang et al. 2008a; Seco et al. 2012; Wang et al. 2014).

So far, many studies have been carried out regarding the analysis of water vapor and precipitation variability throughout the world. As for water vapor analysis, Rao et al. (1996) calculated vertically integrated water vapor flux and its divergence for South America, and Trenberth et al. (2005) performed an analysis and evaluation of global datasets on column-integrated water vapor. National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data are common in water vapor research (Liu & Stewart 2003; Mestas-Nuñez et al. 2007). In terms of precipitation variation, Pasquini et al. (2006) focused on hydroclimatic records (rainfall and
river runoff) from an area in central Argentina and Tabari & Talaee (2011) analyzed the annual and seasonal precipitation trends of 41 stations in Iran for the period 1966–2005 using the Mann–Kendall test, the Sen’s slope estimator and linear regression. In addition, Bretherton et al. (2004) analyzed the relationship between water vapor path and surface precipitation rate over tropical oceanic regions using 4-year gridded daily Special Sensor Microwave/Image (SSM/I) satellite microwave radiometer data.

The atmospheric water vapor research in China began in the 1950s. Xu (1958) analyzed the water vapor transport and balance in China, and Xie & Dai (1959) studied the water vapor transport during the heavy precipitation period in the Yellow River area. After the upper-air sounding data came out, Lu & Gao (1984) performed further analysis on the climatological distribution of water vapor over China. Studies of the distribution, interannual variation and trends of atmospheric water in China were released continuously in the 1990s (Zhai & Eskridge 1997; Zhai & Zhou 1997; Simmonds et al. 1999). The water vapor research in the past was limited by the shortage and inhomogeneity of data, thus the NCEP and NCAR reanalysis data from 1948 to 2010 were selected for trend analysis in this paper. Beyond the water vapor analysis, precipitation variation has been discussed in recent years. Liu et al. (2008) investigated the spatial and temporal trends of the precipitation in the Yellow river basin during 1960–2006 using the Shannon entropy method, Mann–Kendall method and linear fitted model. Zhang et al. (2011) did extensive investigation on the changes in precipitation and streamflow in both space and time across China during 1960–2000.

In the last 50 years, there have been significant changes in precipitation in the Haihe river basin. The total precipitation from 1980 to 2000 reduced by 11% compared with the 1956–1979 time series. At the same time, the evolution of water resources was deeply influenced, compared with the 1956–1979 time series, and the surface water resources decreased by 40% during 1980–2000, making the intense water resource condition even worse (Yu et al. 2010).

However, there has been little quantitative research carried out in the Haihe river basin on trends and variability of atmospheric water vapor content and its correlation with precipitation. The existing studies mainly focused on the water vapor flux in latitude and longitude directions in the years when serious droughts or loggings occurred (Zhang et al. 2008a) and the water vapor budget and transport in summer over the Haihe river basin from 1951 to 2008 (Zhu et al. 2011). In addition, Chu et al. (2010) examined and compared the precipitation data from 30 weather stations for 1958–2007 and 248 rain gauges for 1995–2004 in the Haihe river basin using linear regression, 5-year moving average, Mann–Kendall trend analysis, Kolmogorov–Smirnov test, Z test and F test methods.

The main objectives of this study were to analyze the temporal and spatial variations of water vapor content from 1948 to 2010 and precipitation from 1957 to 2010 then detect the relationship between the two using correlation analysis, which could be the basis of future research and provide important information for proper use of atmospheric water.

**STUDY AREA**

The Haihe river basin (Figure 1), located in the northern part of China, lies on longitude 112 to 120 E and latitude 35 to 43 N with a drainage area of 318,200 km², which accounts for 3.3% of the national total. The eastern, western, southern and northern boundaries are the Bohai Sea, Taihang Mountain, Yellow River and Mongolian Plateau, respectively. Of the three river systems (Haihe River system, Luanhe River system and Tuhaimajiahe River system) in the Haihe river basin, the Haihe River system is the biggest one, which is made up of the Jiyun River, Chaobai River, Beiyun River and Yongding River in the north and the Daqing River, Ziya River and Zhangwei River in the south. The Luanhe River system includes the Luanhe River and rivers off the coast of eastern Hebei province. As a plain river that runs into the sea independently, the Tuhaimajiahe River system lies in the most southern part of the Haihe river basin.

The Haihe river basin belongs to the eastern Asia temperate monsoon climate zone. It is always cold and dry in winter because of the Siberian continental air mass. Influenced by the Mongolian continental air mass, spring is windy and droughts become frequent. Summer is humid and hot with intense rainstorms due to the maritime air mass. Autumn is the transition period between summer and winter with cool weather and less rain.

The Haihe river basin slopes from the northwest to the southeast. About 60% of the drainage area is mountainous and the other 40% is plain. As a semi-humid and semi-arid
area, the watershed receives an average precipitation of 539 mm, mostly in summer (70–85%), especially in July and August. It seldom rains in winter while it rains a lot in summer (Chen et al. 2005; Zhang et al. 2008b). The precipitation in the Haihe river basin has obvious regional characteristics. Xu et al. (2009) analyzed the hydrological data during 1951–2005, and the results showed that the precipitation generally decreased from the east to the west and the interannual variation reduced northward. Floods and droughts are more likely to occur in areas with big interannual variations, such as the south Haihe river basin.

**DATA AND METHODS**

**Data**

**Water vapor content**

The NCEP and NCAR have cooperated to produce a retroactive record of more than 50 years of global analyses of atmospheric fields in support of the needs of the research and climate monitoring communities. The NCEP/NCAR reanalysis uses a frozen state-of-the-art global data assimilation system and a database as complete as possible (Kalnay et al. 1996; Kistler et al. 2001).

The NCEP/NCAR daily reanalysis data with a resolution of $2.5^\circ \times 2.5^\circ$ of latitude by longitude were used to calculate the atmospheric water vapor content in the Haihe river basin during 1948–2010. Sixteen gauging points were chosen as displayed in Figure 2. On account of the irregular boundaries of the Haihe river basin, 112 to 120 E, 35 to 43 N was selected as the range of this study.

**Precipitation**

Monthly and annual precipitation data of 53 hydrological stations extracted from ‘China’s Hydrological Year Book’ in the Haihe river basin were selected for the trend analysis of precipitation. There are about 200 hydrological stations in the Haihe river basin, however, only 53 of these had a continuous record. From 1957 to 2010 was the maximum common time period of data recorded at the 53 stations,

![Figure 1](https://iwaponline.com/jwcc/article-pdf/6/2/341/375742/jwc0060341.pdf)

Figure 1 | The Haihe river basin and its location.

![Figure 2](https://iwaponline.com/jwcc/article-pdf/6/2/341/375742/jwc0060341.pdf)

Figure 2 | The 16 gauging points in the Haihe river basin.
all of whose data were for more than 50 years. The geographical location of the stations is shown in Figure 1.

Methods

Calculating the water vapor content

Atmospheric water vapor content, or precipitable water, is the liquid which is generated from the condensation of water vapor in a whole air column. The theory formula is as follows:

\[ W = -\frac{1}{g} \int_{p_s}^{0} q \, dp \] (1)

In practice, water vapor content is the sum of the differences of specific humidity between mandatory levels

\[ W = -\frac{1}{g} \sum_{p_i} q \cdot \Delta p_i \] (2)

\( W \) is the total water vapor content of the atmospheric layer per unit area, \( p \) is air pressure, \( q \) is specific humidity, \( g \) is gravity and \( p_s \) and \( p_t \) are surface pressure and top pressure, respectively. For simplicity, 1,000 hPa is usually selected as the surface pressure, so \( p_s = 1,000 \) hPa. According to the rule that water vapor pressure shows a negative exponent attenuation as rising, there is little water vapor on the 300 hPa level and the pressure is only 1/60 of the surface pressure. Hence 300 hPa is adequate as the top layer, that is, \( p_t = 300 \) hPa. The sum in Equation (2) is evaluated by data at 1,000, 925, 850, 700, 600, 500, 400 and 300 hPa levels.

The Mann–Kendall test

There are several kinds of trend analysis methods on hydrologic data variation such as Regression, Accumulative Anomaly, Moving-average, Quadratic Smooth, and Cubic Spline Function (Chen & Rao 2002). In this paper, the non-parametric Mann–Kendall test (Mann 1945; Kendall 1975) was selected to detect trends and break points of water vapor content and precipitation. It has been widely used in trend analysis of hydrological and meteorological data (Hamed 2008; Gocić & Trajkovic 2013; Zang & Liu 2013) for it not only can handle non-normalities involving seasonality, missing values, censoring, or unusual data reports, such as values marked ‘less than’, but also has a high asymptotic efficiency (Berryman et al. 1988; Gan 1998; Fu et al. 2004), as well as its formulas (Modarres & Silva 2007).

In the Mann–Kendall test, the null hypothesis \( H_0 \) is that \( UF_i \) is not statistically significant. The test statistic \( UF_i \) is formed as follows:

\[ UF_i = \frac{S_i - E(S_i)}{\sqrt{Var(S_i)}} (i = 1, 2, \ldots, n) \] (3)

\[ S_h = \sum_{i=1}^{k} r_i \quad (k = 2, 3, \ldots, n) \] (4)

\[ r_i = \begin{cases} 1, & x_i > x_j \\ 0, & x_i \leq x_j \end{cases} \quad (j = 1, 2, \ldots, i - 1) \] (5)

\( x_i \) is an independent and identically distributed random variable with \( n \) samples. The expected value and variance are calculated as follows:

\[ E(S_i) = \frac{i(i - 1)}{4} \] (6)

\[ Var(S_i) = \frac{i(i - 1)(2i + 5)}{72} \] (7)

On a significance level of \( \alpha \), the null hypothesis \( H_0 \) is accepted if \( |UF_i| < U_{\alpha/2} \), where \( U_{\alpha/2} \) is the standard normal deviation. In contrast, if \( |UF_i| > U_{\alpha/2} \), \( UF_i \) is statistically significant. A positive \( UF_i \) value denotes a positive trend, and a negative \( UF_i \) value denotes a negative trend. According to the inverse time series: \( x_n, x_{n-1}, \ldots, x_1 \), \( UF_i \) could be calculated. By the definition of \( UB_i = -UF_j \), \( j = n, n - 1, \ldots, 1 \) \((j = n + 1 - i)\), the curve of \( UF_i \) and \( UB_i \) could be plotted. If there is a match point of the two curves and the trend of the series is statistically significant, the match point would be regarded as the break point of the series.

Correlation analysis

Correlation analysis between water vapor content and precipitation was carried out to reveal the evolution and
origin of precipitation and provide significant information for analyzing and predicting water resources changes of the Haihe river basin in the future.

Correlation coefficient \( r \) is a statistic used to describe the linear correlation of two random variables. Assume there are two variables \( x \) and \( y \), \( r \) is calculated as follows:

\[
 r_{xy} = \frac{\sum_{t=1}^{n} x_t y_t - nx \bar{y}}{\sqrt{\left( \sum_{t=1}^{n} x_t^2 - nx \bar{x} \right) \left( \sum_{t=1}^{n} y_t^2 - ny \bar{y} \right)}}
\]  

(8)

The correlation analysis in this paper involved water vapor content and precipitation data during 1957–2010 with a sample size of 53. So if \( |r| > 0.268 \), the correlation is above the 0.05 significance level. If \( |r| > 0.348 \), the correlation is above the 0.01 significance level.

**RESULTS**

**Temporal and spatial variation of water vapor content**

The time series of water vapor content from 1948 to 2010 in the Haihe river basin are shown in Figure 3(a). It can be seen that there was a significant downward trend during the 63 years with evident interannual and interdecadal variation. The annual water vapor content in 1961 reached the peak at 23.12 mm and bottomed out at 15.75 mm in 2009, the average was 18.79 mm. From the late 1940s to the late 1960s, the annual values remained at a high level and began to taper off from the mid-1960s until the 1980s. After a slight rise in the 1990s, the annual water vapor content declined again in the 21st century and reached the lowest period. The result of the Mann–Kendall test showed a decreasing trend of annual water vapor content and it was statistically significant after 1952 at the \( \alpha = 0.05 \) level, 1970 was detected as the break point. The same decreasing trend and break point had also been detected by Zhu et al. (2011) who found that the southerly strong moisture transfer belt below 850 hPa is the primary contributor of water vapor for the Haihe river basin, and also the major influential factor for precipitation. As shown in Figure 3(b), the water vapor content in summer fell significantly, which was verified by the result of the Mann–Kendall test. The break

![Figure 3](https://iwaponline.com/jwcc/article-pdf/6/2/341/375742/jwc0060341.pdf)
point in summer was 1970, the same as the annual test result. However, there was only a slight decrease in winter (Figure 3(c)) and no significant trend was detected by the Mann–Kendall test at the \( \alpha = 0.05 \) level.

It is manifest from Figure 4 that the average monthly value peaked at 40.37 mm in July and reached the minimum at 4.63 mm in January. The figures for spring, summer, autumn and winter were 40.97 mm, 106.77 mm, 48.57 mm and 15.81 mm respectively, which accounted for 19.31, 50.33, 22.91 and 7.45% of the annual water vapor content. The average summer water vapor content was 6.8 times the figure for winter and 1.91 times the annual average value, obviously the main source of annual water vapor content. All of the 12 months showed a decreasing trend, among which 3 decreased insignificantly at the \( \alpha = 0.05 \) level.

The spatial distribution of water vapor content in the Haihe river basin was mainly influenced by the atmospheric circulation and land use/land cover factors with evident seasonal changes. According to Figure 5, the annual average water vapor content was around 17.68 mm and decreased generally from the southeast (about 24 mm) to the northwest (about 12 mm).

The spatial distribution of water vapor content for the four seasons is shown in Figure 6. Spring was the transition period between winter and summer monsoons during which time the water vapor content began to increase, rising from

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**Figure 5** | The spatial distribution of annual water vapor content in the Haihe river basin.

**Figure 6** | The spatial distribution of seasonal water vapor content in the Haihe river basin (a) spring; (b) summer; (c) autumn; (d) winter.
8 mm in the north to 20 mm in the south (Figure 6(a)). In summer, the Asian continent was controlled by the warm cyclone and the subtropical high moved northwards. The water vapor in the air current was abundant, ascending from 26 mm in the northwest to 46 mm in the southeast (Figure 6(b)). In autumn the water vapor content decreased as the latitude rose, ranging from 2 to 8 mm (Figure 6(d)).

It is evident from Table 1 that the proportion of water vapor content from each gauging point to the 700 hPa level in the whole atmospheric layer ranged from 66.1 to 81.7% and the average value for the Haihe river basin was 72.9%, that is, the water vapor of the Haihe river basin was mainly in the air close to the ground.

### Variation of precipitation

The annual and monthly precipitation in the Haihe river basin was calculated by Thiessen polygons using the observation data of 53 hydrological stations. As can be seen from Figure 7(a), the annual precipitation in the Haihe river basin from 1957 to 2010 showed an insignificant decreasing trend. The annual precipitation peaked at 649 mm in 1964 and reached the lowest point at 283 mm in 1972. It is manifest from Figure 7(a) that from 1957 to 1967 the precipitation stayed at a high level. During 1968–1974, it fluctuated around the average value of 421 mm. From 1975 to 1980 was another wet period but the precipitation was not as much as 1957–1967. From 1981 to 1990 was a long dry period during which the precipitation was far below the

### Table 1

<table>
<thead>
<tr>
<th>Gauging points</th>
<th>Ground to 700 hPa level (mm)</th>
<th>The whole layer (mm)</th>
<th>Proportion</th>
</tr>
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<tbody>
<tr>
<td>112.5 E 42.5 N</td>
<td>8.201</td>
<td>12.411</td>
<td>0.661</td>
</tr>
<tr>
<td>112.5 E 40 N</td>
<td>12.609</td>
<td>15.002</td>
<td>0.817</td>
</tr>
<tr>
<td>112.5 E 37.5 N</td>
<td>11.307</td>
<td>16.801</td>
<td>0.673</td>
</tr>
<tr>
<td>112.5 E 35 N</td>
<td>18.915</td>
<td>25.338</td>
<td>0.747</td>
</tr>
<tr>
<td>115 E 42.5 N</td>
<td>7.949</td>
<td>11.818</td>
<td>0.672</td>
</tr>
<tr>
<td>115 E 40 N</td>
<td>9.977</td>
<td>14.649</td>
<td>0.681</td>
</tr>
<tr>
<td>115 E 37.5 N</td>
<td>15.593</td>
<td>20.783</td>
<td>0.751</td>
</tr>
<tr>
<td>115 E 35 N</td>
<td>16.889</td>
<td>22.995</td>
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</tr>
<tr>
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<td>8.122</td>
<td>12.212</td>
<td>0.664</td>
</tr>
<tr>
<td>117.5 E 40 N</td>
<td>13.6734</td>
<td>18.198</td>
<td>0.752</td>
</tr>
<tr>
<td>117.5 E 37.5 N</td>
<td>13.866</td>
<td>18.821</td>
<td>0.737</td>
</tr>
<tr>
<td>117.5 E 35 N</td>
<td>15.754</td>
<td>21.642</td>
<td>0.729</td>
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<tr>
<td>120 E 42.5 N</td>
<td>12.137</td>
<td>16.134</td>
<td>0.752</td>
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<tr>
<td>120 E 40 N</td>
<td>12.692</td>
<td>17.051</td>
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<tr>
<td>120 E 37.5 N</td>
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<td>17.912</td>
<td>0.731</td>
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<td>120 E 35 N</td>
<td>15.367</td>
<td>21.105</td>
<td>0.729</td>
</tr>
<tr>
<td>Average values</td>
<td>12.883</td>
<td>17.678</td>
<td>0.729</td>
</tr>
</tbody>
</table>

![Figure 7](https://iwaponline.com/jwcc/article-pdf/6/2/341/375742/jwcc0060341.pdf)
average value. From 1991 to 1996 was a grace period, followed by another long dry period in 1997–2010. Compared with the study of Bao et al. (2012), there were some differences in the highest and lowest values of precipitation, which were 817 mm in 1964 and 355 mm in 1965, respectively. Gong et al. (2004), Chu et al. (2010) and Cong et al. (2010) detected the same decreasing trend and found that the decreasing trend for precipitation in the north of China was mainly due to the weakening monsoon over the past 50 years.

According to the results of the Mann–Kendall test (Figure 7(a)), 1976 was detected as the break point, relatively lagging compared with the annual water vapor content. There was an insignificant downward trend and it was the same in winter (Figure 7(c)). However, the precipitation in summer (Figure 7(b)) decreased evidently and was statistically significant after 2002 at the $\alpha = 0.05$ level.

According to the variation of monthly precipitation in the Haihe river basin during 1957–2010 (Figure 8), the figure for July reached the maximum at 1,458 mm while the figure for January bottomed out at 29 mm. Of the 12 months, April, May, June, September, October and December showed an increasing trend with a statistically significant trend in May at the $\alpha = 0.05$ level. The other 6 months showed a decreasing trend, among which July and November were significant at the $\alpha = 0.05$ level, the decreasing trend in July was even statistically significant at the $\alpha = 0.01$ level. The decrease of summer precipitation was obviously the main factor for the drop in annual precipitation. As the main source of annual precipitation, precipitation in summer accounted for the majority (66.9%) of the annual precipitation, 29.33 times the annual average value. As previously mentioned, there was a statistically significant trend from 1965, however, the variation of precipitation had also been analyzed by Simmonds et al. (1999) and Zhu et al. (2011), who found that the water vapor content over the Haihe river basin had obvious interdecadal variations and was significantly correlated with precipitation. As previously mentioned, there was a significant change for the water vapor content in 1970 and the break point for precipitation was relatively lagging in 1976. Although the break points were not the same, they centered in the 1970s. They both began to show a fluctuating downward trend from 1965, however, the variation of precipitation was of smaller magnitude than the variation of water vapor content. The summer correlation coefficient reached 0.56, which means the relationship of water vapor content and precipitation was closest in summer. Likewise, the time series of water vapor content and precipitation showed good correlation in summer (Figure 9(b)), but it was not the case in winter (Figure 9(c)) with a correlation coefficient of 0.20.

**Correlation analysis**

Precipitation is a complicated process with three essential elements: adequate water vapor, dynamic lifting and unstable energy. Water vapor in the low layers of the troposphere near the precipitation area is collected, lifted and condensed through horizontal transport and dynamic lifting, thus there is a close relationship between water vapor content and precipitation.

It can be seen from Figure 9(a) that the interannual variation of water vapor content and precipitation was basically consistent. The correlation coefficient between water vapor content and precipitation was 0.52, statistically significant at the $\alpha = 0.01$ level, which proved water vapor content had a close relationship with precipitation. The same correlation had also been analyzed by Simmonds et al. (1999) and Zhu et al. (2011), who found that the water vapor content over the Haihe river basin had obvious interdecadal variations and was significantly correlated with precipitation. As previously mentioned, there was a significant change for the water vapor content in 1970 and the break point for precipitation was relatively lagging in 1976. Although the break points were not the same, they centered in the 1970s. They both began to show a fluctuating downward trend from 1965, however, the variation of precipitation was of smaller magnitude than the variation of water vapor content. The summer correlation coefficient reached 0.56, which means the relationship of water vapor content and precipitation was closest in summer. Likewise, the time series of water vapor content and precipitation showed good correlation in summer (Figure 9(b)), but it was not the case in winter (Figure 9(c)) with a correlation coefficient of 0.20.
Due to re-evaporation of rain and local atmospheric moistening, not all condensation or moisture fluxes are used to produce precipitation. Therefore, precipitation efficiency is used to evaluate how efficiently the convective system produces precipitation (Sui et al. 2007) and is defined as the ratio of precipitation to water vapor content per unit area atmospheric column

$$\eta = \frac{P}{W}$$

(9)

The variation of precipitation and precipitation efficiency was generally consistent (Figure 10) and the precipitation efficiency was relatively low in drought years and high in flood years. The scatter plot of precipitation and precipitation efficiency showed good correlation with a positive correlation coefficient of 0.87 (Figure 11).

Based on the above results, it can be seen that water vapor content was one of the most critical influences on precipitation variation in the Haihe river basin. However, the trend of the two was not always the same, in several years such as 1959, 1970, 1977 and from 2004 to 2007, one variable showed an upward trend while the other decreased (Figure 9(a)). The Haihe river basin is one of the areas that lack of water resources in China, the variation of precipitation is on account of complicated factors such as climate change and long-term human activities of high intensity. In the last 100 years, the global climate has been suffering from significant changes characterized by global warming and the temporal and spatial variation of precipitation. Atmospheric circulation and aerosol are two main factors affecting the regional precipitation. In addition, human beings have been changing regional water circulation characteristics through changing land use/land cover patterns, for example by constructing water conservancy projects and large-scale water usage, which has a significant influence on precipitation. As one of the areas which has been heavily affected by human activities, the Haihe river basin has witnessed great changes in precipitation patterns. This study
mainly focused on statistical analysis, the results of which could form the basis of initial work for future studies.

CONCLUSIONS

This study analyzed the variation of water vapor content and precipitation in the Haihe river basin and revealed the correlation between the two during 1957–2010. The results showed that there was a significant downward trend in annual water vapor content from 1948 to 2010 and 1970 was detected as the break point. From 1948 to the late 1960s, the annual values remained at a high level but stabilized at a low level from the 1970s to the early 21st century. The water vapor decrease in summer was the main reason for the drop of annual water vapor content. The average summer water vapor content was 6.8 times the figure for winter and 1.91 times the annual average value.

The spatial distribution of water vapor content generally declined from southeast to northwest. For vertical distribution, water vapor content from the ground to the 700 hPa pressure level accounted for 72.9% of the whole atmospheric layer, which indicated that the water vapor of the Haihe river basin was mainly in the air close to the ground.

The interannual variations of water vapor content and precipitation were basically consistent and the correlation of water vapor content and precipitation was closest in summer. Water vapor content was one of the most critical influences on variation of precipitation in the Haihe river basin during 1957–2010.

Water resources shortage has become a constraint of economic development in China. Capturing the characteristics of water resources plays a significant role in solving water resources problems. The analysis of the spatial and temporal variability of water vapor content and precipitation and their correlation will provide an effective way to reveal the evolution law of water resources and predict their changes, which is of great importance to their sustainability.

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