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Relationship between drought and air temperature and actual water vapor pressure in the Heihe River Basin, Northwest China

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ABSTRACT

In our constantly changing climate, drought was the most severe natural hazard in the Heihe River Basin, which is located in the arid inland region of Northwest China. Previous studies have focused on drought and climatic change in the basin individually, but research concerning the combined effects of drought and the temperature and water vapor pressure has yet to be performed. In this paper, an analysis was proposed on the change of temperature and water vapor pressure during the drought period by utilizing linear regression analysis and inverse distance weighted interpolation based on geographic information system. According to local records of typical drought events, the characteristics of air temperature and water vapor pressure during the drought period were analyzed and the key drought period of the crop growth period was identified. The drought period was computed using the drought index of continuous non-effective rainy days based on the daily precipitation data of 14 weather stations located in the Heihe River Basin. Then, using daily mean temperature and actual water vapor pressure data, the differences in temperature and water vapor pressure in the drought, normal and no-drought periods were acquired. The key sensitive time was summer, and the sensitive areas were identified using the sensitive rate recorded at each weather station. The results showed that, during the drought period, air temperature increased and water vapor pressure decreased along with the prolongation of continuous non-effective rainy days. The respective sensitivities of temperature and water vapor pressure gradually decreased from the upstream to the downstream of the basin.

Keywords: Drought; Air temperature; Actual water vapor pressure; Heihe River Basin; Northwest China

1. Introduction

Against the background of climate change, water cycle and water balance changed significantly in recent years. IPCC Fourth Assessment Report showed that drier regions became drier, and the increases in the frequency and intensity of extreme events (e.g., higher temperature and more frequent drought events) were associated with climate change. More persistent circulation enhanced the severity of temperature extremes over Europe [1]. Human-induced global warming contributed to the occurrence of droughts around the world [2]. Increase in intensity, frequency and spatio-temporal variability, as well as prolonged drought periods were observed in recent years in the case of temperature for some regions [3–8].

Climate change had the potential to impact temperature and water vapor pressure, which were related to potential evapotranspiration and water demand of crop irrigation, especially in arid and semi-arid regions [9–11]. High temperature

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and drought often occurred simultaneously, and their effects on crops usually occurred during crop growth time [12–14]. Higher temperatures tended to cause an increase in evaporation rates, which accelerated drought development. Previous studies mainly focused on the drought, air temperature and water vapor pressure individually, and little research was performed regarding the combined effects of climatic factors and drought, which were capable of altering the water demand in the water resource system.

Analysis on the temperature and water vapor pressure during the drought period required an estimation of drought, which could be calculated by a number of methods. Numerous indexes and definitions were proposed to quantify the drought, including the Palmer Drought Severity Index [15]; Surface Water Supply Index [16,17]; Standardized Precipitation Index [18]; Z-Index [19] and the index of continuous non-effective rainy days drafted by the Ministry of Water Resources of the People's Republic of China [20]. Among these, the index of continuous non-effective rainy days was widely used to provide estimations of both the first and final days of drought during crop growth period, and satisfied the practical requirements in China, thus this index was selected for the comparative analysis of the change in climatic factors during the drought period of crop growth.

Although a number of studies have been conducted to examine the spatio-temporal variations of drought and meteorological variables, regional studies designed specifically for the Heihe River Basin remained underdeveloped. The Heihe River Basin was a key sensitive area to climate change, where the temperature has been rising and the precipitation has been increasing rapidly. The water resource system in the basin was also strongly interfered by human activities. The upstream mainly contributed to the runoff, while the precipitation in the midstream and downstream yielded almost no runoff; with the midstream being the economic and social center, and due to the degraded water discharge in the lower reaches [21], the ecological environment in the downstream became more vulnerable [22]. Therefore, an inter-basin water diversion project was implemented from the upstream to downstream in order to meet the water requirement in different sectors. When the drought events occurred, air temperature and water vapor pressure changed, resulting in changes to both the precipitation and available water resources throughout the basin, as well as water demand in the midstream and downstream, leading to a requirement for the revision of the region's water diversion scheme.

Therefore, this study aimed to perform the following: (1) analyzed the spatio-temporal variation of drought events occurring in the past 50 years in the Heihe River Basin; (2) recognized and quantified the changes of each climatic factor in the drought period compared with those of the normal and no-drought periods; and (3) identified the sensitive areas and times of temperature and water vapor pressure during the drought period. In order to achieve these objectives, according to the actual records of drought, the temperature and water vapor pressure during typical drought periods were analyzed. Drought was calculated by using the index of continuous non-effective rainy days and the temperature and water vapor pressure in drought period were analyzed based on the data acquired from 14 meteorological stations located in the Heihe River Basin. Based on the sensitive rate of each weather station in the key sensitive time of June, the sensitive areas were identified. Finally, a methodology of identifying the changes in the climatic factors during the drought period was proposed, and the theories of the spatio-temporal distribution of temperature and water vapor pressure during the drought period were acquired.

2. Study area

Feng et al. [23] showed the respective locations of the meteorological stations of the study area, the Heihe River Basin, which is located in the north-by-east side of the Qinghai-Tibet Plateau, and was influenced by polar cold air mass with little water vapor. The basin, originating from the Qilian Mountains, consisted of 11 counties or cities including Qilian County, Gaotai County, Zhangye City, etc., and were divided into three distinct zones, namely the upstream, midstream and downstream. The Heihe River Basin was in an arid climate, with strong pan-evaporation, and high annual and daily variation of air temperature. The region had a very low level of precipitation, which was distributed from June to September. During the period of 1960–2010, the mean annual precipitation and annual daily mean temperature were 184.4 mm and 5.1°C, respectively.

In order to restore the eco-environment in the downstream, China State Council began to implement an inter-basin water diversion project for the Heihe River Basin. After the implementation of the project, surface water amount flowing into the downstream and groundwater both increased, while the average groundwater table in the midstream decreased. Complicated water issues and associated persistent droughts were drastically affected the socio-economic development in the Heihe River Basin, especially in the midstream and downstream. The development of water diversion project, coupled with drought and climate change, posed a serious threat to the region's water resource system. The data of daily precipitation, daily mean air temperature and daily actual water vapor pressure were used, which were obtained from the China Meteorological Administration (http://cdc.cma.gov.cn/), from a total of 14 stations located in the Heihe River Basin, and covered the period of 1960–2010.

3. Methodology

Here the technical methodology of the article was briefly summarized. First, based on the records of historical climatic hazards and drought-prone areas, the total change of temperature and water vapor pressure in the drought period and the sensitive time of drought were determined. Second, according to the regional crop growth period, the drought index of continuous non-effective rainy days was applied to reflect the first and final days of the drought period, thus giving the drought, normal and no-drought periods. Third, the respective differences in the climatic factors of the drought, normal and no-drought periods were calculated. The total change of climatic factors in the drought period at each weather station of the Heihe River Basin was then evaluated, and the changes in temperature and water vapor pressure in the drought period were plotted against the continuous no-effective rainy days. The changes in climatic factors along with drought during the sensitive time were observed in the past 50 years. Finally, the spatial distribution of the sensitivity of climatic factors during the most sensitive period was represented and the sensitive areas were determined.

3.1. Drought index of continuous no-effective rainy days

Irrigational agriculture depended on the rainfall in spring and summer. Crop growth could be affected without effective rain in continuous days. The crop productivity reduced when the crop experienced higher temperatures during reproductive period [24]. In order to estimate the first and final drought days in crop growth period, the drought index of continuous non-effective rainy days was used to quantify the duration and intensity of drought. The term of continuous non-effective rainy days referred to the sum of the days without effective rain during the crop growth period, as defined by the office of the State Flood Control and Drought Relief Headquarters (drafted by Ministry of Water Resources of the People's Republic of China, 2009). Based on this standard, this paper selected the maximum of the continuous non-effective rainy days as the criterion to divide drought classes, and effective rain was 3 mm/d [23]. The drought categorization was shown below (Table 1).

The no-drought, normal and drought periods were distinguished throughout the entire period of 1960–2010. The drought periods were classified as mild, moderate, severe or extreme drought. As the reference period, the no-drought period was the month beside drought period, and normal period was the average condition of the month in the years 1960–2010. The values in the normal and no-drought periods were derived from the monthly means (February–December).

3.2. Inverse distance weighted interpolation based on geographic information system

Based on ArcGIS 9.0, the inverse distance weighted (IDW) interpolation method was used to analyze the spatial distribution of the sensitivity of temperature and water vapor pressure during drought period [25]. The IDW interpolation was based on similarity principles for weighted average with the distance between the interpolation point and sample point as the weight. The principle and equation of IDW interpolation was described in previous research [26]. The general equation of IDW interpolation was shown as below:

$$\hat{Z}_{(s_0)} = \sum_{i=1}^{N} \lambda_i Z_{(s_i)} \tag{1}$$

Table 1
Drought categories derived from continuous no-effective rainy days

Drought class	Drought category	Continuous no-effective rainy days (d)
0	No drought	<15
1	Mild drought	15~30
2	Moderate drought	31~50
3	Severe drought	51~75
4	Extreme drought	>75

where $\hat{Z}_{(s_0)}$ was the predicted value at the position of s_0; N was the quantity of sample points surrounding the predicted point used for predicting calculation; λ_i was the weight of various sample points used for predicting calculation, which was reduced with an increase in the distance between the sample point and predicted point; and $Z_{(s_i)}$ was the measured value obtained at the position of s_i.

The calculation equation for determining the weight was as follows:

$$\lambda_i = \frac{d_{i0}^{-p}}{\sum_{i=1}^{N} d_{i0}^{-p}} \tag{2}$$

$$\sum_{i=1}^{N} \lambda_i = 1 \tag{3}$$

where p was the index value, and d_{i0} was the distance between predicted point s_0 and known sample point s_i.

3.3. Sensitivity rate

In order to detect the trend of climate factors during the drought period, the sensitivity rate was performed to estimate the magnitude of climatic changes in the drought period relative to the changes in the normal period [25]. Based on the identification of the drought and normal periods, the sensitivity rates were calculated as follows:

$$R_i = \frac{X_{\text{id}} - X_{\text{in}}}{X_{\text{in}}} \tag{4}$$

where R_i was the sensitivity rate of the change X_{id} on the variation of X_{in}; X_{id} was the climate factor value in drought period and X_{in} was the climate factor value in normal period. If $R_i > 0$, the climatic factor of X_i had a positive trend during drought period; If $R_i < 0$, the climatic factor of X_i had a negative trend during drought period.

4. Results

4.1. Evolutionary characteristics of drought in the Heihe River Basin

The drought events in the Heihe River Basin were analyzed by using the index of continuous non-effective rainfall days for the period of 1960–2010. Thus, the first and final days of each drought event were determined. The index was also able to accurately determine the drought, normal and no-drought periods derived from the monthly means, which had varying degrees of temperature and water vapor pressure. The number of drought events derived from the annual means was plotted against the year using a conventional linear regression analysis. Numbers of drought events increased, indicating that Heihe River Basin had a clear tendency of gradually becoming drier, and this phenomenon was still apparent.

Table 2 summarized the numbers of drought events and the proportion of different drought classes. D was the sum of the numbers of all drought events from 1960 to 2010, and P

referred to the various drought degrees in the proportion of the total drought numbers of different regions. The numbers of extreme drought showed an increasing trend from the upstream to the downstream. The upstream and midstream areas were dominated by mild drought, while the downstream was dominated by extreme drought. It showed that extreme drought rose and mild drought dropped from the upstream to the downstream. The proportions of mild and extreme droughts among the total number of droughts in the upstream area were 58.60% and 29.94%, respectively; those in the midstream area were 45.41% and 26.15%; and that in the downstream area was 43.17%.

The duration time of drought referred to the average of the continuous non-effective rainy days from 1960 to 2010. The drought annual duration times in the upstream, midstream and downstream areas were approximately 67, 71 and 128 d, respectively, which reflected the higher duration of the droughts, but the longer drought durations often occurred during the late winter to early spring, and had little effects on the crops. The last occurrence of drought increased from the upstream region to the downstream region. Only drought events which occurred during the crop growth period (late spring and summer) had significant impacts on the crop harvest.

4.2. Changes in temperature and water vapor pressure during typical drought periods

In order to analyze the changes in temperature and water vapor pressure during drought events, in this paper drought records were used to analyze the temperature and water vapor pressure during drought periods, which were then compared with normal and no-drought periods. Drought records existed for major administrative regions (Qilian County, Zhangye City and Gaotai County), but the data concerning climatic factors were observed from the weather stations. Therefore, based on the drought records of the administrative regions, the drought index was used to quantify the drought period at each of the weather stations. Table 3 showed the average monthly water vapor pressure and daily mean temperature anomalies at the weather stations (relative to the 1960–2010 long-term monthly average shown in Table 4).

Station No. 52657 was selected as the representative weather station for that area. Based on the drought records of Qilian County, the drought temperature and water vapor pressure at station No. 52657 were shown in Table 2. In 1978, Qilian County recorded a spring–summer drought. Using the drought index, the drought occurred at station No. 52657 during the period of April–June. The respective monthly values of daily mean temperature and water vapor pressure for April, May and June in 1978 were 4.1°C and 2.73 hpa, 8.73°C and 4.85 hpa, and 11.33°C and 6.9 hpa, while those of the 1960–2010 long-term monthly average values were 2.87°C and 3.23 hpa, 7.65°C and 5.14 hpa, and 11.10°C and

Table 2
Continuous no-effective rainfall days in the upstream, midstream and downstream of Heihe River Basin

Drought class	Upstream		Midstream		Downstream	
	D(*n*)	*P* (%)	*D*(*n*)	*P* (%)	*D*(*n*)	*P* (%)
Mild drought	92	58.60	99	45.41	38	27.34
Moderate drought	15	9.55	43	19.72	29	20.86
Severe drought	3	1.91	19	8.72	12	8.63
Extreme drought	47	29.94	57	26.15	60	43.17

Table 4
1960–2010 long-term monthly average values of temperature and water vapor pressure in representative weather stations (No. 52652, No. 52546 and No. 52657)

Month	No. 52657		No. 52652		No. 52546	
	T	VP	TA	VP	*T*	VP
April	2.87	3.23	9.98	4.28	10.39	4.43
May	7.65	5.14	15.91	7.05	16.39	7.52
June	11.10	7.29	19.90	10.56	20.46	11.36
July	13.09	9.58	21.84	13.46	22.38	14.45
August	12.18	9.15	20.58	12.78	20.85	13.82
September	7.99	6.77	14.75	9.50	14.89	9.89

T, daily mean temperature; VP, daily actual water vapor pressure.

Table 3
Changes in temperature and water vapor pressure in typical drought periods in Qilian County (station No. 52657)

Year	Drought record of Qilian County	Station No. 52657	
		Drought period	Monthly mean temperature and water vapor pressure anomaly in typical drought period
1978	Spring–summer drought	April–June	MT and MV in April, May and June were 4.1°C and 2.73 hpa, 8.73°C and 4.85 hpa, and 11.33°C and 6.9 hpa
1979	Spring–summer drought	April–June	MT and MV in April, May and June were 3.14°C and 3.06 hpa, 7.86°C and 4.33 hpa, and 11.36°C and 6.67 hpa
1992	Spring drought	April	MT and MV in April was 3.89°C and 3.04 hpa
1994	Spring drought	April–May	MT and MV in April and May were 3.82°C and 3.49 hpa, and 8.29°C and 4.68 hpa
1996	Drought	May	MT and MV in May was 8.19°C and 4.95 hpa
1997	Drought	May	MT and MV in May was 8.95°C and 5.57 hpa
2000	Summer drought	June	MT and MV in June was 11.64°C and 8.24 hpa

MT, monthly values of daily mean temperature; MV, monthly values of actual water vapor pressure.

7.29 hpa. In 1994, Qilian County recorded a spring drought, which occurred from April to May at station No. 52657. The respective monthly values of daily mean temperature and water vapor pressure in the April–May, 1994 period were 3.82°C and 3.49 hpa, and 8.29°C and 4.68 hpa. Qilian County recorded a summer drought in 2000 and the respective monthly values of the daily mean temperature and water vapor pressure in June were 11.64°C and 8.24 hpa. The temperature at station No. 52657 was higher than the long-term average and the water vapor pressure was lower than that shown in the records.

The changes of temperature and water vapor pressure at station No. 52652 in Zhangye City indicated as follows: In 1970, a drought event occurred in Zhangye City in late June–late July. According to result of the drought index, the drought at station No. 52652 was determined and occurred in July. The respective monthly values of daily mean temperature and daily water vapor pressure in 1970 were 22.33°C and 12.84 hpa. The respective long-term average values of daily mean temperature and daily water vapor pressure in July were 21.84°C and 13.46 hpa. In 1978, a summer drought lasted for more than 50 d, and the drought at station No. 52652 occurred from June to July, with the respective monthly values of the daily mean temperature and daily water vapor pressure at 20.39°C and 10.75 hpa, and 21.51°C and 13.2 hpa. The respective long-term monthly average values of daily mean temperature and daily water vapor pressure in June were 19.90°C and 10.56 hpa. In 1981, a drought event occurred in April–June. The respective monthly values of the daily mean temperature and water vapor pressure in April and May were 11.6°C and 4.83 hpa, and 15.5°C and 5.26 hpa. The respective long-term monthly average values of daily mean temperature and daily water vapor pressure in April and May were 9.98°C and 4.28 hpa, and 15.91°C and 7.05 hpa. In 2008, severe drought struck Zhangye City from May to July. The respective long-term monthly average values of daily mean temperature and water vapor pressure in May and June were 18.39°C and 6.12 hpa, and 22.12°C and 9.38 hpa. The data series in Table 5 show that each drought was associated with higher mean temperatures and lower water vapor pressure, but 2008 was an exception due to the record of high temperatures which occurred in that year.

Table 5
Comparison of average daily mean temperature (°C) and actual water vapor pressure (hpa) for different periods

Month	Drought period		Normal period		No-drought period	
	T	VP	*T*	VP	*T*	VP
April	6.33	3.14	6.33	3.30	5.16	3.92
May	12.99	5.07	12.97	5.46	12.10	5.82
June	17.39	7.78	17.24	8.29	15.99	8.63
July	20.19	10.70	19.28	10.95	18.78	11.13
August	18.51	9.54	17.99	10.20	17.75	10.64
September	12.25	6.55	12.48	7.20	12.27	8.31
Average	14.61	7.13	14.38	7.56	13.68	8.07

T, daily mean temperature; VP, daily actual water vapor pressure.

Station No. 52546 for Gaotai County was selected as the representative weather station to show the changes in temperature and water vapor pressure during drought period. In 1960, a severe drought struck Gaotai County beginning in early July. The respective monthly values of daily mean temperature and water vapor pressure in June and July in 1960 were 20.59°C and 9.66 hpa, and 23.15°C and 13.4 hpa. The respective long-term monthly average values of daily mean temperature and water vapor pressure in June and July were 20.46°C and 11.36 hpa, and 22.38°C and 14.45 hpa. In 1985, Gaotai County recorded a severe drought in March–April, following a warming trend during which the respective monthly values of daily mean temperature and water vapor pressure of station No. 52546 in April were 10.99°C and 4.53 hpa. In 2006, a spring drought occurred in April–June. The respective monthly values of the daily mean temperature and water vapor pressure in April, May and June were 11.76°C and 3.57 hpa, 16.9°C and 6.56 hpa, and 22.14°C and 9.42 hpa. Based on the drought records from different weather stations collected between 1960 and 2010, similar to the data shown in Table 3, higher temperatures and lower water vapor pressure often occurred during drought.

4.3. Changes in temperature and water vapor pressure in drought periods

4.3.1. Total change of temperature and water vapor pressure in drought periods

Average conditions in drought periods for the Heihe River Basin were estimated for each month from March to November since 1960 (Table 5). The daily mean temperature and actual water vapor pressure were analyzed and compared with those of normal and no-drought periods. The mean monthly temperatures and water vapor pressure were derived from an average of the daily mean temperature and daily actual water vapor pressure. During 1960–2010, the daily mean temperature of April during drought periods was 6.33°C, while monthly average value during normal periods was 6.33°C, and during no-drought periods was 5.16°C. The daily mean temperature of May during drought periods was 12.99°C, while monthly average value during normal periods was 12.97°C, and during no-drought periods was 12.10°C. The respective daily mean temperatures of June during drought, normal and no-drought periods were 17.39°C, 17.24°C and 15.99°C; July: 20.19°C, 19.28°C and 18.78°C; August: 18.51°C, 17.99°C and 17.75°C; September: 12.25°C, 12.48°C and 12.27°C (Fig. 1(a)).

The changes in water vapor pressure during drought, normal and no-drought periods were analyzed. The respective average daily water vapor pressures of April during drought, normal and no-drought periods were 3.14, 3.30 and 3.92 hpa; those for May were 5.07, 5.46 and 5.82 hpa; June: 7.78, 8.29 and 8.63 hpa; July: 10.70, 10.95 and 11.13 hpa; August: 9.54, 10.20 and 10.64 hpa; September: 6.55, 7.20 and 8.31 hpa. It was found that the daily water vapor pressure of the total crop growth period during the drought period was less than those in the normal and no-drought periods (Fig. 1(b)). It was noted that drought produced higher temperature and less water vapor pressure during the drought period than the normal period.

4.3.2. Changes in temperature and water vapor pressure along with continuous non-effective rainy days during drought periods in the Heihe River Basin

To analyze the changes in temperature and water vapor pressure with the duration of drought during the crop growth period (April–September), the days of continuous non-effective rainy represented the duration time of drought. Given the certain continuous non-effective rainy days, the respective daily mean temperature and actual water vapor pressure for the six months of April–October during drought periods since 1960 were averaged, and the daily mean temperatures and water vapor pressures were plotted against those of continuous non-effective rainy days. Based on the linear regression analysis, it was shown that there was an increasing trend of temperature and a decreasing trend of water vapor pressure with the aggravation of drought.

Due to the fact that summer is the rainy season in the Heihe River Basin and droughts occurring in summer commonly affect agriculture, this section of the study was conducted during the three drought-prone months of June, July and August, where the growth of crops face the most severe impacts of droughts. The respective changes in temperature and water vapor pressure along with the durations of drought in June, July and August were analyzed. As the drought intensity increased, the daily temperature rose and water vapor pressure declined with the aggravation of drought, and these changes were quite significant, implying a high correlation between climatic factors and drought (Fig. 2).

The changes in drought temperature and water vapor pressure for June were extraordinary when compared with the two major drought months. Based on the linear regression analysis and slope, the largest increase amplitude of daily mean temperature was that of June, with the slope of 0.1286°C/d being higher than that of 0.1133°C/d in July, followed by August with 0.0703°C/d. The slopes of water vapor pressure in June, July and August were –0.1062, –0.0424 and –0.0327 hpa/d, respectively. These observations imply that June was the most sensitive month of the drought period.

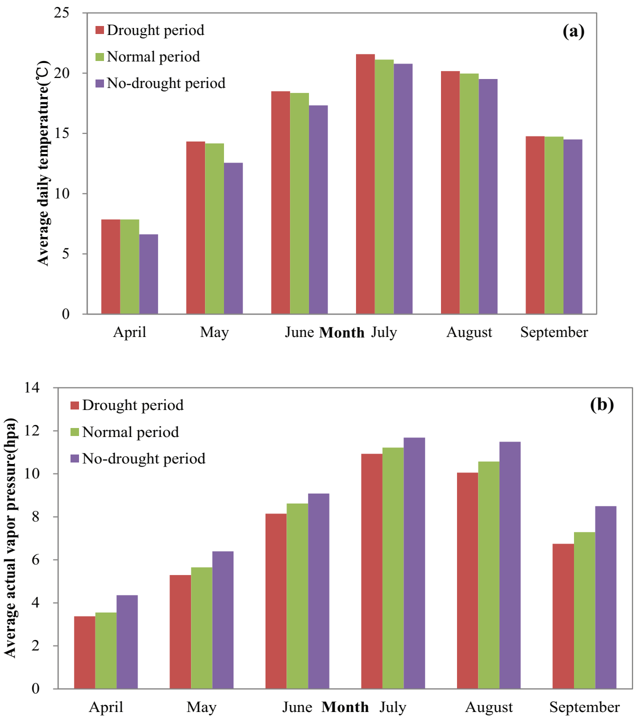

Fig. 1. Average values for climatic factors for different periods ((a) daily mean temperature [°C]; (b) daily actual water vapor pressure [hpa]).

4.3.3. Spatial distribution of the sensitivity of daily mean temperature and water vapor pressure in drought periods

As mentioned earlier in this paper, this study explored the changes in temperature and water vapor pressure with

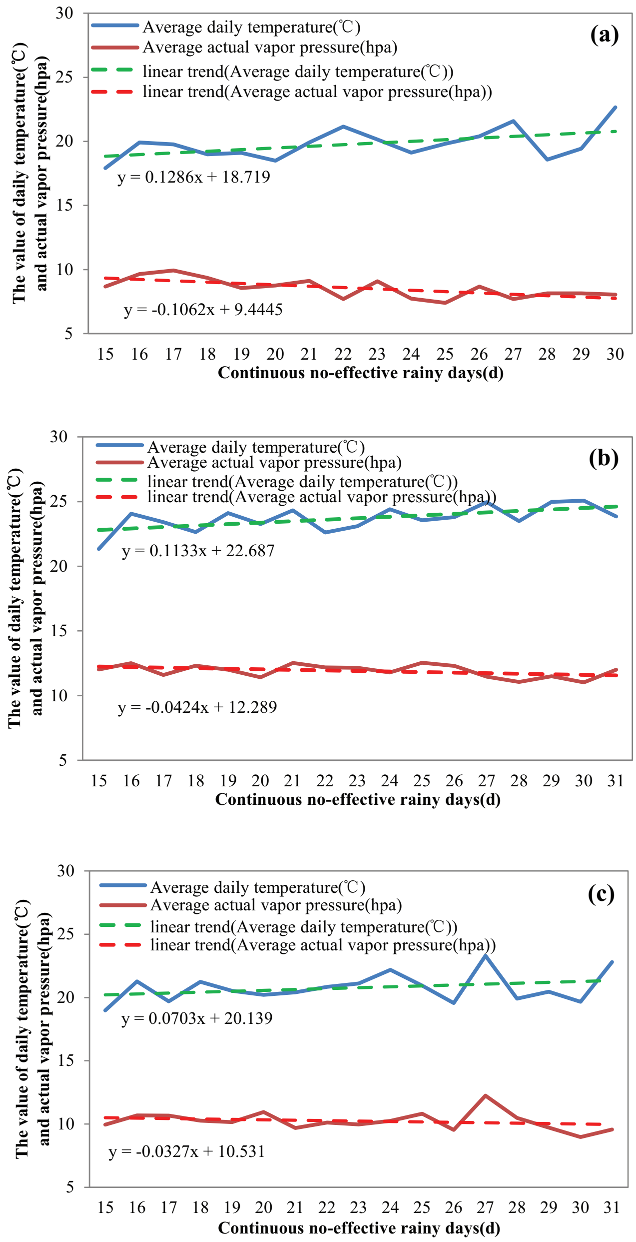

Fig. 2. Changes in temperature and water vapor pressure, and the duration of drought events occurring in summer ((a) June; (b) July and (c) August).

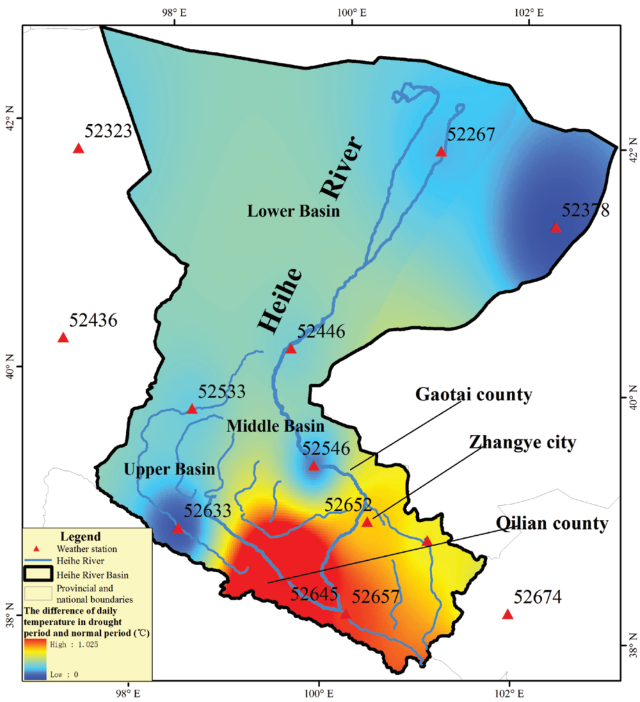

Fig. 3. Spatial distribution of the differences in daily mean temperature during drought and normal periods.

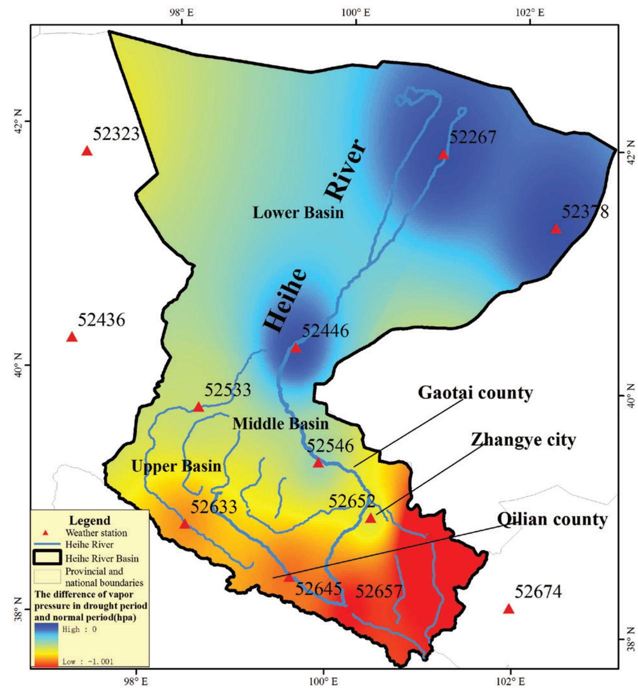

Fig. 4. Spatial distribution of the differences in daily water vapor pressure during drought and normal periods.

continuous rainy days, and it was shown that the most sensitive month was June. Therefore, using the approach of IDW interpolation in ArcGIS, this study attempted to determine the spatial distribution of the differences in climatic factors between drought and normal periods in June and the spatial distribution of sensitivity. The results indicated that the differences in climatic factors during drought and normal periods in June decreased from the upper reaches to lower reaches (Figs. 3 and 4), with the exceptions that the difference in water vapor pressure at station No. 52267 during drought and normal periods was negative, and the difference in temperature at station No. 52633 exhibited positive values. The sensitivity rate of temperature was positive, while water vapor pressure negative. Similar to the spatial distribution of the difference in the two climatic factors between drought and normal periods, these findings suggested that drought effects decreased from the upper to lower reaches, and the changes in temperature and water vapor pressure gradually weakened from upstream to downstream in the same degree of drought.

5. Discussion

The drought events resulted in higher temperatures and lower amounts of water vapor pressure. This conclusion was in accordance with the results of previous studies, in which it was shown that in Australia temperatures during drought were higher [3,27]. Although the overall trends of the spatial distribution of temperature and water vapor pressure during drought periods were significant, abnormal values also appeared. It was important to note that the appearances of abnormal values might be due to natural random fluctuations, meaning that no significant statistical trend was present. It was also worth noting that station No. 52633 was located in the upper reaches of the mountains and the climate there might be influenced by the elevation. For station No. 52378, located on the edge of the Badain Jaran Desert, the perennial extreme drought and no-drought periods were selected, and as a result the values during the drought period were equal to those of the normal period, and no observable trends were detected in the signal, as expected.

A variety of factors were likely to contribute to the changes in temperature and water vapor pressure during drought periods, particularly including changes in evaporation capacity and available evaporation of water vapor, which determined water vapor amount being transferred into the atmosphere. In arid and semi-arid regions, water vapor transferring into the atmosphere was limited by water supply. During drought periods, there was little precipitation and soil moisture, resulting in less water for evaporation and thus less water vapor in the atmosphere. The perceptible water of the atmosphere was related to water vapor pressure. Also during drought periods, both the density of water vapor in atmosphere and water vapor pressure were lower.

6. Conclusion

In our currently changing climate, the droughts occurring in the Heihe River Basin were characterized as being increasingly more frequent and more intense, with clear spatio-temporal differences and increased duration. Based on the data derived from the 14 weather stations and the drought records which covered the period of 1960–2010, it was shown that the temperature during droughts in crop growth periods was greater than in normal periods, and the water vapor pressure was lower. The following conclusions were drawn as follows:

By applying the index of continuous non-effective rainy days, the drought, normal and no-drought periods were distinguished. Compared with the monthly average values during drought and no-drought periods, monthly changes in temperature (for April–September) and water vapor pressure during drought period were estimated. The results showed that the daily mean temperatures during drought periods were higher than in normal and no-drought periods, while the daily water vapor pressure during drought periods demonstrated an inverse trend.

In order to analyze the changes in daily mean temperature and water vapor pressure with the aggravation of drought, the average daily mean temperature and water vapor pressure during drought periods were plotted against continuous non-effective rainy days. With an increase in continuous non-effective rainy days, the temperature increased and water vapor pressure decreased. An emphasis was laid on the changes in climatic factors during summer (June–August) with the aggravation of drought. Increase in amplitude of temperature and decrease in amplitude of water vapor pressure were the highest in June, followed in order by July and August.

The spatial distribution of the differences in temperature and water vapor pressure during drought and normal periods in June (the most sensitive time) was drawn. The differences gradually decreased from the upstream to downstream of the basin. The sensitivity of the temperature and water vapor pressure during the drought period in the upper reaches were higher than in the lower reaches. The sensitivity of the temperature was positive and the sensitivity of water vapor pressure was negative.

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