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Article

Variation Trend and Abrupt Change in Temperature Around Hongze Lake from 1981 to 2020

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Abstract: In global warming, the influence of lakes on climate change in surrounding areas has attracted extensive attention from many scholars. Based on 40 years of observation of the daily mean temperature, maximum temperature, and minimum temperature of 16 meteorological observation stations around Hongze Lake, we analyzed the trend and characteristics of temperature change in the area around Hongze Lake from 1981 to 2020. The Mann-Kendall trend analysis method and mutation detection method were used for the analysis. The daily mean, maximum, and minimum temperatures have fluctuated but increased. The daily minimum temperature showed the largest increase (0.55°C/10 years). The daily mean, minimum, and maximum temperatures changed significantly with the seasonal variation, and the warming trend in spring was most significantly observed, followed by those in winter and summer. The historic increase in temperature in autumn was the least significant. The abrupt change points of daily mean, minimum, and maximum temperatures were observed in 1996. Fluctuation became more severe and frequent after such abrupt changes. The increase in temperature in seasons was significant before and after 1998. The abrupt change air temperature of Hongze Lake was observed most frequently in winter, followed by autumn but in spring and summer, there were no such outliers observed in temperature. The closer the area to Hongze Lake, the temperature changes became smaller, the minimum temperature became higher, and the maximum temperature became lower. This verified the climate regulation effect of Hongze Lake on the surrounding area. The research results provide a reference for creating a protocol for possible natural disasters in the future and for transportation in water and agricultural structure adjustment.

Keywords: Temperature trend, Abrupt change in temperature, Interannual variation, Seasonal variation during the year, The area around Hongze Lake

1. Introduction

Climate change has a profound impact on the global ecology, social economy, and human activities. Lakes are known to regulate local climate changes in the surrounding areas, and the dual effects of global climate change and regulation of local climate by lakes have drawn more research interest nowadays. Climate provides energy and materials in the form of light, heat, and water for agriculture. Although climate change affects agriculture considerably, its effects are still under investigation [1,2]. At the same time, the regulating effect of lakes on climate is significant but the trend and intensity of the effect on the surrounding areas are not consistent [3]. The study on the abrupt change in climate in the surrounding areas of lakes is important for the construction of farms, stable grain yield, agricultural structure adjustment, and disaster prevention [4]. Many scholars have researched the impact of artificial water bodies such as water conservancy hubs and reservoirs on climate. Wang et al. [5,6] analyzed the influence of land water on climate. Shang [7] analyzed the impact of Xiaolangdi water conservancy on the surrounding local climate. Chen [8] evaluated the effect of water ecological environment on hydropower projects. Feng [9] and Zhang [10] analyzed the climate change in Chongqing before and after the Three Gorges Reservoir was impounded and the change trend of climate elements in the reservoir after impoundment. Liu et al. [11] studied the influence of reservoir on local climate by numerical simulation, and Zheng et al. [12] studied the climate effect of a large artificial lake in Miyun Reservoir.

The lake climate is affected by the thermal difference between the land and water as the lake-land wind circulation is formed to make the heat and water exchanged between the land and water. The larger and deeper the lake, the more obvious the effect of the lake on climate and the surrounding area. Cheng [13] studied the effect of runoff in Dongting Lake Basin on local climate change and human activities. Chen [14] and Ju [15] studied the characteristics of climate change in Dongting Lake region and its possible climate effect on the Three Gorges Reservoir and found that Dongting Lake had a regulating effect on temperature causing moderating extreme temperature changes, reduced the number of days with highest and lowest temperatures, and decreased the daily temperature difference by 1.6−2.4℃. After analyzing the temperature effect of Taihu Lake, Lu et al. [16] found that the mean annual maximum temperature of Taihu Lake was 0.3−1.0℃ lower than that of the far lake. Wu [17] and Ding [18] found that the diurnal temperature range in Poyang Lake was 2−4℃ smaller than that in mountainous areas of Jiangxi Province, and the number of hot days was half of those in other areas at the same latitude in Jiangxi Province.

At present, there are reports about the latest climate changes, the influence of lakes on temperature, and the abrupt climate change of lakes. However, there has been no research on Hongze Lake’s influence on the local climate. Although Chen [19] and Zhao [20] studied the temperature distribution of the Hongze Lake and its vicinity from 1971 to 2000 and its influence on the temperature distribution in northern Jiangsu with the surface variation of the lake, they did not carry out detailed research on the annual and seasonal variations of daily mean, maximum, and minimum temperatures. Therefore, based on 40 years of observation at sixteen meteorological observation stations around Hongze Lake, we analyzed the trend and characteristics of temperature change from 1981 to 2020 with the Mann-Kendall trend analysis and mutation detection method. The results provided a reference for further investigation of grain production, the adjustment of agricultural structure, the construction of the lake's ecological environment, and ecological tourism in northern Jiangsu.

2. Methods

2.1. Study Area

Hongze Lake is located at 33°06' N-33 °40'N and 118°10' E-118 °52'E) and is the fourth largest freshwater lake in China. Huaihe River is connected to the lake which extends from the central to the western part of the Northern Jiangsu Plain. The latitude and longitude of Hongze Lake's center of mass is at 33°28'N and 118°56'E. The catchment area reaches 15.8×10^4 km^2 with functions for flood control, irrigation, water transfer and transportation, climate regulation, and biodiversity protection [20]. The area around Hongze Lake includes Huaian, Suqian and Yangzhou in Jiangsu Province, Bengbu, Chuzhou and Suzhou in Anhui Province. The climate of the area around Hongze Lake belongs to the transition is characterized by a subtropical to temperate monsoon climate and distinctive four seasons. The climate in this area is both continental and marine and has the characteristics of microclimate of the lake wetland.

2.2. Weather Stations

The data were collected from 16 meteorological stations in Jiangsu and Anhui, including 5 stations in Anhui and 11 stations in Jiangsu. Hongze Lake has a radius of 60 km and has a center of a 98 km concentric circle. The meteorological stations are located in Sihong, Siyang, Huaian, Chuzhou, Hongze, Jinhu, and Xuyi at a distance of 60 km from the center of the lake. Weather stations in Sixian, Suqian, Shuyang, Lianshui, Baoying, Tianchang, Lai 'an, Mingguang, and Wuhe are 60−98 km away from the center of the lake (Figure 1). Huaian weather station is the base station, Sihong, Xuyi, Shuyang for the basic station, the others are general stations.

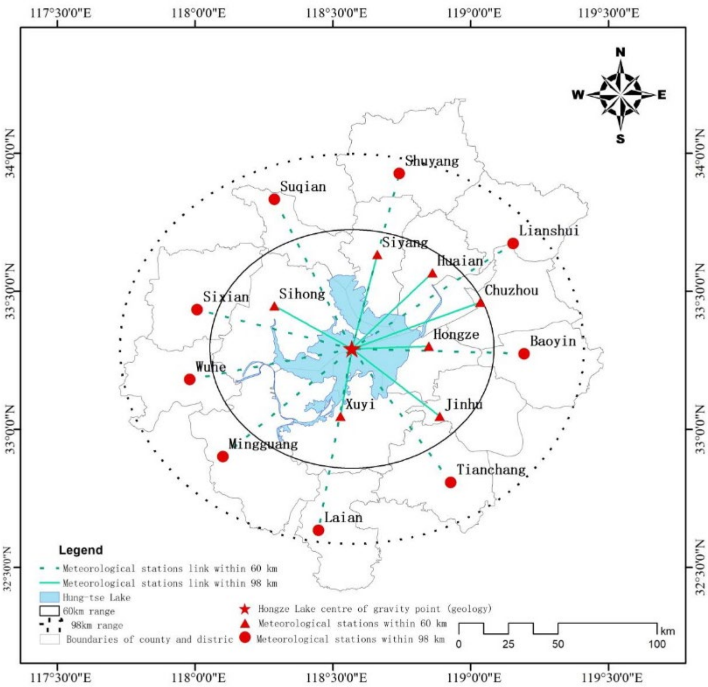

Figure 1. Location of stations around Hongze Lake.

2.3 Methods

2.3.1 Mann-Kendall Trend Analysis

Mann-Kendall trend analysis is a non-parametric statistical method developed by the World Meteorological Organization (WMO). It is widely applied in the trend analysis of precipitation and drought under climate change as the method effectively distinguishes natural fluctuation and abnormal changes [21]. In the M-K trend test, a set of time series data is assumed in n independent samples with the same distribution of random variables. For any distribution of i,j≤n, and i≠j, and, the statistic S of the test is calculated as follows.

$$\mathrm{S} = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} Sgn(X_j - X_k) \tag{1}$$

$$\mathrm{Sgn}(X_j - X_k) = \begin{cases} +1, & (X_j > X_k) \\ 0, & (X_j = X_k) \\ -1, & (X_j < X_k) \end{cases} \tag{2}$$

Variance Var(S) is defined as

$$\mathrm{Var}(S) = n(n-1)(2n+5)/18 - \sum_{p=1}^{g} tp(tp-1)(2tp+5) \tag{3}$$

where g is the number of groups, and tp is the number of data in each group.

If a set of data (3, 6, 6, 6, 7, 7, 8, 8, 8) is divided into 4 groups in the format of (elements, number of elements), (3, 1), (6, 4), (7, 2), (8, 3) are obtained. When g=4, the sum is calculated as 1 × (1-1) + 4 (2 x $_1$ + 5) × (4-1) (2 x $_4$ + 5 + 2 × (2-1) + 3 × (2 × 2 + 5) (3, 1) (2 x $_3$ + 5). If the sequence of each element appears only once, the sum becomes zero. The variance equation is simplified to Var(S)=n(n-1)(2n+5)/18. When n > 10, the standard normal statistic is calculated as follows.

$$Z = \begin{cases} \frac{S+1}{\sqrt{Var(S)}}, (S > 0) \\ 0, (S = 0) \\ \frac{S-1}{\sqrt{Var(S)}}, (S < 0) \end{cases} \quad (4)$$

The resulting Z is a statistic of normal distribution, where Z>0 indicates a gradually increasing trend over time, and Z<0 indicates a decreasing trend.

Using Sen slope calculation method, the trend coefficient is calculated.

$$Q = \text{Median}\left(\frac{X_i - X_j}{i-j}\right) \quad (5)$$

where j<i<n, the size of Q represents the size of the change trend.

2.3.2 Mann-Kendall mutation detection

When the Mann-Kendall mutation detection method is applied to analyze the outliers of time series data [22], the test statistic must be different from Z. Suppose that the time series $(X_1, X_2, \ldots X_n)$ is the sum of the number of the i th sample > (1≤j≤i), the statistic is defined as

$$S_k = \sum_{i=1}^{k} \sum_{j}^{i-1} a_{ij} \quad (k = 2,3,4 \cdots, n) \quad (6)$$

$$a_{ij} = \begin{cases} 1 & (X_i > X_j) \\ 0 & (X_i \le X_j) \end{cases} \quad (7)$$

Standardized S_k is included in

$$UF_k = \frac{|S_k - E(S_k)|}{\sqrt{Var(S_k)}} (k = 1,2,3 \cdots, n) \quad (8)$$

$$E(S_k) = \frac{k(k+1)}{4} \quad (9)$$

$$Var(S_k) = \frac{k(k-1)(2k+5)}{72} \quad (10)$$

When UF_1=0, the significance level α is set. If the absolute value of UF_k is greater than that of U_α, it proves that the change trend of the sequence is significant. Antisequence,X_n, X_{n-1},...., X_1 is expressed as,X'_1, X'_2,...., X'_n,perform the same calculation.

$$\begin{cases} UB_k = -UF_k \\ k = n + 1 - k \end{cases} \quad (k = 1,2,3 \cdots, n) \quad (11)$$

where UB_1=0. UB_k is to invert the time series of UF_k and then take the negative. The significance level is set as α=0.05. The critical value is calculated as ±1.96, and the UF_k and UB_k curves and the two lines of the critical value are drawn on a chart. If UF_k>0, it proves an increasing trend, while UF_k<0, it shows a downward trend. When the critical line is exceeded, the trend is significant. If the two curves UF_k and UB_k have an intersection within the critical boundary, then the moment corresponding to the intersection is the time when the mutation begins, that is, outliers appear.

3. Result and Discussion

3.1 Temperature Change Trend

3.1.1 Daily trend

Table 1 shows the result of the M-K trend analysis of the daily mean maximum, and minimum temperatures in the years in the area around Hongze Lake from 1981 to 2020 (Table 1). According to Eqs. (1)-(4), the Z-statistics of the annual mean daily mean, maximum and minimum temperature are 4.38, 4.17 and 4.40, respectively, and their values were greater than 0, indicating that the three increased every year. According to Eq. (5), the trend coefficients of annual mean, maximum, and minimum temperatures were

0.50, 0.53, and 0.55℃/10 years, respectively. The larger the value was, the larger the variation was. The daily mean minimum temperature showed the largest variation through the years, followed by the maximum and mean temperatures. The increase in daily minimum temperature through the years was one of the main causes of warming in the area of Hongze Lake.

Table 1. Result of M-K trend analysis of daily temperature trend from 1971 to 2000 around Hongze Lake

	Z statistic	**Trend coefficient（℃/10 years）**
Mean temperature	4.380788995	0.50
Mean maximum temperature	4.171070373	0.53
Mean minimum temperature	4.404091064	0.55

3.1.2 Seasonal trend

The seasonal Z statistics of daily mean, maximum, and minimum temperatures from 1971 to 2000 were greater than 0, indicating that the temperatures increased through seasons over the years. The increasing trend in spring was the most obvious, the trend in winter and summer was similar, and the increasing trend in autumn was the least significant. The trend coefficients were higher than 0.76℃/10 years. In winter, the trend coefficient ranged from 0.53 to 0.61℃/10 years. The trend coefficient in summer ranged from 0.38 to 0.45℃/10 years. The trend coefficient in autumn was 0.36℃/10 years which was the lowest. The temperature increase was the largest in spring, followed by winter and summer, and the smallest in autumn.

Table 2. Result of M-K trend analysis of seasonal temperature trend from 1971 to 2000 around Hongze Lake

	Mean temperature				**Minimum temperature**				**Maximum temperature**			
Season	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Z statistic	4.57	2.92	2.90	3.15	4.57	3.62	2.38	3.32	4.01	2.38	1.57	2.01
Trend coefficient（℃／10 years）	0.81	0.38	0.32	0.58	0.76	0.45	0.36	0.61	0.86	0.39	0.31	0.53

3.2 Temperature Changes in Surrounding Area of Hongze Lake

3.2.1 Daily Change

Equations (6)-(11) were used to calculate and draw the Mann-Kendall curve of changes in temperatures in the area near Hongze Lake (Figure 2). The intersection point of the solid line and the corresponding dotted line represents the time when the abrupt temperature change occurred. The outliers of daily mean, minimum, and maximum temperatures (mutation points in figures) were found in 1996. The daily mean temperature showed the largest change, followed by the daily minimum and maximum temperatures. In general, an increasing trend was observed before the abrupt change occurred, and after the abrupt change, the fluctuation became larger. The variation degree of daily maximum temperature was larger than that of daily minimum temperature and daily mean temperature.

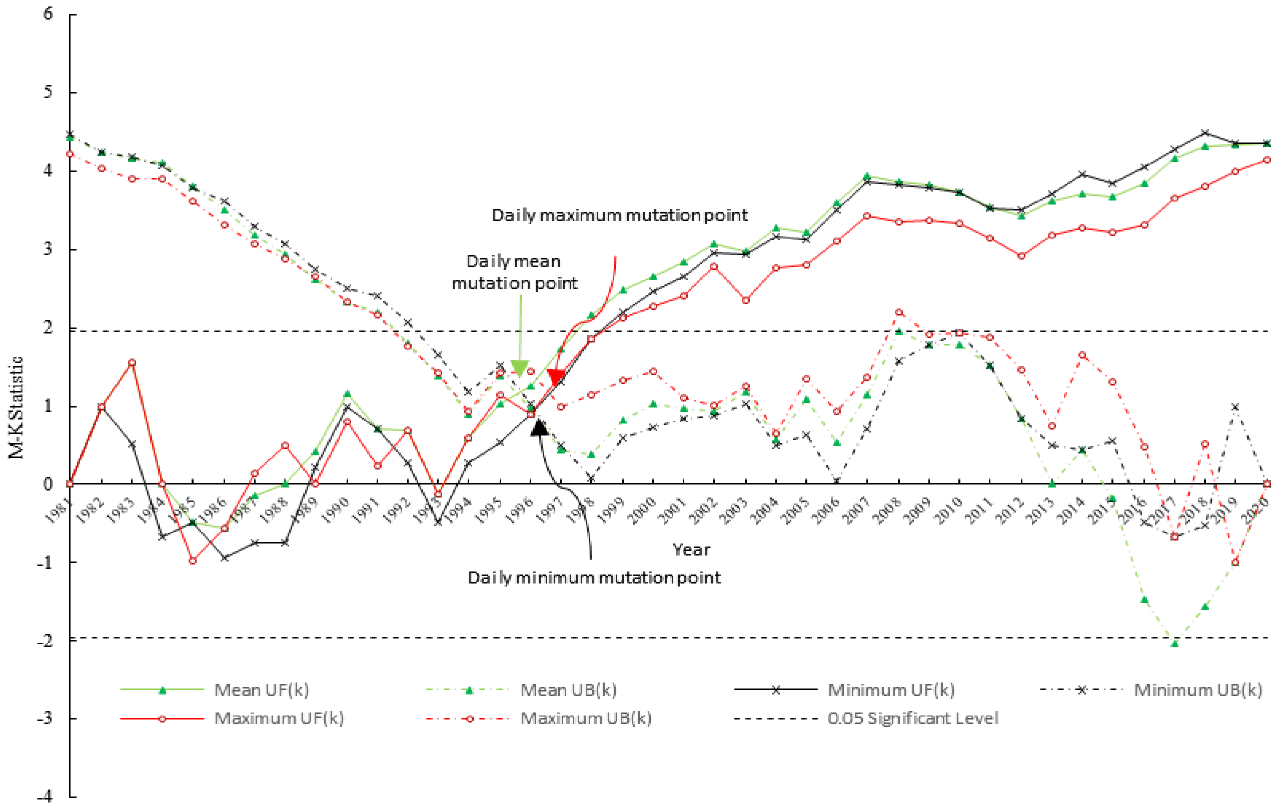

Figure 2. Mann-Kendall curve of abrupt change of daily temperature in area around Hongze Lake.

3.2.2 Seasonal change

The abrupt change of seasonal temperatures in the area around Hongze Lake is shown in Figure 3. The intersection point of the solid line and the corresponding dotted line represents the time when the temperature abrupt change occurred. The abrupt change in daily mean and minimum temperatures was observed in the spring of 2001 and 1998. There were 4 abrupt changes in daily maximum temperature from 2000 to 2003. Abrupt changes were most obvious in the daily minimum temperature, followed by the daily mean and maximum temperatures. In summer, the daily mean and minimum temperatures showed two abrupt changes in 1997 and 2000. The abrupt change in the daily maximum temperature occurred in 2001 and 2003. In autumn, there were three abrupt changes in the daily mean temperature (1990, 1991, and 1992), two abrupt changes in the daily minimum temperature (1993 and 1995), and five abrupt changes in the daily maximum temperature (1982, 1984, 1987, 2015, and 2018). In winter, the abrupt change in daily mean and minimum temperatures were found in 1988 and 1987 while those in the daily maximum temperature occurred in 1983, 1987, 1989, 1991, 2011, and 2012.

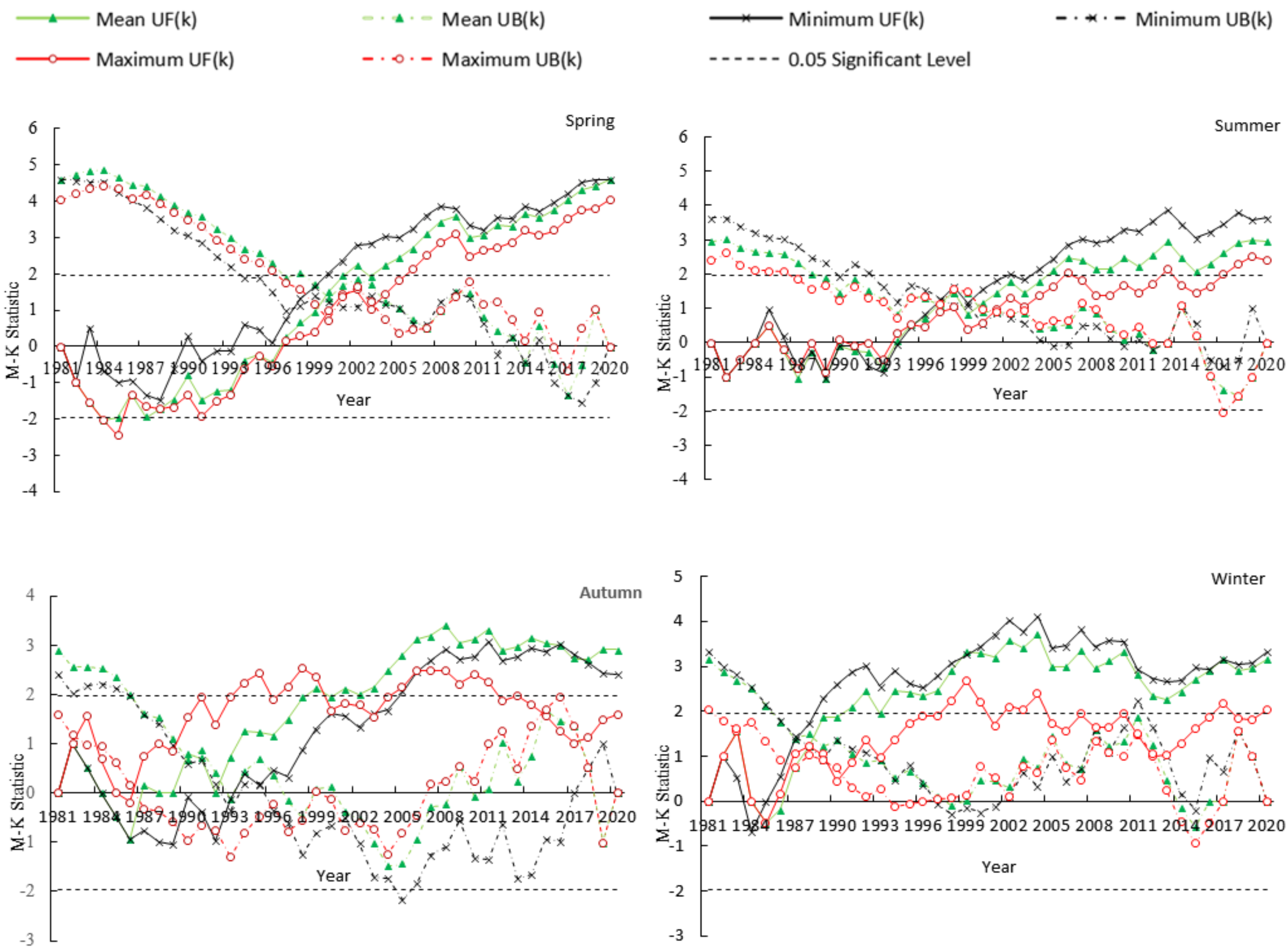

Figure 3. Mann-Kendall curve of abrupt change of seasonal temperature in area around Hongze Lake

In summary, from 1981 to 2020, the daily mean temperature in the four seasons around Hongze Lake showed an overall increasing trend. Springs and summers were colder before the 1990s. In autumn and winter, temperatures decreased only in three years. In other years, temperatures increased. Winter showed the most obvious increasing trend with the fastest rate, and abrupt changes were observed in early winter, spring, and summer. The daily minimum temperature showed an overall increasing trend, too. Before the 1990s, temperatures in spring and summer decreased but in winter, only one year showed such a decrease. In winter, the increase was more obvious with the fastest rate than in autumn, spring, and summer in order of the degree of the increase. The daily maximum temperature also showed an increasing trend but the significance level of the change was lower than that of the mean and minimum temperatures. The abrupt changes of the daily maximum temperature in summer, autumn and winter were more frequent than the daily mean and minimum temperatures. In autumn and winter, abrupt changes in temperatures were observed more obviously.

3.3 Spatial Analysis

To compare the spatial trend of temperature, the data from 16 weather stations for 40 years around Hongze Lake were used. According to the distance from the center of Hongze Lake, two groups were defined within 60 and 60−98 km. The mean, maximum, and minimum temperatures were compared as shown in Figure 4. The mean annual temperature at the stations within 60 km of Hongze Lake from 1981 to 2020 ranged from 14.60 to 15.29°C with a difference of 0.69°C and a mean of 15.03°C. Within the range of 60−98 km, the mean annual temperature ranged from 14.42 to 15.69°C with a difference of 1.21°C and a mean of 15.05°C. The mean annual temperature and its difference at the stations within 60 km of the lake were smaller than those within 60−98 km, and the mean temperature in the stations located in the south of the lake was higher than that in the north. The lowest temperature at the stations within 60 km of Hongze Lake was 10.72−11.65°C with a difference of 0.93°C and a mean of 11.19°C. Within 60−98 km, the minimum temperature was 10.16−11.86℃ with a difference of 1.70℃ and a mean temperature of 11.09℃. The mean minimum temperature at the stations within 60 km from the lake was higher than that within 60−98 km, but the difference was smaller, and the minimum temperature gradually decreased from south to north. The maximum temperature at the stations within 60 km of Hongze Lake ranged from 19.33 to 20.01℃ with a difference of 0.68℃ and a mean of 19.70℃. Within 60−98 km, the lowest temperature was 19.35−20.44℃ with a difference of 1.09℃ and a mean of 19.89℃. The difference and mean value of the maximum temperature at the stations within 60 km of the lake were smaller than those within 60−98 km, and the maximum temperature in the north of the lake was lower, showing a gradually decreasing trend from southwest to northeast.

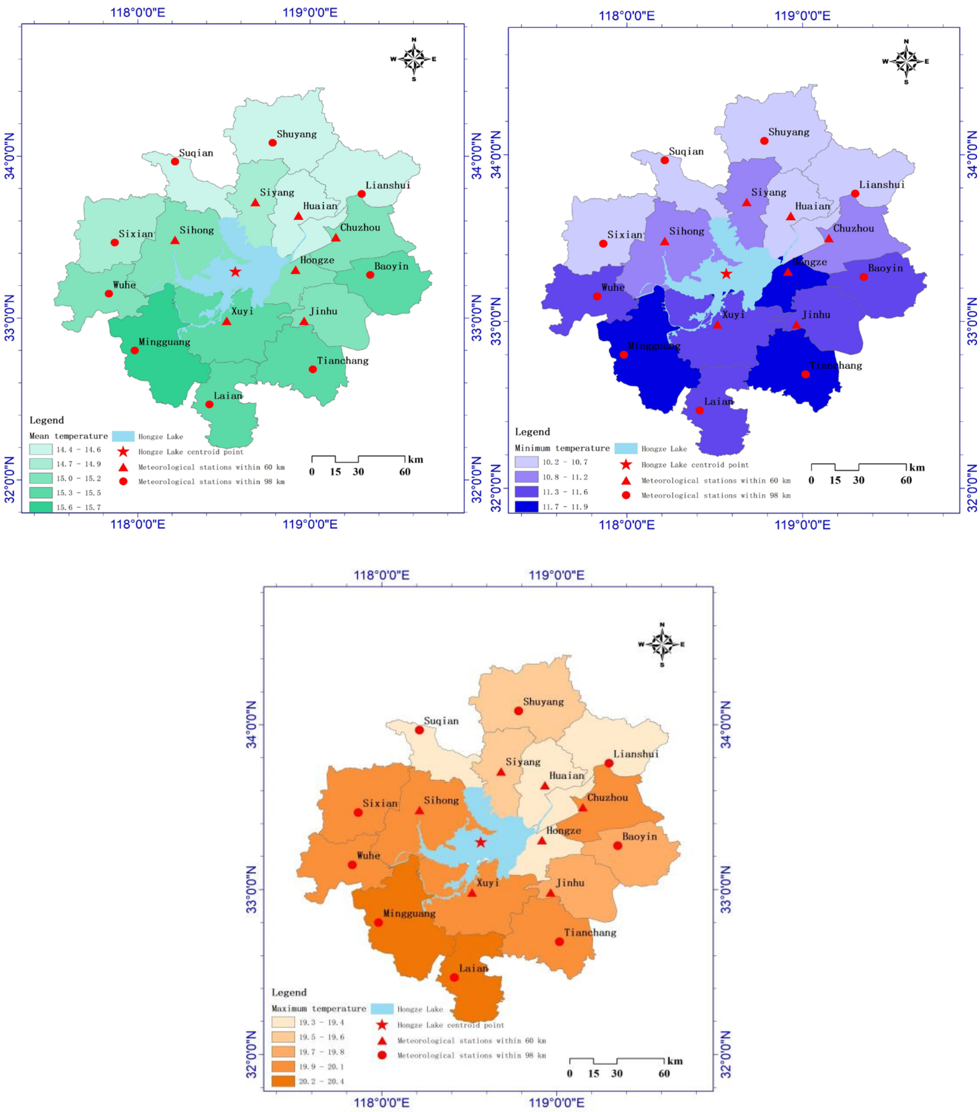

Figure. 4. Spatial variation of temperature in surrounding areas of Hongze Lake.

In summary, the closer to Hongze Lake, the temperature changes became smaller. The minimum temperature was higher and the maximum temperature was lower at the stations nearer to the lake. This indicated the climate regulation effect of the lake on the surrounding area with the overall temperature decreasing from south to north.

4. Conclusions

From 1981 to 2020, the daily mean, minimum, and maximum temperatures were analyzed in the surrounding area of Hongze Lake. The result showed a fluctuating but generally increasing trend, and the increase in the daily minimum temperature was the largest (0.55℃/10 years), followed by the daily maximum and mean temperatures. Increased minimum temperatures were one of the main causes of local warming. The research results on the temperature changes of the Huaihe River Basin, the Yangtze River

Basin, and the Yellow River Basin [23,24] were similar to those in this study. This phenomenon was also observed in other regions of the world. However, the decrease in the number of warm days and the daily maximum temperature was unique in the Huaihe River Basin. The seasonal temperature around Hongze Lake showed an increasing trend which was most obvious in spring and least obvious in autumn. The temperature increase was the largest in spring, followed by winter and summer, and the smallest in autumn, which was also consistent with the conclusion of the IPCC [25].

The abrupt changes in temperature in the area around Hongze Lake occurred in 1996, and the daily mean temperature showed the largest abrupt changes, followed by the daily minimum and maximum temperatures. Before the abrupt change occurred, temperature showed a smaller degree in the change but after the abrupt change happened, the daily maximum temperature increased rapidly. The mutation degree of the daily maximum temperature was more obvious than that of the daily minimum and mean temperatures. Since the 20th century, the temperature in China has shown an increasing trend, and the warming rate is higher than that of the global and northern hemisphere. The abrupt changes occurred after the 1990s [26], which was generally consistent with the conclusions of this study. The seasonal temperature in the area around Hongze Lake showed an overall increasing trend. In winter, the abrupt changes occurred more frequently than in autumn, spring, and summer in order of its frequency. The significance level of the daily maximum temperature was lower than that of the daily mean and minimum temperatures. The abrupt changes in the daily mean temperature were more frequent than the daily minimum temperature in summer, autumn, and winter in order of frequency. The nearer to Hongze Lake, the smaller the temperature changes. The occurrence of the minimum temperatures was more frequent, and the maximum temperature was lower in the area nearer to the lake. Such results verified the regulation effect of lakes in climate on surrounding areas. The lake-land wind circulation formed in the area caused heat and water exchanges between land and water, which was the major cause of the regulation effect. In the future research, it is necessary to further study the influence of the size and depth of the lake on the lake-land wind circulation.

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