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Article

Change in Humidity around Hongze Lake from 1981 to 2020

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Abstract: To study the change and influence of humidity around Hongze Lake, the absolute humidity was calculated by using the observation data of 16 weather stations from 1981 to 2020. The absolute and relative humidity were then compared. The influence of Hongze Lake on the humidity in the surrounding area was investigated by comparing it with that of other stations. In the past 40 years, humidity showed significant changes interannually. The annual absolute humidity showed a peak and decreased while the relative humidity showed two peak values. Under the influence of global warming, the absolute humidity decreased during the past 40 years but the relative humidity increased. This showed overall warming and drying. The humidity around Hongze Lake was slightly higher than that in other places. The humidity around Hongze Lake was affected by the Lake and the location, which needs further study. The regulating effect of Hongze Lake on the humidity in the surrounding area was verified in this study. The result provides a basis for meteorological service and environmental protection of the ecosystem in the surrounding area of Hongze Lake.

Keywords: Relative humidity, Absolute humidity, Hongze Lake

1. Introduction

As an important water resource and an integral part of the "landscape, forest, lake, field, grass, and sand", lakes have important ecological functions [1] in regulating humidity [2]. There are studies on the influence of lakes on relative humidity in China but few studies have been conducted on the influence on absolute humidity. There have been no reports on the influence of Hongze Lake on the relative and absolute humidity. Therefore, we analyzed the characteristics and variations of humidity in the area around Hongze Lake using the K-W test. Significant differences in absolute and relative humidity between Hongze Station and the other stations around Hongze Lake were determined to understand the regulating effect of Hongze Lake on humidity in the surrounding area. Aavudai et al. [3] predicted the daily relative humidity of the river basin. Matxalen et al. [4] studied the heat, relative humidity, and temperature of two traditional building models in the Lea River Valley. Gong et al. [5] found that the average relative humidity of Nansi Lake (the general term for the four conjoined lakes of Nanhu, Dushan, Zhaoyang, and Weishan) was higher than that of the land along the lake, especially in winter. Ren et al. [6] found that in the past 30 years, the relative humidity of ten lakes in the middle and lower reaches of the Yangtze River decreased by 3.9% with a rate of -0.013%/10 years. Chen et al. [7] found that the relative humidity in the Five Lakes of central Yunnan showed a decrease in a change cycle of 20–25 years with a larger change in spring and summer. Li et al. [8] conducted experiments with and without lakes in Lanzhou urban area and found that the relative humidity decreased and then increased with the absolute humidity increased.

2. Data and Methods

2.1. Research Area

Hongze Lake (33°06′–33°40′ N, 118°10′–118°52′ E) is in the territory of Huai'an and Suqian cities, northwest of Jiangsu Province [9], and is one of the five major freshwater lakes in China. Hongze Lake is connected to the Yellow River in the north, the Yangtze River in the south, the Huaihe River in the west, and the sea in the east. Main streams gather in the lake including the middle reaches of the Huaihe River [10]. The total area of the Hongze Lake basin is 18090 km^2 with Laishui in the upper and middle reaches of the Huaihe River with a watershed area of 15.8 × 104 km^2 [11]. The bottom elevation is 10−11 m, the average water level is 13.0 m, and the flood limit is 12.5 m[12]. The research area includes Xuyi County, Hongze District, Sihong County, Huaiyin District, Qingjiangpu District, Sucheng District, and the area south of the middle section of Jinghang Canal in Siyang County [13]. Hongze Lake belongs to the transition area between the Huang-Huai-hai Plain and the middle and lower reaches of

the Yangtze River in the monsoon climate as it reaches from the warm temperate zone in the north subtropical zone [14]. The humidity in spring and the sunlight in summer have been decreased [15].

2.2. Data

The data were obtained from 7 meteorological stations in Hongze, Xuyi, Jinhu, Chuzhou, Huai'an, Siyang and Sihong (as shown in Fig. 1). From the China meteorological data network (Available online: http://data.cma.cn:8888/site/article/id/41316.html, accessed on November 29, 2021), data from 1964 to 2014 were obtained including temperature, relative humidity, average, saturated vapor pressure, average pressure observation data, absolute humidity, annual and interannual variation. To study the regulating effect of Hongze Lake on relative and absolute humidity in surrounding areas, Hongze meteorological stations (33°06′ N, 118°45′ E) within 0–60 km of Hongze Lake were selected. The observation stations include Shuyang Meteorological Station (34°14′ N, 118°58′ E), Lai'an Meteorological Station (32°27′ N, 118°25′ E), Baoying Meteorological Station (33°10′ N, 118°57′ E), and Sixian meteorological Station (33°28′ N, 117°52′ E). They are 60–98 km away from Hongze Lake.

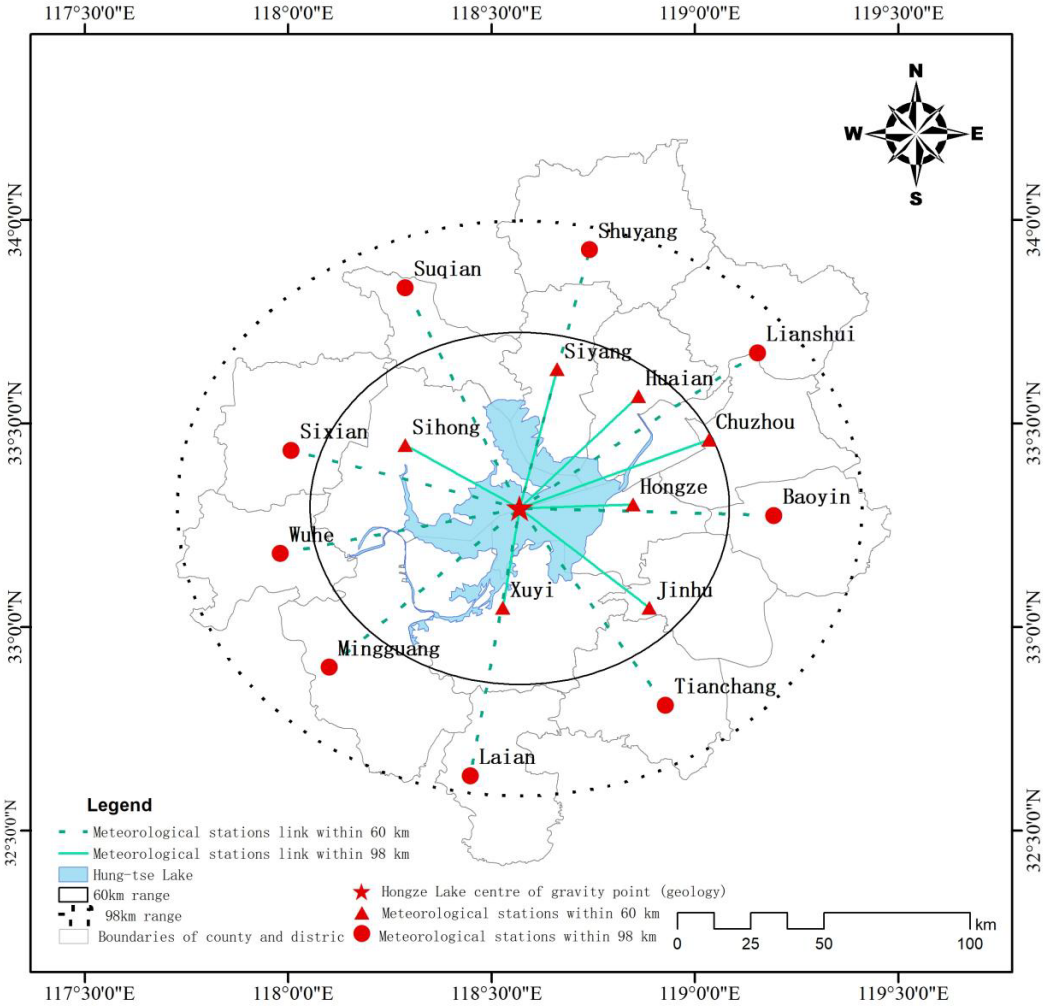

Fig. 1. Stations around Hongze Lake.

The longitude and latitude of the five meteorological stations are similar (Table 1). Shuyang and Lai'an Stations have similar longitudes, while Hongze, Baoying, and Sixian Stations have similar latitudes.

Table 1. Longitude and latitude of main meteorological stations around Hongze Lake.

Prefecture-Level City	Site	Latitude (°N)	Longitude (°E)
Huai'an	Hongze	33.06	118.45
Suqian	Shuyang	34.14	118.57
Chuzhou	Lai'an	32.27	118.25
Yangzhou	Baoying	33.10	119.21
Suzhou	Sixian	33.28	117.52

2.3. Analysis Methods

Humidity is an important index to measure the atmospheric environment and reflects the change in atmospheric moisture content [16]. It is mainly expressed as absolute and relative humidity. Relative humidity refers to the ratio between the actual water vapor pressure in the air and the saturated water vapor pressure at the temperature, that is, the ratio between the absolute humidity in the atmosphere and the maximum absolute humidity at the same temperature. Absolute humidity refers to the water vapor mass contained in the unit volume of air [17]. There is no functional relationship between relative and absolute humidity. When the temperature rises, water vapor evaporation intensifies, the water vapor content in the air increases, and then, the absolute humidity increases. With the increase in temperature, the saturated pressure increases but the relative humidity does not necessarily increase correspondingly. Therefore, the moisture content of the air in the afternoon is higher than that in the morning, and that in the summer is higher than that in the other seasons. Then, absolute humidity becomes larger. For absolute humidity, the density of water vapor in the air is measured to explain the atmospheric characteristics. The humidity in the surrounding areas of Hongze Lake can be explained more comprehensively from the perspectives of relative and absolute humidity.

2.3.1. Absolute Humidity

The calculation of absolute humidity was referred to from the book Commonly Used Formulas of Atmospheric Science edited by Wang et al. [18]. The saturated water vapor pressure E_s is obtained by using the saturated water vapor pressure E at 0 °C, which is 6.11 hPa. a and b are constants of the meteorological observation standards on the ground. Under water surface conditions, a = 7.69, b = 243.92. In ice, a = 9.5, b = 265.5 [19]. Then, the actual vapor pressure e is obtained by the relative humidity RH and the saturated water pressure E_s.

$$\boldsymbol{E_s = E_0 \times 10^{\frac{at}{b+t}}} \tag{1}$$

$$RH \approx \frac{e}{E_s} \times 100\% \tag{2}$$

Finally, the absolute humidity is obtained from the actual water vapor pressure e and temperature t.

$$\boldsymbol{a = A\frac{e}{t}} \tag{3}$$

2.3.2. K-W Test Method

The K-W test method is a non-parametric method to test whether two or more samples come from the same probability distribution. The samples must be independent or unrelated. The parameter test equivalent to this test is one-way ANOVA. In the K-W test method, the sample with a normal distribution is not assumed. Its original assumption is that the probability distribution of each sample has the same median and the rejection of the original assumption means that the median of the probability distribution of at least one sample is different from other samples. The magnitude of these differences is not identified. If there are n samples, the test value $\boldsymbol{H = \sum_{i=1}^{k} n_i, n_i}$ representing the sample size of each group, $\boldsymbol{R_i}$ is the sum of each group of samples. Under the level of a = 0.05, $\boldsymbol{H > X^2_{(0.05,1)}}$ indicates significant differences among samples. According to the method, the daily average of absolute humidity around Hongze Lake was calculated, and the annual average relative and absolute humidity of each weather station was also calculated. In order to analyze the basic characteristics of relative and absolute humidity in different seasons, we divided the seasons into spring (March to May), summer (June to August), autumn (September to November), and winter (December to February of the following year) [20] and established a one-year time series dataset. The anomalies and cumulative anomalies were calculated respectively. By using the pairwise comparison with the advance adjustment in the K-W test method, a significant difference in

humidity between Hongze Station and other stations was analyzed to understand the influence of Hongze Lake on humidity in the surrounding areas.

3. Result and Discussion

3.1. Humidity in Surrounding Area of Hongze Lake

Table 2 shows the average relative humidity in the area around Hongze Lake from 1981 to 2020. The average relative humidity of 76.23% in 1990 and 66.27% in 2011. Over the past 40 years, the highest average relative humidity in both summer and autumn was found in 2014. The highest average relative humidity in spring was observed in 1990, while the highest in winter was found in 1983. The minimum humidity in summer and autumn was observed in 2012, the minimum in spring was in 2001, and the minimum in winter was in 2011. In a year, the annual average relative humidity was the highest in summer at 81.06%, autumn at 76.47%, winter at 72.26%, and spring at 71.82%. The mean standard deviation was 11.30% with a maximum of 13.15% and a minimum of 8.21%.

Table 2. Relative humidity in Hongze Lake.

Parameter	Year	Spring	Summer	Autumn	Winter
Mean value (%)	76.23	71.82	81.06	76.47	72.26
Standard deviation (%)	11.30	12.80	8.21	10.80	13.15
Coefficient of variation	0.15	0.15	0.13	0.14	0.18
Highest value (%)	80.23/1990	78.27/1991	85.65/2014	82.84/2014	82.71/1983
Lowest value (%)	66.27/2011	54.73/2001	75.82/2012	68.57/2012	58.15/2011

Table 3 presents the annual average absolute humidity from 1981 to 2020 which was 9.72 g/m^3. The highest humidity of 10.59 g/m^3 was observed in 1998, and the lowest humidity was 8.35 g/m^3 in 2011. The annual average absolute humidity in spring 2011 was 7.05 g/m^3, and the annual average absolute humidity in summer was 18.87 g/m^3, both of which were the lowest in 40 years. In 1998, it was 21.61 g/m^3 in summer and 11.82 g/m^3 in autumn which were the highest in 40 years. The maximum annual average absolute humidity was 21.60 g/m^3 in summer, 11.73 g/m^3 in autumn, 9.70 g/m^3 in spring, and 4.12 g/m^3 in winter. The standard deviation was 0.53 g/m^3, the maximum value was 2.73 g/m^3 in spring, and the minimum value was 0.21 g/m^3 in autumn. The variation was the largest in summer and the smallest in autumn.

Table 3. Absolute humidity in surrounding areas of Hongze Lake.

Parameter	Year	Spring	Summer	Autumn	Winter
Mean value (g/m^3)	9.72	9.70	21.60	11.73	4.12
Standard deviation (g/m^3)	0.53	2.73	2.42	0.21	0.24
Coefficient of variation	0.10	0.28	0.11	0.32	0.38
Maximum value (g/m^3)/a	10.59/1998	10.87/1987	21.61/1998	11.82/1998	4.97/1984
Minimum value (%)/a	8.35/2011	7.05/2011	18.87/2011	9.38/2012	2.94/1999

3.2. Humidity Change around Hongze Lake

3.2.1. Annual Variation of Humidity

Table 4 lists the annual and inter-monthly changes in relative humidity in the surrounding areas of Hongze Lake. In the area, the average relative humidity varied over the months. The lowest humidity was 70.5% in March and the highest was 83.6% in July. Temperature is one of the most important factors affecting humidity. In global warming, in most months, the humidity decreased. During January-March, June, and September-December, it decreased, and during April-May and July-August, it increased. The humidity increased by 24 % in July, decreased by 4% in April, and by 9 % in September and October. The humidity decreassed by 2% in November and December.

Table 4. Annual variation of relative humidity around Hongze Lake.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Mean (%)	72.9	71.4	70.5	71.3	77.8	72.2	83.6	83.2	79.0	75.6	73.4	71.0
Intermonthly variability	−5	−4	−3	4	5	−3	24	7	−9	−9	−2	−2

Table 5 shows the annual and inter-monthly changes in absolute humidity around Hongze Lake over the months. The monthly average absolute humidity ranged from 3.6−1.2g/m3, which was similar to the variation of relative humidity. The maximum absolute humidity was observed in July. The minimum relative humidity was found in March while that of the absolute humidity was observed in January. The absolute humidity showed an overall decrease in January-April, June, and August-December but increased in May and August. The largest increase of 40% was found in May, and in July, the increase was 39%,. In April, 68% was decreased, and in February, 14% was decreased. Absolute and relative humidity decreased on the whole being related to the rise of global temperature and drying climate due to the global warming.

Table 5. Annual variation of absolute humidity around Hongze Lake.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Meanvalue (g/m^3)	3.6	4.0	5.5	8.5	12.2	16.5	21.0	21.2	15.1	10.5	6.7	4.2
Intermonthly variability	−20	−14	−40	−68	40	−31	39	−5	−32	−34	−38	−34

Fig. 2 shows the annual variation of humidity in the area around Hongze Lake. The variation of relative humidity was bimodal. In January-March, relative humidity decreased as in March, it decreased by 70.5%. The first peak was reached in May at 77.8%. Then, it decreased again reaching 72.2% in June, and then increased. The second peak was found in August with a maximum relative humidity of 83.2%, and decreased again till December. Absolute humidity ranged from 3.6 to 21.20 g/m^3. It showed the minimum value in January and increased till summer. In January, it was 3.65 g/m^3, while in August, it was 21.20 g/m^3.

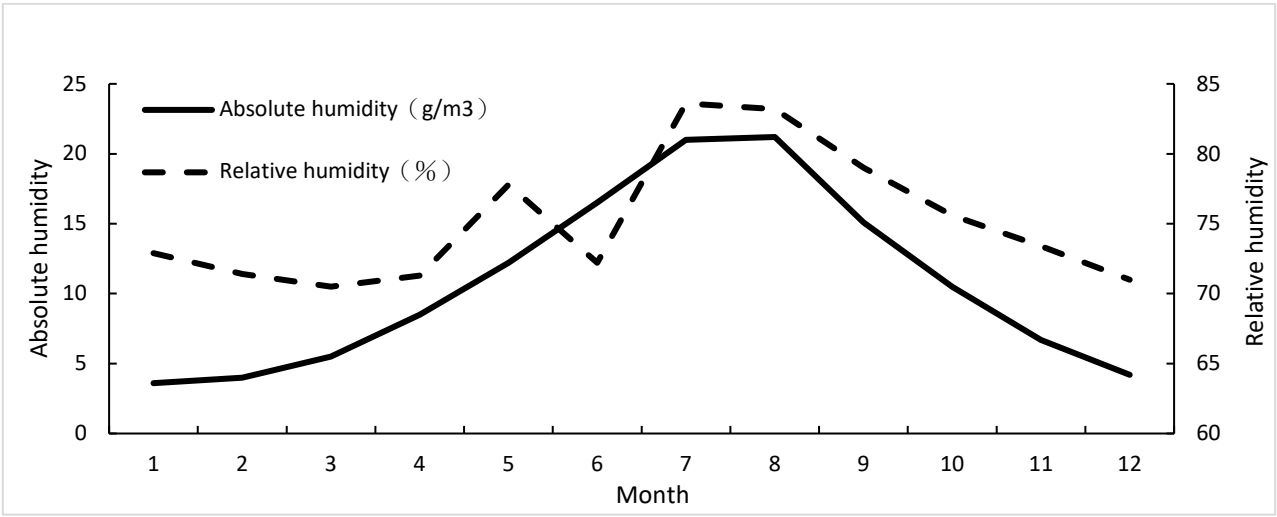

Fig. 2. Annual variation of humidity in the surrounding area of Hongze Lake.

3.2.2. Interannual Variation of Humidity

Figs. 3 and 4 show the change in annual average relative humidity and anomalies from 1981 to 2020. The annual average absolute humidity showed a rate of 0.02 g/m^3/10 years. Relative humidity showed a different trend from absolute humidity. It had an overall decrease with a rate of −0.12%/10 years. In global warming, the evaporation of Hongze Lake increased, which increased moisture content in the air so the absolute humidity increased. However, as the temperature increased, the saturated water vapor pressure increased, and the rate was 0.125 hPa/10 years, which is higher than the actual dip rate of water vapor pressure (0.036 hPa/10 years). Thus, relative humidity showed a decreasing trend [21]. Although the interannual variation of relative and absolute humidity does not accurately and objectively reflect the drought degree of Hongze Lake and its influence on the surrounding areas, the temperature increase was one of the main factors of drought.

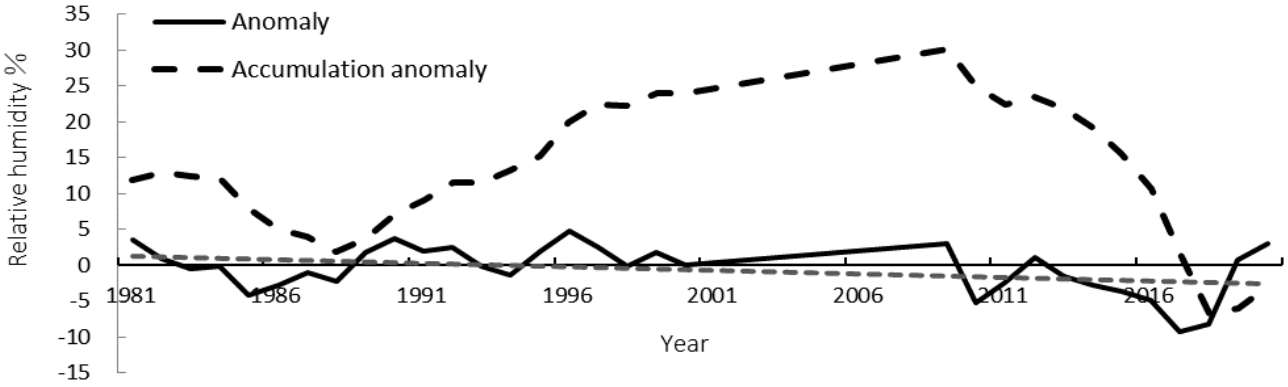

Fig. 3. Relative humidity and anomalies in surrounding area of Hongze Lake.

The annual average relative humidity of Hongze Lake changed significantly from 1981 to 2020. Relative humidity had been lowered with a negative anomaly up to 75%. From 1988 to 2010, relative humidity increased, and the proportion of positive anomalies reached 63%. From 2011 to 2020, the relative humidity decreased and the negative anomaly ratio was 69%. The changes in annual mean absolute humidity were different from 1981 to 2006. Absolute humidity was lower and the negative anomaly ratio was about 60%. During 2006–2020, the absolute humidity was higher, and the positive anomaly ratio was about 69%.

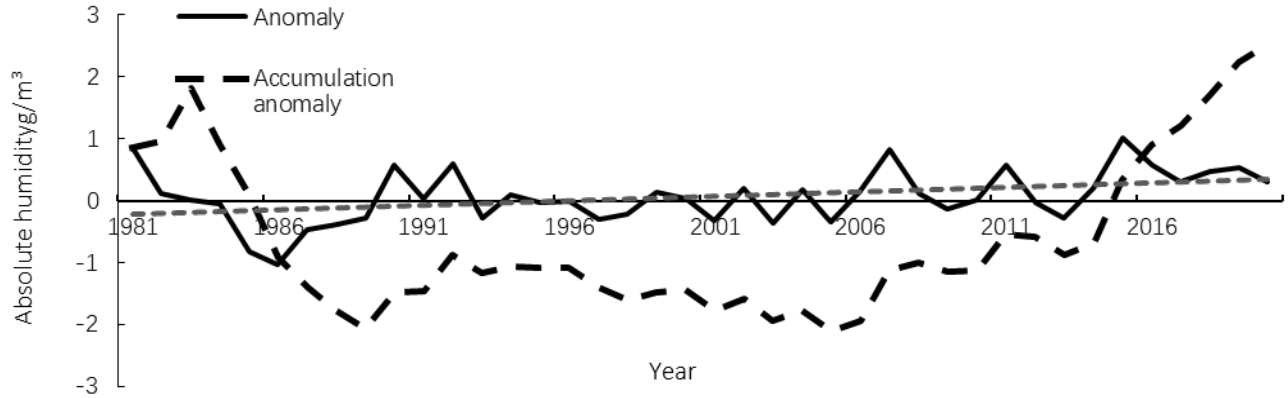

Fig. 4. Absolute humidity and anomal**ies** in surrounding area of Hongze Lake.

3.3. Humidity Variation in Seasons

Table 6 shows the seasonal trend of relative and absolute humidity. The average relative and absolute humidity increased in autumn but the increase of relative humidity was much larger than that of absolute humidity. The increasing rate of the relative humidity was 0.92%/10 years, while the absolute humidity increased by 0.01 g/m^3/10 years. The average absolute humidity in winter increased more significantly, and its value was 0.03 g/m^3/10 years, which was larger than that in autumn. The average absolute humidity in spring and summer decreased [22] at a rate of 0.04 and 0.06 g/m^3/10 years. The changes in average relative humidity in autumn and winter were most obvious.

Table 6. Tendency rate of seasonal variation of humidity in Hongze Lake.

Tendency Rate	Year	Spring	Summer	Autumn	Winter
Relative humidity %/10 years	−0.52	−1.52	−0.57	0.92	−0.69
Absolute humidity g/m³/10 years	0.02	−0.04	−0.06	0.01	0.03

3.4. Influence of Hongze Lake on Humidity

Table 7 presents the average annual relative humidity of Hongze Station (75.23%). The average annual relative humidity of Shuyang, Baoying, Sixian, and Lai'an Stations was 76.94, 74.26, 74.27, and 75.12%, respectively. Lai'an Station showed the highest humidity followed by Shuyang and Baoying Stations. The difference from that of Hongze Station was 1.71% at Lai'an Station, 0.97 and 0.96% at Baoying and Sixian Stations, and 0.11% at Shuyang Station. Compared with Hongze Station, only Lai'an Station shows a significant difference.

Table 7. Relative humidity difference test between Hongze Station and the other four stations.

		Lai'an	Baoying	Sixian	Shuyang
Relative humidity %	Annual mean	76.94	74.26	74.27	75.12
	Difference value	1.71	−0.97	−0.96	−0.11
	KW test value	2.68	1.60	1.04	0.48
	Significant level	0.04	non-significant	non-significant	non-significant

The average annual absolute humidity of Hongze Station was 9.61 g/m^3, while that of other stations was 9.76, 9.50, 9.55, and 9.55 g/m^3. Lai'an Station showed the highest humidity while Sixian Station had the same humidity as Shuyang Station, and Baoying Station showed the lowest. Compared with Hong Station, the maximum difference was 0.16g/m^3 at Baoying Station, 0.11g/m^3 at Shuyang and Sixian Stations, and the minimum difference was 0.1g/m^3 at Lai'an Station. Compared with Hongze Station, only Lai'an Station showed a higher absolute humidity and the other three stations showed lower humidity. The K-W test result of the annual average absolute humidity of the four stations showed that Lai'an and Sixian Stations had significant differences which were 0.01 and 0.00.

Table 8. Difference test of absolute humidity between Hongze Station and other four stations.

		Lai'an	Baoying	Sixian	Shuyang
Absolute humidityg g/m³	Annual mean	9.76	9.50	9.55	9.55
	Difference value	0.10	−0.16	−0.11	−0.11
	KW test value	3.33	2.08	5.91	0.31
	Significant level	0.01	non-significant	0.00	non-significant

By comparing the annual mean relative and absolute humidity of Hongze Station, Lai'an Station, Shuyang Station, Baoying Station, and Sixian Station, it was found that Hongze Lake increased the surrounding humidity limitedly. As many factors affect humidity, such as latitude, land and sea location, terrain, soil, vegetation coverage, and urbanization, the dominant factors in different regions need to be found in detail in further studies.

4. Conclusions

Characteristics and influence of humidity in the area around Hongze Lake were investigated using the observation data of 16 weather stations from 1964 to 2014. In the past 40 years, the interannual variation of humidity changed significantly. Relative humidity changed in two stages while absolute humidity changed in three stages. Absolute humidity increased till summer and decreased gradually, while relative humidity repeatedly decreased and increased in a year. In global warming, absolute humidity decreased in the past 40 years but relative humidity increased showing warming and drying. The influence of Hongze Lake on the surrounding area in terms of humidity was validated. However, there are other factors such as longitude and latitude, terrain, and atmospheric circulation which need to be further studied. The result of this study provides a basis for meteorological service and the protection and development of the ecosystem around Hongze Lake.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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