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Research Article

Climate Change Characteristics of Extreme Temperature in the Minjiang River Basin

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Based on the daily temperature data from 26 meteorological stations in the Minjiang River Basin, for 1961 to 2016, the temporal trend and spatial distribution of extreme temperature in this region were analyzed using 16 extreme temperature indices. The results show that in terms of time variation, determined using linear trend analysis and a Mann–Kendall trend test, the warm and day indices mainly show an upward trend while the cold and night indices mainly show a downward trend in the entire basin. Among them, FD0, TN10, and CSDI significantly decrease at −1.3, −2.9, and −1.1 d/10a, respectively. TN90, TX90, SU25, and TR20 significantly increase at 3.0, 2.6, 2.1, and 2.2 d/10a, respectively. The crop growth period in the basin showed a significant increasing trend at 1.4 days/decade, while the diurnal temperature range showed a nonsignificant increasing trend at 0.03 days/decade. On comparing the change range of each index, it was found that the change range of the warm index is greater than that of the cold index, while the change range of the day index is smaller than that of the night index; thus, the change trends of the maximum and minimum temperatures in the whole basin are not obvious. Analysis of the changing trend at each station showed that the relative index of the extreme temperature in the basin has good climatic consistency in terms of spatial distribution. The distributions of the absolute and extreme indices are not uniform, which is consistent with the change in elevation in the basin. Further, the diurnal temperature range in the upper reaches of the basin is greater than that in the middle and lower reaches. However, because of the more obvious upward trends of the day and warm indices in the middle and lower reaches, and the more obvious downward trends of the night and cold indices in the upper reaches, the daily temperature differences in the upper, middle, and lower reaches of the Minjiang River Basin tend to be consistent. Therefore, the precipitation in the Minjiang River Basin shows a significant decreasing trend; thus, the basin shows a trend of drying and warming.

1. Introduction

According to the Intergovernmental Panel on Climate Change Fifth Assessment Report, the mean global surface temperature has risen by 0.85°C from 1880 to 2012. It is an undisputed fact that the globe has warmed resulting in a serious impact on human society [1–6]. With the increase in temperature, the ability of the atmosphere to retain water is increased, and the extreme value of temperature has changed significantly, resulting in frequent droughts and forest fires. Meanwhile, with the change of temperature, the global average sea level rose by 19 centimeters between 1901 and 2010. In the past 10 years, the speed of glacier melting has been several times faster than that in the 1990s. The changes in temperature extremes have increased the frequency and intensity of extreme climatic events such as high temperatures, droughts, rainstorms, and flooding. Some extreme climatic phenomena cannot be described by a single meteorological element. For example, when the temperature increases, evaporation will intensify and soil moisture and infiltration intensity will also change. A change in the water cycle is caused by an increase in temperature. An increase in temperature will also change the redistribution of river runoff and water resource characteristics of a basin. Extreme temperature events are an important part of extreme climatic events; thus, it is of great significance to study the changes in extreme temperature under global warming.

Thus far, many studies have been completed regarding extreme temperature [7, 8]. For example, Alexander et al. [9] found that 70% of the world's regions underwent a significant decrease in cold nights and a significant increase in warm nights during the past 50 years. Manton et al. [10] analyzed 91 temperature stations of 15 countries in Southeast Asia where climate change is extremely evident. The result showed that the number of warm days and nights significantly increased, while the number of cold days and nights significantly decreased during 1961–1988. Overall, the annual average temperature shows a relatively consistent and significant increasing trend worldwide, but the temperature indicators in different regions have different characteristics, particularly extreme temperature indicators.

In China, the annual average surface temperature increased by 1.1°C at a rate of 0.22°C/10a [11], which is higher than the global average during the last 50 years. However, regarding extreme temperature, Ren et al. [12] found that cold extreme events such as cold waves, nights, and days and frost days significantly decreased. In contrast, warm events such as warm nights and days significantly decreased, particularly warm nights in China. Zhang et al. [13] found that the annual and seasonal extreme low temperatures in China showed a steady increasing trend by calculating the daily maximum and minimum temperatures of 234 meteorological stations in China from 1955 to 2005. Wang et al. [14] considered that the cold index increased more than the warm index, and the night index increased more than the day index. From the aforementioned studies, it is clear that due to global warming, extreme temperature indices in different regions do respond differently, and the variation range of cold and warm indices in different regions varies from day to night. Overall, studies show that the frequency and intensity of cold wave events in most parts of China have significantly decreased, but the intensity of heat wave events in China shows regional asymmetry [15–17]. The frequency of heat wave events has strong interdecadal characteristics, and the long-term linear trend is not obvious. This shows that with an increase in temperature, the frequency of cold extreme events decreases while the frequency of warm extreme events has different characteristics in different regions. The Yangtze River is the largest river in China, and the third largest river in the world. The basin has a dense population and is among the areas with a highly developed economy. The Yangtze River is affected not only by the southeast and southwest monsoons but also by the Qinghai-Tibet Plateau. It is a vulnerable area of climate change and a frequent area of drought and flood disasters [18]. Zhou et al. [19] considered that extreme low temperature days began to decrease and extreme high temperature days began to increase after 1987 in the lower reaches of the Yangtze River. Both extreme high temperature and extreme low temperature showed a significant upward trend, particularly extreme low temperature. Zhong et al. [20] found that the annual and seasonal mean temperature of the Yangtze River Basin showed a significant upward trend from 1961 to 2013 and is more obvious during winter than summer. Wang et al. [21] showed that the annual average temperature in most areas of the upper reaches of the Yangtze River showed an upward trend, particularly during the 1990s; the most significant increase in temperature occurring during winter mainly distributed in the source area of the Yangtze River and the Jinsha River Basin. Wang et al. [14] noted that the average temperature in the upper reaches of the Yangtze River showed an upward trend and, at the same time, the increase in temperature reflected a trend of drought aggravation. At present, a large number of studies have focused on the Yangtze River Basin or the upper and middle reaches of the Yangtze River as a whole, to study its trend changes. Analysis of extreme temperature indicators in the Yangtze River Basin is relatively general, mainly focusing on changes in the highest and lowest temperatures and average temperatures. At the same time, the results show that there is regional asymmetry in the upper reaches and in the middle and lower reaches of the Yangtze River. The mean summer temperature in the middle and lower reaches of the Yangtze River has significantly decreased because of the obvious decrease in the maximum temperature, while the upper reaches of the Yangtze River showed an upward trend [12]. The change trend of high temperature days is also different. There is a significant decreasing trend in the middle and lower reaches of the Yangtze River, while there is an increasing trend in the upper reaches [15].

The Minjiang River Basin is in a transitional area from high altitudes to basins on the eastern side of the Qinghai-Tibet Plateau. There are great differences in altitude, topography, and climatic conditions. There are differences between the extreme temperature changes and the overall situation in the Yangtze River Basin. Therefore, it is of great significance to study the spatial differences within the Minjiang River Basin. Based on the daily temperature data of 26 meteorological stations in the Minjiang River Basin from 1961 to 2016, the temporal and spatial variations of extreme temperature in the Minjiang River Basin were analyzed by linear trend analysis and Mann–Kendall (MK) tests. The reasons for the spatial variations in extreme temperature are discussed.

1.1. Study Area. The Minjiang River is the first tributary on the west bank of the upper reaches of the Yangtze River. Figure 1 is the drainage map of the Minjiang River. The Minjiang River is also the largest tributary of runoff in the Yangtze River Basin. Its total length is 790 km. The total elevational drop of the Minjiang River is 3560 m. It originates from the southern foot of Minshan Mountain in Aba Prefecture, Sichuan Province. The area of the basin is 135,881 square km. Because it is rich in hydropower resources, it is an important area for hydropower development in Southwest China. The upper reaches of the Dujiangyan River are mainly hydroelectric power generation and the middle

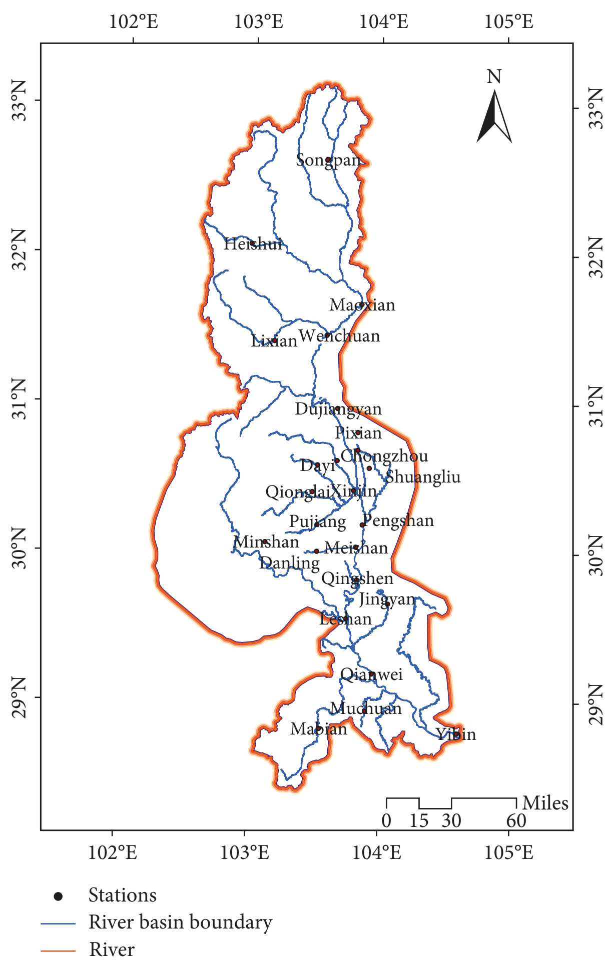


Figure 1: Minjiang River drainage map.

reaches of the Dujiangyan to Leshan flow through the Chengdu Plain area, together with the Tuojiang River system and many artificial river networks, forming the Dujiangyan irrigation area. The lower reaches, from Leshan to Yibin, are mainly used for shipping. It finally flows into the Yangtze River in Yibin.

2. Materials and Methods

2.1. Materials. In this study, the daily temperature data of 26 national basic stations and national general stations (Table 1) in the Minjiang River Basin provided by the China Meteorological Administration (CMA) were used, including daily average temperature, daily maximum temperature, and daily minimum temperature. The time period was 1961–2016. The data have passed strict quality control, including extreme value and time consistency tests.

2.2. Extreme Temperature Index. In this study, 16 important extreme temperature indices recommended and defined by the World Meteorological Organization (WMO) were used, as shown in Table 2. These indices reflect the changes in different aspects of extreme climate [9] and have the characteristics of weak extremes, low noise, and strong significance.

2.2.1. Linear Tendency Estimation Method. In this study, the linear trend estimation method was used to analyze the trend of climate change. The arithmetic of the climatic tendency rate is as follows: Let the time series of a meteorological element of a station be $y_1, y_2, \ldots, y_n$, which can be expressed by a polynomial as follows:

$$y(t) = a_0 + a_1 t_1 + a_2 t_2 + \cdots + a_m t_n. \tag{1}$$

In the formula, t is the time in unit a (year). $a_1{}^*10$ is termed the climatic tendency rate in d/10a or °C/10a. The coefficients in the equation can be determined by the least squares method or an empirical orthogonal polynomial.

2.2.2. MK Trend Test. A MK test is a nonparametric test recommended and widely used by the WMO. It was first proposed by Mann and Kendall and has been applied by many scholars [22–25]. A MK trend test was used to analyze the trend change of time series of precipitation, runoff, temperature, and water quality. A MK test does not require samples to follow a certain distribution, nor is it disturbed by a few abnormal values. It is suitable for non-normal distribution data such as hydrology and meteorology and is easy to calculate [6, 26–29].

In the MK test, the zero hypothesis H_0 and alternative hypothesis H_1 are equal to each other for the question of whether there is a time series trend in the observed data. Statistical value S and standard test statistic value Z_{MK} are calculated as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(X_j - X_i\right),$$

$$\operatorname{sgn}\left(X_j - X_i\right) = \begin{cases} +1, & \text{if}\left(X_j - X_i\right) > 0, \\ 0, & \text{if}\left(X_j - X_i\right) = 0, \\ -1, & \text{if}\left(X_j - X_i\right) = 0, \end{cases} \tag{2}$$

$$Z_{MK} = \begin{cases} \dfrac{S+1}{\sqrt{\operatorname{Var}(S)}}, & \text{if } S > 0, \\ 0, & \text{if } S = 0, \\ \dfrac{S-1}{\sqrt{\operatorname{Var}(S)}}, & \text{if } S < 0. \end{cases}$$

In the formula, X_i and X_j are the corresponding values of X of the i-th and j-th years; n is the length of time series data; and Z_{MK} is the trend of the data. If $Z_{\mathrm{MK}} > 0$, the time series data show an increasing trend over time; conversely, the time series data show a decreasing trend over time. When $|Z_{MK}| > Z_{(1-(a/2))}$, the zero hypothesis is rejected and the time series data have a significant trend. The $Z_{(1-(a/2))}$ value can be found in the

Table 1: Basic information of the meteorological stations in the Minjiang River Basin.

Station number	Longitude (°E)	Latitude (°N)	Altitude (m)	Station name	Station class
The upper reaches					
56182	103.57	32.65	2850	Songpan	Bbase station
56185	102.98	32.08	2400	Heishui	Ggeneral stations
56180	103.85	31.68	1591	Maoxian	Ggeneral stations
56183	103.58	31.47	1326	Wenchuan	Ggeneral stations
56184	103.17	31.43	1885	Lixian	Ggeneral stations
The middle reaches					
56188	103.67	30.98	699	Dujiangyan	Bbase station
56189	103.93	30.98	582	Pengzhou	Ggeneral stations
56187	103.83	30.7	539	Wenjiang	Bbase station
56288	103.92	30.58	495	Shuangliu	Ggeneral stations
56181	103.67	30.63	534	Chongzhou	Ggeneral stations
56272	103.83	30.82	559	Pixian	Ggeneral stations
56276	103.8	30.43	468	Xinjin	Ggeneral stations
56285	103.52	30.6	524	Dayi	Ggeneral stations
56284	103.48	30.42	501	Qionglai	Ggeneral stations
56281	103.52	30.2	511	Pujiang	Ggeneral stations
56391	103.82	30.05	415	Meishan	Ggeneral stations
56289	103.87	30.2	437	Pengshan	Ggeneral stations
56381	103.52	30.02	496	Dangling	Ggeneral stations
56383	103.83	29.83	455	Qingshen	Ggeneral stations
56386	103.75	29.57	424	Leshan	Bbase station
56280	103.12	30.08	691	Minshan	Ggeneral stations
The lower reaches					
56390	104.07	29.67	404	Jingyan	Ggeneral stations
56389	103.95	29.2	388	Qianwei	Ggeneral stations
56480	103.55	28.83	541	Mabian	Ggeneral stations
56490	103.9	28.95	397	Muchuan	Ggeneral stations
56492	104.6	28.8	341	Yibin	Bbase station

Table 2: Mean extreme temperatures in the upper, middle, and lower reaches of the Minjiang River Basin from 1961 to 2016 (°C or days).

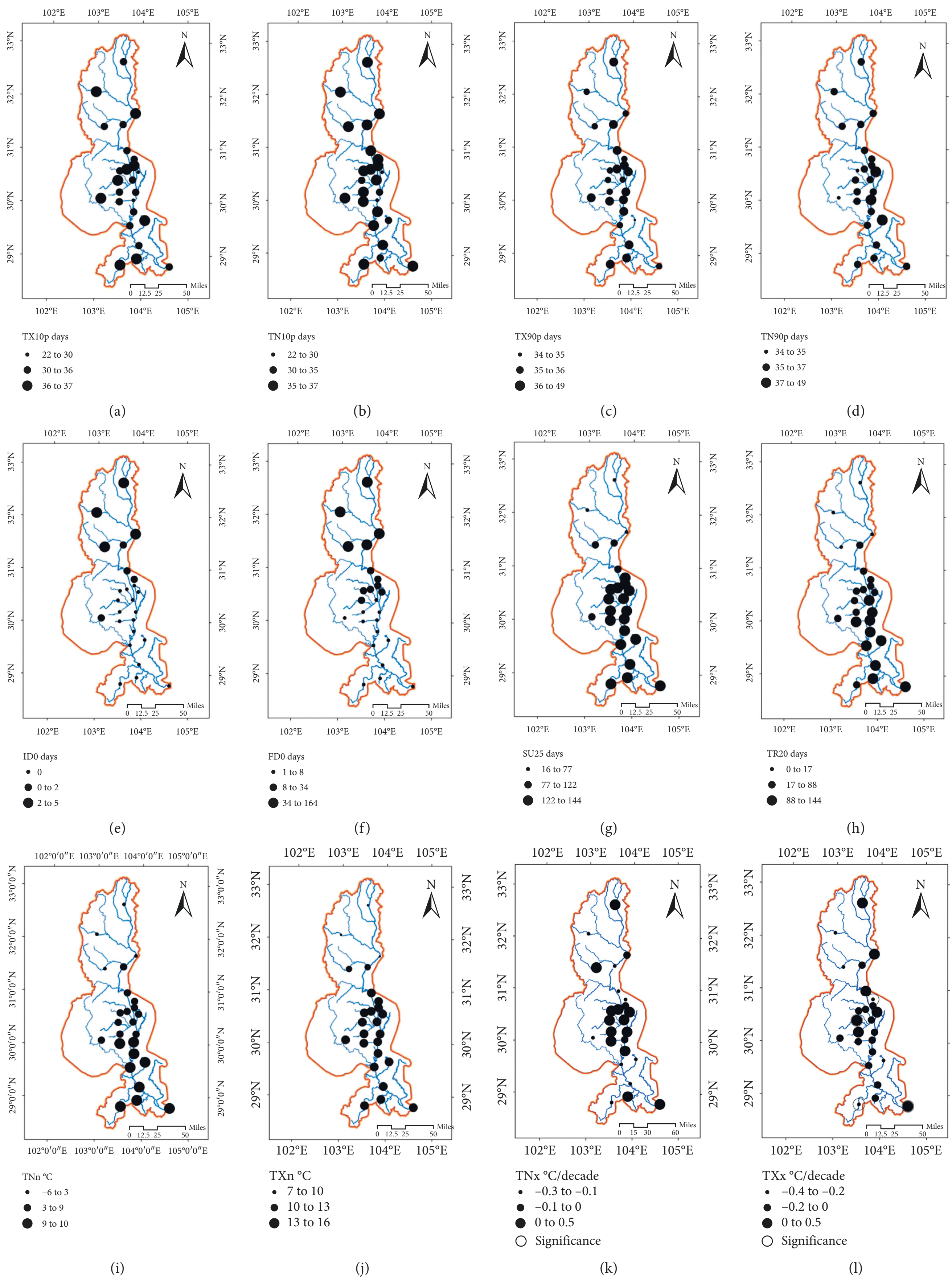
Index	The upper reaches	The middle reaches	The lower reaches
TX10p	35.77	34.63	36.10
TN10p	35.81	34.47	35.33
TX90p	35.92	37.13	35.78
TN90p	35.76	36.91	36.21
ID0	2.92	0.28	0.00
FD0	95.16	7.60	2.23
SU25	59.14	126.64	139.05
TR20	5.09	86.04	98.29
TXn	9.91	14.29	15.06
TNn	0.13	8.43	10.00
TXx	23.55	26.19	27.55
TNx	9.98	17.34	18.70
WSDI	7.07	7.08	6.94
CSDI	8.91	10.61	11.70
GSL	120.32	171.43	178.28
DTR	23.21	17.28	17.20

standard normal distribution table. When the significance level $a = 5\%$, the corresponding $Z_{(1-(a/2))}$ value is 1.96.

3. Results

3.1. Spatial Distribution. As can be seen from Table 2, the annual average of the relative index of the upper and middle reaches is basically the same as that of the lower and middle reaches of the Minjiang River Basin. In the extreme index, the high values of the extreme cold index and extreme warm index are in the downstream of the basin, while the low values are in the upstream of the basin. In the absolute index, the high value of the cold index (ID0, FD0) is in the upstream of the basin, the low value is in the downstream of the basin, the high value of the warm index (SU25, TR20) is in the downstream of the basin, and the low value is in the upstream of the basin. Among other indicators, DTR in the upper reaches of the basin is higher than that in the middle and lower reaches of the basin. The high values of WSDI is in the upper and middle reaches of the basin, and the difference between the upper, middle, and lower reaches is not obvious. The high values of CSDI and GSL are in the lower reaches of the basin, while the low values are in the upper reaches of the basin.

3.1.1. Relative Index (TX10p, TN10p, TX90p, and TN90p). Figure 2 shows the spatial distribution characteristics of the extreme temperature indicators in the Minjiang River Basin. It can be seen that the spatial distribution of cold nights (TN10p) and cold days (TX10p) in the Minjiang River Basin is relatively uniform, except for the lower days at Shuangliu and Meishan stations in the middle reaches of the Minjiang River Basin, most of which are 34–36 days and 34-35 days, respectively. At the same time, the number of warm nights (TN90p) and warm days (TX90p) at Shuangliu and Meishan



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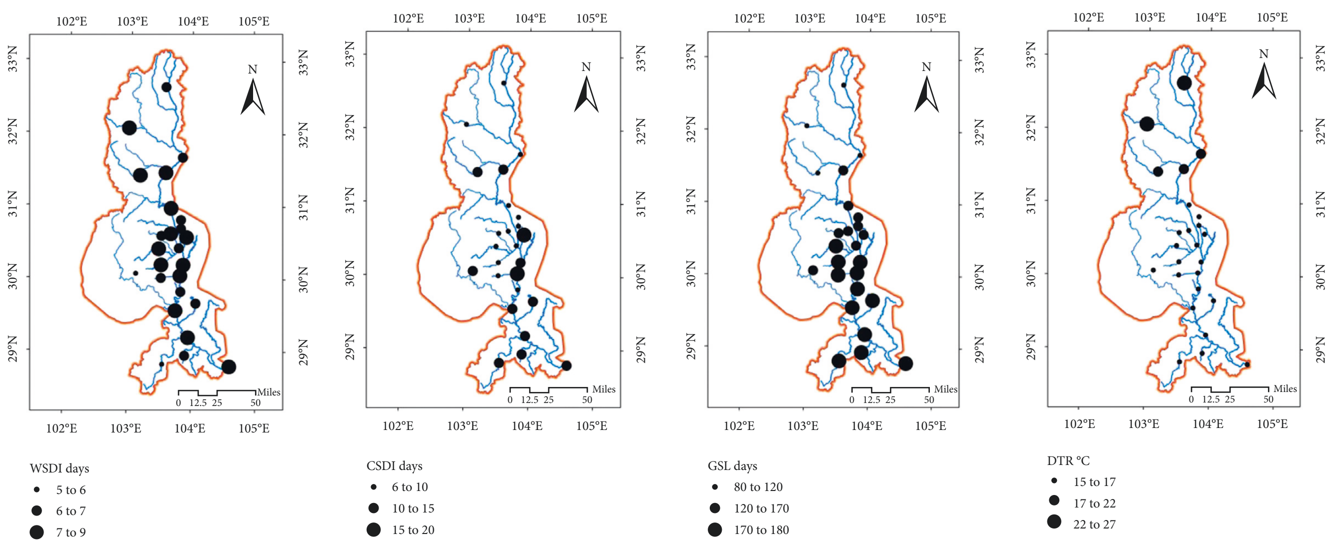


(m) (n) (o) (p)

Figure 2: Spatial distribution of extreme temperature index in the Minjiang River Basin from 1961 to 2016.

stations in the middle reaches of the Minjiang River Basin was higher than average, while the remainder was 34–36 days and 36-37 days, respectively. This shows that the climatic consistency of the relative index in the Minjiang River Basin is good.

3.1.2. Absolute Index (ID0, FD0, SU25, and TR20). It can be seen that the high value of ID0 and FD0 in the Minjiang River Basin mainly occurs in the upper reaches of the basin. The maximum value of ID0 is at Maoxian station in the upper reaches of 4.4 days, and the maximum value of FD0 is at Songpan station in the upper reaches of 163 days. The low value of SU25 is in the upper reaches of the basin, while the high value area is in the middle and lower reaches of the basin. The minimum value is at Songpan station in the upper reaches of 16 days, and the maximum value is at Yibin station in the lower reaches of 144 days. The value of the TR20 is zero at Songpan and Heishui stations in the upper reaches of the basin. This shows that the distribution of the absolute index is not uniform in the basin. The number of ID0 and FD0 mainly occurs in the upper reaches of the basin at high altitude, while the high value of SU25 and TR20 mainly occurs in the middle and lower reaches of the basin in the Sichuan basin. The extreme values occur in the lower reaches of the basin.

3.1.3. Extreme Value Index (TXn, TNn, TXx, and TNx). TXn in the upper reaches of the basin is 7–12°C, and the lowest is 7.2°C at Songpan station in the upper reaches. TXn in the middle and lower reaches of the basin is 13–15°C, and the highest value is 15.4°C at Yibin station in the lower reaches. TNn in the upper reaches of the basin is −6 to −4°C, and the lowest is −6.5°C at Songpan station in the upper reaches. TNn in the middle and lower reaches of the basin is 7–10°C, and the highest value is 10.8°C at Yibin station in the lower reaches. TXx in the upper reaches of the basin is 21–25°C, and the lowest value is 21.4°C at Songpan station in the upper reaches. TXx in the middle and lower reaches of the basin is 25–27°C, and the highest value is 27.9°C at Yibin station in the lower reaches. In summary, the low value of the basin extreme value index is in the upper reaches of the basin, while the high value is in the middle and lower reaches of the basin.

3.1.4. Other Indices (GSL, DTR, WSDI, and CSDI). WSDI of the Minjiang River Basin is 5–8 days, and the difference between the upper, middle, and lower reaches is not obvious. CSDI in the upper reaches of the Minjiang River Basin is 6–11 days, and the minimum value of the basin is 6 days at Songpan station. CSDI in the middle and the lower reaches of the Minjiang River Basin is mostly 8–13 days, and the maximum value of the basin is 13 days at Meishan station in the middle reaches of the Minjiang River Basin. There is no obvious difference between the upper, middle, and lower reaches. GSL in the upper reaches of the Minjiang River Basin is lower than that in the middle and lower reaches of the basin. The minimum value of the basin is 86 days at Songpan station in the upper reaches. GSL in the middle and lower reaches of the Minjiang River Basin is greater than 160 days. The maximum value in the basin is 178 days at Qianwei, Mabian, Muchuan, and Yibin stations in the lower reaches. The maximum daily temperature difference in the upper reaches of the Minjiang River Basin is 27°C at Songpan station, while that in the remainder of the basin is greater than 20°C. DTR in the middle and lower reaches of the Minjiang River Basin is between 16 and 17°C. Because there are more FD0 values in the upper reaches of the basin, GSL in the middle and lower reaches of the basin is obviously longer than that in the upper reaches of the basin (approximately twice as long as that in the upper reaches). At the same time, DTR in the upper reaches of the basin is larger than that in the middle and lower reaches of the basin. In summary, the extreme cold temperature indices such as FD0 and ID0 in the upper reaches are higher than those in the middle and lower reaches. At the same time, the extreme warm temperature indices such as TN90, TX90, SU25, TR20, and GSL are lower in the upper reaches than in the middle and lower reaches. DTR is higher in the upper reaches than in the middle and lower reaches.

3.2. Spatial Variation Trend of Extreme Temperature Indicators. From Table 3, it can be seen that the change trend of relative indices in the upper, middle, and lower reaches of the basin is relatively consistent. The extreme cold temperature indices are consistently decreasing. The decreasing trend of TX10 in the middle and lower reaches is greater than that in the upper reaches, while that of TN10 in the upper reaches is greater than that in the middle and lower reaches. The extreme warm temperature indices are consistently increasing. The increasing trend of TX90 in the middle and lower reaches is greater than that in the upper reaches, and the increasing trend of TN90 in the upper reaches is greater than that in the middle and lower reaches. It can be seen that the relative index in the middle and lower reaches has a greater trend during the day, while the relative index in the upper reaches has a greater trend during the night.

The change trend of the absolute index indices in the upper, middle, and lower reaches of the basin is relatively consistent. The decreasing trend of FD0 in the upper reaches is greater than that in the middle and lower reaches. SU25 showed an increasing trend in the Minjiang Basin, and the increasing trend of SU25 in the middle reaches is greater that in the upstream and downstream. It can be seen that the absolute warm index in the middle and lower reaches has a greater trend while the absolute cold index in the upper reaches has a greater trend in the upper reaches. The trend of the extreme index is weak.

Among other indicators, WSDI has an upward trend and the upward trend in the middle and lower reaches is greater than that in the upper reaches. CSDI has a downward trend, and the downward trend in the upper reaches is greater than that in the middle and lower reaches. It can be seen that the other indicators are similar to the absolute indicators. Warm indicators are larger in the middle and lower reaches than in the upstream, while cold indicators are larger in the upstream than in the middle and lower reaches. In the middle reaches for GSL, the trend is increasing, while the trend is decreasing in the upstream and downstream. DTR is decreasing in the upstream, middle, and downstream.

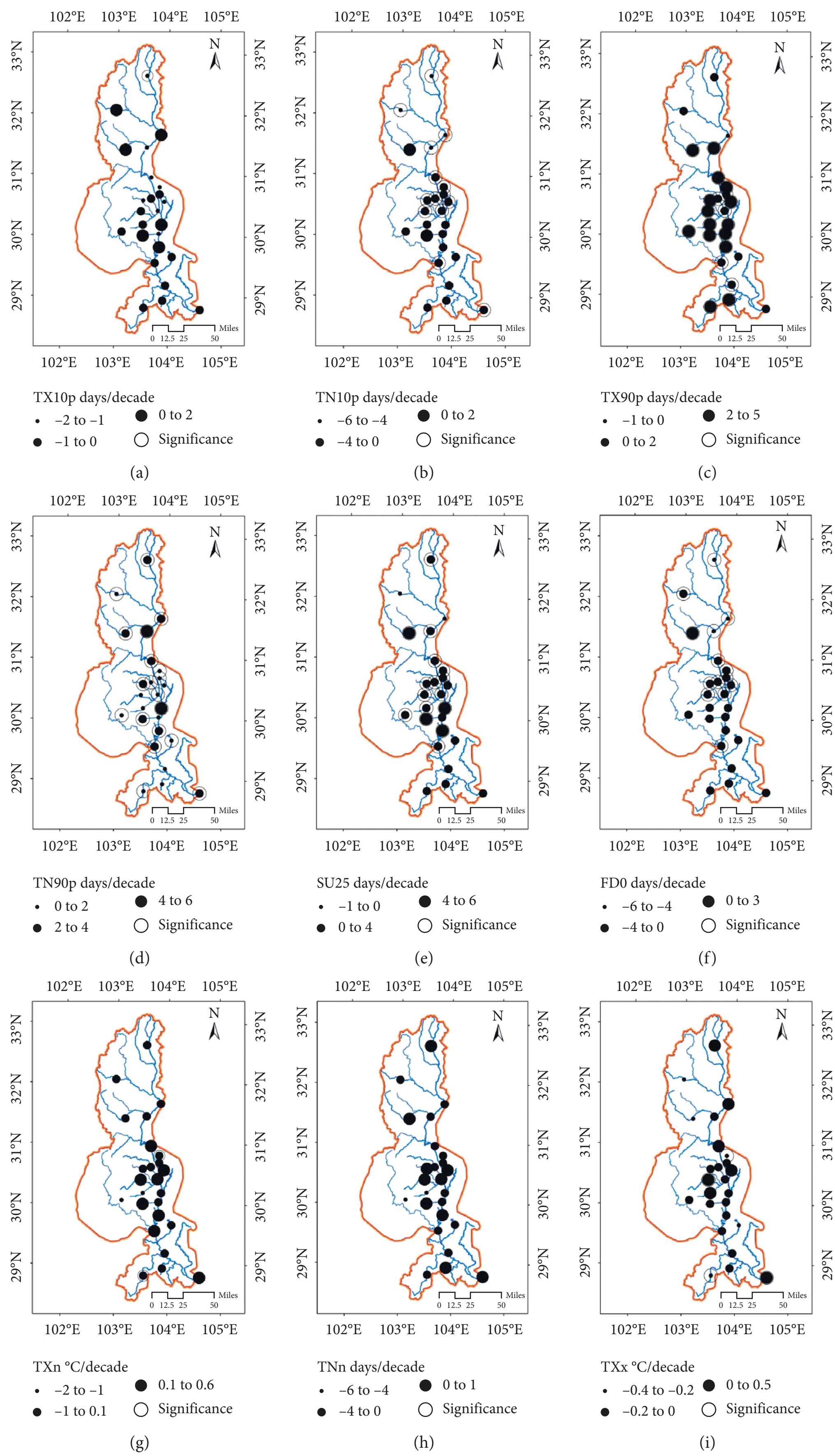
3.2.1. Relative Index (TX10p, TN10p, TX90p, and TN90p). Figure 3 shows the spatial distribution of the extreme temperature variation trend in Minjiang River Basin. It can be seen that TX10p is increasing at 60% of the stations in the upper reaches of the Minjiang River Basin and decreasing at 80% of the stations in the middle reaches and 100% of the stations in the lower reaches. In total, 7% of the stations in the Minjiang River Basin passed the 0.05 significance test. TN10p showed a downward trend in 92% of the stations in the Minjiang River Basin; 57% of the stations in the basin passed the 0.05 significance test. TN90p is increasing in 100% of the stations in the Minjiang River Basin, while TX90p is increasing in 96% of the stations in the Minjiang River Basin; 81% and 77% of the stations in the basin passed the 0.05 significance test, respectively. This shows that TN90p and TX90p in the basin show mainly an upward trend, while TN10p shows mainly a downward trend. TX10p shows mainly a downward trend in the middle and lower reaches of the basin and an upward trend in the upper reaches.

Table 3: Mean values of trends in the upper, middle, and lower reaches of the Minjiang River Basin from 1961 to 2016 (°C/10a or d/10a).

Index	Upper reaches	Middle reaches	Lower reaches
TX10p	−0.12	−0.50	−0.50
TN10p	−3.98	−2.28	−1.73
TX90p	1.52	3.81	2.49
TN90p	4.86	3.50	2.34
FD0	−2.93	−1.07	−0.14
SU25	2.00	4.82	1.63
TXn	−0.06	0.12	0.04
TNn	−0.66	0.11	0.05
TXx	0.00	0.03	−0.04
TNx	−0.05	0.08	−0.02
WSDI	0.62	1.12	1.00
CSDI	−1.67	−0.90	−1.17
GSL	−3.87	1.49	−2.34
DTR	−0.27	−0.12	−0.09

3.2.2. Absolute Index (ID0, FD0, SU25, and TR20). FD0 is decreasing at 96% of the stations in the Minjiang River Basin; 57% of the stations in the Minjiang River Basin passed the 0.05 significance test. SU25 is increasing at 92% of the stations in the Minjiang River Basin; 65% of the stations in the basin passed the 0.05 significance test, particularly Pengshan, Danling, and Qingshen stations in the middle reaches of the basin. The change rate is 17 d/10a, 11 d/10a, and 11 d/10a, respectively. Because the middle and lower reaches of the Minjiang River Basin are in a subtropical zone, ID0 is mostly 0. The upper reaches of the Minjiang River Basin are at a high altitude and the TR20 value is mostly 0, so trend analysis was not completed for ID0 and TR20. This shows that the FD0 in the basin mainly decreases, while SU25 in the basin mainly increases, particularly in the middle reaches of the basin.

3.2.3. Extreme Value Index (TXn, TNn, TXx, and TNx). TXn showed a downward trend at 60% of the stations in the upper reaches of the Minjiang River Basin, an upward trend at 68% of the stations in the middle reaches of the Minjiang River Basin, and a downward trend at 60% of the stations in the lower reaches of the basin; 15% of the stations in the basin passed the significance test. TNn showed a downward trend at 57% of the stations in the Minjiang River Basin. TXx



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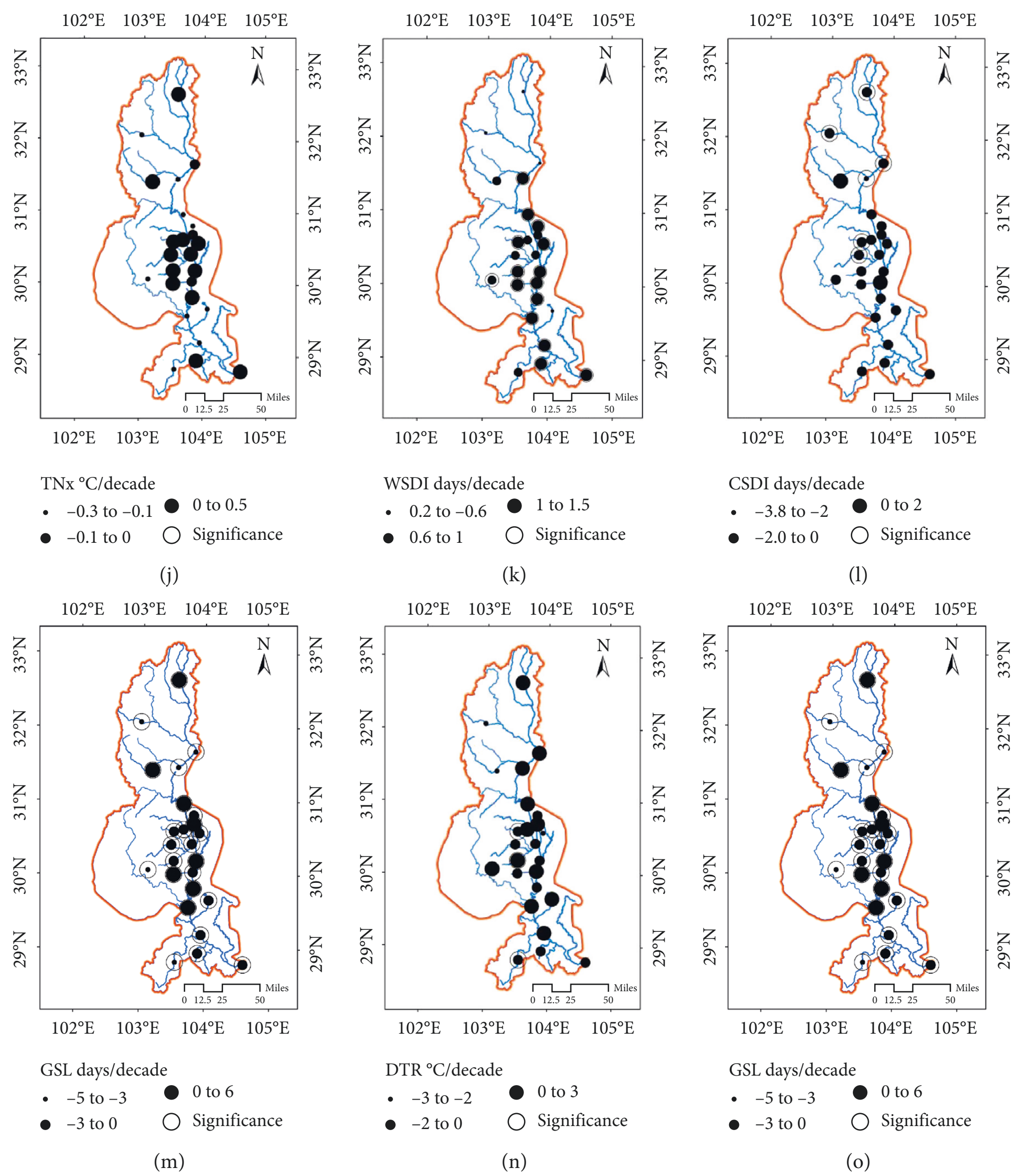

Figure 3: Spatial distribution of the extreme temperature variation trend in the Minjiang River Basin from 1961 to 2016.

showed an upward trend at 73% of the stations in the Minjiang River Basin; 15% of the stations in the basin passed the significance test. The TNx showed an upward trend at 50% of the stations. This shows that the minimum values of the maximum temperature and minimum temperature are increasing mainly in the basin, while the maximum values of the maximum temperature and minimum temperature are mainly decreasing in the basin.

3.2.4. Other Indices (WSDI, CSDI, GSL, and DTR). WSDI is increasing at 100% of the stations in the basin and 61% of which passed the significance test. CSDI is decreasing at 92% of the stations in the basin; 26% of the stations in the basin passed the significance test. GSL is decreasing at 69% of the stations in the basin; 15% of the stations in the basin passed the significance test. DTR is not obvious in the whole basin. This shows that the heat persistence index of the basin is mainly increasing, the cold persistence days of the basin are mainly decreasing, and DTR is mainly decreasing in most parts of the basin except for some parts of the middle reaches.

3.3. Time Trend of Extreme Temperature Indicators

3.3.1. Relative Index (TX10p, TN10p, TX90p, and TN90p). Figure 4 shows the interannual variation in the extreme temperature index in the Minjiang River Basin. It can be seen that TN10p and TX10p are decreasing in the Minjiang River Basin. Their annual tendency rates are −2.9 d/10a and −0.8 d/10a, respectively. TN90p and TX90p are increasing in the Minjiang River Basin. Their annual tendency rates are 3.0 d/10a and 2.6 d/10a, respectively. Combining the MK trend test results in Table 4, it can be seen that the linear trend analysis and MK trend test results are consistent. TX10p

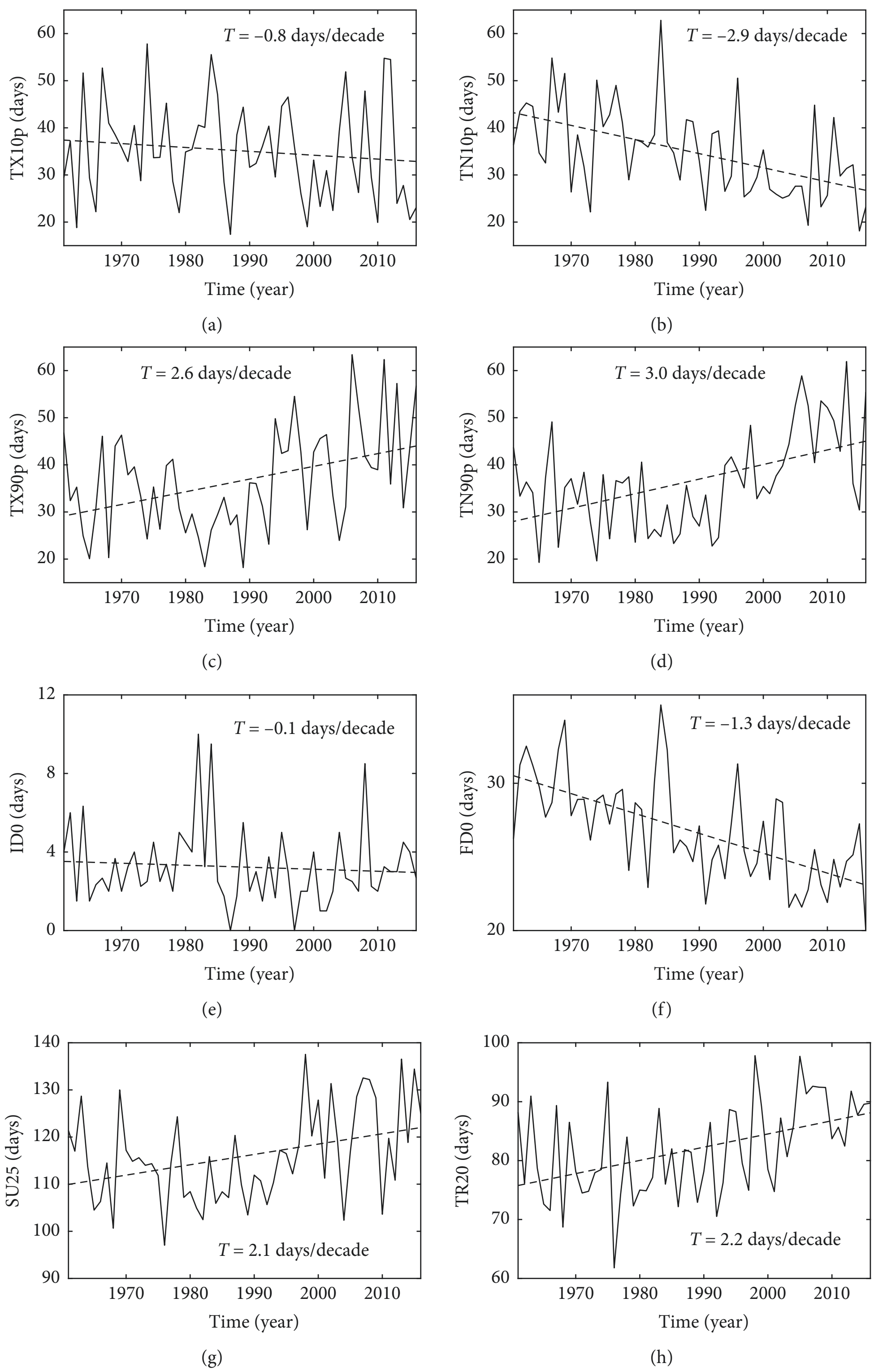

Figure 4: Continued.

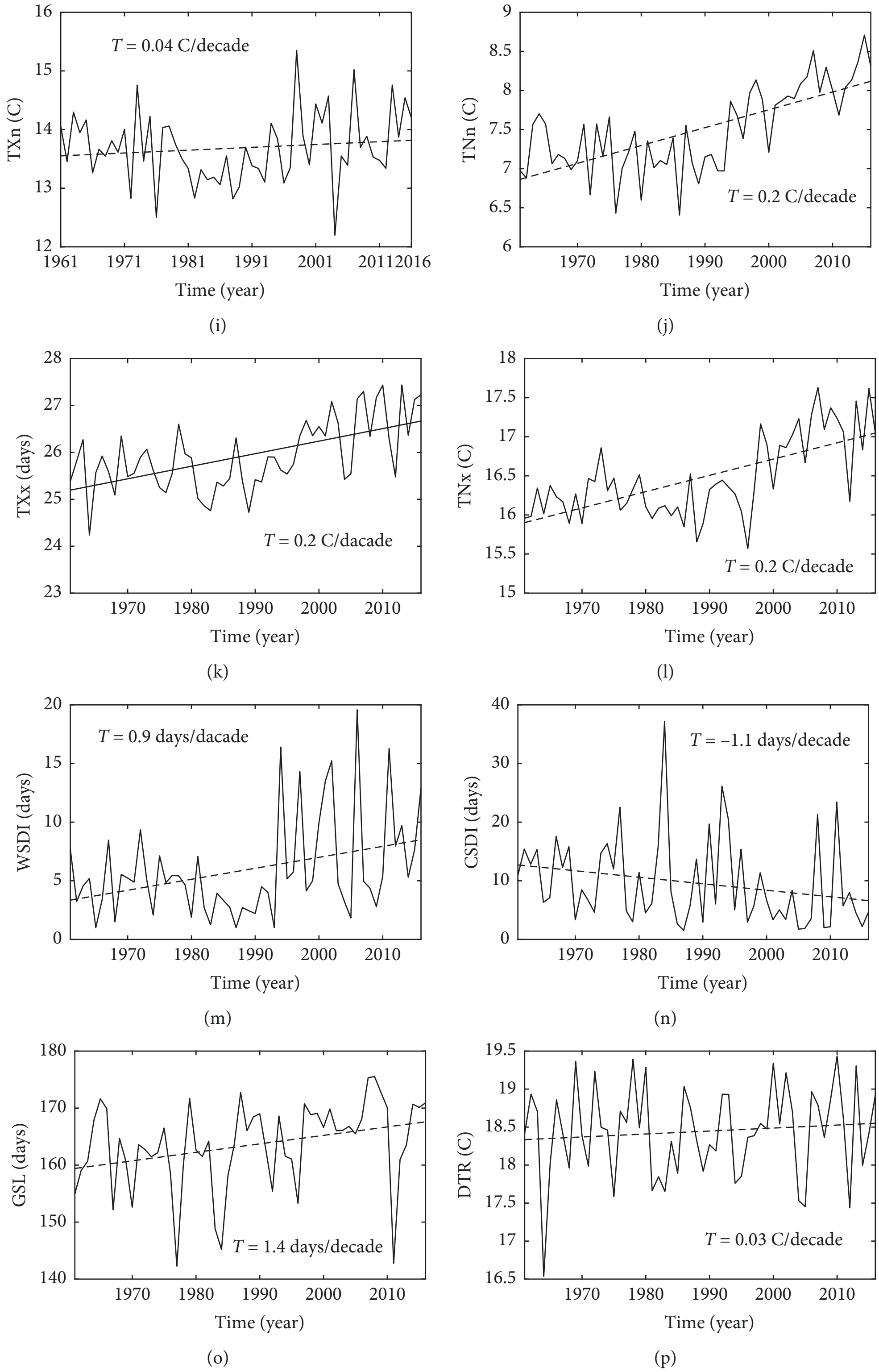

Figure 4: Interannual variation in the extreme temperature index in the Minjiang River Basin from 1961 to 2016.

shows a nonsignificant decrease, TN10p shows a significant decrease, and the TX90p and TN90p show a significant increase. The change trend of the night index (TN10p and TN90p) is more obvious than that of the day index (TX10p and TX10p).

3.3.2. Absolute Index (ID0, FD0, SU25, and TR20). During the past 56 years, the absolute index and relative index of the Minjiang River Basin have a similar change trend. The cold index shows a decreasing trend, while the warm index shows an increasing trend, but the degree of

Table 4: Temporal trends of the extreme temperature indicators in the Minjiang River Basin.

Index	MK	T
TX10p	−1.13	−0.8
TN10p	**−4.09**	−2.9
TX90p	**2.51**	2.6
TN90p	**3.49**	3
ID0	−0.36	−0.1
FD0	**−4.93**	−1.3
SU25	**2.45**	2.1
TR20	**3.39**	2.2
TXn	0.68	0.04
TNn	**4.79**	0.2
TXx	**4.1**	0.2
TNx	**4.63**	0.2
WSDI	1.8	0.9
CSDI	**−2.58**	−1.1
GSL	**3.13**	1.4
DTR	0.79	0.03

MK denotes MK statistics. *T* denotes trends ($decade^{-1}$). Values for the trends at the 0.05 significance level are shown in bold.

change in the cold and warm indices is different. FD0 and ID0 show a downward trend. The change rates are −1.3 d/10a and −0.1 d/10a, respectively, while SU25 and TR20 show an upward trend of 2.1 d/10a and 2.2 d/10a, respectively. The trend of the warm index is more obvious than that of the cold index. At the same time, the results of the MK trend test shown in Table 4 show that the linear trend analysis and MK trend test have the same results. This shows that FD0 has significantly decreased over the past 56 years, ID0 nonsignificantly decreased, while summer days and heat wave days significantly increased.

3.3.3. Extreme Value Index (TXn, TNn, TXx, and TNx). From the change trend of the extreme value index, we can see that TXn shows a nonsignificant increase; TNn, TXx, and TNx show a significant increase; and the change rate is 0.2°C/10a, 0.2°C/10a, 0.04°C/10a, and 0.2°C/10a, respectively. Combining with the linear trend analysis and MK trend test shown in Table 4, we can see that TXn shows a nonsignificant increase, TNn shows a significant increase, and TXx and TNx show a significant increase.

3.3.4. Other Indices (WSDI, CSDI, GSL, and DTR). WSDI is increasing in the Minjiang River Basin, with a change trend of 0.9 d/10a, while CSDI is decreasing, with a change trend of −1.1 d/10a. The GSL is increasing with a change trend of 1.4 d/10a and DTR is increasing with a change rate of 0.03°C/10a. From the time variation trend of the extreme temperature index in the Minjiang River Basin shown in Table 4, it can be seen that the linear trend analysis and MK trend test show the same trend. WSDI shows a nonsignificant upward trend, CSDI shows a significant downward trend, and GSL shows a significant upward trend. And, DTR is nonsignificantly trending upward.

As can be seen from Figure 4, the interannual variation of the Minjiang River Basin can be divided into two phases. Table 5 calculates the variation rates of extreme temperature indices before and after 1990. It can be seen that the change rates of warm and cold indices before 1990 are mainly decreased, while after 1990, the change rates of warm indices are mainly increased, cold indices are mainly decreased, and the change rate of the warm index is higher than that of the cold index.

4. Results

In this study, 16 extreme temperature indices were used to study the temporal and spatial characteristics of extreme temperature events in the Minjiang River Basin during the recent 56 years. The main conclusions are as follows:

(1) The spatial distribution of the relative index of extreme temperature in the basin is consistent. The distribution of the absolute index and extreme index is not consistent. The cold extreme temperature index (FD0 and ID0) mainly occurs in the upper reaches of the basin at high altitude, while the warm extreme event index (TXx, TNx, TN90p, TX90p, TN90p, SU25, and TR20) mainly occurs in the Sichuan basin. In the middle and lower reaches of the basin, the extreme values are distributed in the lower reaches of the basin. Because the high values of FD0 occur in the upper reaches of the basin, the GSL in the middle and lower reaches of the basin is obviously greater than that in the upper reaches and is approximately twice as large as that in the upper reaches. At the same time, the DTR in the upper reaches of the basin is greater than that in the middle and lower reaches.

(2) The spatial variation in each index is consistent, but the degree of variation shows a spatial difference. The warm index and daytime index mainly show an upward trend in the whole basin. The cold index and nighttime index mainly show a downward trend in the whole basin. The warm index and daytime index are more obvious in the middle and lower reaches, while the cold index and nighttime index are more obvious in the upper reaches.

(3) The variation range between the cold and warm extreme temperature indices and the variation range between the daytime and nighttime in the Minjiang River Basin show an obvious asymmetry. The variation range of the warm index (SU25, TR20) is greater than that of the cold index (ID0, FD0), and that of the night index (TN10p, TN90p) is greater than that of day index (TX10p, TX90p). The increasing trend of the warm index in the middle and lower reaches of the basin is greater than that in the upper reaches, and the decreasing trend of the night index in the upper reaches of the basin is greater than that in the middle and lower reaches of the basin.

(4) On a time scale, cold extreme temperature indices such as FD0, TN10p, and CSDI significantly decrease

Table 5: Temporal trends of the extreme temperature indicators in the Minjiang River Basin before and after 1990.

	T (before 1990)	T (after 1990)	T (1961–2016)
TX10p	0.7	−1.7	−0.8
TN10p	−1	−2.1	−2.9
TX90p	−3.2	4.4	2.6
TN90p	−2.9	7.5	3
ID0	0.1	0.5	−0.1
FD0	−1.2	−0.9	−1.3
SU25	−3	5	2.1
TR20	−1	3.8	2.2
TXn	−0.3	0.2	0.04
TNn	−0.1	0.4	0.2
TXx	−0.1	0.5	0.2
TNx	−0.04	0.4	0.2
WSDI	−1	1	0.9
CSDI	−1.2	−3.5	−1.0
GSL	0.6	2.1	1.4
DTR	−0.1	0.1	0.03

from 1961 to 2016 at −1.3, −2.9, and −1.1 d/10a, respectively, while TX10p and ID0 nonsignificantly decrease at −0.8 and −0.1 d/10a, respectively. The warm extreme temperature indices TXx and TNx increase from 1961 to 2016 at 0.2 and 0.2°C/10a, respectively. Indices such as TN90p, TX90p, SU25, and TR20 significantly increase from 1961 to 2016 at 3.0, 2.6, 2.1, and 2.2 d/10a, respectively, while the WSDI nonsignificantly increases at 0.9 d/10a. The GSL in the basin significantly increases from 1961 to 2016 at 1.4 d/10a, while the DTR shows a nonsignificant upward trend at 0.03°C/10a. The change rates of warm and cold indices before 1990 are mainly decreased, while after 1990, the change rates of warm indices are mainly increased and cold indices are mainly decreased and the change rate of warm index is higher than that of cold index.

5. Discussion

Surface warming due to global warming has changed the thermal difference between land and sea and large-scale circulation, intensified the regional and global water cycle, and further affected the spatial distribution characteristics of precipitation and heavy rainfall. Surface warming has also increased the frequency of floods, droughts, and other disasters, resulting in serious adverse effects on agricultural production and food security. Although the Minjiang River Basin has also shown a warming trend during the past 50 years, the increasing trend of temperature is 0.15°C/10a, but significantly lower than the average level of 0.22°C/10a seen in China. Under different ranges of mean temperature, the characteristics of extreme temperature will be different. In addition, the Minjiang River Basin is mainly on the eastern side of the Qinghai-Tibet Plateau, which is in a transitional area between plateau terrain and the eastern plain of China. The Minjiang River Basin gradually lowers in elevation from the western mountain areas to the eastern plain areas. The altitude difference is large, and it is among the most complex topographic areas in China. Complex topographic conditions lead to temporal and spatial distribution characteristics of extreme temperature in the Minjiang River Basin that are not exactly the same as the overall trend in China.

(1) The extreme high temperature days (TX90 and TN90) in the Minjiang River Basin show an increasing trend, while the extreme low temperature days (TX10 and TN10) show a decreasing trend, which is consistent with the trend in most other parts of China owing to global warming [12]. However, at the same time, the intensity of short-term extreme precipitation is decreasing, resulting in a downward trend in the total precipitation [30] which is different from the runoff in the Yangtze River Basin [31]. The warming and drying of the climate in the Minjiang River Basin has led to a significant reduction in runoff, providing conditions for the occurrence of regional extreme climate.

(2) TR20 in the Minjiang River Basin shows a consistent upward trend. TR20 in China has a strong interdecadal variation, but the long-term linear trend is not obvious [17]. This is related to the fact that the Minjiang River Basin is on the western periphery of the subtropical high during summer. The westward advance of the subtropical high is stronger. The Minjiang River Basin is subject to hot weather, the eastward recession of the subtropical high is weakened, and the Minjiang River Basin is on the edge of the subtropical high. Previous studies also show that [32, 33] since the 1980s, the subtropical high intensity has gradually increased and the western boundary has moved west. The northern boundary is in the south, which results in the Minjiang River Basin being affected by the lower airflow of a subtropical high for a long period creating conditions for a heat wave. As a result, heat wave events in the Minjiang River Basin have significantly increased. The frequency and intensity of cold wave events in the Minjiang River Basin have obviously decreased, which is the same as the overall trend of cold wave weather in the Yangtze River Basin [17]. This may lead to faster warming during winter at midhigh latitudes under global warming, leading to a decrease in the north-south temperature gradient and atmospheric baroclinicity at midlatitudes of the Northern Hemisphere. Disturbances in the midlatitude atmosphere are also reduced. The decrease in weather disturbance also leads to a decrease in cold waves during winter (October to April).

(3) The variation in minimum temperature (TNx and TXx) and maximum temperature (TNn and TXn) in the Minjiang River Basin is not significant. Studies show that the average minimum temperature in most other regions of China has increased significantly more than the average maximum temperature; this can be related to urbanization [12, 34]. This asymmetric variation in minimum and maximum

temperatures results in a significant decrease in the diurnal temperature range [35, 36].

(4) FD0 in the Minjiang River Basin is significantly decreasing, with a change rate of −1.3 d/10a. Correspondingly, the GSL is ahead of schedule, showing a significant growth trend. The change trend of the Minjiang River Basin is 1.4 d/10a. These changes lead to an increased instability in agricultural production, increased local drought and high temperature, and earlier crop development; they can be attributed to climate warming [37].

The Minjiang River Basin, as an important tributary of the Yangtze River, is also an important food-producing area in China. Changes in climate and runoff in the region play a significant role in the sustainable development of regional resources, the environment, and society. In this case, understanding the characteristics of regional climate change and the response of runoff is of great importance for promoting agricultural development, economic growth, and harmonious coexistence between people and society in the region. The factors affecting extreme temperature change and the mechanism their effects bring about are worth studying and will be further explored in future research.

Data Availability

The data used in this paper are provided by the State Meteorological Administration of China. Relevant station data are available at https://data.cma.cn/ through registered scientific research users.

Conflicts of Interest

There are no conflicts of interest regarding the publication of this paper.

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