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The Spatial-Temporal Change of Extreme Precipitation in the Southwest Region of Zhejiang Province during 1953-2022

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Abstract

Based on the daily precipitation from 17 meteorological stations in the southwest of Zhejiang from 1953 to 2022, 11 extreme precipitation indices were calculated, and the temporal-spatial characteristic of extreme precipitation were analyzed. The results indicate that 1) Except for the number of consecutive dry days (CDD), all the other extreme precipitation indices had low values in the northeast of the study area and high value around Liuchun Lake; 2) CDD had a decreasing trend in most part of study area, while the other indices were on the rise, especially at Suichang (SC) and Tonglu (TL) stations, the change was significant ($p < 0.05$); 3) The annual variation showed that CDD declined with the trend of 0.83 d/10a, however, all the other indices increased, especially after 2000, the increase was more obvious. In general, the extreme precipitation mount, the extreme precipitation days showed an increasing trend, drought was less likely to happen, and the possibility of heavy precipitation is less, however, at some individual station such as SC, heavy precipitation and storm is much more likely to occur.

Keywords

Southwest of Zhejiang Province, Extreme Precipitation Indices, Temporal-Spatial Characteristic

1. Introduction

According to the International Panel on Climate Change's Sixth Assessment Report states, the global mean temperature increased by 1.1˚C, compared with the temperature record before the industrial revolution, and it will be expected to increase by 1.5˚C in the next 20 years (Fyfe et al., 2013; IPCC, 2014). The warming climate generally holds more moisture, and accelerates the hydrological cycle, which can increase regional and even global mean precipitation as well as extreme precipitation (Allan & Soden, 2008; Allan et al., 2020). In recent years, the extreme precipitation events frequently occurred around the globe (Zarekarizi & Rana, 2018), which had a serious impact on social, economy, human health (Zhang et al., 2019; House et al., 2011). For example, rare recording-breaking extreme precipitation events occurred in Hennan, China, in July 2021 (Nie & Sun, 2022), it caused tremendous disaster to devastating impacts on social economy (Shen et al., 2022). Thus, extreme precipitation events have attracted extensive research attention.

In recent years, many studies focused on the extreme precipitation on the global or the regional scale. The global extreme precipitation had an increasing trend similar to climate warming (Donat et al., 2016), the extreme precipitation in China also had the same characteristic with the global trend (Zhou et al., 2016), however, on the regional scale, the changes in extreme precipitation were not consistent in different regions, and had obvious regional characteristics (Qian et al., 2007). Extreme precipitation showed an increasing trend in Xijiang (Jiang et al., 2023), Tibet Plateau (Yang et al., 2007), while a decreasing trend was found in the Inner Mongolia (Bai et al., 2014; Yan et al., 2014). Dong & Yu (2022) also found that precipitation days had a decreasing trend, and it became drier in Shanxi province. Some research also studied the change in extreme precipitation in mountain area, such as the Wuling mountain area, where the extreme precipitation tends to have a shorter duration and stronger intensity. Therefore, the geographic feature and the local characteristics put more complexity and uncertainty on the changes in extreme precipitation (Du et al., 2022), it is necessary to study the extreme precipitation on the regional scale.

Zhejiang, located in the Delta of the Yangtze River, belongs to the humid monsoon climate. As the climate is warmer globally, high temperature and heat waves frequently occur in Zhejiang, which may have an impact on the extreme precipitation. Therefore, this study aims to explore the spatiotemporal characteristic of extreme precipitation in the southwest of Zhejiang, the findings of the study may enhance our understanding of the complicated extreme precipitation variability, which is very helpful for the climate service, risk assessment and disaster prevention and water resource management.

2. Data and Methods

Based on the standards of the continuity and the longest period, after the strict quality control and the error values correction, daily precipitation from 18 meteorological stations was used, the information of stations can be seen in **Table 1**.

In this paper, 11 extreme precipitation indices (Zhai & Liu, 2012), defined by the Expert Team on Climate Change Detection and Indices (ETCCDI), are calculated to analyze the change of extreme precipitation around Liuchun Lake. The definition of extreme temperature indices can be seen in **Table 2**.

Table 1. The information of stations used in this paper.

Stations	Longitude	latitude	Altitude (m)	Stations	Longitude	latitude	Altitude (m)
CS	118°30'25"	28°54'26"	136.2	CA	119°1'57"	29°36'22"	222.1
JD	119°16'28"	29°28'29"	89.1	JS	118°36'6"	28°42'36"	126.1
JH	119°39'21"	29°6'46"	62.6	LX	119°28'32"	29°13'5"	50.2
LQ	119°7'57"	28°4'50"	105.1	LY	119°11'7"	29°2'1"	161.4
PJ	119°52'20"	29°28'30"	115.6	QZ	118°53'27"	28°59'38"	82.4
SC	119°16'9"	28°35'42"	236.6	TL	119°40'8"	29°48'21"	44.4
WY	119°48'33"	28°53'24"	105.1	YW	120°5'14"	29°20'27"	90
YH	119°35'51"	28°6'25"	169.1	LCHSY	119°5'1"	28°46'56"	903
LCHSD	119°4'18"	28°45'2"	1327	BJDC	119°7'32"	28°47'9"	273

Table 2. Definition of the extreme precipitation indices. Daily precipitation amount can be abbreviated PR.

Index	Indicator Name	Definition	Units
RX1day	Maximum 1-day PR	Annual maximum 1-day PR	mm
RX5day	Maximum 5-day PR	Annual maximum consecutive 5-day PR	mm
R95p	Very wet days	Total annual precipitation from days with PR > 95th percentile	mm
R99p	Extreme wet days	Total annual precipitation from days with PR > 99th percentile	mm
SDII	Simple precipitation intensity index	The ratio of annual total wet-day precipitation to the number of wet days	mm/d
PRCPTOT	Annual total wet-day precipitation	Total annual precipitation from days with PR ≥ 1 mm	mm
CDD	Consecutive dry days	Maximum number of consecutive days with PR < 1 mm	d
CWD	Consecutive wet days	Maximum number of consecutive days with PR ≥ 1 mm	d
R10	Number of heavy precipitation days	Annual count days with PR ≥ 10 mm	d
R20	Number of very heavy precipitation days	Annual count days with PR ≥ 20 mm	d
R25	Number of extreme heavy precipitation days	Annual count days with PR ≥ 50 mm	d

3. Results

3.1. The Spatial Change of Extreme Precipitation

Figure 1 indicates the spatial distribution of Maximum 1-day precipitation (Rx1day) in the southwest region of Zhejiang province. It can be seen that Rx1day had larger spatial difference, and gradually increased from the northeast to the southwest region of the study area, it is basically consistent with the altitude characteristic. Rx1day ranges from 77 mm to 130 mm, and the maximum value occurred around the Liuchun Lake. Maximum 5-day precipitation (Rx5day), very wet days (R95p), extreme wet days (R99p), simple precipitation intensity index (SDII) and annual total wet-day precipitation (PRCPTOT) had the same spatial characteristic with Rx1day.

Figure 2 shows the spatial distribution of extreme precipitation indices

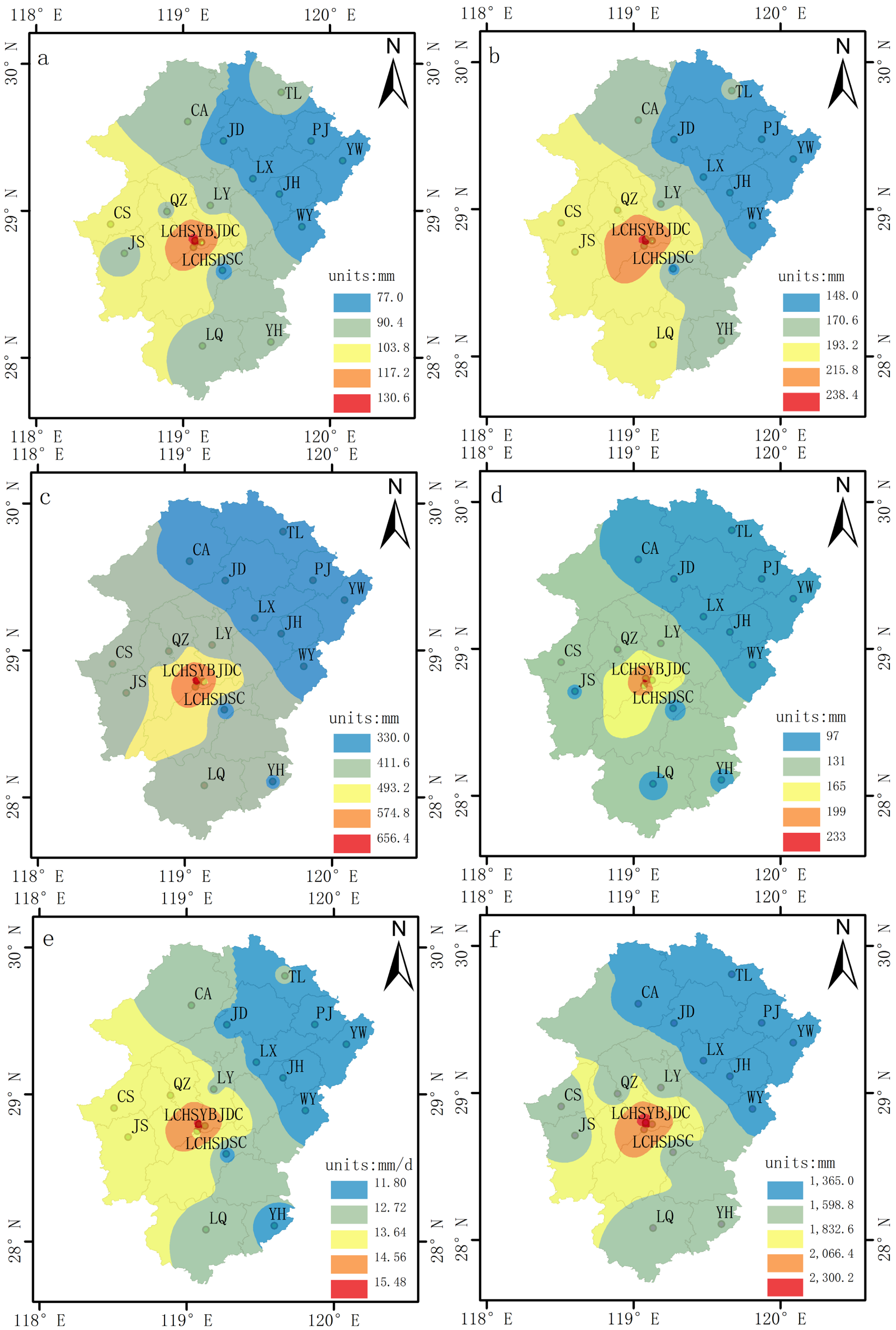

Figure 1. The spatial distribution of the annual averaged Rx1day (a), Rx5day (b), R95p (c), R99p (c), SDII (e), PRCPTOT (f) in the southwest part of Zhejiang province during the period of 1953-2022.

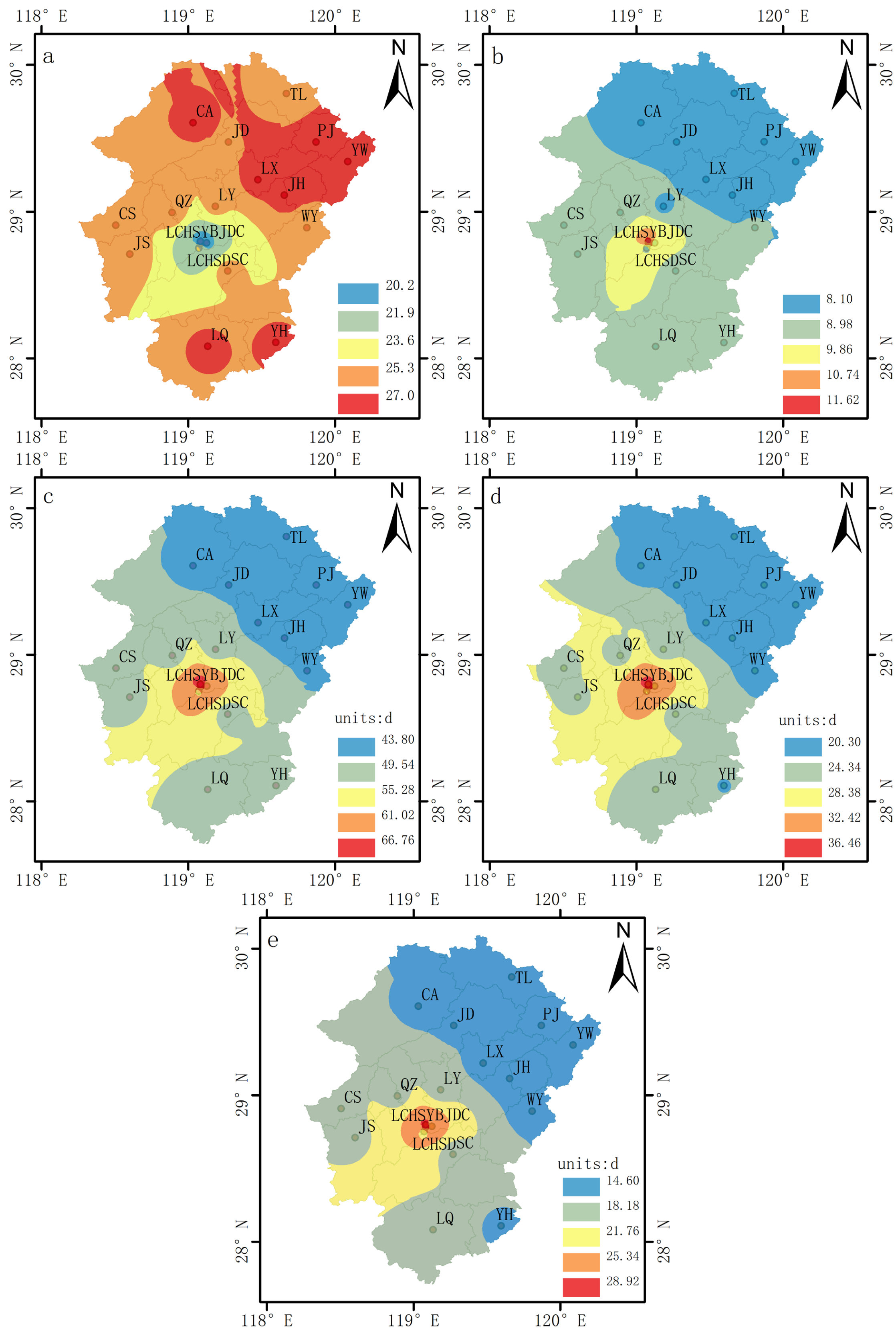

Figure 2. The spatial distribution of the annual averaged CDD (a), CWD (b), R10 (c), R20 (d), R25 (e) in the southwest part of Zhejiang province during the period of 1953-2022.

representing precipitation days. Consecutive wet days (CWD), number of heavy precipitation days (R10), number of very heavy precipitation days (R20), number of extreme heavy precipitation days (R25) had the same spatial characteristic with the indices representing the precipitation mount. However, the number of consecutive dry days (CDD) had the opposite feature, CDD ranged from 20 d to 27 d, the maximum value of CDD appeared in the northeast and the LQ and YH station in the south of the study area, where the precipitation mount and precipitation days were little, so CDD had larger value, this means in this region drought was likely to happen. The minimum value of CDD occurred around the Liuchun Lake, where the precipitation mount and precipitation days were larger, and CDD was lower, this implies that around Liuchun Lake drought was less likely to occur than that in the northeast and south of the study area.

Figure 3 displays the spatial trend distribution of extreme precipitation indices representing the precipitation mount. The change of Rx1day had larger spatial difference, it increased in the central region of the study area, especially at the LX, JH, JS and SC stations, it increased significantly with the trend of 3.29 mm/10a ($p < 0.05$). However, it increased insignificantly in the north and south of the study area. 66.67% of the stations had an significant increase. Rx5day was on upward trend in all the regions, and about 26.67% of the stations passed the significant level ($p < 0.01$). R95p also increased at all the stations, but there are only 40% stations passing the significant level ($p < 0.01$), and at the other stations R95p had insignificant increase. R99p basically showed a positive feature, and about 33.33% of the stations passed the 99% significant level. SDII also increased at the all station, the maximum trend was about 0.32 mm/10a ($p < 0.05$), SDII changed significantly at 26.67% stations, and insignificantly at the other stations. PRCPTOT still had an increasing trend, with the most significant change at TL station and the insignificant change at LQ and YH stations.

Figure 4 shows the spatial distribution of precipitation indices representing precipitation days. CDD displayed a negative trend in the regions, the maximum value of trend was about −0.234 d/10a, it was not significant. CDD had an increased at almost stations, except the JS and WY stations, and 13.33% of stations passed the significant level ($p < 0.01$), the maximum trend was 0.29 d/10a, occurring at the CA and PJ stations. R10 was on the rise in the study area, it's change was larger at WY and SC stations, with the trend of 0.92 d/10a, but is was also insignificant. Both R20 and R25 had an increasing trend, and about 13.77% of the stations passed the significant level ($p < 0.01$).

At the JS and CS stations, all the indices representing the precipitation mount showed an increasing trend, while the indices including CWD, R20 and R25 increased significantly at CA and TL stations. Although most of the extreme precipitation indices (except for CDD) increased, they were not significant, this implies that in this area precipitation had a positive feature, but heavy precipitation was less likely to happen. While most precipitation indices increased significantly at SC and TL stations, this mean where the possibility of heavy precipitation

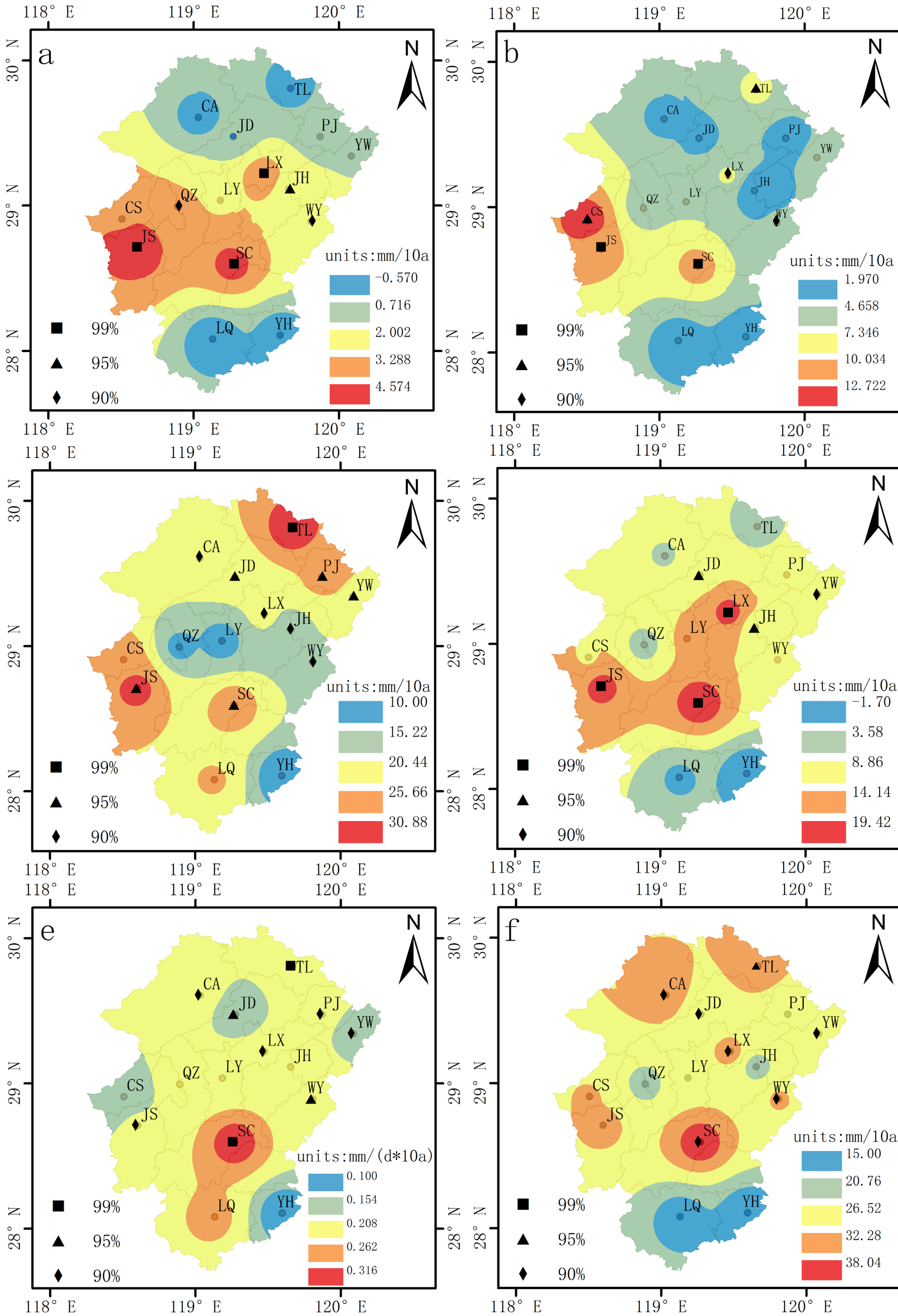

Figure 3. The spatial distribution of the change trend of Rx1day (a), Rx5day (b), R95p (c), R99p (d), SDII (e), PRCPTOT (f) in the southwest part of Zhejiang province during the period of 1953-2022.

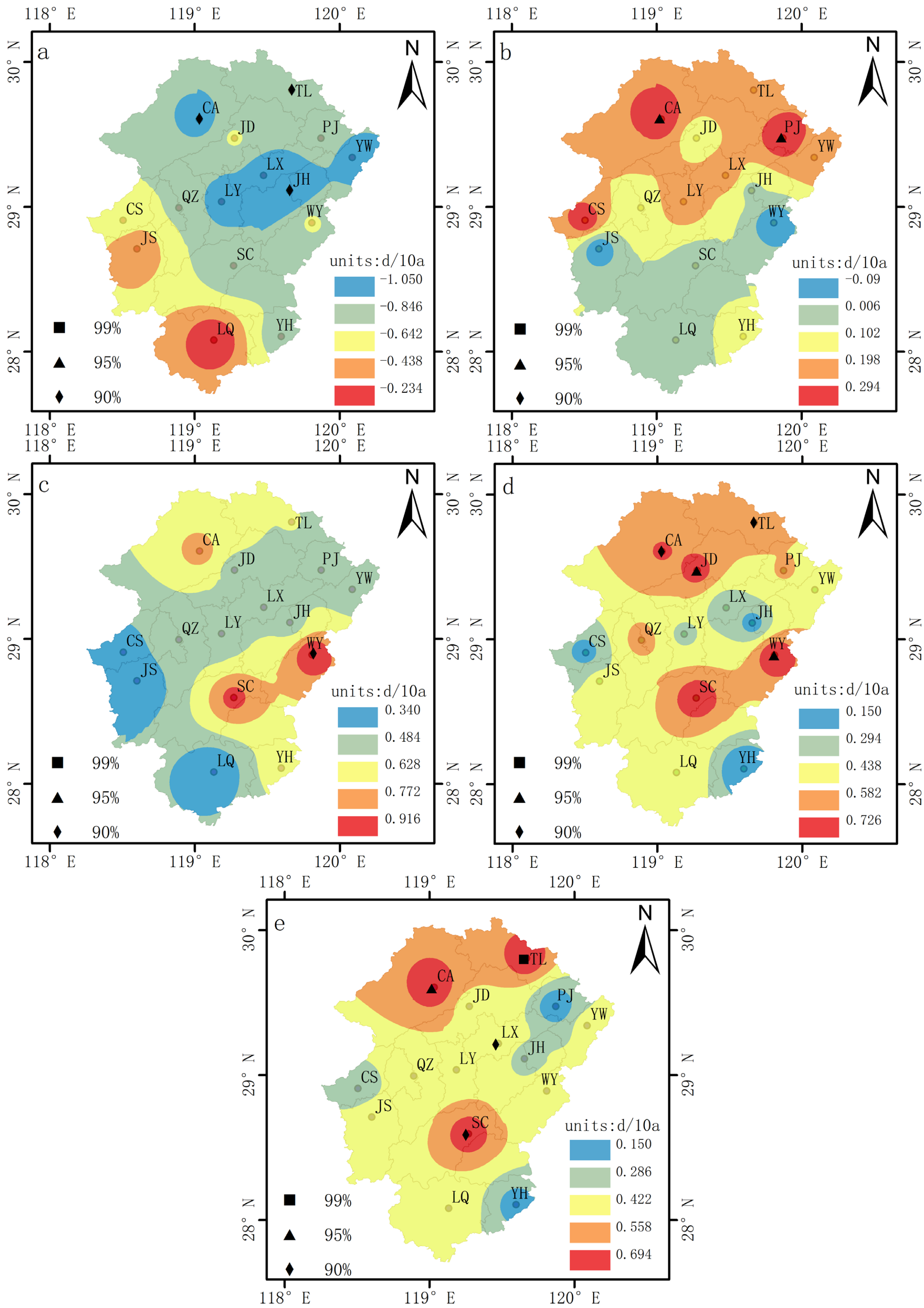

Figure 4. The spatial distribution of the change trend of CDD (a), CWD (b), R10 (c), R20 (d), R25 (f) in the southwest part of Zhejiang province during the period of 1953-2022.

and storm was larger. At LQ and YH stations, CDD had significantly declined trend, and the other indices increased insignificantly, this indicates that in this region it gradually became wetter, and drought was less likely to occur.

3.2. The Temporal Change of Extreme Precipitation

Figure 5 displays that all the indices including Rx1day, Rx5day, R95p, R99p, SDII, PRCPTOT had an increasing trend, with the trend of 2.34 mm/10a, 3.67 mm/10, 17.80 mm/10a, 7.32 mm/10a, 0.13 (mm/d)/10a, 30.57 mm/10a. Although all the indices had low value during 2003-2008, and then had larger increase amplitude, this implies that after 2000a the total precipitation increased in the study area.

Figure 6 illustrates that CWD, R10, R20 and R25 were on the rise, with the trend of 0.13 d/10a, 0.80 d/10a, 0.53 d/10a, 0.47 d/10a. However, CDD showed a decreasing trend, this means that extreme precipitation days had an increasing trend, this is consistent with the previous study (Yin, 2019).

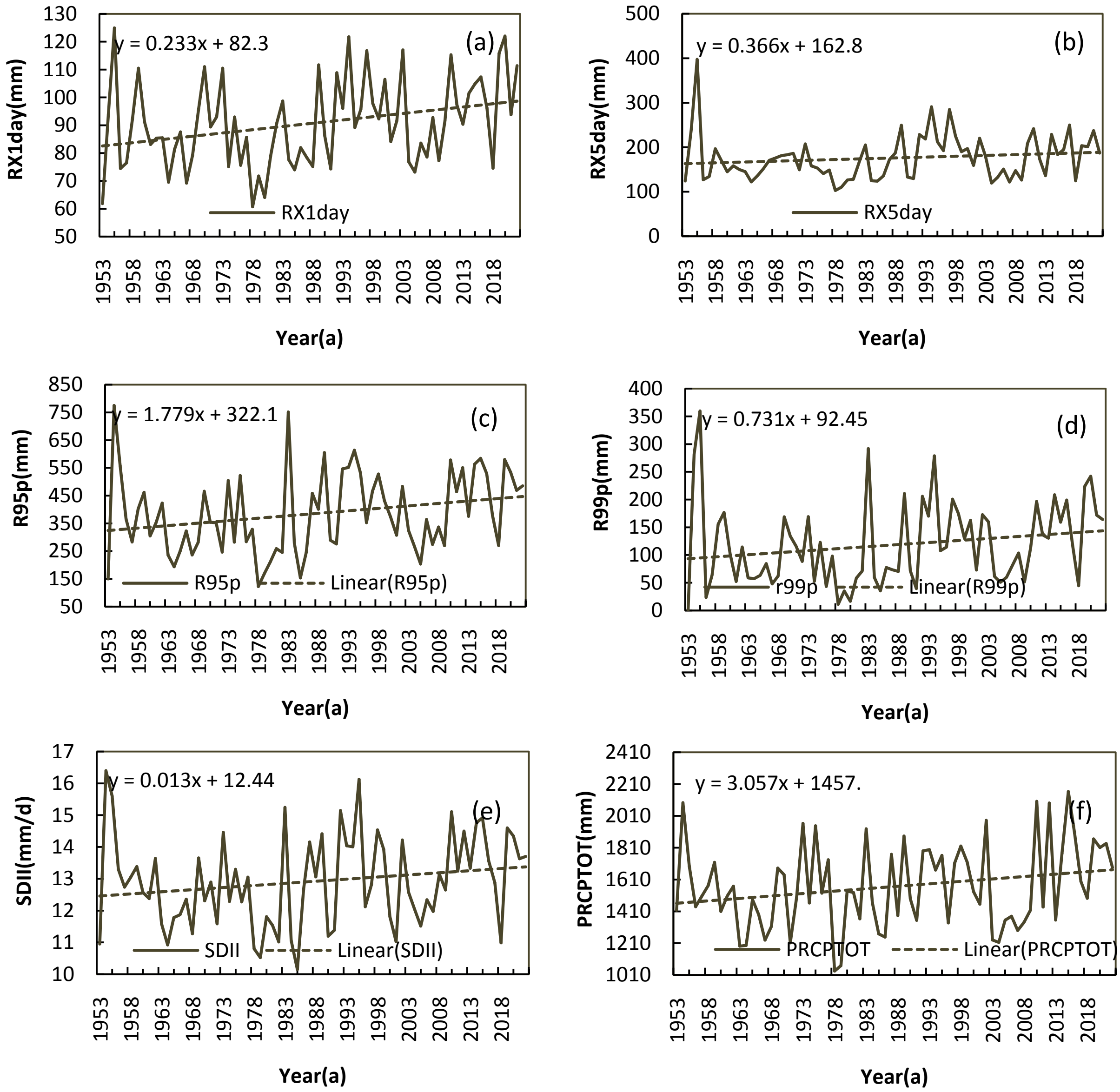

Figure 5. Annual variations of RX1day (a), RX5day (b), R95p (c), R99p (d), SDII (e), PRCPTOT (f) averaged over the southwest part of Zhejiang Province during 1953-2022.

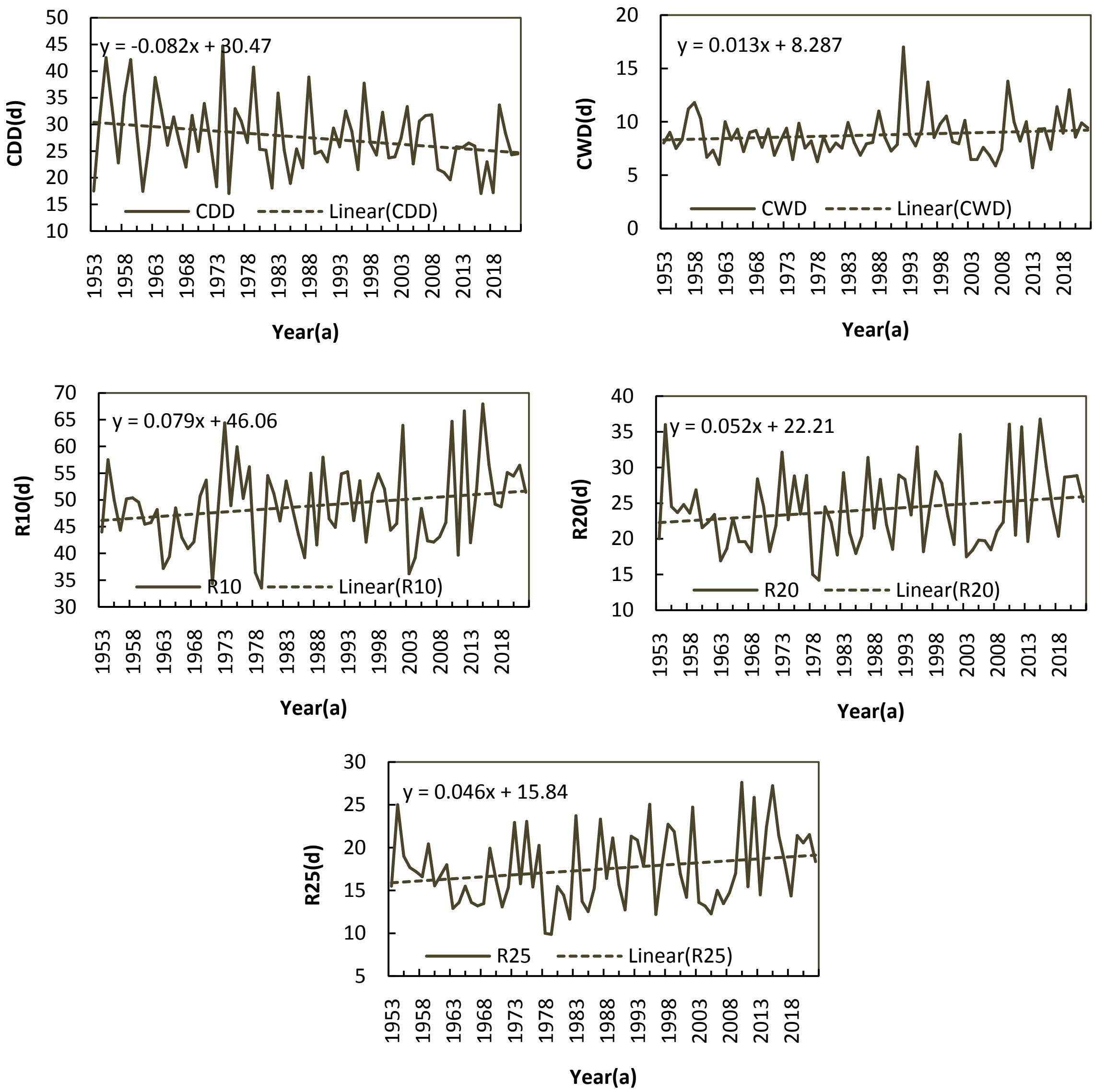

Figure 6. Annual variations of CDD (a), CWD (b), R10 (c), R20 (d), R25 (e) averaged over the southwest part of Zhejiang Province during 1953-2022.

4. Conclusion

Liuchun Lake is a model area of ecotourism in the southwest region of Zhejiang province, extreme precipitation had a larger impact on the tourism. Therefore, understanding the variation of extreme precipitation around Liuchun Lake is useful for scheduling and managing the water resources, and human safety. Based on 11 extreme precipitation indices, the characteristics of extreme precipitation in the southwest region of Zhejiang are analyzed. The main results are as follows:

Except for CDD, the other extreme precipitation indices showed the same spatial distribution, with low value in the northeast, and high value in the central region of the study area, while CDD basically had the opposite feature, with the maximum around Liuchun Lake.

CDD had a decreasing trend at all the stations, and only 20% of the stations passed the 90% significant level ($p < 0.1$), at the other stations, the change of CDD was not obvious. Although the other indices showed an increasing trend at most of the stations, and the larger increase in amplitude basically occurred in the north and central of the study area.

The annual variation of the extreme precipitation indices demonstrates that the extreme precipitation days and extreme precipitation mount had an increasing trend, this implies that it became wetter in the southwest region of Zhejiang province, but heavy precipitation was less likely to happen in most regions of the study area.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

Fund

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