

Article

Analysis of Spatial and Temporal Distribution and Changes in Extreme Climate Events in Northwest China from 1960 to 2021: A Case Study of Xinjiang

Yang Yang and Wei Chang *

School of Economics and Management, Shihezi University, Shihezi 832003, China; 20222316113@stu.shzu.edu.cn

* Correspondence: ahchangw@126.com

Abstract: Xinjiang, as a climate-sensitive region in Northwest China, holds significant importance in studying extreme climate events for agricultural production and socioeconomic development. Using data spanning from 1960 to 2021 from 52 meteorological stations across Xinjiang, encompassing 23 indices of extreme climate events, the 5-year moving average, linear trend fitting, and inverse distance weighting (IDW) are used to analyze the distribution patterns and temporal changes in extreme climatic phenomena within the region. The results indicate that, over the period from 1960 to 2021, the Amplitude Temperature Index, Heat Index, and Warm Spell Duration Index in Xinjiang exhibited a marked increasing trend, whereas the Cold Index and Cold Spell Duration Index displayed a significant decreasing trend. The range of changes in the extreme temperature indices from 1990 to 2021 is higher than that of 1960 to 1989. The areas with high values of amplitude temperature extreme indices are primarily concentrated in the southern part, while the areas with high values of cold indices are mainly distributed in the northern part. The upward/downward trends all account for over 80.00% of the entire region. The precipitation scale indices, precipitation day indices, intense precipitation index, and extreme precipitation index all showed a significant growth trend from 1960 to 2021, and the range of change in the extreme precipitation indices from 1990 to 2021 was lower than that from 1960 to 1989. Furthermore, areas with high precipitation values and regions with high trend values of climate tendency are predominantly concentrated in the northern and western parts of Xinjiang, with over 71.00% of the entire region experiencing an upward trend. The research results provide theoretical foundations for formulating climate risk strategies in the northwest region of China.

Keywords: extreme climate; climate tendency rate; spatial–temporal differentiation; variation characteristics



Citation: Yang, Y.; Chang, W. Analysis of Spatial and Temporal Distribution and Changes in Extreme Climate Events in Northwest China from 1960 to 2021: A Case Study of Xinjiang. *Sustainability* **2024**, *16*, 4960. <https://doi.org/10.3390/su16124960>

Academic Editor: Michalis Diakakis

Received: 26 March 2024

Revised: 20 May 2024

Accepted: 31 May 2024

Published: 10 June 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Extreme weather, as a phenomenon where regional weather surpasses the threshold of long-term climate variability within a short period, can lead to natural disasters such as heatwaves caused by exceptionally high temperatures, cold snaps resulting from extreme low temperatures, droughts caused by prolonged insufficient precipitation, and floods due to intense rainfall [1–3]. Although extreme climate events have low statistical occurrence probabilities, they exhibit strong abruptness and destructiveness, leading to significant negative impacts on ecological environments and human socioeconomic systems [4–7], thus garnering widespread attention from scholars both domestically and internationally. Against the backdrop of global warming, approximately 70% of regions globally exhibit an increasing trend in extreme warm events, while most extreme cold events tend to decrease [8–12]. In addition, the frequency and intensity of extreme precipitation are continuously increasing in most regions globally, with the phenomenon of enhanced response to extreme precipitation observed in both humid and arid regions [13–19]. Since the 1960s, extreme low-temperature events in China have significantly decreased while

extreme high-temperature events have markedly increased [20–23]. Regionally, extreme high/low air temperatures in the Yangtze River Basin [24], Dongting Lake basin [25], and Northwest China [26] have shown an upward trend. The trend changes in extreme precipitation events exhibit strong regional differences, with decreasing trends in the central part of Inner Mongolia, and the Sichuan Basin, while increases are noted in most areas of China like Northwest China [27,28]. The increasing frequency and intensity of extreme climate events have already caused significant impacts on agricultural production and socioeconomic conditions in China, particularly evident in China's climate-sensitive regions [29–31].

Xinjiang is not only a crucial agricultural production region in China but also globally renowned as the land of melons and fruits and a prime cotton-producing base, and it holds a strategically significant position in national development and social stability [32]. Xinjiang features a temperate continental arid climate characterized by scarce and highly unevenly distributed precipitation [33]. Its diverse land-forms encompass mountains, basins, plateaus, deserts, gravel plains, and oases, making it one of China's most ecologically sensitive and climatically vulnerable areas [34]. In recent years, numerous scholars have conducted relevant research on the extreme climate in Xinjiang. Chen et al. show a high correlation between extreme temperature changes and climate warming in Hami, Xinjiang, and the increase in TN10p and TX10 is the main reason for the temperature increase [35]. Lv et al. found that the extreme temperature warm indices in Altay, Xinjiang showed an upward trend, while the extreme temperature cold indices showed a downward trend, with the change in the warm indices being smaller than the cold indices [36]. Ding et al. have shown that the extreme precipitation and humidity indices in the Abihu Basin of Xinjiang are showing an increasing trend, and most of the extreme precipitation indices are significantly positively correlated with the total annual precipitation [37,38].

Previous studies have mainly focused on a few extreme climate events in a certain region of Xinjiang, and there is relatively little comprehensive research on various extreme climate events, especially in terms of the combination of spatio-temporal distribution and changing characteristics of extreme climate events. Therefore, this article utilizes daily maximum temperature, minimum temperature, and precipitation data from 52 meteorological stations from 1960 to 2021 to quantitatively describe the spatio-temporal distribution and change patterns of 23 extreme climate indicators in Xinjiang. The aim is to provide theoretical support for reducing the impact of natural disasters in Northwest China and formulating climate risk strategies.

2. Materials and Methods

2.1. Study Area

Xinjiang (73°20' E~96°25' E and 34°15' N~49°10' N) is located in the northwest border of China, within the hinterland of the Eurasian continent, occupying one-sixth of China's total land area and thus being the country's largest province [39]. The total area of mountainous areas in Xinjiang is 637,100 km², with 83,100 km² of plateaus, 107,300 km² of inter-mountain basins, 85,800 km² of hills, and 746,800 km² of plains (including deserts and Gobi) and the terrain and land-forms can be summarized as "Three mountains sandwiched by two basins" [40]. Xinjiang features a typical continental climate, with ample sunshine, high solar radiation, significant temperature variations between day and night, and low humidity [39,41]. The mountainous areas receive ample precipitation, which provides a relatively stable source of irrigation water for plain oases agriculture [34]. The barrier of high mountains makes it difficult for moist ocean air to penetrate inland and numerous inland rivers originating from high mountain ice and snow melt water flow profusely, giving birth to a unique mountain–oasis–desert ecosystem, which is one of the most fragile ecological environments in China and highly sensitive to extreme weather responses [42]. The distribution of meteorological stations in the study area are illustrated in Figure 1.

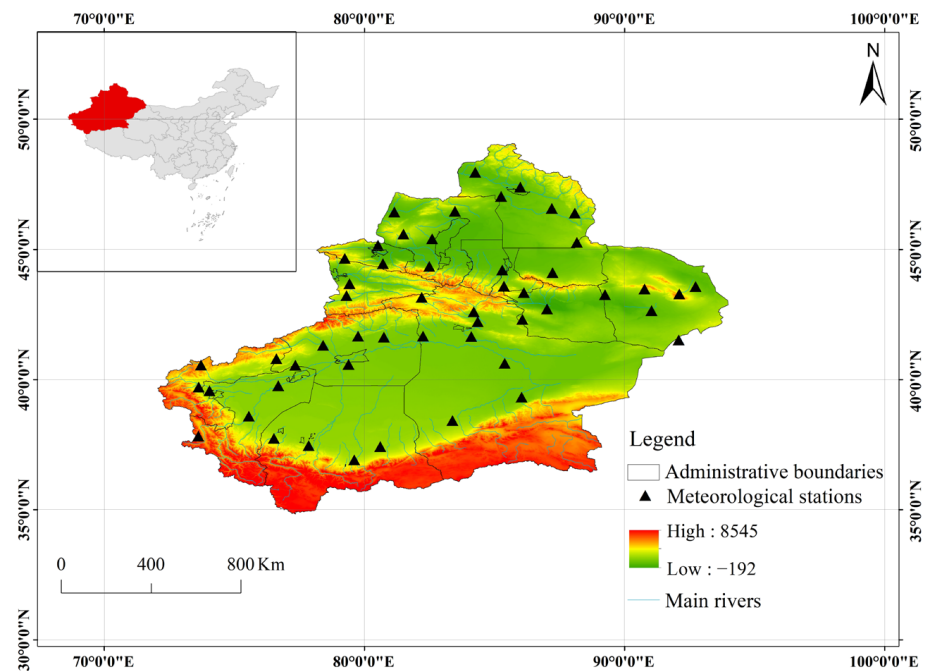


Figure 1. Research area and meteorological station distribution.

2.2. Data and Methods

The data generation process comprises three primary segments: obtaining raw data, enforcing data quality control, and arranging extreme climate indices. The comprehensive workflow is graphically illustrated in Figure 2.

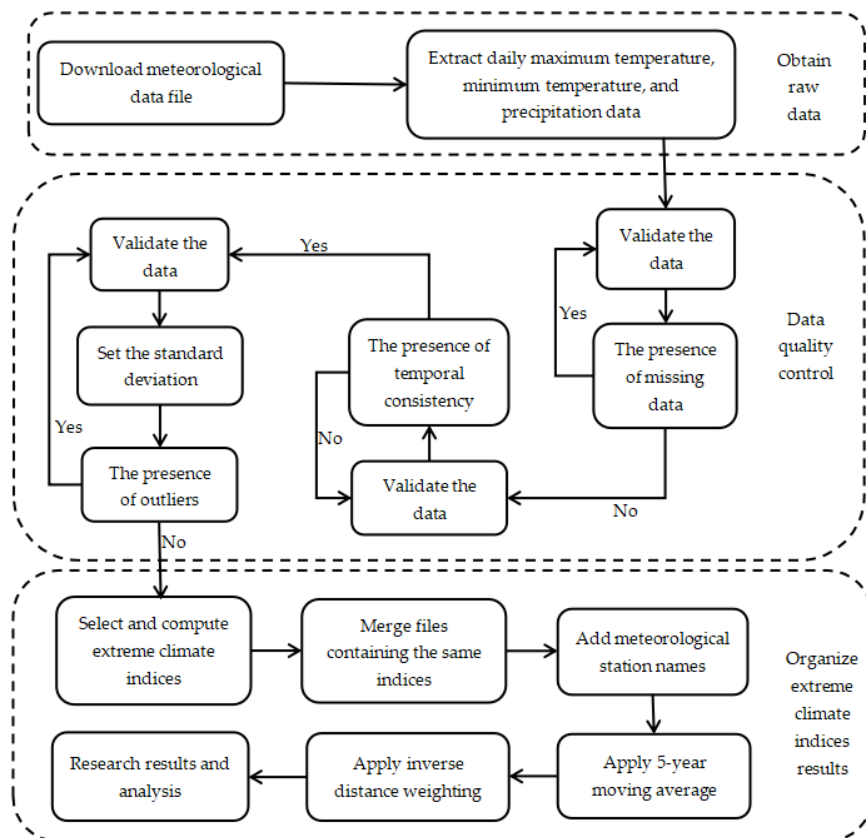


Figure 2. Production process for extreme climate indices.

Before conducting calculations, the station data undergo quality control: if the consecutive days with missing data at a station exceed 5% of the total days, the data from that station are removed and if data for a specific date at a station are missing, interpolation is performed using the average value of the same date from other years at that station [43]. Employing these methods, observation data for daily maximum temperature, minimum temperature, and precipitation from 52 stations are obtained from January 1, 1960, to December 31, 2021. The original observation data were sourced from the China Meteorological Data Service Center (<https://www.cma.gov.cn/>), accessed on 1 January 2023.

Before processing the meteorological data, rigorous quality control is conducted, including temporal consistency tests and extreme value checks [44]. Temporal consistency checks serve primarily to validate the accuracy and uniformity of time attributes inherent in data across various records, datasets, or systems, thereby ensuring temporal correspondence among meteorological elements [44]. Time consistency verification relies on manual examination, corroborating the integrity of file data, and implementing necessary amendments or deletions as warranted. Extreme value testing is primarily employed to identify outliers, such as instances where the daily maximum temperature is lower than the corresponding daily minimum temperature, daily precipitation amounts to below zero millimeters, and values either greatly surpass or significantly undershoot the limits demarcated by three times the standard deviation of the daily climate time series average in Xinjiang [44]. This multifaceted approach to anomaly detection not only employs common-sense logical constraints but also adheres to a statistically rigorous framework grounded in the established principles of outlier identification, thereby enhancing the methodological rigor and scientific credibility of the analysis. The records within the quality control result file are examined and filtered, eliminating unreasonable entries or assigning them as missing values. After the implementation of rigorous data quality control measures, the computation of the extreme climate index is permissible.

The calculation methods for the extreme climate index used in the study are derived from the relevant literature [45–54]. The 14 extreme temperature indices can fully reflect the changes in extreme temperature events in four aspects: extreme, cold, warm, and duration; the 9 extreme precipitation indices can fully reflect the changes in extreme precipitation events in three aspects: scale, intensity, and precipitation days. All of them are highly representative (Table 1).

Table 1. Extreme climate index.

Categories	Name	Indices	Definition
Amplitude Temperature Index	Maximum Value of Daily Maximum Temperature	TXx	The maximum daily maximum temperature within each year
	Maximum Value of Daily Minimum Temperature	TNx	The maximum daily minimum temperature within each year
	Minimum Value of Daily Maximum Temperature	TXn	The minimum daily maximum temperature within each year
	Minimum Value of Daily Minimum Temperature	TNn	The minimum daily minimum temperature within each year
Cold Index	Frost Day	FD	Annual count when $TN < 0\text{ }^{\circ}\text{C}$
	Icing Day	ID	Annual count when $TX < 0\text{ }^{\circ}\text{C}$
	Cold Night	TN10p	Percentage of days when $TN < 10\text{th percentile}$
	Cold Daytime	TX10p	Percentage of days when $TX < 10\text{th percentile}$
Heat Index	Summer Day	SU	Annual count when $TX > 25\text{ }^{\circ}\text{C}$
	Tropical Night	TR	Annual count when $TN > 20\text{ }^{\circ}\text{C}$
	Warm Night	TN90p	Percentage of days when $TN > 90\text{th percentile}$
	Warm Daytime	TX90p	Percentage of days when $TX > 90\text{th percentile}$
Duration Index	Cold Spell Duration Index	CSDI	Annual count of days with at least 6 consecutive days when $TN < 10\text{th percentile}$
	Warm Spell Duration Index	WSDI	Annual count of days with at least 6 consecutive days when $TX > 90\text{th percentile}$

Table 1. Cont.

Categories	Name	Indices	Definition
Precipitation Scale Index	Maximum 1-day Precipitation	Rx1day	Maximum daily precipitation
	Maximum Consecutive 5-day Precipitation	Rx5day	Maximum precipitation for 5 consecutive days
	Annual Precipitation	PRCPTOT	Total precipitation on wet days
Precipitation Intensity Index	Simple Precipitation Intensity Index	SDII	Annual precipitation divided by wet days
	Intense Precipitation	R95p	Annual total PRCP when RR > 95th percentile
	Extreme Precipitation	R99p	Annual total PRCP when RR > 99th percentile
Precipitation Day Index	Moderate Precipitation	R10mm	Annual count of days when PRCP of 10–20 mm
	Heavy Precipitation	R20mm	Annual count of days when PRCP of 20–25 mm
	Rainstorm Precipitation	Rnnmm	Annual count of days when PRCP $\geq$ 25 mm

Note: ‘Annual’ denotes ‘each year’ and ‘value’ refers to the size of the data.

Firstly, the 5-year moving average method is utilized to process the time series data, eliminating the instability of each index’s time series. Specifically, the 5-year moving average is calculated by sequentially adding and subtracting the data of the preceding and subsequent 5 years to compute the moving average value [37]. Next, the linear trend fitting method is employed to infer the inter-annual variation trend and magnitude of the extreme climate index. The climate tendency rate is calculated as ten times the regression coefficient of the linear trend line [35]. A positive climate tendency rate indicates an upward trend of the extreme climate index over time, while a negative trend indicates a downward trend. Finally, inverse distance weighting (IDW) is employed for spatial interpolation, utilizing the weighted average of distances based on the known locations and distribution characteristics of spatial points to estimate values at unknown points, thereby obtaining the distribution features across the spatial surface [55].

3. Results

3.1. Spatio-Temporal Pattern and Change in Extreme Temperature

3.1.1. Analysis of Time Characteristics

(1) Amplitude Temperature Index

The extreme value indices of Maximum Value of Daily Maximum Temperature (TXx), Maximum Value of Daily Minimum Temperature (TNx), Minimum Value of Daily Maximum Temperature (TXn), and Minimum Value of Daily Minimum Temperature (TNn) exhibited significant increasing trends ($p < 0.01$) from 1960 to 2021 (Table 2). These four amplitude temperature indices ranged from 34.18 to 38.78 °C, 20.65 to 24.93 °C, −18.78 to 9.30 °C, and −29.72 to 20.97 °C, with respective averages of 36.42 °C, 22.43 °C, −13.51 °C, and −24.92 °C. The climate tendency rates were measured at 0.14 °C/decade, 0.34 °C/decade, 0.37 °C/decade, and 0.68 °C/decade. Notably, the climate tendency rates of TXx and TNx during 1990–2021 exceeded those during 1960–1989, while the trends for the other two indices were opposite. TXx continues its upward trajectory, directly impacting crop growth and subsequently leading to decreased agricultural yield and quality, thereby affecting food safety. The fluctuations in TXn and TNn not only disrupt ecological balance but also potentially prompt alterations in agricultural planting structures in high-latitude areas due to changes in heat distribution.

Table 2. Analysis of the temporal characteristics of extreme temperature.

Categories	Name	Indices	Minimum	Maximum	Average	B	B 1960–1989.	B 1990–2021.
Amplitude Temperature Index	Maximum Value of Daily Maximum Temperature	TXx	34.18	38.78	36.42	0.014 ***	0.010	0.036 ***
	Maximum Value of Daily Minimum Temperature	TNx	20.65	24.93	22.43	0.034 ***	0.026 ***	0.044 ***
	Minimum Value of Daily Maximum Temperature	TXn	−18.78	−9.30	−13.51	0.037 ***	0.074 ***	−0.039 ***
	Minimum Value of Daily Minimum Temperature	TNn	−29.72	−20.97	−24.92	0.068 ***	0.111 ***	0.001
Cold Index	Frost Day	FD	141.02	176.54	158.49	−0.347 ***	−0.112 ***	−0.441 ***
	Icing Day	ID	52.69	88.56	67.76	−0.102 ***	−0.018	0.127 ***
	Cold Night	TN10p	8.26	43.97	21.18	−0.395 ***	−0.421 ***	−0.218 ***
	Cold Daytime	TX10p	11.11	33.47	21.26	−0.106 ***	0.050	−0.040
Heat Index	Summer Day	SU	95.73	124.04	110.78	0.185 ***	0.045	0.238 ***
	Tropical Night	TR	10.62	26.85	17.59	0.203 ***	0.084 ***	0.337 ***
	Warm Night	TN90p	4.52	42.81	19.94	0.207 ***	0.123 ***	0.495 ***
	Warm Daytime	TX90p	6.17	35.10	20.07	0.412 ***	−0.026	0.235 ***
Duration Index	Cold Spell Duration Index	CSDI	0.35	21.90	5.80	−0.170 ***	−0.179 ***	−0.008
	Warm Spell Duration Index	WSDI	0.65	17.08	5.95	0.113 ***	−0.000	0.151 ***

Note: *** denotes that the trend is significant at the 0.01 level of significance.

(2) Cold Index

The cold indices of Frost Day (FD), Icing Day (ID), Cold Night (TN10p), and Cold Daytime (TX10p) demonstrated significant increasing trends ($p < 0.01$) from 1960 to 2021 (Table 2). These four cold indices ranged from 141.02 to 176.54 days, 52.69 to 88.56 days, 8.26 to 43.97 days, and 11.11 to 33.47 days, with respective averages of 158.49 days, 67.76 days, 21.18 days, and 21.26 days. The climate tendency rates were calculated at −3.47 days/decade, −1.02 days/decade, −3.95 days/decade, and −1.06 days/decade. Interestingly, the climatic tendency rates of FD and ID during 1990–2021 surpassed those observed during 1960–1989, while the trends for the other two indices were opposite. The decrease in FD results in an increase in accumulated temperature, which proves beneficial for plant growth. Moreover, the reduction in TN10p and TX10p might lead to decreased heating demands for residents and businesses, consequently contributing to energy conservation and a reduction in greenhouse gas emissions.

(3) Heat Index

The heat indices for Summer Day (SU), Tropical Night (TR), Warm Night (TN90p), and Warm Daytime (TX90) displayed significant increasing trends ($p < 0.01$) from 1960 to

2021 (Table 2). These four heat indices ranged from 95.73 to 124.04 days, 10.62 to 26.85 days, 4.52 to 42.81 days, and 6.17 to 35.10 days, respectively, with average values of 110.78 days, 17.59 days, 19.94 days, and 20.07 days. The climate tendency rates were measured at 1.85 days/decade, 2.03 days/decade, 2.07 days/decade, and 4.12 days/decade. Notably, the climatic tendency rates of all four indices during 1990–2021 exceeded those observed during 1960–1989. On one hand, the continuous rise in heat indices provides more heat for crop growth, thus promoting improvements in agricultural productivity. On the other hand, it exacerbates high-temperature disasters and heat waves, potentially leading to crop reduction or even total crop failure.

(4) Persistence Index

From 1960 to 2021, the Cold Spell Duration Index (CSDI) ranged from 0.35 to 21.90 days, with an average of 5.80 days (Table 2). The climatic tendency rates of the Cold Duration Index during both 1960–1989 and 1990–2021 exhibited significant increasing trends, with rates of -1.79 days/decade and -0.08 days/decade, respectively ($p < 0.01$). Similarly, the Warm Spell Duration Index (WSDI) ranged from 0.65 days to 17.08 days during 1960–2021, with an average of 5.95 days and a climatic tendency rate of 1.13 days/decade. Notably, the climate tendency rate from 1990 to 2021 (1.15 days/decade) surpassed that from 1960 to 1989. The sustained output of high temperatures can lead to adverse effects, including reduced crop yields, etc., as it may surpass the adaptive capacity of people, animals, and plants.

3.1.2. Analysis of Spatial Characteristics

(1) Amplitude Temperature Index

In Xinjiang, the TXx, TNx, TXn, and TNn ranged between 19.85 and 45.62 °C, 7.97 and 30.84 °C, -28.97 and 5.74 °C, and -40.99 and 14.24 °C, respectively, with average values of 36.42 °C, 22.43 °C, -13.51 °C, and -24.92 °C (Figure 3). The distribution patterns of TXx and TNx exhibited similarities, with high values observed in Bazhou, Tulufan, Yicheng, and other areas, while low values were prevalent in Yili, Bozhou, and Kezhou, etc. Similarly, the distribution patterns of TXn and TNn displayed resemblances. The regions with high values were typically found in Kashi, Hetian, Bazhou, and other southern areas, whereas the regions with low values were concentrated in Aletai and other northern regions. This distribution pattern underscores a geographical trend where the southern region surpassed the northern region in amplitude temperature values.

The climate tendency rates of TXx, TNx, TXn, and TNn in Xinjiang over the past 62 years ranged from -0.42 °C/decade to 0.61 °C/decade, -0.53 °C/decade to 1.04 °C/decade, -0.08 °C/decade to 1.18 °C/decade, and -0.06 °C/decade to 2.04 °C/decade, respectively (Figure 4). These changes spanned from -2.604 to 3.782 °C, -3.29 to 6.45 °C, -0.50 to 7.32 °C, and -0.37 to 12.65 °C, with an upward trend accounting for 80.77%, 94.23%, 98.08%, and 98.08%, respectively (Table 3). Specifically, the areas with high trend values of the climate tendency rate of TXx were observed in Aletai, Hami, and Bazhou, etc., while areas with low trend values were evident in Bozhou and Youcheng, etc. Similarly, TNx exhibited high trend values of climate tendency rates in Aletai and Hami, etc., while areas with low trend values were observed in Aksu, etc. For TXn, the areas with high trend values of climate tendency rate were identified in Aletai, Aksu, and Yili, etc., while areas with low trend values included Kezhou, Kashi, Hetian, and Bazhou, etc. As for TNn, areas with high trend values were found in Tulufan, Hami, and Aletai, etc., while areas with low trend values located in Bazhou and Aksu, etc.

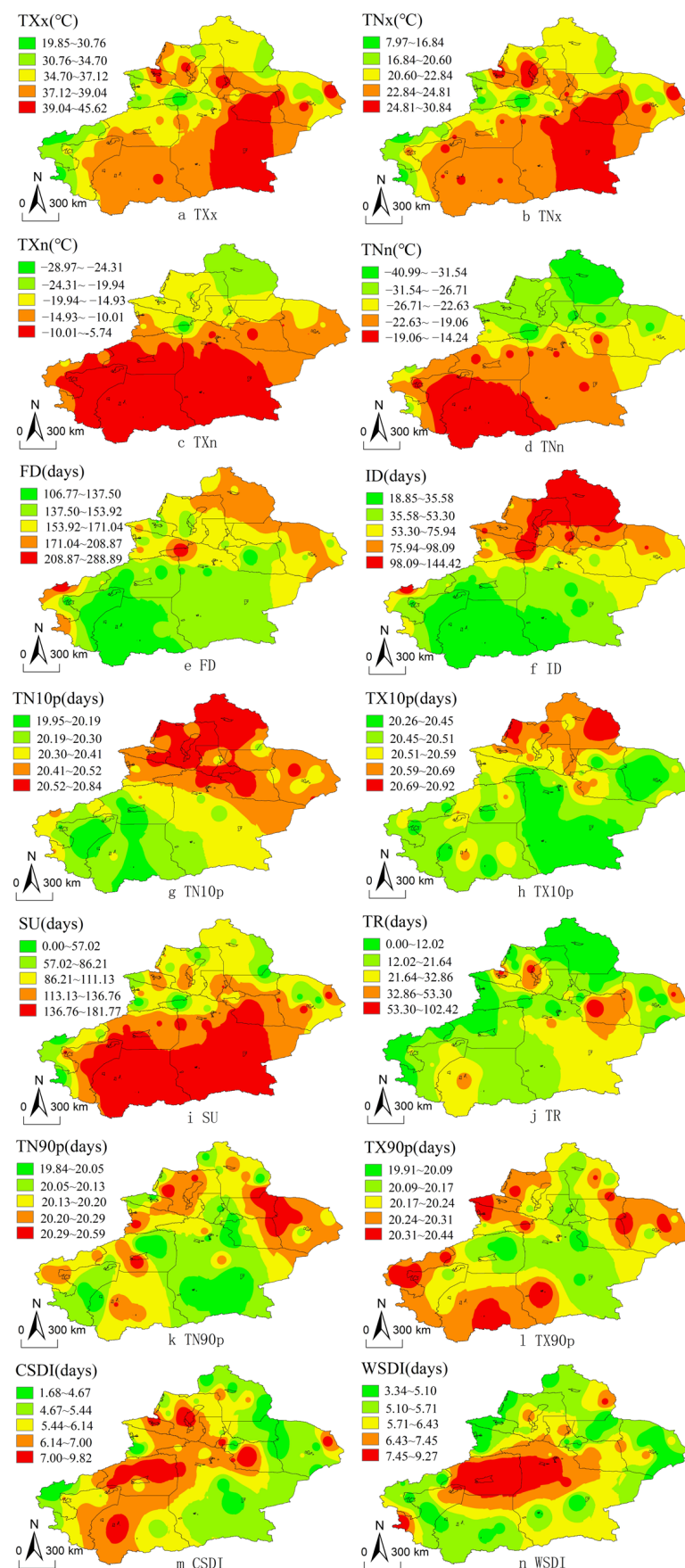


Figure 3. Spatial distribution characteristics of extreme temperature.

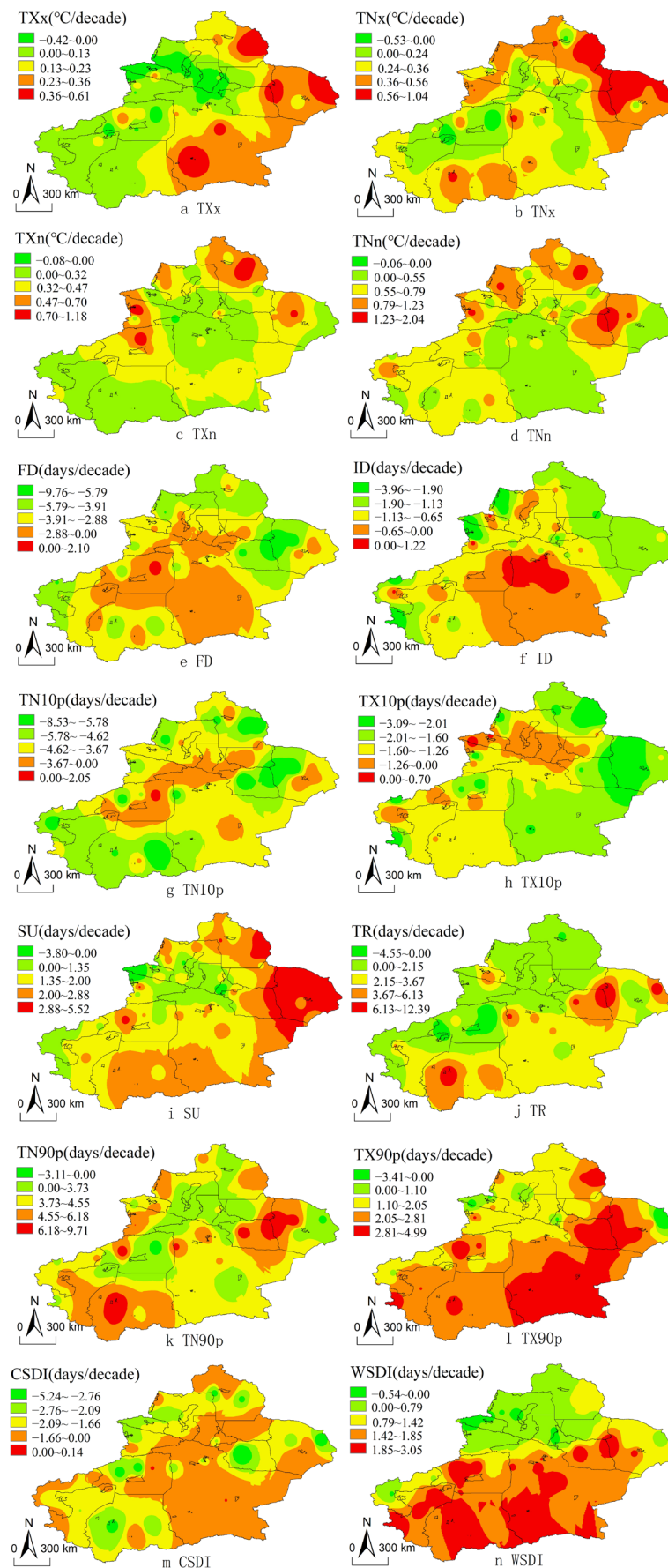


Figure 4. Spatial variation characteristics of extreme temperature.

Table 3. Statistical analysis of spatial characteristics of extreme temperature.

Categories	Name	Indices	Significant	Uptrend	Significant Uptrend	Decline	Significant Decline	0 Value
Amplitude Temperature Index	Maximum Value of Daily Maximum Temperature	TXx	78.85	42	34	10	7	
	Maximum Value of Daily Minimum Temperature	TNx	88.46	49	44	3	2	
	Minimum Value of Daily Maximum Temperature	TXn	82.69	51	43	1	0	
	Minimum Value of Daily Minimum Temperature	TNn	92.31	51	48	1	0	
Cold Index	Frost Day	FD	98.08	1	1	51	50	
	Icing Day	ID	63.46	7	2	45	31	
	Cold Night	TN10p	100.00	1	1	51	51	
	Cold Daytime	TX10p	96.15	1	1	51	49	
Heat Index	Summer Day	SU	94.12	47	46	4	2	1
	Tropical Night	TR	95.83	44	43	4	3	4
	Warm Night	TN90p	96.15	50	49	2	1	
	Warm Daytime	TX90p	94.23	47	47	5	2	
Duration Index	Cold Spell Duration Index	CSDI	88.46	3	-	49	46	
	Warm Spell Duration Index	WSDI	84.62	45	41	7	3	

(2) Cold Index

The FD, ID, TN10p, and TX10p indices ranged from 106.77 to 288.89 days, 18.85 to 144.42 days, 19.95 to 20.84 days, and 20.26 to 20.92 days, respectively, with average values of 158.49 days, 67.76 days, 20.41 days, and 20.53 days. All four cold indices exhibited a geographical distribution pattern characterized by higher values in the north and lower values in the south (Figure 2).

The climate tendency rates of FD, ID, TN10p, and TX10p in Xinjiang over the past 62 years ranged from −9.76 to 2.10 days/decade, −3.96 to 1.22 days/decade, −8.53 to 2.05 days/decade, and −3.09 to 0.70 days/decade, respectively, with changes ranging from −60.51 to 13.02 days, −24.55 to 7.56 days, −52.89 to 12.71 days, and −19.16 to 4.34 days (Figure 3). The decreasing tendency accounted for 98.08%, 86.54%, 98.08%, and 98.08%, respectively (Table 3). Specifically, the climate tendency rate of FD was higher in Aksu and Bazhou, etc., while being lower in Hami and Tulufan, etc. Similarly, the areas with high trend values of the climate tendency rates of ID were situated in Aksu and Bazhou, etc., while areas with low trend values were observed in Bozhou, Yili, and Tacheng, etc. Regarding TN10p, the areas with high trend values of the climate tendency rates were identified in Aksu, Wushi, and Changji, etc., while areas with low trend values were found

in Kezhou, Aletai, and Tulufan, etc. Similarly, the areas with high trend values of climate tendency rates for TX10p were located in Youcheng, Changji, and Wushi, etc., whereas areas with low trend values were observed in Aletai, Hami, and Tulufan, etc.

(3) Heat Index

The SU, TR, TN90p, and TX90p indices in Xinjiang ranged from 0.00 to 181.77 days, 0.00 to 102.42 days, 19.84 to 20.59 days, and 19.91 to 20.44 days, respectively, with average values of 110.78 days, 17.59 days, 20.16 days, and 20.23 days (Figure 2). The distribution characteristics of SU showed higher values in the south and lower values in the north. The areas with higher values of TR were clustered in Tulufan, etc., whereas lower values were observed in Aletai, Yili, and Kezhou, etc. Similarly, the regions with high values of TN90p were situated in Changji, Hami, Tulufan, etc., while areas with low values were found in Bazhou and Akesu, etc. For TX90p, the regions with high values were identified in Kezhou, Hetian, Bozhou, and Hami, etc., and areas with low values were observed in Bazhou and Akesu, etc.

The climate tendency rates of SU, TR, TN90p, and TX90p in Xinjiang ranged from -3.80 to 5.52 days/decade, -4.55 to 12.39 days/decade, -3.11 to 9.71 days/decade, and -3.41 to 4.99 days/decade, respectively (Figure 3). These changes spanned from -23.56 to 34.22 days, -28.21 to 76.82 days, -19.28 to 60.20 days, and -21.14 to 30.94 days, with upward trends accounting for 90.38%, 84.62%, 96.15%, and 90.38%, respectively (Table 3). Specifically, the climate tendency rates of SU were higher in Aletai and Hami, etc., lower in Bozhou and Wushi, etc., and Tuerqate Station in western Kezhou recorded values of zero. The areas with high trend values of climate tendency rates of TR were located in Tulufan and Hami, etc., while areas with low trend values were found in Akesu and Aletai, etc., demonstrating a west-to-east decreasing trend, with zero TR occurrences in Zhaosu and four other stations. Similarly, the areas with high trend values of climate tendency rates of TN90p were situated in Hami, Tulufan, Hetian, etc., while areas with low trend values were observed in Akesu, Youcheng, Changji, etc. For TX90p, the areas with high trend values of climate tendency rates were located in Bazhou, Tulufan, and Hami, etc., and areas with low trend values observed in Bozhou and Youcheng, etc.

(4) Duration Index

The CSDI and WSDI in Xinjiang ranged between 1.68 and 9.82 days and 3.34 and 9.27 days, respectively, with averages of 5.80 days and 5.95 days (Figure 2). Areas with higher CSDI values are concentrated in Akesu, Youcheng, and Tulufan, etc., while lower values are observed in Aletai, Changji, Hami, and surrounding regions. Meanwhile, the WSDI indicates that higher values are prominent in Akesu and Bazhou, etc., gradually declining towards adjacent areas.

The climatic tendency rates of CSDI and WSDI in Xinjiang ranged between -5.24 and 0.14 days/decade and -0.54 and 3.05 days/decade (Figure 3), respectively. The variation spanned from -32.49 to 0.87 days and -3.35 to 18.91 days, with upward trends constituting 94.23% and 86.54%, respectively (Table 3). The climatic tendency rates of CSDI are notably high in Bazhou and Changji, etc., whereas they are lower in Bozhou, Tacheng, and Tulufan, etc. Similarly, areas with higher WSDI values are concentrated in southern regions such as Hetian and Bazhou, whereas lower values prevail in northern regions like Tacheng, Youcheng, and Aletai, indicating a geographical distribution trend where the south experiences more significant changes compared to the north.

3.2. Spatio-Temporal Pattern and Changes in Extreme Precipitation

3.2.1. Analysis of Temporal Characteristics

(1) Precipitation Scale index

The analysis of precipitation scale indices, including Maximum 1-day precipitation (Rx1day), Maximum Consecutive 5-day Precipitation (Rx5day), and Annual precipitation (PRCPTOT), reveals significant increasing trends ($p < 0.01$) from 1960 to 2021 (Table 4). Over this period, the values of these indices varied within ranges of 12.59 to 23.93 mm, 15.93 to 35.33 mm, and 60.57 to 192.54 mm, respectively, with corresponding average values of

17.26 mm, 24.39 mm, and 114.20 mm. Notably, the climate tendency rates were calculated at 0.72 mm/decade, 1.24 mm/decade, and 13.22 mm/decade. While the Rx1day index did not exhibit a significant increasing trend from 1990 to 2021, the other two indices demonstrated significant increases ($p < 0.01$) during both the 1960–1989 and 1990–2021 periods. Xinjiang, being an inland region characterized by an arid climate and relatively low precipitation, stands to benefit from increased precipitation. This rise in precipitation levels holds promise for alleviating water resource shortages, thereby playing a crucial role in promoting agricultural production and enhancing the ecological environment. However, it is essential to note that the heightened precipitation may result in extreme hydrological events such as flash floods. These events pose significant risks, potentially damaging farmlands, infrastructure including roads and bridges, and even endangering residents' lives.

Table 4. Analysis of time characteristics of extreme precipitation.

Categories	Name	Indices	Minimum	Maximum	Average	B	B 1960–1989	B 1990–2021
Precipitation Scale Index	Maximum 1-day Precipitation	Rx1day	12.59	23.93	17.26	0.072 ***	0.061 ***	−0.002
	Maximum Consecutive 5-day Precipitation	Rx5day	15.93	35.33	24.39	0.124 ***	0.077 ***	0.037 *
	Annual Precipitation	PRCPTOT	60.57	192.54	114.20	1.322 ***	1.495 ***	0.599 ***
Precipitation Intensity Index	Simple Precipitation Intensity Index	SDII	3.65	5.25	4.52	−0.001	−0.010 **	0.002
	Intense Precipitation	R95p	10.22	57.46	24.82	0.316 ***	0.208 ***	0.146 ***
	Extreme Precipitation	R99p	1.88	21.74	7.46	0.113 ***	0.061 ***	0.044 **
Precipitation Day Index	Moderate Precipitation	R10mm	1.06	4.96	2.57	0.031 ***	0.025 ***	0.020 ***
	Heavy Precipitation	R20mm	0.21	1.29	0.53	0.007 ***	0.003 *	0.003 **
	Rainstorm Precipitation	Rnnmm	0.06	0.67	0.25	0.004 ***	0.002 ***	0.001

Note: * denotes that the trend is significant at the 0.10 level of significance; **denotes that the trend is significant at the 0.05 level of significance; *** denotes that the trend is significant at the 0.01 level of significance.

(2) Precipitation Intensity Index

The Simple Precipitation Intensity Index (SDII) exhibited an insignificant downward trend ($p \geq 0.01$), while the two indices of Intense precipitation (R95p) and Extreme precipitation (R99) exhibited significant increasing trends ($p < 0.01$) from 1960 to 2021 (Table 4). The values of the three precipitation intensity indices ranged from 3.65 to 5.25 mm/d, 10.22 to 57.46 mm, and 1.88 to 21.74 mm, with an average of 4.52 mm/d, 24.82 mm, and 7.46 mm. The calculated climate tendency rates were −0.010 mm/(days·decade), 1.13 mm/decade, and 3.16 mm/decade. Interestingly, while SDII exhibited a significant downward trend during 1960–1989, it displayed an insignificant upward trend during 1990–2021. In contrast, both R95p and R99 exhibited significant increasing trends ($p < 0.01$) throughout the entire period. In mountainous regions, heavy rainfall can precipitate geological disasters such as landslides and mud-rock flows, particularly prevalent in certain mountainous areas of southern Xinjiang, owing to topographic factors.

(3) Precipitation Day Index

The precipitation day indices for Moderate precipitation (R10mm), Heavy precipitation (R20mm), and Rainstorm precipitation (Rnnmm) showed significant increasing trends ($p < 0.01$) from 1960 to 2021 (Table 4). These indices ranged from 1.06 to 4.96 days, 0.21 to 1.29 days, and 0.06 to 0.67 days, with respective averages of 2.57 days, 0.53 days, and 0.25 days. The climate tendency rates were measured at 0.31 days/decade, 0.07 d/decade, and 0.04 d/decade. From 1960 to 1989 and 1990 to 2021, all three indices exhibited increasing trends, with significance noted in all cases except for the number of heavy rain days from 1990 to 2021. Across the board, the minimum, maximum, average, and climate tendency rates of the three indices adhere to a consistent pattern: the number of moderate precipitation days (R10mm) > the number of heavy precipitation days (R20mm) > the number of rainstorm precipitation days (Rnnmm). Despite the relatively small rainfall intensity of Moderate precipitation (R10mm), prolonged occurrences can lead to delayed ground water discharge, potentially resulting in waterlogging of croplands and adversely affecting agricultural production.

3.2.2. Analysis of Spatial Characteristics

(1) Precipitation Scale Index

The Rx1day, Rx5day, and PRCPTOT in Xinjiang exhibited ranges of 5.34 to 34.93 mm, 5.84 to 47.00 mm, and 10.69 to 458.15 mm, respectively, with average values of 17.26 mm, 24.39 mm, and 114.20 mm. The geographical distribution of these three indices displayed similarities. Areas with higher values were notably present in Bozhou, Yili, and Tacheng, while regions with lower values were observed in Bazhou, Tulufan, and Hetian. This pattern signifies a decreasing geographical distribution from northwest to southeast (Figure 5).

The climate tendency rates of Rx1day, Rx5day, and PRCPTOT in Xinjiang over the past 62 years ranged between -1.14 and 2.11 mm/decade, -0.84 and 4.52 mm/decade, and -2.81 and 58.19 mm/decade, respectively (Figure 6). Changes in these rates spanned from -7.07 to 13.08 mm, -5.21 to 28.02 mm, and -17.42 to 360.78 mm, with upward trends accounting for 84.62%, 88.46%, and 96.16%, respectively (Table 5). The geographical distribution of climate tendency rates for these three indices is similar, the areas with high trend values primarily concentrated in Kezhou, Yili, Aletai, and Hami, while areas with low trend values are predominantly found in Bazhou and Tulufan. This distribution pattern suggests a trend of higher rates in the west and northeast, and lower rates in the southeast.

(2) Precipitation Intensity Index

The SDII, R95p, and R99p indices in Xinjiang ranged from 3.01 to 7.13 mm/days, 2.10 to 89.25 mm, and 0.55 to 25.63 mm, respectively, with averages of 4.52 mm/days, 24.82 mm, and 7.46 mm (Figure 4). The areas with high values of SDII were predominantly distributed in southern regions such as Wushi, Bazhou, and Hetian, whereas areas with low values were found in northern regions like Tulufan and Aletai. The geographical distribution of R95p and R99p exhibits similarities. The areas with high values were mainly concentrated in western regions such as Kezhou, Yili, and Bozhou, as well as northern regions like Aletai, while areas with low values were primarily located in southern and eastern regions such as Hetian, Bazhou, Tulufan, and Hami.

The climate tendency rates of SDII, R95p, and R99p in Xinjiang ranged from -0.39 to 0.21 mm/(days-decade), -2.86 to 13.05 mm/decade, and -1.98 to 5.20 mm/decade, respectively (Figure 5). Changes in these rates ranged from -2.42 to 1.30 mm/days, -17.73 to 80.91 mm, and -12.28 to 32.24 mm, with upward trends accounting for 44.23%, 86.54%, and 73.08%, respectively (Table 5). High climatic tendency rates of SDII were observed in Yili, Bozhou, Wushi, Aletai, and Hami, etc., while lower rates were noted in Hetian and Bazhou, etc. The geographical distribution patterns for R95p and R99p mirror each other. The areas with high trend values of climate tendency rates encompass Yili, Aletai, and Hami, etc, and areas with low trend values are situated in Tulufan and Bazhou, among others.

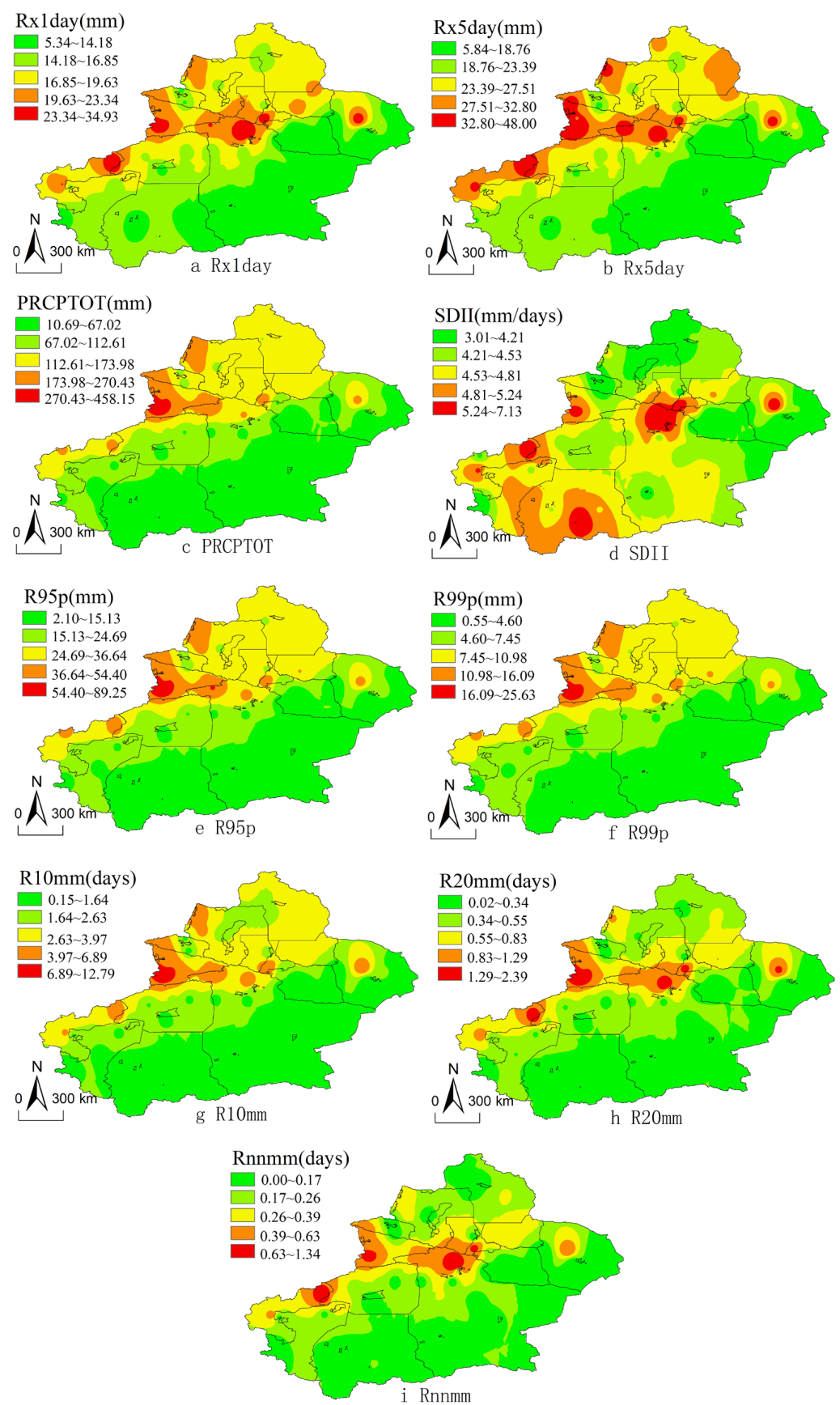


Figure 5. Spatial distribution characteristics of extreme precipitation.

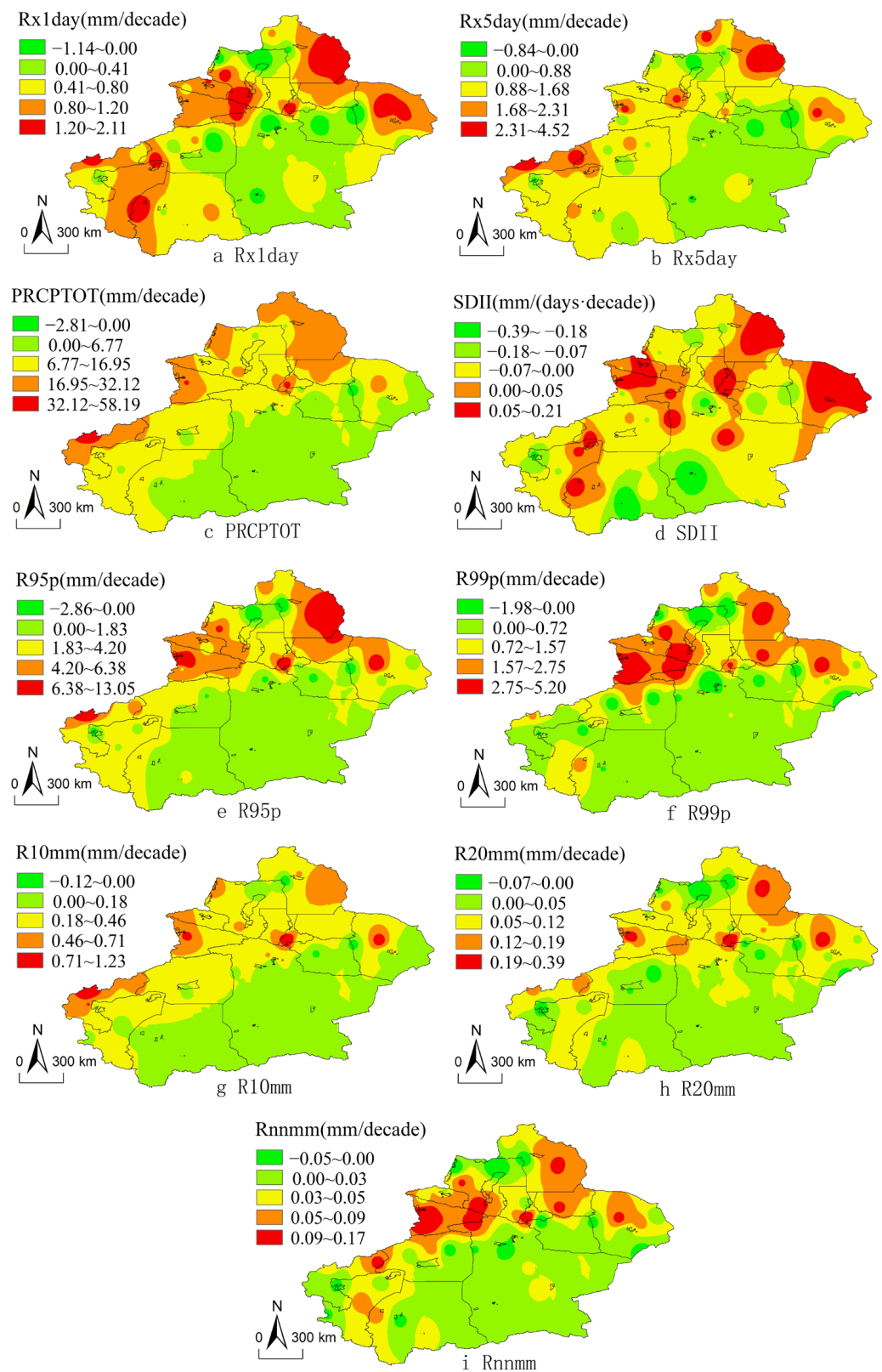


Figure 6. Spatial variation characteristics of extreme precipitation.

Table 5. Statistical analysis of spatial characteristics of extreme precipitation.

Categories	Name	Indices	Significant	Uptrend	Significant Uptrend	Decline	Significant Decline	0 Value
Precipitation Scale Index	Maximum 1-day Precipitation	Rx1day	69.23	44	32	8	4	
	Maximum Consecutive 5-day Precipitation	Rx5day	73.08	46	35	6	3	
	Annual Precipitation	PRCPTOT	98.08	50	49	2	1	
Precipitation Intensity Index	Simple Precipitation	SDII	57.69	23	15	29	15	
	Intense Precipitation	R95p	80.77	45	37	7	5	
	Extreme Precipitation	R99p	63.46	38	27	14	6	
Precipitation Day Index	Moderate Precipitation	R10mm	88.46	49	44	3	2	
	Heavy Precipitation	R20mm	73.08	41	31	11	7	
	Rainstorm Precipitation	Rnnmm	63.46	37	24	14	9	1

(3) Precipitation Day Index

The R10mm, R20mm, and Rnnmm indices in Xinjiang exhibited a range of 0.15 to 12.79 days, 0.02 to 2.39 days, and 0.00 to 1.34 days, respectively, with averages of 2.57 days, 0.53 days, and 0.25 days (Figure 4). The geographical distribution of these indices was similar, as the areas with high values clustered in Kezhou, Yili, Bozhou, and other regions, while areas with low values were predominantly distributed in Bazhou and Tulufan, etc.

Over the past 62 years, the climate tendency rates of R10mm, R20mm, and Rnnmm in Xinjiang ranged between -0.12 and 1.23 days/decade, -0.07 and 0.39 days/decade, and -0.05 and 0.17 days/decade, respectively (Figure 5). Changes in these rates ranged from -0.74 to 7.63 days, -0.43 to 2.42 days, and -0.31 to 1.05 days, with upward trends accounting for 94.23%, 78.85%, and 71.15%, respectively (Table 5). The climate tendency rate of R10mm was notably high in Kezhou, Wushi, and Hami, etc., while being low in Tulufan, etc., indicating a decreasing geographical distribution pattern from northwest to southeast. Regions with high values of the climate tendency rate of R20mm were concentrated in Yili, Wushi, Aletai, and Hami, while lower values were observed in Tacheng, Tulufan, Aksu, etc. The areas with high values of the climate tendency rate of Rnnmm were located in Yili, Wushi, Aletai, and other regions, and areas with low trend values were situated in Hetian, Aksu, and Bazhou, etc. Notably, in Tulufan Station, the number of Rnnmm recorded over the 62-year period was zero.

4. Discussion

The interannual variation in extreme temperature indices in Xinjiang from 1960 to 2021 illustrates a marked increase in warm temperature indices (such as SU, TR, TN90p, TX90p, and WSDI) and a significant decrease in cold temperature indices (including FD, ID, TN10p, TX10p, and CSDI). The trends of extreme temperature index changes are similar to those in the Yangtze River Basin [24], Dongting Lake Basin [25], and Songhua River Basin [43]. Additionally, the trends for extreme low temperatures are more pronounced than those for extreme high temperatures (with TXn exceeding TXx and TNn surpassing TNx), resulting in a decline in the Diurnal Temperature Range (DTR). The winter nighttime temperature variations are notably more volatile in TN10p compared to TX10p, while

summer daytime temperatures exhibit greater intensity in TX90p than in TN90p. The trends in extreme precipitation indices, such as Rx1day, Rx5day, PRCPTOT, R95p, R99p, R10mm, R20mm, and Rnnmm, show significant increases, but their average values remain relatively low, especially R20 (0.53 days) and Rnnmm (0.25 days), suggesting that high-intensity precipitation events remain relatively rare.

When comparing the trends in Xinjiang's extreme temperature indices with those in other regions, it is evident that both the direction and magnitude of changes in Xinjiang are consistent with global and national patterns. Indices such as TXx, TNx, TXn, TNn, FD, and ID exhibit greater fluctuations than the global land average [56], and the increased rates for TNx, TXn, TNn, and TR surpass the national average [57]. This indicates that Xinjiang's extreme temperature variations are highly sensitive to global warming, which can be attributed to the region's arid conditions, sparse vegetation, high surface albedo, and rapid heat absorption and dissipation, leading to significant daily and seasonal temperature fluctuations. Additionally, extreme precipitation indices such as Rx1day, Rx5day, and R20mm exceed those recorded in Northwestern China [58], and the growth rates for Rx1day, Rx5day, PRCPTOT, R95p, R99p, R10mm, R20mm, and Rnnmm are higher than those in the northern deserts [59]. Compared to the more humid southern regions, Xinjiang's PRCPTOT has increased significantly [60], which aligns with the global trend of an intensified hydrological cycle and more frequent extreme climate events under the influence of global warming. Temperature escalations, coupled with amplified land surface evapotranspiration and a surge in water vapor flux from oceanic sources to Xinjiang, have collectively induced notable transformations of extreme precipitation events.

The correlation coefficients (detailed in Table 6) between change trends of extreme climate indices and elevation, longitude, and latitude reveals that indices such as TXx, TXn, TNn, FD, ID, TX10p, SU, and TR inversely correlate with altitude, while TNx, TN10p, TN90p, and CSDI correlate positively. Indices such as TXx, TNx, TXn, and TNn, along with SU, positively correlate with both latitude and longitude, indicating faster warming trends in the northeastern parts of the region. Conversely, FD and ID show a negative correlation with longitude but a positive one with latitude, highlighting rapid temperature increases in the southeastern areas. For example, Rx1day, Rx5day, PRCPTOT, R95p, R10mm, and Rnnmm correlate positively with altitude and negatively with longitude, indicating that higher altitudes and positions closer to the northwest exhibit more pronounced rising trends. Similarly, R99p and R20mm also correlate positively with altitude. The fragile geological structures in these high-altitude mountainous regions, combined with intense precipitation, can trigger severe natural disasters like mudslides and waterlogging, posing significant threats to both life and property. Consequently, it is imperative to strengthen infrastructure and systematically enhance disaster prevention, mitigation, and resilience capabilities.

This study focuses on the spatio-temporal distribution and variation characteristics of extreme climate events in Xinjiang. It identifies significant trends towards warmer and more humid conditions, with a notable decline in cold indices, highlighting a distinct shift towards warmer and wetter conditions. These insights offer valuable contributions to shaping policies and strategies for disaster risk reduction and climate resilience in Xinjiang. However, there is a need for more detailed research that closely aligns extreme climate events with agricultural productivity and economic development, to foster ecological sustainability and high-quality growth in the region effectively. Additionally, although this research utilizes the widely adopted inverse distance weighting (IDW) method for spatial interpolation, Xinjiang's extensive and uneven geographic spread presents unique challenges. Future efforts will explore the use of geostatistical Kriging techniques to address these regional variations and improve the precision of spatial interpolations.

Table 6. Correlation coefficients between change trends of extreme climate indices and elevation, longitude, and latitude.

Indices	Elevation	Longitude	Latitude	Indices	Elevation	Longitude	Latitude
TXx	−0.0725	0.4033 ***	0.0002	Rx1day	0.1541	−0.0239	0.0869
TNx	0.0084	0.3117 **	0.2194	Rx5day	0.2847 **	−0.1702	0.1054
TXn	−0.1610	0.0530	0.2809 **	PRCPTOT	0.3588 ***	−0.2161	0.3271 **
TNn	−0.2668 *	0.0004	0.2862 **	SDII	−0.1409	0.1903	0.2689 *
FD	−0.0993	−0.0565	−0.1723	R95p	0.2342 *	−0.0413	0.2861 **
ID	−0.2833 **	−0.0151	−0.1779	R99p	0.0594	0.0198	0.2694 *
TN10p	0.0824	0.0440	−0.0228	R10mm	0.3219 **	−0.1678	0.2472 *
TX10p	−0.0553	0.2564	−0.0226	R20mm	0.1898	0.0656	0.2043
SU	−0.2030	0.4046 ***	0.0213	Rnnmm	0.1025	−0.0142	0.1708
TR	−0.3489 **	−0.1316	0.1820				
TN90p	0.0166	−0.0710	−0.0927				
TX90p	0.0506	−0.0059	−0.2925 **				
CSDI	0.3342 **	0.0488	−0.0423				
WSDI	0.0680	−0.0482	−0.5723 ***				

Note: * denotes that the trend is significant at the 0.10 level of significance; **denotes that the trend is significant at the 0.05 level of significance; *** denotes that the trend is significant at the 0.01 level of significance.

5. Conclusions and Suggestions

5.1. Conclusions

This study employs 23 extreme climate indices to analyze the spatial and temporal distribution, as well as the characteristics of changes in extreme climates, in Xinjiang from 1960 to 2021. The principal findings are summarized as follows:

(1) From 1960 to 2021, Xinjiang witnessed a conspicuous decline in cold-related indices and a marked increase in warm-related indices. More precisely, the Frost Days (FD), Icing Days (ID), Cold Night (TN10p), Cold Daytime (TX10p), and the Cold Spell Duration Index (CSDI) decreased at respective rates of −3.47 days per decade, −1.02 days per decade, −3.95 days per decade, −1.06 days per decade, and −1.70 days per decade. In contrast, the Summer Days (SU), Tropical Nights (TR), Warm Night (TN90p), Warm Daytime (TX90p), and the Warm Spell Duration Index (WSDI) showed increases at rates of 1.85 days per decade, 2.03 days per decade, 2.07 days per decade, 4.12 days per decade, and 1.13 days per decade, respectively, consistent with the broader pattern of global warming. Furthermore, the trends in amplitude temperature indices, including the Maximum Value of Daily Maximum Temperature (TXx), the Maximum Value of Daily Minimum Temperature (TNx), the Minimum Value of Daily Maximum Temperature (TXn), and the Minimum Value of Daily Minimum Temperature (TNn), revealed respective increases of 0.14 °C, 0.34 °C, 0.37 °C, and 0.68 °C per decade.

(2) The distribution of and changes in extreme temperature events in Xinjiang exhibit regional disparities. The areas with high values of amplitude temperature indices (TXx, TNx, TXn, and TNn) are predominantly situated in the northern part, whereas the areas with high values of the cold indices (FD, ID, TN10p, and TX10p) are primarily found in the southern region. Although variations exist in the distribution characteristics of climate tendency rates among different extreme temperature indices in Xinjiang, there is strong consistency in their statistical properties. The 16 extreme temperature indices have all shown an upward/downward trend of over 80.00% in the entire Xinjiang region. Among them, TXn, TNn, FD, TN10p, and TX10p account for 98.08% across Xinjiang, indicating pervasive extreme warming.

(3) From 1960 to 2021, extreme precipitation indices in Xinjiang, including the Maximum 1-day Precipitation (Rx1day), Maximum Consecutive 5-day Precipitation (Rx5day), Annual Precipitation (PRCPTOT), Intense Precipitation (R95p), Extreme Precipitation (R99p), Moderate Precipitation (R10), Heavy Precipitation (R20), and Rainstorm Precipitation (R25), exhibited increasing trends at rates of 0.72 mm, 1.24 mm, 13.22 mm, 3.16 mm,

1.13 mm, 0.31 days, 0.07 days, and 0.04 days per decade, respectively. These trends suggest a progression towards more extreme precipitation in the region.

(4) The distribution of and changes in extreme precipitation events in Xinjiang have spatial similarities. The areas with high values of Rx1day, Rx5day, PRCPTOT, R95p, R99p, R10mm, R20mm, and Rnnmm, as well as regions exhibiting a high climate tendency, are predominantly concentrated in the northern and western parts of the region. Their trends of change correlate positively with altitude and latitude, and inversely with longitude, implying that areas with higher elevations and those located further northwest exhibit a more pronounced upward trend. With over 71.00% of the entire region experiencing an upward trend, extreme precipitation in the majority of Xinjiang's areas is on the rise. Nonetheless, the frequency of extreme precipitation events is still limited, particularly for R20mm, ranging from 0.02 to 2.39 days, and Rnnmm, varying from 0.00 to 1.34 days.

5.2. Suggestions

Based on the above analysis, this study proposes the following three policy recommendations, aiming to provide a scientific basis and practical guidance for decision-makers, and striving to lead agricultural production towards a more resilient and sustainable development trajectory in the prevailing backdrop of frequent and severe extreme climate events.

(1) Emphasize enhancements in weather forecasting capabilities and ensure prompt responses to extreme climate events. Given the discernible upward trend in the intensity, duration, and frequency of extreme weather phenomena in Xinjiang, the government is advised to supply high-resolution weather forecasts tailored to agricultural production requirements. This should be complemented by the establishment of early warning systems for calamities such as cold waves, heatwaves, droughts, and floods to mitigate their impacts promptly and effectively.

(2) Carry out climate zoning work and adjust the agricultural industry structure. In most regions of Xinjiang, both temperature and precipitation have exhibited an upward trend, leading to improved water and heat conditions in formerly unsuitable low-temperature, high-latitude areas, as well as in regions grappling with extreme water scarcity for crop cultivation. The government should proactively organize research to understand the law of climate change, conduct climate zoning based on crop growth needs, implement guidance policies to encourage farmers to adjust crop structure, and ultimately achieve the goal of improving crop production quality.

(3) Enhance investment in agricultural infrastructure to bolster the resilience of crops against risks. In recent years, with the support of government and social investment, agricultural infrastructure has seen significant improvement, leading to a continuous expansion of effective irrigation areas. Nevertheless, weaknesses persist in farmland drainage. It is imperative to strengthen the development of agricultural infrastructure, particularly flood and drought prevention facilities and the application of supporting technologies, to systematically enhance our capability to prevent, resist, and mitigate disasters.

Author Contributions: Y.Y. designed the experiments and analyzed the results. W.C. assisted in paper design and review. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the National Social Science Fund of China (12CJY052), High-level Talent Program of Shihezi University (KX019102), Philosophy and Social Science Planning Youth Project of Henan Province (2023CJJ181).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original observation data were sourced from the China Meteorological Data Service Center (<http://data.cma.cn/>), accessed on 1 January 2023.

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

References

1. Doktycz, C.; Abkowitz, M. Loss and Damage Estimation for Extreme Weather Events: State of the Practice. *Sustainability* **2019**, *11*, 4243. [\[CrossRef\]](#)
2. IPCC Climate Change. *Managing the Risks of Extreme Events and Disaster to Advance Climate Change Adaptation*; Cambridge University Press: Cambridge, UK, 2013.
3. Webber, R.J.; Plotkin, D.A.; O'Neill, M.E.; Abbot, D.S.; Weare, J. Practical rare event sampling for extreme weather. *Chaos Interdiscip. J. Nonlinear Sci.* **2019**, *29*, 053109. [\[CrossRef\]](#)
4. Lin, Q.; Wang, Y. Spatial and temporal analysis of a fatal landslide inventory in China from 1950 to 2016. *Landslides* **2018**, *15*, 2357–2372. [\[CrossRef\]](#)
5. Oliver, E.C.; Donat, M.G.; Burrows, M.T.; Moore, P.J.; Smale, D.A.; Alexander, L.V.; Benthuyssen, J.A.; Feng, M.; Sen Gupta, A.; Hobday, A.J.; et al. Longer and more frequent marine heatwaves over the past century. *Nat. Commun.* **2018**, *9*, 1324. [\[CrossRef\]](#)
6. Zhang, W.; Yang, X. Extreme weather and climate events: Physical drivers, modeling and impact assessment. *J. Mar. Sci. Eng.* **2020**, *8*, 448. [\[CrossRef\]](#)
7. Centre for Research on the Epidemiology of Disasters (CRED); United Nations Office for Disaster Risk Reduction (UNISDR). *The Human Cost of Weather-Related Disasters 1995–2015*; UNISDR: Geneva, Switzerland, 2015.
8. Alexander, L.V.X.; Zhang, T.C.; Peterson, J.; Caesar, B.G.; Tank, A.K.; Haylock, M.; Collins, D.; Trewin, B.; Rahimzadeh, F.; Tagipour, A.; et al. Global observed changes in daily climate extremes of temperature and precipitation. *J. Geophys. Res.* **2006**, *111*, 85–109. [\[CrossRef\]](#)
9. Founda, D.; Pierros, F.; Petrakis, M.; Zerefos, C. Variations and trends of the Urban Heat Island in Athens (Greece) and its response to heat waves. *Atmos. Res.* **2015**, *161*, 1–13. [\[CrossRef\]](#)
10. Alfieri, L.; Feyen, L.; Dottori, F.; Bianchi, A. Ensemble flood risk assessment in Europe under high end climate scenarios. *Glob. Environ. Chang.* **2015**, *35*, 199–212. [\[CrossRef\]](#)
11. Chakraborty, D.; Sehgal, V.K.; Dhakar, R.; Varghese, E.; Das, D.K. Increase in spatial spread of extreme warm day temperature events: Regional to national perspective for India (1951–2014). *Curr. Sci.* **2020**, *118*, 1930–1938. [\[CrossRef\]](#)
12. Kron, W.; Löw, P.; Kundzewicz, Z.W. Changes in risk of extreme weather events in Europe. *Sci. Policy* **2019**, *100*, 74–83. [\[CrossRef\]](#)
13. Donat, M.G.; Alexander, L.V.; Yang, H.; Durre, I.; Vose, R.; Dunn, R.J.; Willett, K.M.; Aguilar, E.; Brunet, M.; Caesar, J.; et al. Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. *J. Geophys. Res. Atmos.* **2013**, *118*, 2098–2118. [\[CrossRef\]](#)
14. Zhang, W.; Furtado, K.; Wu, P.; Zhou, T.; Chadwick, R.; Marzin, C.; Rostron, J.; Sexton, D. Increasing precipitation variability on daily-to-multiple year time scales in a warmer world. *Sci. Adv.* **2021**, *7*, 25–50. [\[CrossRef\]](#)
15. Cheng, S.; Xu, L.; Qin, W.; Guo, Q. Temporal and spatial variation of extreme precipitation in the Longchuan River Basin in 1978–2015 years. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *208*, 012026. [\[CrossRef\]](#)
16. Taye, M.T.; Ntegeka, V.; Ogiramoi, N.P.; Willems, P. Assessment of climate change impact on hydrological extremes in two source regions of the Nile River Basin. *Hydrol. Earth Syst. Sci. Discuss.* **2010**, *15*, 209–222. [\[CrossRef\]](#)
17. Yu, S.; Luo, Y.; Wu, C.; Xu, W. Subseasonal Variations of Convective and Microphysical Characteristics of Extreme Precipitation Over the Pearl River Delta at Monsoon Coast. *J. Geophys. Res. Atmos.* **2023**, *128*, e2022JD037804. [\[CrossRef\]](#)
18. Singhal, A.; Jaseem, M.; Jha, S.K. Spatial connections in extreme precipitation events obtained from NWP forecasts: A complex network approach. *Atmos. Res.* **2023**, *282*, 106538. [\[CrossRef\]](#)
19. Kay, A.L.; Davies, H.N.; Bell, V.A.; Jones, R.G. Comparison of uncertainty sources for climate change impacts: Flood frequency in England. *Clim. Chang.* **2009**, *92*, 41–63. [\[CrossRef\]](#)
20. Li, S.; Xiao, Z.; Tian, L. Interannual variation of the number of winter extreme low temperature days in southern China and influencing factors. *Atmos. Res.* **2023**, *294*, 106957. [\[CrossRef\]](#)
21. Qiu, J.; Yang, X.; Cao, B.; Chen, Z.; Li, Y. Effects of Urbanization on Regional Extreme-Temperature Changes in China, 1960–2016. *Sustainability* **2020**, *12*, 6560. [\[CrossRef\]](#)
22. Fu, D.; Ding, Y. The study of changing characteristics of the winter temperature and extreme cold events in China over the past six decades. *Int. J. Climatol.* **2021**, *41*, 2480–2494. [\[CrossRef\]](#)
23. Tian, W.; Zong, L.; Dong, Y.; Liu, D.; Yang, Y. Long-Term Variations in Warm and Cold Events in Nanjing, China: Roles of Synoptic Weather Patterns and Urbanization. *Land* **2023**, *12*, 162. [\[CrossRef\]](#)
24. Guan, Y.; Zhang, X.; Zheng, F.; Wang, B. Trends and variability of daily temperature extremes during 1960–2012 in the Yangtze River Basin, China. *Glob. Planet. Chang.* **2015**, *124*, 79–94. [\[CrossRef\]](#)
25. Chen, J.; Li, B.; Li, Y.; Zhou, L.; Zou, J.; Yao, R. Spatio-temporal variation characteristics of extreme precipitation over the Dongting Lake basin. *J. Water Clim. Chang.* **2022**, *13*, 1448–1461. [\[CrossRef\]](#)
26. Pi, Y.; Yu, Y.; Zhang, Y.; Xu, C.; Yu, R. Extreme Temperature Events during 1960–2017 in the Arid Region of Northwest China: Spatiotemporal Dynamics and Associated Large-Scale Atmospheric Circulation. *Sustainability* **2020**, *12*, 1198. [\[CrossRef\]](#)
27. He, B.R.; Zhai, P.M. Changes in persistent and non-persistent extreme precipitation in China from 1961 to 2016. *Adv. Clim. Chang. Res.* **2018**, *9*, 177–184. [\[CrossRef\]](#)
28. Wang, Y.; Zhou, L. Observed trends in extreme precipitation events in China during 1961–2001 and the associated changes in large-scale circulation. *Geophys. Res. Lett.* **2005**, *32*, 9707.

29. Xing, H.; Fang, K.; Yao, Q.; Zhou, F.; Ou, T.; Liu, J.; Zhou, S.; Jiang, S.; Chen, Y.; Bai, M.; et al. Impacts of changes in climate extremes on wildfire occurrences in China. *Ecol. Indic.* **2023**, *157*, 111288. [\[CrossRef\]](#)
30. Horton, R.M.; Mankin, J.S.; Lesk, C.; Coffel, E.; Raymond, C. A Review of Recent Advances in Research on Extreme Heat Events. *Curr. Clim. Chang. Rep.* **2016**, *2*, 242–259. [\[CrossRef\]](#)
31. Ning, G.; Luo, M.; Zhang, W.; Liu, Z.; Wang, S.; Gao, T. Rising risks of compound extreme heat-precipitation events in China. *Int. J. Climatol.* **2022**, *42*, 5785–5795. [\[CrossRef\]](#)
32. Tao, J.; Qing, W.; Zhang, S. Climate, Human Behavior and Settlement Morphology: A Case Study in Kashigar, Xinjiang Autonomous Region. In Proceedings of the 11th International Symposium on Environmental Behavior Research, Guangzhou, China, 7–9 November 2014; p. 7.
33. Fang, X.; Liang, Y.; Gu, J.; Xuan, J. Study on Potential Geographical Distribution of Diphtheria Aconitum in Xinjiang under the Scenario of Future Climate Change. *Acad. J. Environ. Earth Sci.* **2023**, *5*, 28–34.
34. Kang, Z.; Zhang, Z.; Liu, L.; Wang, T.; Tian, H.; Chen, H.; Zhang, X. Spatio-temporal variation characteristics of land surface temperature in Xinjiang based on MODIS. *Geogr. Res.* **2022**, *41*, 997–1017.
35. Chen, Y.; Wu, S.; Zhao, X.; Zhang, Y. Spatial and temporal variation characteristics of extreme temperatures in Hami City in the past 60 years. *Geogr. Arid. Areas* **2023**, *46*, 868–879.
36. Lv, T.; Wu, S.; Ge, H.; Li, J. Spatial and temporal variation characteristics of extreme air temperature in Altay Prefecture, Xinjiang, 1962–2013. *Glacier Permafrost* **2020**, *42*, 745–755.
37. Ding, Z.Y.; Ge, Y.X.; Abuduwaili, J.; Jia, P.U. Trends of extreme temperature and precipitation in Ebinur Lake basin in Xinjiang during the period from 1957 to 2012. *J. Univ. Chin. Acad. Sci.* **2018**, *35*, 160–171.
38. Huang, Y.; Ma, Y.; Liu, T.; Luo, M. Climate Change Impacts on Extreme Flows Under IPCC RCP Scenarios in the Mountainous Kaidu Watershed, Tarim River Basin. *Sustainability* **2020**, *12*, 2090. [\[CrossRef\]](#)
39. Yao, J.Q.; Mao, W.Y.; Chen, J.; Dilinuer, T. Recent signal and impact of wet-to-dry climatic shift in Xinjiang, China. *J. Geogr. Sci.* **2021**, *31*, 1283–1298.
40. Li, J.; Pu, Z.; Zhang, S. *The Impact and Zoning of Climate Change on Agriculture in Xinjiang*; Meteorological Publishing House: Beijing, China, 2018; pp. 12–15.
41. Cao, X.-M.; Xi, C.; Bao, A.-M.; Lao, Y. Net primary productivity (NPP) of oasis changes in trends in Xinjiang and responses to climate change analysis in 1981–2000. In Proceedings of the Intelligent Information Technology Application Association, Melbourne, VIC, Australia, 19–20 November 2011; p. 8.
42. Yu, J.L.; Zhang, J.; Zhang, M.; Yu, R.D. SAPEI-Based spatial and temporal variation characteristics of drought in Xinjiang. *Agric. Res. Arid. Reg.* **2023**, *41*, 275–288.
43. Yu, S.; Zhang, X.; Liu, Z.; Wang, Y.; Shen, Y. The spatio-temporal variation characteristics of extreme climate index in the Songhua River Basin from 1961 to 2020. *J. Appl. Ecol.* **2023**, *34*, 1091–1101.
44. Zhou, Y.; Gao, Q. A dataset of climate extreme indices over the Tibetan Plateau (1960–2012). *Chin. Sci. Data* **2017**, *2*, 70–78.
45. Jiang, C.; Mu, X.; Wang, F.; Zhao, G. Analysis of extreme temperature events in the Qinling Mountains and surrounding area during 1960–2012. *Quat. Int.* **2016**, *392*, 155–167. [\[CrossRef\]](#)
46. Zhao, L.; Xia, J.; Sobkowiak, L.; Wang, Z.; Guo, F. Spatial Pattern Characterization and Multivariate Hydrological Frequency Analysis of Extreme Precipitation in the Pearl River Basin, China. *Water Resour. Manag.* **2012**, *26*, 3619–3637. [\[CrossRef\]](#)
47. Liu, Z.; Yang, H.; Wei, X.; Liang, Z. Spatiotemporal Variation in Extreme Precipitation in Beijing River Basin, Southern Coastal China, from 1959 to 2018. *J. Mar. Sci. Eng.* **2023**, *11*, 73. [\[CrossRef\]](#)
48. Chou, J.; Xu, Y.; Dong, W.; Xian, T.; Wang, Z. Research on the variation characteristics of climatic elements from April to September in China's main grain-producing areas. *Theor. Appl. Climatol.* **2019**, *137*, 3197–3207. [\[CrossRef\]](#)
49. Luo, M.; Liu, T.; Meng, F.; Duan, Y.; Huang, Y.; Frankl, A.; De Maeyer, P. Proportional coefficient method applied to TRMM rainfall data: Case study of hydrological simulations of the Hotan River Basin (China). *J. Water Clim. Chang.* **2017**, *8*, 627–640. [\[CrossRef\]](#)
50. Zhang, Q.; Gu, X.; Singh, V.P.; Sun, P.; Chen, X.; Kong, D. Magnitude, frequency and timing of floods in the Tarim River basin, China: Changes, causes and implications. *Glob. Planet. Chang.* **2016**, *139*, 44–55. [\[CrossRef\]](#)
51. Zhu, G.; Zhao, X. Changes of extreme climate indices on the Mongolian Plateau during 1981–2020 based on ERA5 reanalysis. *Theor. Appl. Climatol.* **2023**, *154*, 467–482. [\[CrossRef\]](#)
52. Chou, J.; Zhao, W.; Li, J.; Xu, Y.; Yang, F.; Sun, M.; Li, Y. Changes in Extreme Climate Events in Rice-Growing Regions Under Different Warming Scenarios in China. *Front. Earth Sci.* **2021**, *9*, 655128. [\[CrossRef\]](#)
53. Zhang, J.; Wang, F. Changes in the Risk of Extreme Climate Events over East Asia at Different Global Warming Levels. *Water* **2019**, *11*, 25–35. [\[CrossRef\]](#)
54. Li, Y.G.; He, D.; Hu, J.M.; Cao, J. Variability of extreme precipitation over Yunnan Province, China 1960–2012. *Int. J. Climatol.* **2015**, *35*, 245–258. [\[CrossRef\]](#)
55. Fung, K.F.; Chew, K.S.; Huang, Y.F.; Ahmed, A.N.; Teo, F.Y.; Ng, J.L.; Elshafie, A. Evaluation of spatial interpolation methods and spatiotemporal modeling of rainfall distribution in Peninsular Malaysia. *Ain Shams Eng. J.* **2022**, *13*, 101571. [\[CrossRef\]](#)
56. Zhang, P.; Ren, G.; Xu, Y.; Wang, X.L.; Qin, Y.; Sun, X.; Ren, Y. Observed changes in extreme temperature over the global land based on a newly developed station daily dataset. *J. Clim.* **2019**, *32*, 8489–8509. [\[CrossRef\]](#)

57. Zhou, B.; Xu, Y.; Wu, J.; Dong, S.; Shi, Y. Changes in temperature and precipitation extreme indices over China: Analysis of a high resolution grid dataset. *Int. J. Climatol.* **2016**, *36*, 1051–1066. [[CrossRef](#)]
58. Wang, B.L.; Zhang, M.J.; Wei, J.L.; Wang, S.J.; Ma, Q.; Li, X.F. The Change in Extreme Events of Temperature and Precipitation over Northwest China in Recent 50 Years. *J. Nat. Resour.* **2012**, *27*, 1720–1733.
59. Tong, S.; Li, X.; Zhang, J.; Bao, Y.; Bao, Y.; Na, L.; Si, A. Spatiotemporal variations of climate extremes and influential factors in deserts and sandy fields of northern China from 1961 to 2019. *Geogr. Sci.* **2023**, *43*, 1495–1505.
60. Chen, Q.; Mao, F.J.; Du, H.-Q.; Li, X.J.; Yin, S.Y.; Yan, M.J. Spatiotemporal variations of subtropical extreme precipitation and its influence on potential net primary productivity in China. *J. Ecol.* **2022**, *41*, 2117–2127.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.