Journal of the Korean Society of Agricultural Engineers
DOI : https://doi.org/10.5389/KSAE.2022.64.6.101

Vol. 64, No. 6, pp.101~112, November 2022
ISSN 1738-3692 | eISSN 2093-7709

충청지역 극한강우지수의 시공간적 경향과 변동성 분석

Analysis of Spatial-temporal Variability and Trends of Extreme Precipitation Indices over Chungcheong Province, South Korea

Bashir Adelodun[a] · Golden Odey[b] · Seulgi Lee[c] · Kyung Sook Choi[d†]

ABSTRACT

Extreme precipitation events have recently become a leading cause of disasters. Thus, investigating the variability and trends of extreme precipitation is crucial to mitigate the increasing impact of such events. Spatial distribution and temporal trends in annual precipitation and four extreme precipitation indices of duration (CWD), frequency (R10 mm), intensity (Rx1day), and percentile-based threshold (R95pTOT) were analyzed using the daily precipitation data of 10 observation stations in Chungcheong province during 1974–2020. The precipitation at all observation stations, except the Boryeong station, showed nonsignificant increasing trends at 95% confidence level (CL) and increasing magnitudes from the west to east regions. The high variability in mean annual precipitation was more pronounced around the northeast and northwest regions. Similarly, there were moderate to high patterns in extreme precipitation indices around the northeast region. However, the precipitation indices of duration and frequency consistently increased from the west to east regions, while those of intensity and percentile-based threshold increased from the south to east regions. Nonsignificant increasing trends dominated in CWD, R10 mm, and Rx1day at all stations, except for R10 mm at Boeun station and Rx1day at Cheongju and Jecheon stations, which showed a significantly increasing trend. The spatial distribution of trend magnitude shows that R10 mm increased from the west to east regions. Furthermore, variations in precipitation were very strongly correlated (99% CL) with R10 mm, Rx1day, and R95pTOT at all stations, except with wR10 mm at Cheongju station, which was strongly correlated with a 95% CL.

Keywords: Trend analysis; extreme precipitation; climate variability; spatial and temporal distribution

Ⅰ. INTRODUCTION

One of the consequences of climate change and variability is extreme precipitation events such as floods and droughts, which have continued to wreak havoc in many sectors and cause loss of lives. Globally, the events of climate-related disasters have become increasingly popular in recent times, with floods causing the greatest damage in South Korea (Azam et al., 2017). For instance, a record-breaking extreme precipitation event occurred in two South Korean provinces and the country capital, Seoul, causing loss of lives and the destruction of several properties in 2022 (Jang et al., 2022). Similar events have also been reported in many other countries and regions, including China, Pakistan, Brazil, the United States, and South Asian floods (CDP, 2022).

Precipitation is an important climatic variable and forms part of the influencing factors that dictate the occurrence of flood and drought events. South Korea is characterized by varying climatic and topographic features (Bae et al., 2008). Moreover, studies have reported the spatial and temporal variability of precipitation in South Korea due to the complexity of its climatic and topographic characteristics (Azam et al., 2018; Chang and Kwon, 2007; Jung et al., 2017), which responsible for the major problems of hydrological extremes and water resources management (Adelodun et al., 2022; Felix et al., 2021; Shah et al., 2022). Aside from the episodic impact of precipitation variability on flood and drought events, it is also critical for the availability of water resources for human

[a] Researcher, Department of Agricultural Civil Engineering; Institute of Agricultural Science & Technology, Kyungpook National University, Daegu 41566, Korea; Department of Agricultural and Biosystems Engineering, University of Ilorin, PMB 1515, Ilorin 240003, Nigeria
[b] Graduate Student, Department of Agricultural Civil Engineering, Kyungpook National University, Daegu 41566, Korea
[c] Researcher, Department of Agricultural Civil Engineering; Institute of Agricultural Science & Technology, Kyungpook National University, Daegu 41566, Korea
[d] Professor, Department of Agricultural Civil Engineering; Institute of Agricultural Science & Technology, Kyungpook National University, Daegu 41566, Korea
† **Corresponding author**
Tel.: +82-53-950-5731, Fax: +82-53-950-6752
E-mail: ks.choi@knu.ac.kr
Received: September 26, 2022
Revised: October 16, 2022
Accepted: October 20, 2022

consumption and ecosystem sustainability (Kim and Jain, 2011).

Investigating the historical changes in precipitation to assess the trends of extreme climate events is essential to provide a policy framework for mitigating the impact of extreme events and water resources management. Besides, analyzing the extreme precipitation indices is essential for detailed analysis of flood and drought-related events rather than analyzing ordinary precipitation (Jung et al., 2011). In this regard, many studies have been conducted to analyze the trends and spatial distribution of precipitation and extreme precipitation (Chen et al., 2015; Lupikasza, 2010; Tabari et al., 2014; Xu et al., 2022). In South Korea, Jung et al. (2011) analyzed extreme precipitation indices based on the daily precipitation data period of 1973-2005. Similarly, Choi (2004) investigated the change in the severity of precipitation based on extreme precipitation from 1954 to 1999. Majority of these studies used daily precipitation data that are not recent. Meanwhile, a recent study conducted by Felix et al. (2021) analyzed the trend of extreme precipitation indices in the Upper Geum River Basin using recent daily precipitation data of 33 years (1988-2020). However, spatial analysis was not considered in their study. The recently reoccurring extreme events required updated data to adequately capture the dynamics of the climate change and variability of the extreme precipitation events both in space and time.

Thus, it is essential to investigate the precipitation and extreme precipitation indices that can dictate the occurrence of extreme climate events such as floods and drought, especially by using the recently available data. This study investigates the spatial and temporal variability and trends in annual precipitation and extreme precipitation indices over Chungcheong province at 10 observation stations for 1973 – 2020.

II. MATERIALS AND METHODS

1. Study area and data source

Chungcheong province, the area for this study is located in the west-central of South Korea between Latitude 35°58′ N - 36°00′ N and Longitude 127°38′ E - 125°32′ E and occupies an area of about 16,642 km^2 (Fig. 1). The Province includes Chungcheongnam-do, Chungcheongbuk-do, Sejong, and Daejeon Metropolitan city. The study area has an elevation ranging from 11.3 m in the west with a flat surface and 263.6 m in the east around the mountainous area. The climate conditions can be regarded as the continental and temperate monsoon in part with four major distinct seasons such as spring (March - May), summer (June - August), autumn (September - November), and winter (December - March). The study area

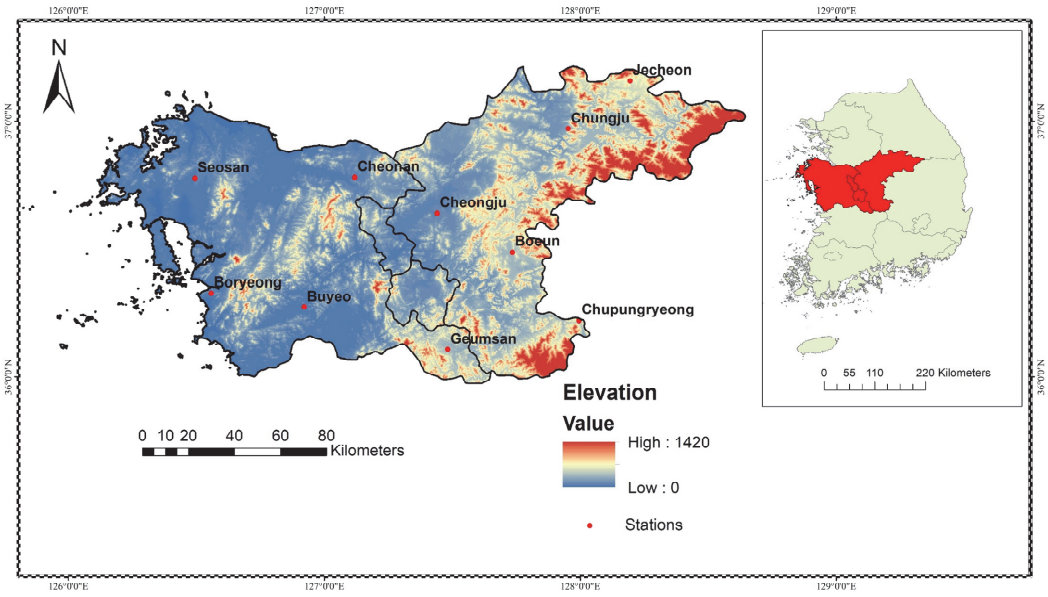


Fig. 1 Map of the study area showing the observation stations and elevation

is one of the provinces with variable climate conditions and highly impacted by flood and drought events (Kim et al., 2021). Besides, it is one of the major agricultural-based areas in South Korea that climate variability has significantly impacted; thus, making it to be selected as a pilot study area to investigate and develop real-time monitoring ICT-based solution and improved drainage system to address the reoccurring inundation of farmlands. Therefore, the study area is considered appropriate to investigate the variability and trends of the extreme precipitation indices.

The daily precipitation data from 1973 to 2020 used in this study was provided by the Korean Meteorological Administration, an institution in charge of maintaining the meteorological data across South Korea (KMA, 2022). The daily precipitation data were obtained from 10 synoptic stations homogenously distributed across the Chungcheong Province (Table 2). The highest elevation value of 263.6 m is located at Jecheon station while lowest elevation (11.3 m) is located at Buyeo station. Similarly, the maximum recorded amount of annual precipitation during 1973 - 2020 over the Chungcheong province occurred at Jecheon station with the mean annual value of 1331.1 mm and coefficient of variation of 25.76%. However, the lowest annual precipitation amount of 685.6 m was recorded at Seosan station with coefficient variation of 24.82%. On the average, Jecheon station recorded the highest mean annual precipitation amount of 1331.1 mm, while Chupungryeong recorded the lowest mean annual precipitation amount of 1174.1 mm. The data set records from these stations are complete and consistent; thus are considered appropriate for studying the trends in extreme precipitation intensity, frequency, and duration (Chang and Kwon, 2007). The obtained data were subjected to data quality checks, including homogeneity, to ensure the fitness of the data for time series trend analysis (Adelodun et al., 2022).

2. Extreme precipitation indices

In this study, four extreme precipitation indices were computed using the ClimPACT2 software (Version 3.1.3) (https://climpact-sci.org/). The ClimPACT2 was developed to calculate sector-specific climate indices which are essentially of temperature and precipitation based as these two variables are considered important for water resources management and climate change assessment, among others. The definitions of the selected indices are provided in Table 1. These indices are part of the 11 precipitation indices defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) that reflect the precipitation extremes (Zhang et al., 2011). The four extreme precipitation indices were selected from each of the precipitation intensity, frequency, and duration classifications (WMO, 2009). The four selected indices were considered robust and less noisy indicators (Choi, 2004). Besides, these indices have been widely used and adopted to understand variability and changes in extreme precipitation events in many regions of the world including South Korea (Felix et al., 2021; Gebremichael et al., 2022; Mondal et al., 2022; Vondou et al., 2021). The indices were calculated from the daily precipitation data at each observation station.

3. Statistical analysis and spatial interpolation

The presence of a monotonic trend in the data series of the extreme precipitation indices was examined using the Mann-Kendall (MK) statistical test, a rank-based non-parametric test method for trend analysis, for the period of 1973 to 2020. The Mann-Kendall test has been widely used in the field of climatology and hydrology and is mostly preferred over parametric methods such as linear regression due to some underline advantages, which include non-requirement of

Table 1 Definitions of the selected extreme precipitation indices used in this study

Indices (type)	Name	Definition	Unit
CWD (Duration)	Consecutive wet days	Maximum number of consecutive days when precipitation ≥1 mm	days
R10 mm (Frequency)	Number of very heavy precipitation days	Annual days with precipitation ≥10 mm.	days
Rx1day (Intensity)	Max 1 day precipitation amount	Annual maximum 1-day precipitation	mm
R95pTOT (Percentile-based threshold)	Very wet-day precipitation	Total precipitation where daily precipitation exceeds the 95th percentile of daily precipitation in the period	mm

normality assumption, less sensitivity to non-homogenous time series data, and less affected by outliers or skewed data (Azam et al., 2018; Bae et al., 2008; Shah et al., 2022). The null hypothesis of MK is that the data series is independent and identically distributed, which is regarded as no existence of a trend while the test hypothesis states that the data series follows a monotonic trend. The mathematical representations of the MK statistic test are such that for the time series data, $x_1, x_2, \ldots, x_n$, the MK test statistic (Z_{MK}) is computed using:

$$S = \sum_{k=1}^{n=1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (1)$$

$$sgn(x_j - x_k) = \begin{cases} +1 \; if \; (x_j - x_k) > 0 \\ 0 \; if \; (x_j - x_k) = 0 \\ -1 \; if \; (x_j - x_k) > 0 \end{cases} \quad (2)$$

$$V(s) = \frac{n(n-1)(2n+5)}{18} \quad (3)$$

$$Z_{MK} = \begin{cases} \frac{S-1}{V(S)} \; for \; S > 0 \\ 0 \; for \; S = 0 \\ \frac{S+1}{V(S)} \; for \; S <) \end{cases} \quad (4)$$

Where n is the observations in the time series dataset, x_j and x_k are the time series values at times j and k, respectively, for a given time series with n observations, sgn represents the sign function with the values 1, 0, or -1, if $x_j > x_k$, $x_j = x_k$, or $x_j < x_k$, respectively. S is the Kendall sum statistic, $V(S)$ represents the variance, and Z_{MK} is the Mann-Kendall test statistic.

The trend significance was measured based on the 95% confidence level when the critical value $Z_{MK} \geq Z_{\alpha/2} = |\pm 1.96|$, where $Z_{\alpha/2}$ is the standard normal deviate, α is the significance level of the test statistic, and the positive value (negative value) of Z_{MK} denotes an increasing (decreasing) trend.

However, there has been recent concern about autocorrelation, which meteorological variable such as precipitation could possibly exhibit. To address this concern, the time series data of the extreme precipitation indices were first checked for the presence of autocorrelation, and if it exists, a bias-corrected pre-whitening technique (also known as Modified Mann-Kendall) was proposed by Hamed (Hamed, 2009) was employed to correct the effect of an autocorrelation.

The magnitude of the MK trends in the extreme precipitation indices data series was further estimated using the non-parametric Theil-Sen's slope approach. The Theil-Sen's slope is considered advantageous since it is not sensitive to extreme outliers and produced a robust estimate of the trend magnitude (Sen, 1968; Shifteh Some'e et al., 2012; Theil, 1992). The computation of Theil-Sen's slope estimation follows the Eq. 5.

$$\beta_s = Median \left(\frac{x_j - x_k}{j-k} \right) \quad (5)$$

Where x_j and x_k are data values at times j and k (j > k), respectively.

The MK test and Theil-Sen's slope have been recommended by the World Meteorological Organization to assess the trends in the hydro-meteorological variables and their associated indices (WMO, 2009). Furthermore, the Spearman correlation analysis was conducted to investigate the relationship between the variation of the mean annual precipitation and extreme precipitation indices. The correlation between the mean annual precipitation and extreme precipitation indices was based on 1%, 5%, and 10% significance level for very strong, strong, and weak correlations, respectively.

The spatial analysis of the extreme precipitation indices on an annual scale was conducted using inverse distance weighting (IDW), a deterministic interpolation technique. The IDW technique has been previously demonstrated to accurately and effectively estimate the spatial interpolation of precipitation data series and other climatic variables (Chen and Liu, 2012; Gebremichael et al., 2022; Jo et al., 2018). Besides, the radius of influence and power factor are considered important factors that influence the accuracy of IDW interpolation (Chen and Liu, 2012). In this study, the distance of <15 km between the observation stations and a power factor of 2 were considered, which are in line with previous studies (Adelodun et al., 2022; Fung et al., 2022; Jung et al., 2011; Kim et al., 2014).

Ⅲ. RESULTS AND DISCUSSION

1. Variability and trends of annual precipitation

The statistical description of the precipitation data used in

this study for the period of 1973 to 2020 at 10 meteorological stations over Chungcheong province is presented in Table 2. The lowest mean annual precipitation of 1174 mm occurred at Chupungryeong with minimum and maximum values of 762 mm/year and 1835 mm/year, respectively. The minimum amount of precipitation was recorded at the Seosan station with a relatively high standard deviation (306.4 mm/year) and coefficient of variation (24.82%). Similarly, Jecheon has the highest mean annual precipitation of 1331 mm with minimum and maximum values of 751 mm/year and 2231 mm/year, respectively. The values of coefficient of variation (25.76%) and standard deviation (342.9 mm/year) at Jecheon indicate significant variability of precipitation received at this station. Coincidentally, this station has the highest altitude (264 m) among the 10 selected stations, which could possibly contribute to the variability and highest amount of precipitation it received annually. Previous studies also noted a correlation between high altitude and increase amount of precipitation by attributing it to orography (Azam et al., 2018; Bae et al., 2008).

The spatial distribution of the mean annual precipitation showing the trend, coefficient of variation, and magnitude of the trend is presented in Fig. 2. A relatively high amount of mean precipitation (above 1300 mm/year) can be observed around the downward south-west and north-east end regions (Fig. 2a). Remarkably, these regions are close to both west and east coastal areas of Korea, respectively. The high amount of mean precipitation received in these regions could be attributed to the increasing typhoon-induced changes and the influence of La Niña events from coastal areas causing heavy downpours during the summer (monsoon) season (Bae et al., 2008; Kim and Jain, 2011). However, the central to northwest regions are characterized by moderate to low precipitation amounts (<1250 mm/annum). The high variability in mean annual precipitation as indicated by the coefficient of variation (> 24.3%) can be clearly observed around the north-east and north-west regions while the central to south region indicates moderate to low variability in the mean annual precipitation (CV < 22%) (Fig. 2b). The high variability in the precipitation amount is an indication of possible flood and drought risks due to the increasing intensity, duration, and amount of precipitation and a prolonged lull in the precipitation event (Adelodun et al., 2022).

The results of MK trend analysis indicate majorly an increasing trend at 90% of the observation stations with the only exception at Boryeong station, where precipitation amount indicates a decreasing trend. The magnitude of the precipitation trend increases from the west region to the east region of the study area, with the highest range values of 3.34 - 4.2 mm/annum observed in the east-end and North-end regions (Fig. 2c). However, none of the trends is significant at the 95% confidence level. Previous studies also reported that annual precipitation at the majority of the observation stations in Korea was characterized by an insignificant trend at a confidence level of 95% (Azam et al., 2018; Bae et al., 2008; Chang and Kwon, 2007; Odey et al., 2022). The available studies that reported significant trends, either increasing or decreasing, were detected

Table 2 Descriptive statistics of precipitation distribution over Chungcheong Province

Stations	Regional classification	Longitude (°N)	Latitude (°E)	Elevation (m)	Min.	Max.	Mean	Std. Dev.	CV (%)
Chungju	North-east	36.97	127.95	115.1	731.8	2073.3	1195.0	289.1	24.19
Seosan	North-west	36.78	126.49	28.9	685.6	2141.8	1234.4	306.4	24.82
Cheongju	North-east	36.64	127.44	57.2	755.4	1805.6	1222.3	258.8	21.17
Chupungryeong	South-east	36.22	127.99	244.7	761.7	1835.3	1174.1	248.5	21.17
Jecheon	North-east	37.16	128.19	263.6	750.7	2230.5	1331.1	342.9	25.76
Boeun	Central	36.49	127.73	175.0	765.3	2085.1	1284.4	322.4	25.10
Cheonan	North-west	36.78	127.12	21.3	711.5	1845.8	1218.9	265.7	21.80
Boryeong	Central	36.33	126.56	15.5	725.0	1897.5	1202.1	285.3	23.74
Buyeo	South-west	36.27	126.92	11.3	752.6	2137.5	1320.3	317.2	24.03
Geumsan		36.11	127.48	170.4	749.8	1827.3	1274.9	276.6	21.70

* Estimation period: 1973–2020. Std. Dev. is the standard deviation, CV is the coefficient of variation

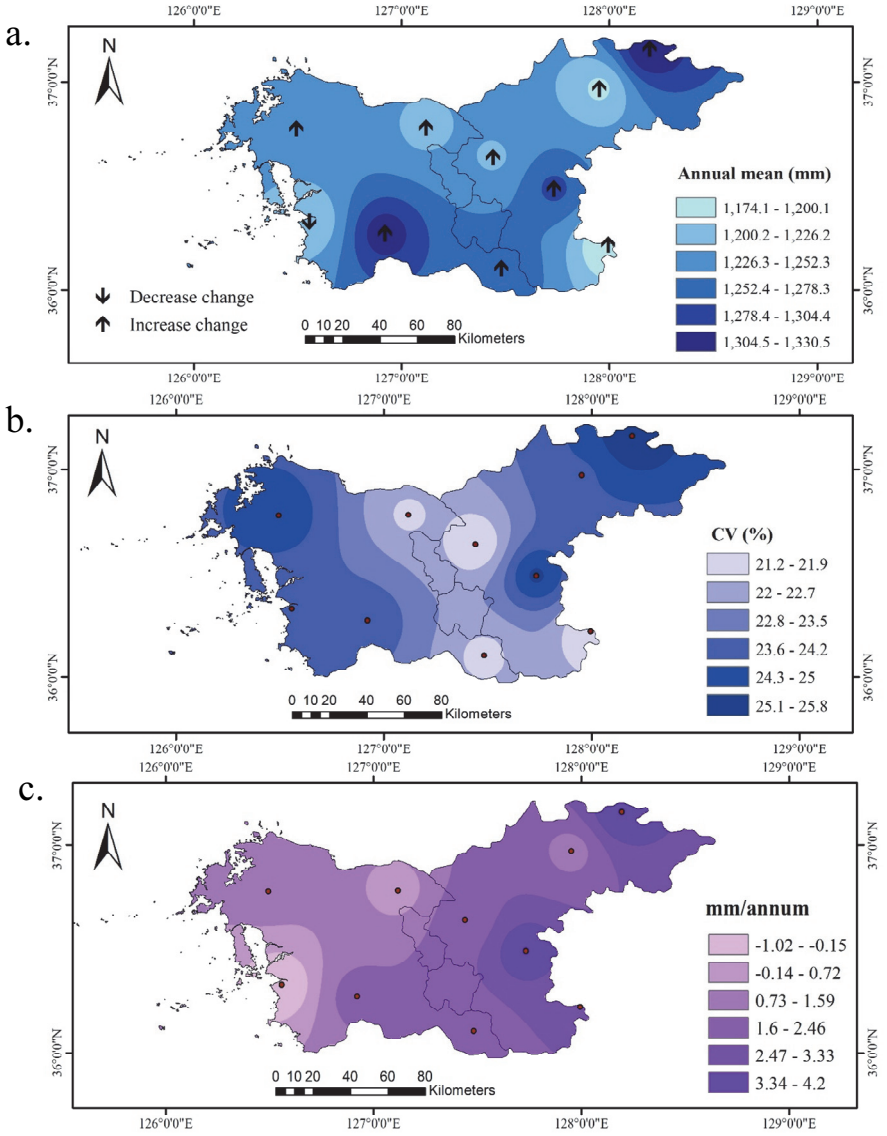


Fig. 2 Spatial distribution of (a) mean annual precipitation indicating the trend status (b) coefficient of variation (c) magnitude of the trend.

along the coastal areas, especially the south coast, and such were attributed to synoptic disturbances within the air mass such as typhoons leading to unstable variable patterns in the precipitation (Kim and Jain, 2011). The data series from each station were also tested for autocorrelation to avoid misleading outcomes from the MK test and were found to be free from autocorrelation.

2. Trends in extreme annual precipitation indices

The spatial pattern of annual variability and trends in extreme precipitation indices over Chungcheong Province at 10 observation stations from 1973 to 2020 was investigated. The variability and trend patterns of mean annual precipitation duration (CWD), frequency (R10mm), intensity (Rx1day), and percentile-based threshold (R95pTOT) are shown in Fig. 3. The four extreme precipitation indices indicate variable patterns across the study area. However, the high to moderate pattern is consistent in the precipitation duration, frequency, and intensity around the northeast end region. Similarly, the mean annual extreme precipitation duration and frequency consistently increase from west to east region of the study area. There is also an observed similar pattern of an increasing

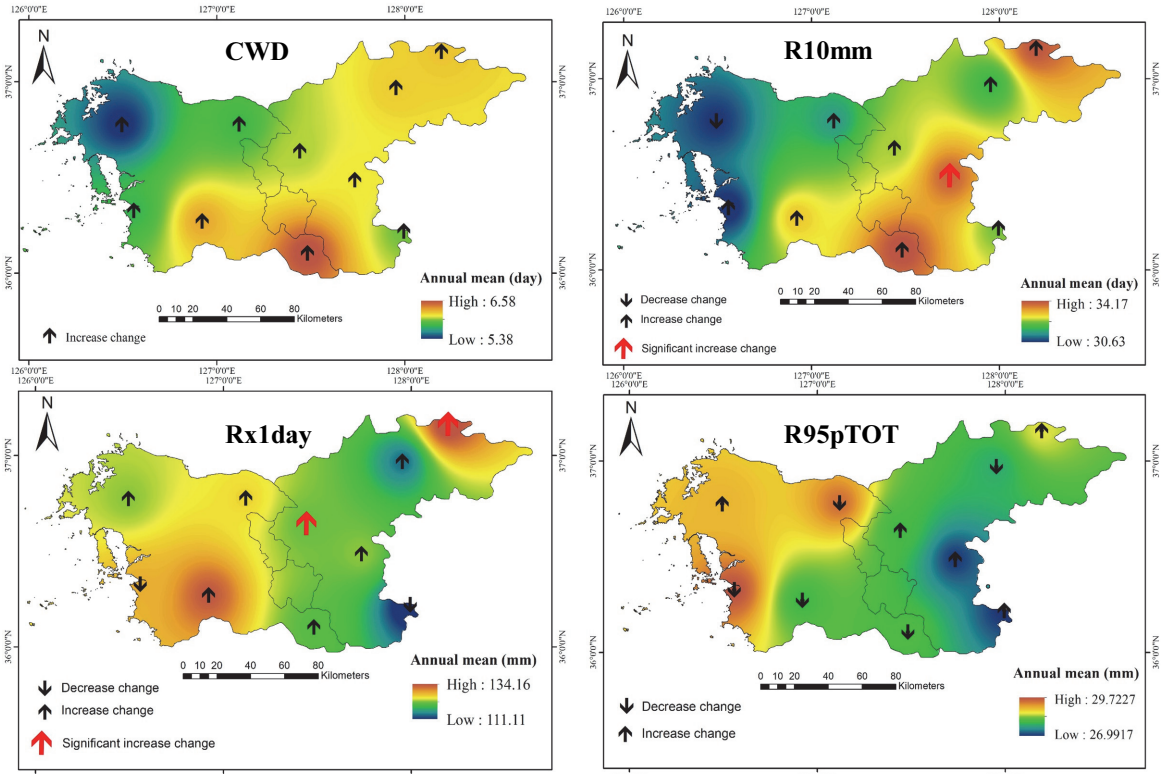


Fig. 3 Spatial distribution and trends in extreme precipitation indices over Chungcheong province during 1974–2020.

amount of precipitation extremes of intensity and percentile-based threshold from south to east regions.

The extreme precipitation indices exhibit increasing, decreasing, and significant increasing trends at different observation stations across the study area. While increasing trends dominate in all the four extreme indices, there are decreasing trends of extreme precipitation frequency (R10mm) at Seosan station, extreme precipitation intensity (Rx1day) at Boryeong and Chupungryeong stations, and percentile-based threshold index at Cheonan, Chungju, Boryeong, Buyeo, and Geumsan stations. Furthermore, it was observed that most of the trends in the extreme precipitation indices are statistically insignificant at the 95% confidence level except for R10mm at Boeun station and Rx1day at Cheongju and Jecheon stations which are significant at the 95% confidence level. The three stations that exhibit statistically significant trends in the R10mm and Rx1day have higher elevations relative to other stations, which could possibly contribute to the presence of a significant trend. Some previously conducted studies also established associations between extreme precipitation indices and elevation changes (Chen et al., 2015; Felix et al., 2021; Song et al., 2019; Xu et al., 2022). While some studies reported a positive association, there are other studies that reported contrasting results; thus, it can be concluded that the associations of extreme precipitation indices and elevation vary regionally. Moreover, the causes of spatial and temporal variations in extreme precipitation in South Korea are very complex and often influenced by the mountainous terrain, monsoon season, and typhoon events (Jung et al., 2017).

It has been previously reported that the increase in amount and frequency of precipitation corresponds to changes in the extreme events of typhoons around the coastal areas (Kim and Jain, 2011), which indicates the possible cause of high extreme values of CWD, R10mm, and Rx1day around the coastal regions. Moreover, Ho et al. (2003) linked the increasing heavy precipitation, especially during the summer season over Korea to a moisture convergence from the strong wind blowing northerly in East Asia since the late 1970s (Ho et al., 2003).

The variation in the trend magnitude of extreme precipitation indices at each observation station and across Chungcheong province is presented in Table 3 and Fig. 4. Spatially, there is an observed diverse pattern in the trend magnitudes of the

Table 3 Results of Mann–Kendall statistics (Z_{MK}) and Sen's slope for the extreme precipitation indices

Stations	CWD		R10 mm		Rx1day		R95pTOT	
	ZM_K	Slope	Z_{MK}	Slope	Z_{MK}	Slope	Z_{MK}	Slope
Chungju	1.010	0.000	0.025	0.562	0.240	0.100	-1.360	-0.208
Seosan	0.302	0.000	-0.758	-0.032	0.969	0.416	1.076	0.206
Cheongju	0.527	0.000	1.087	0.057	2.053*	0.954	1.004	0.094
Chupungryeong	0.795	0.000	0.455	0.000	-0.178	-0.112	1.093	0.123
Jecheon	1.451	0.000	1.122	0.083	2.089*	1.078	0.000	0.000
Boeun	0.695	0.000	2.129*	0.143	0.044	0.033	0.587	0.074
Cheonan	0.618	0.000	0.178	0.000	1.093	0.438	-0.436	-0.053
Boryeong	0.163	0.000	0.000	0.000	-0.213	-0.127	-0.213	-0.014
Buyeo	1.593	0.000	1.204	0.083	0.427	0.186	-0.311	-0.033
Geumsan	0.874	0.000	1.123	0.090	0.658	0.250	-0.293	-0.037

*represents statistical significance at a 95% confidence level.

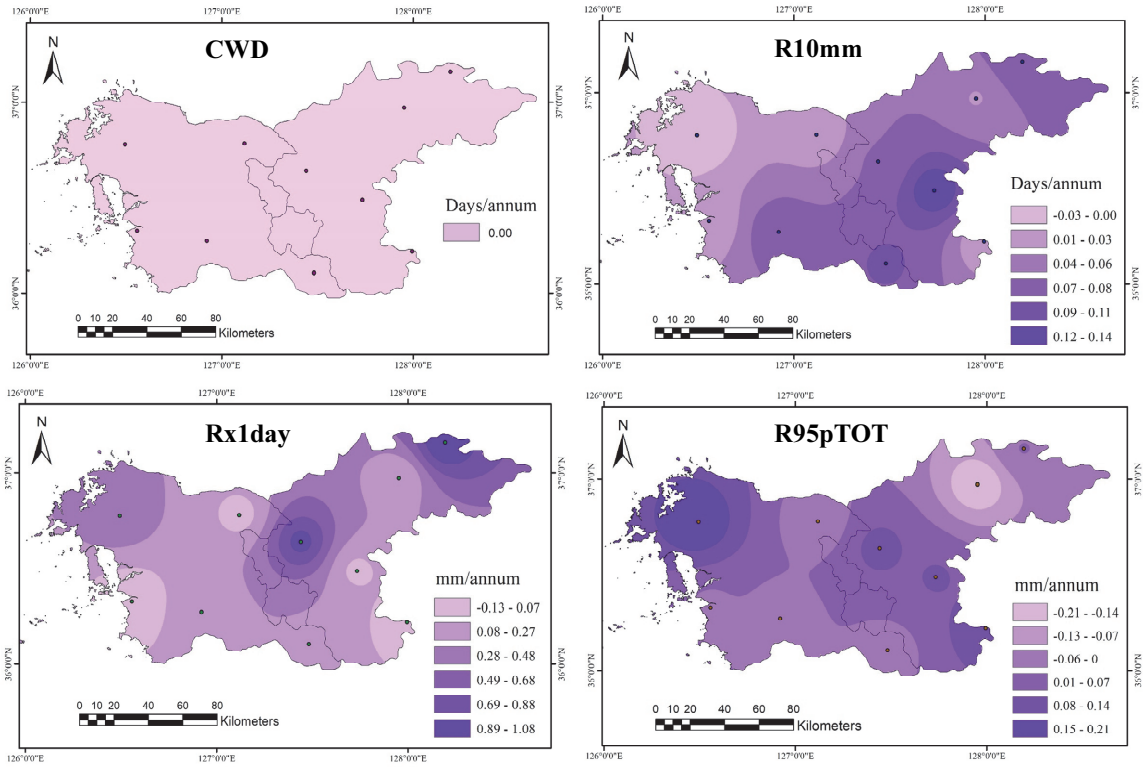


Fig. 4 Spatial distribution of slope magnitude for extreme precipitation indices over Chungcheong province during 1974–2020.

four extreme precipitation indices. The trend magnitude of extreme precipitation intensity (R10mm) increases from west to east regions. However, only the central and north-east end regions indicate a high trend magnitude of 0.89 - 1.08 mm/annum for extreme precipitation intensity (Rx1day) while 0.15 - 0.21 mm/annum occurred in the northwest region for the percentile-based threshold precipitation (R95pTOT). The CWD indicates zero slope magnitude across the entire study area. This indicates that there is little or no relative change in the maximum number of consecutive wet days when precipitation is greater than 10 mm (CWD). A similar study with different time period (1913 - 2012) in South Korea also reported no

Table 4 Correlation between extreme precipitation indices and mean annual precipitation

Stations	CWD	R10 mm	Rx1day	R95pTOT
Chungju	0.22	0.78***	0.49***	0.62***
Seosan	0.46***	0.70***	0.66***	0.65***
Cheongju	0.18	0.82**	0.45***	0.59***
Chupungryeong	0.40***	0.87***	0.44***	0.75***
Jecheon	0.31**	0.83***	0.57***	0.68***
Boeun	0.27*	0.82***	0.69***	0.69***
Cheonan	0.32**	0.74***	0.47***	0.45***
Boryeong	0.24	0.70***	0.71***	0.74***
Buyeo	0.27*	0.80***	0.56***	0.69***
Geumsan	0.29**	0.83***	0.41***	0.70***

*, **, and *** represent statistical significance at 10%, 5%, and 1% levels, respectively.

significant change in the CWD index when analyzed the trends of summer precipitation extreme (Baek et al., 2017). However, the change in percentage of CWD index in the future period (1913 - 2012) was reported to decreasing at the rate of 14% in the north (Chungcheongbuk-do) and 24% in the south (Chungcheongnam-do) (Jeung et al., 2019).

Agricultural production is highly affected by change in precipitation extremes which could lead to severe food insecurity and threat to socio-economic growth. In Chungcheong province, agricultural production is the mainstay and the observed increasing trends in the extreme precipitation indices could make the agricultural sector vulnerable to hazard of flood event. In 2017, about 5000 hectares of farmland and death of 37,000 chicken from 14 poultry farms were reported in North Chungcheong province due to extreme precipitation of flood event (Kim, 2017). The adequate prevention and countermeasures against the future extreme events as indicated by the increasing trends in the frequency, intensity, and duration of the precipitation is urgently required.

3. Correlation between mean annual precipitation and extreme precipitation indices

In order to investigate the indicative characteristics of annual precipitation, the relationship between the amount of mean annual precipitation and precipitation indices of intensity, frequency, duration, and percentile-based threshold was analyzed using Pearson's correlation. The correlation coefficients between mean annualp precipitation and number of heavy precipitation days (R10 mm) (frequency-based index) showed higher significant values (above 0.70) than other indices at all the stations except at Boryeong station where precipitation indices of intensity (Rx1day) and percentage-based threshold (R95pTOT) showed higher significant coefficient values of 0.71 and 0.74, respectively.

Similarly, The variations in mean annual precipitation are very strongly correlated (99% confidence level) to that of R10mm, Rx1day, and R95pTOT across all the stations, except for R10mm at Cheongju station which is found to be strongly correlated at 95% confidence level (Table 4). However, correlations between annual precipitation and CWD index ranged from no significant correlation at Chungju, Cheongju, and Boryeong stations, to weak correlation (90% confidence level) at Boeun and Buyeo stations. Nevertheless, there is the existence of a strong correlation (95% significance level) at the Jecheon, Cheonan, and Geumsan stations, and a very strong correlation at the Seosan and Chupungryeong stations for the CWD index. These results imply that an increase in annual precipitation is more significantly driven or characterized by the frequency of heavy precipitation (R10mm), intensity (Rx1day), and percentile-based threshold (R95pTOT) than precipitation duration (CWD) at the majority of the observation stations, making the study area susceptible to flash flooding and landslide. These results agree with the findings of previous related studies in Korea (Chang and Kwon, 2007; Choi, 2004; Jung et al., 2011). Jung et al. (2011) reported that the increase in annual precipitation in Korea over a period of 1973 - 2005 was strongly related to the increase in frequency and intensity of heavy precipitation. Similarly, Choi (2004) and Chang and

Kwon (2007) reported an increase in precipitation intensity over the during of 1954 - 1999 and 1974 - 2005, respectively, which were correlated to the increase in annual precipitation.

Ⅳ. CONCLUSIONS

The spatial-temporal variability and trends in annual precipitation and four extreme precipitation indices that characterize duration, frequency, intensity, and the percentile-based threshold at 10 observation stations over Chungcheong province during 1974-2020 are investigated. The spatial distribution of precipitation shows a nonsignificant increasing trend at a 95% confidence level with increasing magnitude from the west region to the east region at all the observation stations except the Boryeong station. The high variability in mean annual precipitation amount is more pronounced around the northeast and northwest regions. For the extreme precipitation indices, a high to moderate pattern is consistent in the duration, frequency, and intensity around the northeast end regions while the duration and frequency of precipitation consistently increase from west to east region, and intensity and percentile-based threshold from south to east regions. Nonsignificant increasing trends dominate in the CWD, R10mm, and Rx1day except for R10mm at Boeun station and Rx1day at Cheongju and Jecheon stations which are significant at 95% confidence level. The spatial distribution of trend magnitude shows that R10mm increases from west to east regions. Furthermore, there is a very strong positive correlation between mean annual precipitation and R10mm, Rx1day, and R95pTOT indices except for R10mm which exhibits a strong positive correlation at Cheongju station. However, CWD exhibits varying correlation degrees ranging from statistically insignificant correlation at Chungju, Cheongju, and Boryeong stations to a very strong correlation at Seosan and Chupungryeong stations. This is an indication that the increase in annual precipitation is more related to the extreme indices of frequency, intensity, and percentile-based threshold of heavy precipitation at the majority of the observation stations. Since extreme precipitation events cause farmland disasters and increases the instability in agricultural production, there is a need for disaster prevention and countermeasures against the future extreme precipitation events. The investigated extreme precipitation indices in this study can be utilized to properly design adaptation strategies including drainage system and pumping design to mitigate disasters that could arise from the increasing extreme events and changing precipitation patterns in Chungcheong province. Further investigation on the seasonal variability and trends in precipitation and extreme precipitation indices over Chungcheong province is suggested.

Acknowledgement

This work was conducted with the support of the Korea Agricultural Infrastructure Disaster Response Technology Development Project of the Planning Assessment Service, funded by the Ministry of Agriculture, Food and Rural Affairs (MAFR) (321071-3).

REFERENCES

1. Adelodun, B., G. Odey, H. Cho, S. Lee, K. A. Adeyemi, and K. S. Choi, 2022. Spatial-temporal variability of climate indices in Chungcheong provinces of Korea: Application of graphical innovative methods for trend analysis. *Atmos. Res.* 280: 106420. doi:10.1016/j.atmosres.2022.106420.
2. Azam, M., H. S. Kim, and S. J. Maeng, 2017. Development of flood alert application in Mushim stream watershed Korea. *Int. J. Disaster Risk Reduct.* 21: 11-26. doi: 10.1016/j.ijdrr.2016.11.008.
3. Azam, M., S. Maeng, H. Kim, S. Lee, and J. Lee, 2018. Spatial and temporal trend analysis of precipitation and drought in South Korea. *Water* 10: 765. doi:10.3390/ w10060765.
4. Bae, D., I. Jung, and H. Chang, 2008. Long-term trend of precipitation and runoff in Korean river basins. *Hydrol. Process.* 22: 2644-2656. doi:10.1002/hyp.6861.
5. Baek, H., Kim, M., and Kwon, W., 2017. Observed short- and long-term changes in summer precipitation over South Korea and their links to large-scale circulation anomalies. *Int. J. Climatol.* 37: 972-986. doi:10.1002/joc.4753.
6. CDP, 2022. Center for Disaster Philantropy. Natural hazards & several weather events. https://disasterphilanthropy.org/ disasters/ (accessed 9.25.22).
7. Chang, H., and W. T. Kwon, 2007. Spatial variations of summer precipitation trends in South Korea, 1973-2005. *Environ. Res. Lett.* 2. doi:10.1088/1748-9326/2/4/045012.

8. Chen, F., Chen, H., and Yang, Y., 2015. Annual and seasonal changes in means and extreme events of precipitation and their connection to elevation over Yunnan Province, China. *Quat. Int.* 374: 46-61. doi:10.1016/j.quaint.2015.02.016.
9. Chen, F. W., and C. W. Liu, 2012. Estimation of the spatial rainfall distribution using inverse distance weighting (IDW) in the middle of Taiwan. *Paddy Water Environ.* 10: 209-222. doi:10.1007/s10333-012-0319-1.
10. Choi, Y., 2004. Trends on Temperature and Precipitation Extreme Events in Korea. *J. Korean Geogr. Soc.* 39: 711-721.
11. Felix, M. L., Kim, Y., Choi, M., Kim, J.-C., Do, X. K., Nguyen, T. H., and Jung, K., 2021. Detailed Trend Analysis of Extreme Climate Indices in the Upper Geum River Basin. *Water* 13: 3171. doi:10.3390/w13223171.
12. Fung, K. F., Chew, K. S., Huang, Y. F., Ahmed, A. N., Teo, F. Y., Ng, J. L., and Elshafie, A., 2022. Evaluation of spatial interpolation methods and spatiotemporal modeling of rainfall distribution in Peninsular Malaysia. *Ain Shams Eng. J.* 13: 101571. doi:10.1016/j.asej.2021.09.001.
13. Gebremichael, H. B., Raba, G. A., Beketie, K. T., Feyisa, G. L., and Siyoum, T., 2022. Changes in daily rainfall and temperature extremes of upper Awash Basin. *Ethiopia. Sci. African* 16: e01173. doi:10.1016/j.sciaf.2022.e01173.
14. Hamed, K. H., 2009. Enhancing the effectiveness of prewhitening in trend analysis of hydrologic data. *J. Hydrol.* 368: 143-155. doi:10.1016/j.jhydrol.2009.01.040.
15. Ho, C. -H., Lee, J. -Y., Ahn, M. -H., Lee, and H. -S., 2003. A sudden change in summer rainfall characteristics in Korea during the late 1970s. *Int. J. Climatol.* 23: 117-128. doi:10.1002/joc.864.
16. Jang, N., Lee, K., and Kim, S., 2022. Greater Seoul area battered by heaviest rainfall in 102 years. https://english.hani.co.kr/arti/english_edition/e_national/1054102.html#:~:text=A whopping 380 millimeters (14.9,millimeters inundated the capital city.
17. Jeung, S., Park, J., Yang, D., and Kim, B., 2019. The future of extreme climate change in the Korean peninsula using National Standard Climate Change Scenarios and the ETCCDI Index. *J. Korean Soc. Hazard Mitig.* 19: 105-115. doi:10.9798/KOSHAM.2019.19.7.105.
18. Jo, A., Ryu, J., Chung, H., Choi, Y., and Jeon, S., 2018. Applicability of various interpolation approaches for high resolution spatial mapping of climate data in Korea. Int. Arch. Photogramm. *Remote Sens. Spat. Inf. Sci.* - ISPRS Arch. 42: 703-710. doi:10.5194/isprs-archives-XLII-3-703-2018.
19. Jung, I.- W., Bae, D. -H., and Kim, G., 2011. Recent trends of mean and extreme precipitation in Korea. *Int. J. Climatol.* 31: 359-370. doi:10.1002/joc.2068.
20. Jung, Y., Shin, J. Y., Ahn, H., and Heo, J. H., 2017. The spatial and temporal structure of extreme rainfall trends in South Korea. Water (Switzerland) 9. doi:10.3390/w9100809.
21. Kim, D., 2017. Death toll from weekend rain rises to 4. Korea Her. https://www.koreaherald.com/view.php?ud=20170717000720 (accessed 10.15.22).
22. Kim, E., Ra, I., Rhee, K. H., and Kim, C. S., 2014. Estimation of real-time flood risk on roads based on rainfall calculated by the revised method of missing rainfall. *Sustain.* 6: 6418-6431. doi:10.3390/su6096418.
23. Kim, J. -S., and Jain, S., 2011. Precipitation trends over the Korean peninsula: typhoon-induced changes and a typology for characterizing climate-related risk. *Environ. Res. Lett.* 6: 034033. doi:10.1088/1748-9326/6/3/034033.
24. Kim, J. E., Yu, J., Ryu, J. H., Lee, J. H., and Kim, T. W., 2021. Assessment of regional drought vulnerability and risk using principal component analysis and a Gaussian mixture model. *Nat. Hazards* 109: 707-724. doi:10.1007/s11069-021-04854-y.
25. KMA, 2022. Korea Meteorological Administration. https://www.kma.go.kr/eng/index.jsp (accessed 5.1.22).
26. Lupikasza, E., 2010. Spatial and temporal variability of extreme precipitation in poland in the period 1951-2006. *Int. J. Climatol.* 30: 991-1007. doi:10.1002/joc.1950.
27. Mondal, S. K., Huang, J., Wang, Y., Su, B., Kundzewicz, Z. W., Jiang, S., Zhai, J., Chen, Z., Jing, C., and Jiang, T., 2022. Changes in extreme precipitation across South Asia for each 0.5 °C of warming from 1.5 °C to 3.0°C above pre-industrial levels. *Atmos. Res.* 266: 105961. doi:10.1016/j.atmosres.2021.105961.
28. Odey, G., Adelodun, B., Cho, G., Lee, S., Adeyemi, K. A., and Choi, K. S., 2022. Modeling the influence of seasonal climate variability on soybean yield in a temperate environment: South Korea as a case study. *Int. J. Plant Prod.* 16: 209-222. doi:10.1007/s42106-022-00188-2.
29. Sen, P. K., 1968. Estimates of the regression coefficient based on Kendall's Tau. *J. Am. Stat. Assoc.* 63: 1379-1389.

doi:10.1080/01621459.1968.10480934.

30. Shah, S. A., Jehanzaib, M., Kim, M. J., Kwak, D. -Y., and Kim, T. -W., 2022. Spatial and temporal variation of annual and categorized precipitation in the Han River Basin, South Korea. *KSCE J. Civ. Eng.* 26: 1990-2001. doi:10.1007/s12205-022-1194-y.
31. Shifteh Some'e, B., Ezani, A., and Tabari, H., 2012. Spatiotemporal trends and change point of precipitation in Iran. *Atmos. Res.* 113: 1-12. doi:10.1016/j.atmosres.2012.04.016.
32. Song, X., Zhang, J., Zou, X., Zhang, C., AghaKouchak, A., and Kong, F., 2019. Changes in precipitation extremes in the Beijing metropolitan area during 1960-2012. *Atmos. Res.* 222: 134-153. doi:10.1016/j.atmosres.2019.02.006.
33. Tabari, H., AghaKouchak, A., and Willems, P., 2014. A perturbation approach for assessing trends in precipitation extremes across Iran. *J. Hydrol.* 519: 1420-1427. doi:10.1016/j.jhydrol.2014.09.019.
34. Theil, H., 1992. A Rank-Invariant method of linear and polynomial regression analysis. 345-381. doi:10.1007/978-94-011-2546-8_20.
35. Vondou, D. A., G. M. Guenang, T. L. A. Djiotang, and P. H. Kamsu-Tamo, 2021. Article trends and interannual variability of extreme rainfall indices over Cameroon. *Sustain.* 13: 1-12. doi:10.3390/su13126803.
36. WMO, 2009. Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation, Climate Data and Monitoring WCDMP-No. 72. WCDMP-No 72. CH-1211. Geneva 2, Switzerland. doi:10.1002/9781119548164.ch16.
37. Xu, F., Y. Zhou, and L. Zhao, 2022. Spatial and temporal variability in extreme precipitation in the Pearl River Basin, China from 1960 to 2018. *Int. J. Climatol.* 42: 797-816. doi:10.1002/joc.7273.
38. Zhang, X., L. Alexander, G. C. Hegerl, P. Jones, A. K. Tank, T. C. Peterson, B. Trewin, and F. W. Zwiers, 2011. Indices for monitoring changes in extremes based on daily temperature and precipitation data. *WIREs Clim. Chang.* 2: 851-870. doi:10.1002/wcc.147.