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ORIGINAL ARTICLE

Spatial and temporal characteristics of annual and seasonal precipitation variation in Shijiazhuang region, north China

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Abstract
Understanding spatial and temporal characteristics of annual and seasonal precipitation variation is vital in watershed development and management. In this study, we investigated the spatial and temporal variation characteristics of precipitation and its structure, the correlations between precipitation and large-scale atmospheric circulations in Shijiazhuang region, North China. We used daily precipitation data from 35 meteorological stations for the period 1955–2015 across Shijiazhuang regions. The results show that the number of annual precipitation days at 73.5% of stations showed an upward trend, but the annual precipitation intensity at more than 91% of stations showed a downward trend, indicating that the annual precipitation reduction trend was mainly due to the decrease in annual precipitation intensity. Annual precipitation was negatively correlated with the East Asian Summer Monsoon Index (EASMI), and the negative correlation showed the characteristic of decreasing from north to south. Annual precipitation was positively correlated with the South Asian summer monsoon index (SASMI), and the positive correlation showed the characteristic of decreasing from southwest to northeast.

Keywords Spatial and temporal characteristics · Annual and seasonal variation · Precipitation · Shijiazhuang region

Introduction

Precipitation is one of the most important hydrometeorological elements and a key component of the global water cycle (Trenberth et al. 2013; Schewe et al. 2014; Feng et al. 2013). Many previous studies have shown that anthropogenic activities and climate change have led to changes in precipitation on global and regional scales (Chou et al. 2013; Gloor et al. 2013; Shrestha et al. 2019). Changes in precipitation patterns have exacerbated the occurrence of extreme events such as droughts and floods (Wang et al. 2019), which have a negative impact on ecosystems, the living environment, and economic and social development (Groisman et al., 2005; Allan et al. 2008; Chou and Lan 2012; Lu et al. 2019). It is predicted that precipitation patterns will change further, and extreme weather events are likely to occur more frequently in the future. Therefore, obtaining the characteristics of regional precipitation pattern changes is necessary for flood and drought control (Deng et al. 2018; Donat et al. 2016; Trenberth 2011), effective water management, and regional sustainable development in the context of climate change (Huang et al. 2019).

Shijiazhuang City, located in the semi-humid and semi-arid region of North China, is an important production base for agriculture and industry, as well as a population centre. Precipitation is the main limiting factor for agricultural productivity in this region (Wang et al. 2016; Vyshkvarkova et al. 2018; Rizwan et al. 2019). The main natural disasters in Shijiazhuang are droughts and floods. In the 1960s, floods were the main disaster, but after the 1980s, rainfall was low, and severe droughts occurred (Costa 2012; Xu et al. 2006; Zhang et al. 2010). Since the twenty-first century, droughts and floods have occurred alternately. It is reported that people in Shijiazhuang City are observing more frequent extreme events, such as severe droughts in autumn and winter, accompanied by the first snow-free winter in 2009, and extraordinary rainstorm disasters for four consecutive days in 2016. These extreme events have severely affected

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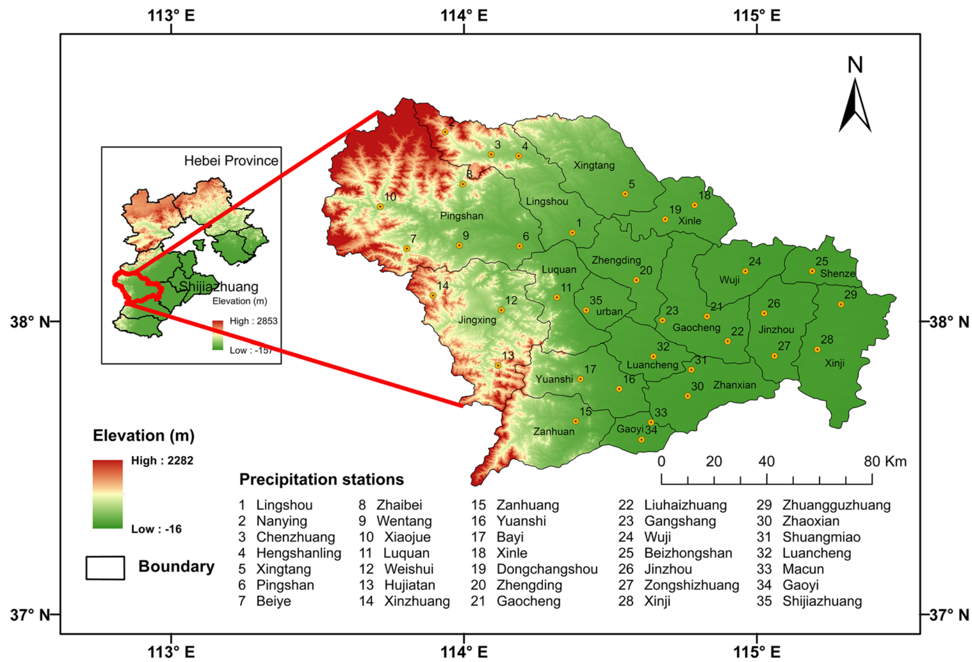
Fig. 1 Study area, elevation, and locations of precipitation stations used in this study



agricultural production, the safety of people's lives and property, and the local economy.

The amount, frequency, and intensity of precipitation are subject to variations related to climate change (Pal and Al-Tabbaa 2011). Even if the amount of precipitation is the same, the frequency and intensity of precipitation may vary (Trenberth 2011). Among them, large-scale atmospheric circulation is the background field of various weather processes, and there have been many studies on the relationship between precipitation changes and large-scale atmospheric circulation changes (IPCC 2014; Polade et al. 2014). For instance, Wu et al. (2019) analyzed the influence of atmospheric circulation patterns, including the East Asian summer monsoon (EASM), Western Pacific subtropical high (WPSH), and Pacific decadal oscillation (PDO), on regional heavy precipitation events. In addition, to better understand the temporal and spatial variations in precipitation and analyze the probability characteristics of extreme events, many precipitation structure analysis methods have been proposed to reflect the characteristics of uneven distributions of precipitation in a certain period, such as different classes of precipitation based on the precipitation amount (CMA 2012), the precipitation concentration index (PCI) for quantitatively evaluating monthly precipitation heterogeneity (Oliver 1980), and the concentration index (CI) for evaluating the contribution of the highest daily precipitation to the total amount (Martin-Vide 2004).

Most previous studies have evaluated precipitation change by annual-scale impact analysis, which can obtain the hydrological effects of climate change in different periods (Sui et al. 2013; Liu et al. 2015). However, to rationally allocate water resources and prevent meteorological disasters, analyses at smaller scales (season, month, week, hour) are essential. At present, there are few studies with a small study timescale, and the relationship between precipitation concentration changes and large-scale circulation changes as well as the prediction of future precipitation trends is not sufficient. Therefore, the objectives of this study are to analyze (1) the spatiotemporal variation characteristics in precipitation concentration indices based on Kendall slope and Mann–Kendall test, (2) precipitation structure characteristics based on precipitation levels and PCI, (3) the relationships between precipitation and four large-scale atmospheric indices.

Materials and methods

Study area

The study area, Shijiazhuang City (113°31' E ~ 115°29' E, 37°27' N ~ 38°46' N), is located in the central and southern part of Hebei Province, China, covering an area of 14,077 km^2 (Fig. 1). Shijiazhuang has a typical warm temperate continental semi-humid monsoon climate characterized by hot, rainy summers and cold, dry winters. The predominant soil types in Shijiazhuang are brown soil, cinnamon soil, skeleton soil, and fluvo-aquic soil. Land use is dominated by rain-fed agricultural land, accounting for approximately 63% of the total land area. Agricultural production relies strongly on precipitation. The mean annual precipitation is approximately 520 mm, and the rainy season

(June–September) accounts for 65–75% of the total annual precipitation. The annual average temperature is 13.3 °C, and the annual average sunshine duration is 2514 h.

Data sources

The daily precipitation dataset covering the period of 1955 to 2015 from 38 gauging stations was provided by the Bureau of Hydrology and Water Resources of Hebei Province. To ensure the continuity and integrity of the recorded data series, stations with missing data accounting for more than 5% of all days for a year were excluded, while, for stations with little missing data, missing data were interpolated by linear regression of data from an adjacent station. Finally, we selected 35 gauging stations with complete daily precipitation data for 1955–2015 in this study (Fig. 1). Daily data values were summed to obtain monthly, seasonal, and annual totals of precipitation. The seasons in a year were defined as winter (December–February), spring (March–May), summer (June–August), and autumn (September–November). To study the effects of regional atmospheric circulation on precipitation under the background of climate change, four large-scale atmospheric indices at a monthly-scale resolution were selected. Two large-scale oceanic and atmospheric circulation patterns, including the Southern Oscillation Index (SOI) and El Niño Southern Oscillation (ENSO), were obtained from the Climate Data Center (CDC) of the China Meteorological Administration (CMA) (http://cdc.nmic.cn/), and the other two summer monsoon indices, including the East Asian Summer Monsoon Index (EASMI) and South Asian summer monsoon index (SASMI), were collected from the personal home page of Jianping Li (http://ljp.gcess.cn/ dct/page/1). EASMI is relative to the land–sea thermal contrast between the Pacific Ocean and the Eurasian continent, and SASMI is relative to the land–sea thermal contrast between the Indian Ocean and the Eurasian continent.

Methods

Trend analysis

The nonparametric Mann–Kendall (MK) test is a robust trend detection method (Mann 1945; Kendall 1975). This method, which does not require samples to fit a normal distribution and is not very sensitive to outliers, has been widely applied to diagnose the trends in hydrometeorological time series (Tang et al. 2018; Yuan et al. 2019). In this study, the MK test is used to analyze the trends and quantify their significance for precipitation-related indices. The statistic S of the MK test is calculated as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right), \tag{1}$$

where n is the number of the data set, x_i and x_j are the data values at times i and j, and $sgn(x_j\text{-}x_i)$ is the sign function:

$$\mathrm{sgn}\left(x_j - x_i\right) = \begin{cases} 1, & x_j > x_i \\ 0, & x_j = x_i \\ -1 & x_j < x_i \end{cases}, \tag{2}$$

When $n > 10$, the statistic S follows a normal distribution. The standardized test statistic (Zs) is obtained after standardized calculation of S. The Zs value can be used as a significance test of the trend. The Zs value can be calculated as:

$$Z(S) = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{var(S)}}, & S < 0 \end{cases}, \tag{3}$$

$$vas(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i i(i-1)(2t+5)}{18}, \tag{4}$$

where m is the number of tied groups and t_i is the number of data points in the i*th* tied group. A positive Z value denotes an increasing trend, and a negative Z value represents a decreasing trend (Xu et al. 2018). In this study, we tested the trend significance at the 0.01, 0.05, and 0.1 levels. The null hypothesis of no trend was rejected if $|Zs| > 2.576$ at the 0.01 significance level, if $|Zs| > 1.960$ at the 0.05 significance level, and if $|Zs| > 1.645$ at the 0.1 significance level.

To quantify the trend changes, the Kendall slope (β), which is an unbiased estimator of monotonic trend magnitude, can be used, and the formula is as follows:

$$\beta = \mathrm{median}\left(\frac{x_j - x_i}{j - i}\right) j > i, \tag{5}$$

A positive value of β indicates an increasing trend, while a negative value indicates a decreasing trend.

The trend analysis of three precipitation-related indices including precipitation amount, precipitation days, and precipitation intensity was studied by using MK test and β value in this study. Among them, precipitation days refer to the number of days with precipitation per unit time (the threshold of daily precipitation amount higher than or equal to 0.1 mm) and precipitation intensity refers to the amount of precipitation per unit time.

Precipitation concentration index

The precipitation concentration index (PCI), originally proposed by Oliver (1980) and developed by De Luis et al. (2011), is used to evaluate the monthly precipitation heterogeneity. The modified equation for annual PCI is described as follows:

$$PCI = \frac{\sum_{I=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2} \times 100, \quad (6)$$

where p_i is the monthly precipitation for the ith month. It can also be calculated to characterize the seasonal precipitation (i.e., SPCI) for spring, summer, autumn, and winter (Eq. (7)).

$$SPCI = \frac{\sum_{i=1}^{3} P_i^2}{\left(\sum_{i=1}^{3} P_i\right)^2} \times 25, \quad (7)$$

Here, PCI or SPCI values below 10 represent a uniform monthly rainfall distribution (low precipitation concentration); the values 10 ≤ PCI/SPCI < 15 indicate a relatively uniform rainfall distribution (moderate precipitation concentration); the values 15 ≤ PCI/SPCI < 20 denote an irregular rainfall distribution (high precipitation concentration); and PCI/SPCI values above 20 mean a strongly irregular rainfall distribution, indicating that most precipitation falls in only a few months. In this study, the characteristics of monthly precipitation heterogeneity were represented by the average PCI or SPCI for each station during the study period. To measure the variability of PCI or SPCI, the coefficient of variation (CV, %) was calculated at each station.

Results and discussion

Spatial and temporal variation characteristics of precipitation

Interannual trend analysis for precipitation

The linear trends of annual and seasonal (spring, summer, autumn, and winter) precipitation in Shijiazhuang during the period from 1955 to 2015 are shown in Fig. 2. The annual precipitation in this region exhibited a decreasing trend with a precipitation tendency rate of 1.327 mm/a in the past 61 years. The maximum annual precipitation value was 998.93 mm and occurred in 1963, while the minimum value was 247.14 mm in 1972, which indicates a significant difference in regional interannual variation. According to the 5-year moving average curve, the annual precipitation of Shijiazhuang showed a fluctuating and decreasing trend, which was increasing before the mid-1960s, mainly decreasing in the following 20 years, slightly increasing in the 10 years after the mid-1980s, and decreasing, then increasing, after the mid-1990s. From the perspective of different seasons, the average precipitation in summer accounted for most of the annual precipitation (66.7%) and showed decreasing trends. The precipitation tendency rate was 0.248 mm/a in spring, showing a rising trend, while the precipitation trends were declined in summer, autumn, and winter with rates of − 1.474 mm/a, − 0.082 mm/a, and − 0.006 mm/a, respectively. Comparatively speaking, the trend variation in spring and summer was more obvious than in autumn and winter.

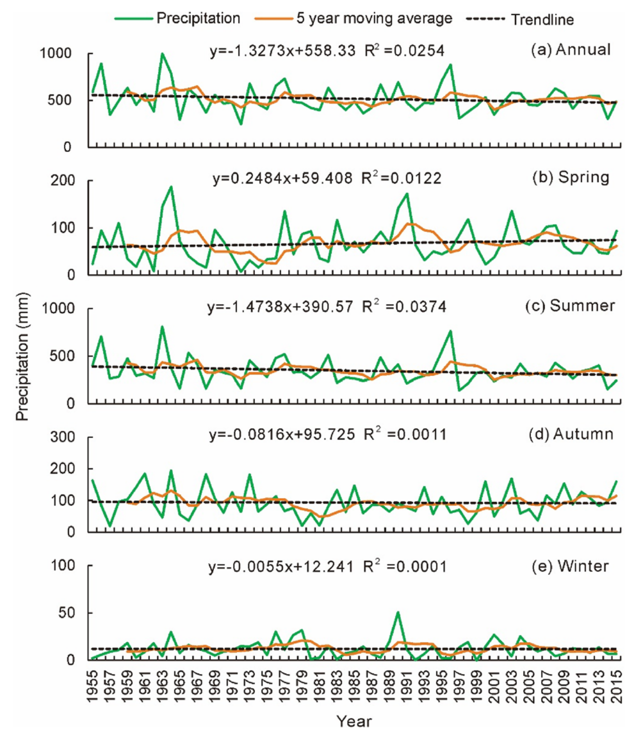


Fig. 2 Trends of study area for annual and seasonal precipitation by liner regression method

Spatial distribution characteristics of precipitation

The spatial distribution of annual and seasonal precipitation and variation trends (β value) is shown in Figs. 3, 4, respectively. The annual precipitation decreased from the northwest to the southeast of Shijiazhuang. The maximum precipitation occurred at Nanying station, with an annual rainfall of 668.13 mm, and the minimum precipitation appeared at Liuhaizhuang station, with an annual rainfall of 442.95 mm. 8 (22.86%) stations showed positive trends. These stations were distributed in the northeast regions of Shijiazhuang

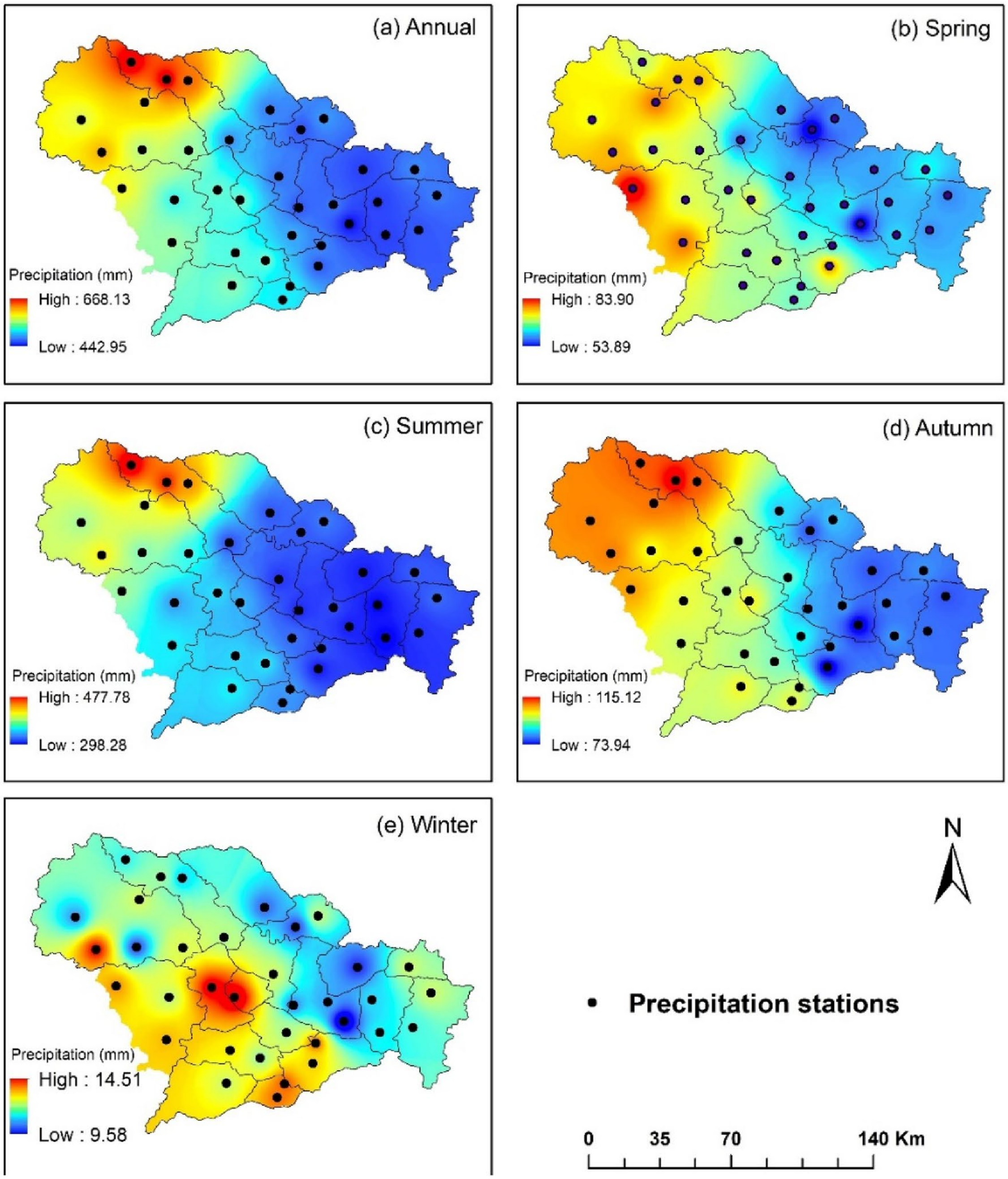


Fig. 3 Spatial distribution of annual and seasonal precipitation

(Xinle, Zhengding, Gaocheng, and Wuji counties). Only Dongchangshou station exceeded the 90% significance level, indicating that the rising trends of precipitation were not obvious. More than 77% of the total stations showed negative trends and passed the significance test: $p < 0.01$ at Weishui station; $p < 0.05$ at Hujiatan, Yuanshi, and Bayi stations; and $p < 0.1$ at Xiaojue and Zanhuang stations. These regions, with significant decreasing trends for precipitation, were mainly concentrated in the northwest and southwest of Shijiazhuang, and among them, Jingxing County exhibited the largest decline of 2.66 mm/a.

The spring precipitation in the western region was considerably higher than that in the eastern region, with the maximum precipitation at Xinzhuang station (83.9 mm) and the minimum precipitation at Liuhaizhuang station (53.89 mm). The β values of all spring precipitation stations were greater than 0, indicating increasing trends in spring precipitation. There were 5 stations, 7 stations, and 4 stations that exceeded the 90%, 95%, and 99% significance levels, accounting for 14.3%, 20.0%, and 11.4% of the total stations, respectively. The precipitation increased significantly in the eastern and northern regions of Shijiazhuang City. The distribution of summer precipitation is similar to that of the whole year, with the maximum value (477.79 mm) at Nanying station and the minimum value (298.28 mm) at Zhangguzhuang station. For summer precipitation, more than 85% of the total stations showed a declining trend, and 11 stations and 1 station exceeded the 95% and 99% significance levels, respectively. The significantly decreasing trends were mainly concentrated in the northwestern and southern regions of Shijiazhuang. The spatial distribution of autumn precipitation was similar to that of the annual precipitation. A total of 54.3% of the stations showed positive trends, mainly distributed in the northern region, while the southern regions were dominated by negative trends ($\beta < 0$). The winter precipitation was obviously low, ranging from 9.58 mm to 14.51 mm. The magnitudes of the trend changes at all stations failed the significance test, varying from − 0.11 to 0.12 mm/a.

Variation trend of precipitation days and precipitation intensity

The annual average number of days with precipitation in Shijiazhuang was 65.1 days. The average number of precipitation days reached a maximum value of 76.8 days at Xiaojue station, but at Liuhaizhuang station, the maximum value was 50.5 days. According to the statistics, approximately 74.3% of all stations showed increasing trends, with 45.7% being statistically significant for the increase in the number of annual precipitation days. However, 20% of all stations exhibited decreasing trends, and the decreasing trends were significant at Bayi station and Xinle station, with the decline rate exceeding − 1.1 d/a (Fig. 4). In terms of seasonality, the number of precipitation days in summer was much higher than those in other seasons, with an average of 30.8 days, while the number of precipitation days was lowest in winter, with an average of 5.8 days. Overall, the number of precipitation days in spring showed positive trends, and the number of precipitation days in autumn showed opposite trends. Of all stations, totals of 62.86% in spring and 51.43% in autumn passed the significance test. There were large spatial differences in the variation trends of the number of summer precipitation days. The proportions of stations with rising, falling, and unchanged trends were 45.71%, 34.29%, and 20%, respectively. There was no significant change in the number of precipitation days in winter.

In this study, annual (seasonal) precipitation was divided by the number of annual (seasonal) precipitation days to obtain the annual (seasonal) precipitation intensity of Shijiazhuang during the study period (1955–2015). The average precipitation intensity in Shijiazhuang for 61 years was 8.13 mm/day, showing a decreasing trend for most of the regions which was consistent with the research conclusion of Miao et al. (2019). The study showed that extreme precipitation intensity decreased and the trend of aridification increased. However, extreme precipitation intensity over most of the mid-latitude land masses and over wet tropical regions will very likely increased according the Climate Change 2014 Synthesis Report (IPCC 2014). The finding for Shijiazhuang region is contrary to the global trend, and the reasons and mechanisms need to be further studied. The precipitation intensity in summer was 11.2 mm/day, which was much higher than in other seasons. The precipitation intensity in spring and autumn was similar (approximately 5–6 mm/day), while the precipitation intensity in winter was the lowest, at only 1.98 mm/day. Figure 4 (a3–e3) shows the spatial distributions of the annual and seasonal precipitation intensity change rates in Shijiazhuang. More than 91% of all stations showed decreasing trends for annual precipitation intensity, and 2.85%, 17.14%, and 40% of the stations passed the significance test of 90%, 95%, and 99%, respectively, with a maximum decline rate of 0.097 mm/(d·a) (Nanying station). Over 74% of all stations showed increasing trends for spring precipitation intensity, and the increasing trends were most significant in the Xinyue and Gaocheng regions, with a maximum increase rate of 0.061 mm/(d·a). Most regions showed a downward trend in precipitation intensity in summer (85.7%), autumn (68.6%), and winter (57.1%). In summer, the precipitation intensity in Lingshou County and Jingxing County showed the most significant decreasing trends, with a maximum decline rate of 0.114 mm/(d·a). The precipitation intensity in Jingxing and Pingshan had obvious decreasing trends in autumn, with a maximum decline rate of 0.057 mm/(d a). In a few places, such as in Gaoyi County and urban areas, the precipitation intensity showed a slight upward trend. In winter, the precipitation intensity in Jinzhou County and Shenze County decreased obviously.

Precipitation structure change characteristics

Spatiotemporal variation in PCI

The distribution characteristics of the annual precipitation concentration in Shijiazhuang show a high precipitation concentration in the north and a low precipitation concentration in the south, with a variation range of 21.95–24.98, all greater than 20, indicating that the annual precipitation distribution in Shijiazhuang is very concentrated in few months, especially in some northern regions (Fig. 5). The variation coefficients of stations 5, 19, and 20 were all above 36%, indicating that the precipitation distribution in Xingtang County, Xinle County, and Zhengding County varied greatly. In spring, the SPCI values ranged from 11.31 to 13.92, indicating that precipitation had a certain concentration and that

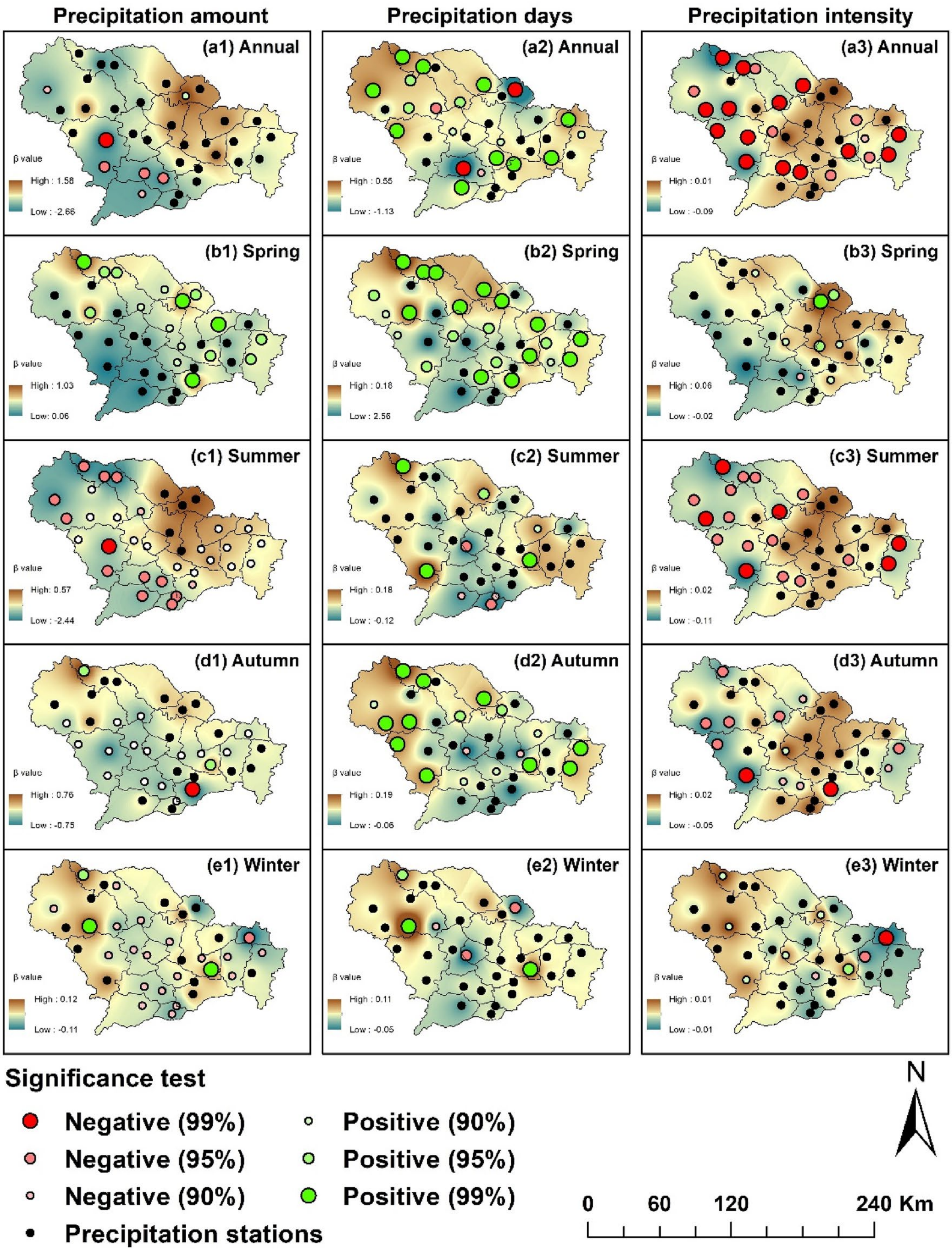


Fig. 4 Spatial distribution of annual and seasonal precipitation concentration index

relatively low spatial variation occurs in the northeast corner of Shijiazhuang City. In summer, SPCI ranged from 10.45 to 11.36, with a relatively low value in the southwest corner of Shijiazhuang. The spatial distribution trend in autumn was completely opposite that in summer. The region with a high precipitation concentration was located in the southwest, and the SPCI value was over 15, showing a trend of high precipitation concentration. The precipitation concentration

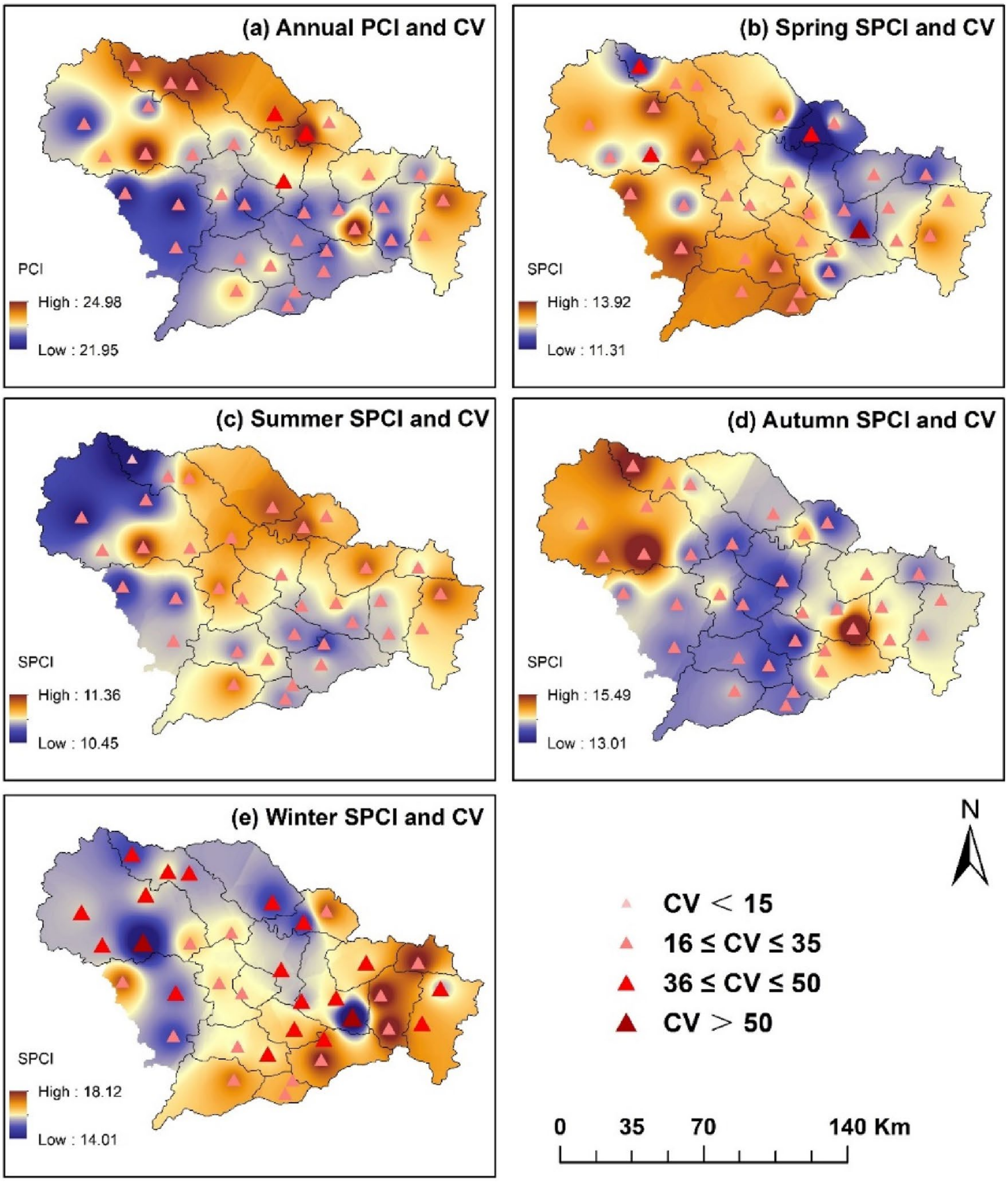


Fig. 5 Spatial distribution of annual and seasonal precipitation concentration index

in winter was between 14.01 and 18.12, and the southeast region had a high concentration degree with an irregular distribution of precipitation. The variation coefficient of the precipitation concentration at each station in spring and autumn was low, indicating that the precipitation distribution in these two seasons had small changes. The precipitation distribution in spring was scattered in the regions with great variation, but the precipitation distribution at most stations had great variability in winter.

Spatial distribution of precipitation of different orders

According to the precipitation classification standard established by the China Meteorological Administration, precipitation can be classified into six categories depending on magnitude: light rain, moderate rain, heavy rain, rainstorm, heavy rainstorm, and extremely heavy rainstorm, referring to the 24 h precipitation between 0.1 and 9.9 mm, 10.0 and

24.9 mm, 25.0 and 49.9 mm, 50.0 and 99.9 mm, 100.0 and 249.9 mm, and ≥ 250.0 mm, respectively. Figure 6 shows the spatial distribution of the annual precipitation values of these six classifications. The spatial distribution of the annual precipitation of light rain and moderate rain was similar, decreasing from northwest to northeast, and the high-value areas are all distributed in Pingshan, Lingshou, and Jingxing. The high-value areas of heavy rain and rainstorm were similar to those of light rain and moderate rain, but the low-value area of heavy rain and rainstorm was located in the central area of Shijiazhuang. The number of rainy days in a year for light rain, moderate rain, heavy rain, and rainstorm was 50,

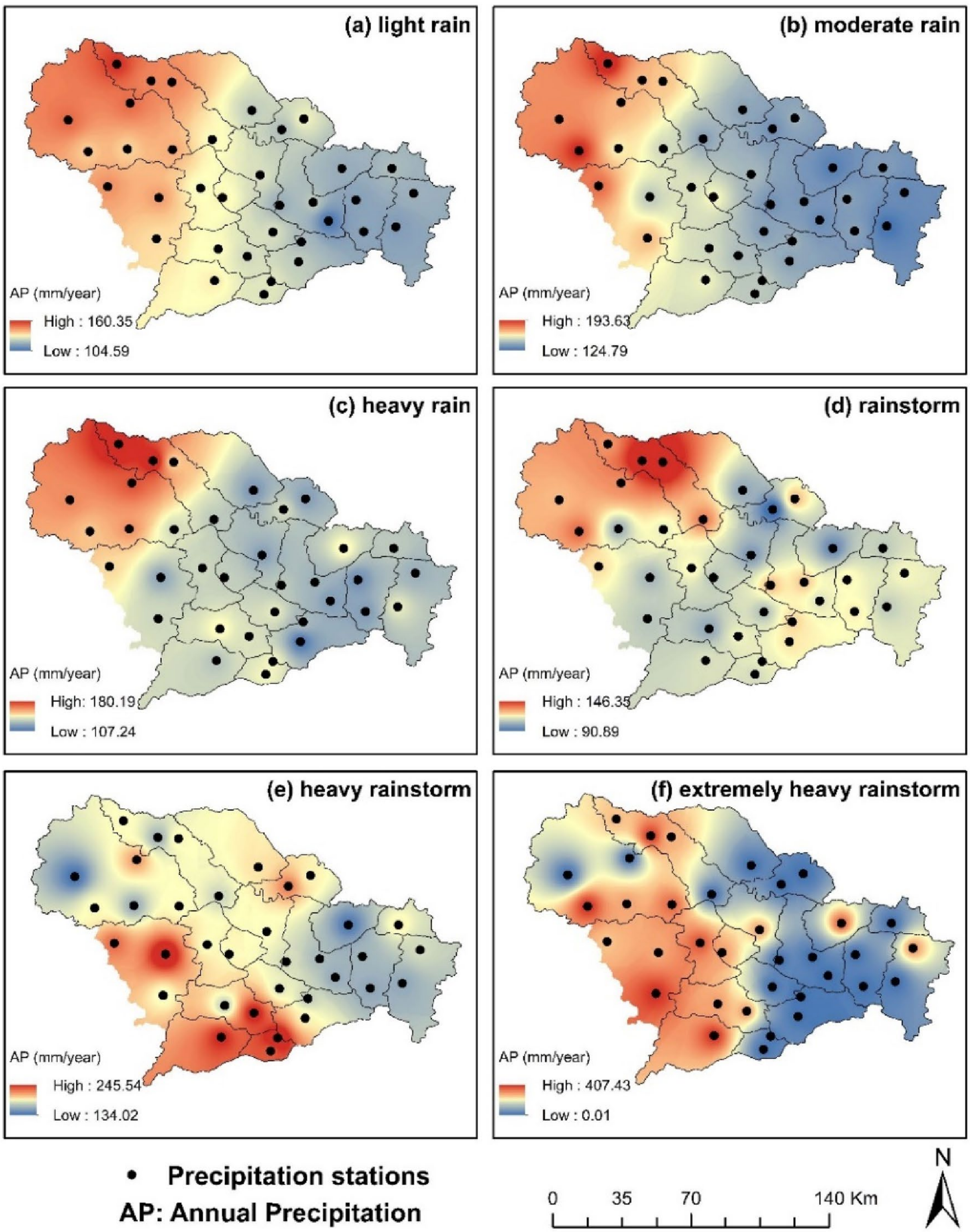


Fig. 6 Spatial distribution for the precipitation of six classifications

9, 4, and 2, respectively. However, there was little difference in the total amount of annual precipitation for these four precipitation types, which was approximately 90–190 mm. The average number of days with heavy rainstorm was 1 day, distributed in the southwest region, and the rainfall was between 134.02 and 245.54 mm. The spatial distribution of extremely heavy rainstorm was obviously different and mainly occurred in areas of Zanhuang, Jingxing, Yuanshi, Luquan, Lingshou, and Pingshan, with a maximum rainfall of 407 mm within 12 h.

Pingshan County and Lingshou County, located in the northwest of Shijiazhuang, were the rainy centres and the heavy-precipitation-prone centres in this study area; these areas have more rainfall and average daily rainfall, especially in summer and autumn, which were more obvious in these two counties than in other regions. This may be because the northwest of Shijiazhuang is located in the Taihang Mountains, where the warm and humid airflow rises along the wind slope of the Taihang Mountains, coupled with the influence of the local microclimate, causing Pingshan and Lingshou to become the precipitation centres of Shijiazhuang City. Although Jingxing, Zanhuang, Yuanshi, and Gaoyi in the southwest were the centres of relatively low precipitation, rainstorms and heavy rainstorms were, on the contrary, more common, which may be due to the influence of the topography of the area and some forms of atmospheric circulation.

Correlation between precipitation and large-scale atmospheric circulation

Figure 7 shows the correlation coefficient distribution between precipitation and four atmospheric circulation indices (SOI, ENSO, EASMI, and SASMI). The precipitation values of 97.1% of the stations were negatively correlated with the EASMI, and that of the Changshou station, located in Xinle County, was significantly negatively correlated. The negative correlations between precipitation and EASMI decreased from the north to south of the Shijiazhuang region. Precipitation at all stations showed a decreasing positive correlation with SASMI from southwest to northeast, and there were 3 significantly positive correlation stations, including Xiaojue, Macun, and Gaoyi stations, distributed in Pingshan Countyand Zanhuang County. The precipitation of the whole region was positively correlated with the SOI, but none of the correlation coefficients passed the significance test. Except for stations 16, 30, 31, 32, and 33, which are located in the southeast, the precipitation values of all stations were negatively correlated with ENSO, but the correlations were not significant and were all below 0.1. By influencing the southeast Asian monsoon circulation and the Pacific subtropical high, the Southern oscillation and the Southeast Asian summer monsoon have exerted different degrees of influence on the climate from coastal to inland regions in China, and the degrees, modes, and results of their influence on different regions in China are also quite different. The mechanism of precipitation in Shijiazhuang needs to be further studied.

Conclusion

In this study, spatiotemporal and abrupt changes in the concentration index and their relationships with large-scale atmospheric circulations over Shijiazhuang region were discovered. The main conclusions are as follows:

(1) In the past 61 years, the average annual precipitation of Shijiazhuang City showed a spatial distribution characteristic of decreasing from northwest to southeast, and the annual precipitation was mainly concentrated in summer and autumn. The annual and summer precipitation in most areas showed a downward trend, and a significant downward trend was seen mainly in the west of Shijiazhuang. The precipitation in spring was on the rise, and the significant increases were mainly in the eastern and northern regions. Approximately half of the stations in autumn and winter had a increasing or decreasing trend, and the change trend was not significant. The number of annual precipitation days at 73.5% of stations showed an upward trend, but the annual precipitation intensity at more than 91% of stations showed a downward trend, indicating that the annual precipitation reduction trend was mainly due to the decrease in annual precipitation intensity.

(2) The annual distribution of precipitation in Shijiazhuang was concentrated in few months, and the values of PCI were high in the north and low in the south. Moreover, the PCI in Xingtang, Xinle, and Zhengding show great variability. The SPCI in autumn and winter was higher than those in spring and summer, and the regions with high SPCI were located in the southwest and southeast. Pingshan County and Lingshou County in the northwest are the rainy centres and the heavy-precipitation-prone centres and have more rainfall and average daily rainfall, especially in summer and autumn, which are more obvious than that in other regions. Although Jingxing, Zanhuang, Yuanshi, and Gaoyi in the southwest are the centres of weak precipitation, precipitation amount, and days for heavy rainstorm and extremely heavy rainstorm are more common. The monitoring and control of precipitation events should be strengthened in these areas.

(3) Annual precipitation was negatively correlated with EASMI, and the negative correlation showed the characteristic of decreasing from north to south. Annual precipitation was positively correlated with SASMI, and the positive correlation showed the characteristic of decreasing from southwest to northeast. The annual precipitation had a weak

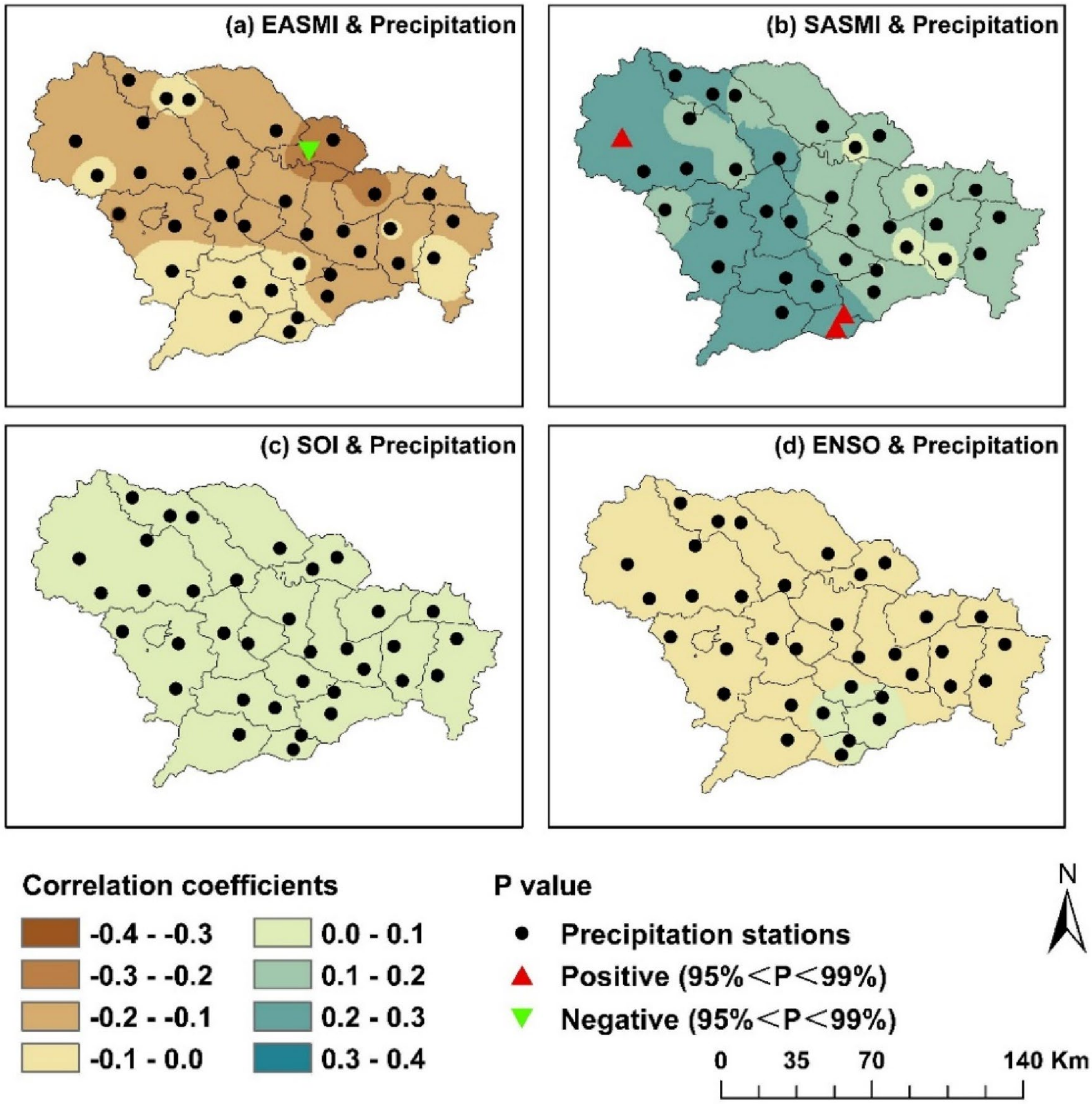


Fig. 7 Statistically correlation between the precipitation and four climate indices—SOI, ENSO, EASMI, and SASMI

positive correlation and a negative correlation with the SOI and ENSO, respectively.

The above results are helpful to understand the precipitation characteristics in Shijiazhuang, a typical city in northern China as a whole, and the precipitation variation in different regions and seasons. This research provides scientific basis for drought prevention and flood prevention measures in this study area and is of great significance for water resources management in China. In the future, complex regional climate model will be used to further study the mechanism of precipitation concentration change and trend prediction.

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Declarations

Conflict of interest The authors confirm that they have no conflict of interest.

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