Article

Trend Analysis of Rainfall Time Series in Shanxi Province, Northern China (1957–2019)

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Abstract: Changes in rainfall play an important role in agricultural production, water supply and management, and social and economic development in arid and semi-arid regions. The objective of this study was to examine the trend of rainfall series from 18 meteorological stations for monthly, seasonal, and annual scales in Shanxi province over the period 1957–2019. The Mann–Kendall (MK) test, Spearman’s Rho (SR) test, and the Revised Mann–Kendall (RMK) test were used to identify the trends. Sen’s slope estimator (SSE) was used to estimate the magnitude of the rainfall trend. An autocorrelation function (ACF) plot was used to examine the autocorrelation coefficients at various lags in order to improve the trend analysis by the application of the RMK test. The results indicate remarkable differences with positive and negative trends (significant or non-significant) depending on stations. The largest number of stations showing decreasing trends occurred in March, with 10 out of 18 stations at the 10%, 5%, and 1% levels. Wutai Shan station has strong negative trends in January, March, April, November, and December at the level of 1%. In addition, Wutai Shan station also experienced a significant decreasing trend over four seasons at a significance level of 1% and 10%. On the annual scale, there was no significant trend detected by the three identification methods for most stations. MK and SR tests have similar power for detecting monotonic trends in rainfall time series data. Although similar results were obtained by the MK/SR and RMK tests in this study, in some cases, unreasonable trends may be provided by the RMK test. The findings of this study could benefit agricultural production activities, water supply and management, drought monitoring, and socioeconomic development in Shanxi province in the future.

Keywords: trend analysis; nonparametric trend identification; Mann–Kendall test; Spearman’s Rho test; revised Mann–Kendall test

1. Introduction

Rainfall is one of the most important climate elements that can directly affect the availability of water resources, can be used for diagnosing climate change under the background of global warming [1,2], and influence agricultural production activities and the ecohydrological environment [3–5]. Relevant studies have shown that water cycle modification, with rainfall being a key point in the process, is considered the most noticeable consequence of global atmospheric warming [6,7]. In addition,

the spatial and temporal distribution of runoff, soil moisture, and groundwater reserves can be influenced by a change of rainfall distribution and the frequency of droughts and floods can also be altered [8]. Therefore, variations and trends around rainfall should be investigated and analyzed for planning and managing of water resources, and also for the purpose of designing suitable plans to cope with floods and drought conditions [3].

In recent years, many studies related to the trends and variability in precipitation under global warming have investigated different regions, such as India [4,5,9–13], the Mediterranean [14–18], Ethiopia [19], China [1,2,20–25], the Netherlands [26], South Korea [27], Brazil [28], Germany [29], and West Africa [30]. Although various studies on rainfall variation and trend analysis have been investigated in western [31,32], eastern [24], southern [33], north-west [34], south-east [2], and south-west China [23], little investigation has been carried out in the northern regions (e.g., Shanxi province, China). Meanwhile, relevant studies have suggested that various change patterns can be detected for different regions within a country [26,33,35,36]. Liu et al. [37] investigated the spatial and temporal patterns of trends of the precipitation in the Yellow River Basin (YRB) from 81 meteorological stations during the period 1961–2006. They found that most of the precipitation stations showed a downward trend, while only two meteorological stations displayed upward trends. Zhang et al. [33] analyzed the spatial and temporal changes of precipitation structure in the Pearl River Basin based on daily observed precipitation data at 42 rain gauging stations from 1960 to 2005. Decreasing trends in precipitation were found mainly in the middle and upper Pearl River Basin. However, a decreasing number of rainy days was identified almost over the entire basin. Wang et al. [24] analyzed the trend on annual and seasonal rainfall in the Yangtze River Delta, eastern China, using observed data from 14 rain gauging stations during 1961–2016, and found statistically significant upward trends in annual rainfall at all stations. Summer and winter presented increasing trends, while spring and autumn showed decreasing trends. In addition, precipitation extremes under global warming have also been investigated in various regions to better understand the rainfall regime changes due to climate change. Li et al. [38] applied an iterative-based Mann–Kendall trend test and examined the long-term trends in precipitation extremes (1980–2013). Frequency and intensity of precipitation in terms of inter-annual variability was also investigated. They found the frequency and intensity of precipitation extremes in Singapore showed a significant increasing trend. Three potential factors—El Niño–Southern Oscillation (ENSO), global mean temperature, and local temperature—are significantly correlated with precipitation extremes. Chow et al. [39] investigated the impacts of changing frequencies and intensities of extreme weather events on urban settlement, and concluded that the warm environment observed in Singapore and surface dryness have been more intense in recent periods. Change of occurrence of time and length of the extreme precipitation period, as well as influencing factors, were investigated by Guo et al. [40]. They found atmospheric circulation patterns have significant effects on the occurrence time and length of the extreme precipitation period. Changes of extreme precipitation induced by the global mean temperature and ENSO have been investigated by several researchers [41–44]. Meanwhile, the impacts of ENSO on regional rainfall have been examined around the world. Philippon et al. [45] analyzed the relationship between ENSO and South Africa austral winter rainfall using a long-term daily rainfall database, and found seasonal rainfall (May, June, and July) had a positive correlation with the Niño 3.4 index. Räsänen and Kummu [46] examined the impact of ENSO on large inter-annual variations between large floods and severe droughts. The results showed that both precipitation and discharge are influenced by ENSO. The precipitation and discharge decreased in El Niño years, while they increased in La Niña years. In order to understand the nature of the rainfall variations under climate change, more studies should be conducted for different geographical regions [11].

The non-parametric Mann–Kendall (MK) test and Spearman’s Rho (SR) test are commonly employed to detect monotonic trends in time series of climatic and hydrologic variables. However, the results of the test may contain error if significant autocorrelation exists in the data series. To avoid this problem, a Revised Mann–Kendall test has been proposed by Hamed and Rao [47] using a variance correction method to eliminate the effect of autocorrelation in the time series data. The magnitudes of

trend slope for monthly, seasonal, and annual rainfall series in many study areas have been estimated by using Sen's slope estimator [4,8,13,20].

Shanxi is a province with serious soil erosion concerns in northern China, and is also a fragile ecological zones which is sensitive to global climate change [48]. The per capita water resources in Shanxi province is only 456 m³, accounting for 1/5th of the national average and far below the severe water shortage limit of 1000 m³. The average amount of water used by cultivated land is 3255 m³/hm², which is only 1/9th of the national average. Therefore, changes of rainfall in Shanxi province will have a negative effect on the water supply, agricultural irrigation, ecological systems, and socioeconomic development [24,25].

Most studies of rainfall changes in Shanxi province have been concerned with annual rainfall; little research has been undertaken on annual, seasonal, and monthly time series data using all available meteorological stations [48,49]. This study attempts to apply the Mann–Kendall (MK) test, Spearman's Rho (SR) test, Revised Mann–Kendall (RMK) test and Sen's slope estimator (SSE) to detect trends of rainfall on the annual, seasonal, and monthly scales in Shanxi province, based on the latest high-quality observed data from 1957 to 2019. Therefore, the main objectives of this study were to: (1) analyze temporal trend in annual, seasonal, and monthly rainfall time series data using the MK/SR and RMK tests; (2) investigate the magnitude of trend line in annual, seasonal, and monthly time series data using SSE; and (3) compare the difference between MK/SR and RMK in detecting the trends of long-term time series rainfall data.

2. Materials and Methods

2.1. Study Area and Data Availability

Shanxi province is located in the middle of China and lies in the east of the Loess Plateau, which is a typical semi-arid region in northern China. It lies between 34°34' N to 40°43' N latitude and 110°14' E to 114°33' E longitude (Figure 1) and covers an area of 156,700 km². Shanxi has a temperate continental monsoon climate. High temperatures and rainy days occur across the summer, while low temperatures and dry weather conditions characterize the winter. The average annual temperature ranges from 3 °C to 14 °C. The mean annual precipitation is between 350 mm and 700 mm, with 60% of it concentrated in June, July, and August, and the amount of precipitation is greatly affected by the topography. The average elevation of Shanxi province is 1000 m, with the highest elevation being 3059 m and the lowest elevation being 205 m (Figure 1). There are four seasons according to the climatology, namely spring (March to May), summer (June to August), autumn (September to November), and winter (December to the following February). The location of Shanxi province in China, along with the topography and spatial distribution of meteorological stations, is shown in Figure 1.

Monthly rainfall data of 18 meteorological stations of Shanxi province for 63 years (1957–2019), except for Changzhi station (47 years), were collected from the China Meteorological Data Network. Quality checks and homogeneity were carried out and controlled before these data were released. The monthly rainfall data for the 18 meteorological stations were aggregated to total rainfall at seasonal and annual scale for trend analysis. The geographical location and elevation information of the meteorological stations and the corresponding length of the rainfall record is provided in Table 1.

Figure 1. Location map of the study area and the topography and meteorological stations marked as black dot.

Table 1. Description of 18 meteorological stations in the study area considered for analysis.

Station ID	Station	Latitude	Longitude	Elevation (m)	Record Period
53478	Youyu	40°00′	112°27′	1345.8	1957–2019
53487	Datong	40°06′	113°20′	1067.2	1957–2019
53564	Hequ	39°23′	111°09′	861.5	1957–2019
53588	Wutai Shan	38°57′	113°31′	2208.3	1957–2019
53663	Wuzhai	38°55′	111°49′	1401	1957–2019
53664	Xingxian	38°28′	111°08′	1012.6	1957–2019
53673	Yuanping	38°44′	112°43′	828.2	1957–2019
53764	Lishi	37°30′	111°06′	950.8	1957–2019
53772	Taiyuan	37°47′	112°33′	778.3	1957–2019
53782	Yangquan	37°51′	113°33′	741.9	1957–2019
53787	Yushe	37°04′	112°59′	1041.4	1957–2019
53853	Xixian	36°42′	110°57′	1052.7	1957–2019
53863	Jiexiu	37°02′	111°55′	743.9	1957–2019
53868	Linfen	36°04′	111°30′	449.5	1957–2019
53882	Changzhi	36°03′	113°04′	991.8	1973–2019
53959	Yuncheng	35°03′	111°03′	365	1957–2019
53963	Houma	35°39′	111°22′	433.8	1957–2019
53975	Yangcheng	35°29′	112°24′	659.5	1957–2019

2.2. Methodology

2.2.1. The Mann–Kendall Test

The Mann–Kendall test (MK), proposed by Mann [50] and Kendall [51], is a non-parametric test that is widely used to detect monotonic trends for time series of hydrology, meteorological, and environment data. A non-parametric test does not require data to be normally distributed and is flexible to outliers in the time series [52]. The test assumes a null hypothesis, H_0 , of no trend. The alternative hypothesis, H_1 , is that a monotonic trend is identified (increasing or decreasing).

For a given time series $X_i = x_1, x_2, \dots, x_n$, the Mann–Kendall test statistic S is calculated as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(x_j - x_i) \quad (1)$$

where n is the number of data points; x_i and x_j are the data values in time series i and j ($j > i$), respectively; and $\text{sign}(x_j - x_i)$ is the sign function as

$$\text{sign}(x_i - x_j) = \begin{cases} -1 & \text{if } (x_j - x_i) < 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ 1 & \text{if } (x_j - x_i) > 0 \end{cases} \quad (2)$$

The variance is computed as

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^m t_k(k-1)(2k+5)}{18} \quad (3)$$

where n is the number of data points; m is the number of tied groups; and t_k denotes the number of extent k . Standardized test statistics, Z , are used to detect a significant trend, and expressed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (4)$$

The monotonic trend can be identified by the values of Z . Negative values of Z indicate downward trends while positive values of Z indicate upward trends. The statistically significant trend test is undertaken at the specific α significance level. When $|Z| > Z_{1-\frac{\alpha}{2}}$, the null hypothesis is rejected, and a significant trend exists in the time series. Significance levels of $\alpha = 0.05$ and $\alpha = 0.01$ were used in this study. At the 5% significance level, the null hypothesis of no trend is rejected if $|Z| > 1.96$, and it is rejected if $|Z| > 2.33$ at the 1% significance level [3,4,53].

2.2.2. The Spearman's Rho Test

The Spearman's Rho (SR) test [54] is another widely used non-parametric test for detecting monotonic trends in time series data. Yue et al. [55] investigated the power of the MK and SR tests for detecting monotonic trends in hydrological series. The results indicated that these two non-parametric tests have similar power in detecting a trend. For a given time series $X_i = x_1, x_2, \dots, x_n$, the Spearman's correlation coefficient r_{SRC} is given as

$$r_{SRC} = 1 - \left\{ \frac{6 \sum_{i=1}^n [d_i]^2}{n(n^2 - 1)} \right\} \quad (5)$$

where $d_i = (RX_i - RY_i)$. RX_i is the rank of the variable X_i ; RY is the chronological order of observations and $i = 1, 2, \dots, n$ in series of size n . The test statistic t_{SRC} is given by Equation (6).

$$t_{SRC} = r_{SRC} \sqrt{\frac{(n-2)}{1 - r_{SRC}^2}} \quad (6)$$

The test statistic t_{SRC} follows a t-distribution with degree of freedom ν and significance level α [43]. The null hypothesis of no trend is rejected when $|t_{SRC}| > t_{\nu, 1-(\sigma/2)}$.

2.2.3. Sen's Slope Estimator

The Sen's slope estimator [56], a robust non-parametric method, is used to estimate the magnitude of the trend slope. For a given time series $X_i = x_1, x_2, \dots, x_n$, with N pairs of data, the slope is calculated as Sen's [57]

$$f(t) = Qt + B \quad (7)$$

where Q indicates the slope, while B is a constant. The slope of Q_i in the sample of N pairs of data is calculated:

$$Q_i = \frac{x_j - x_k}{j - k} \quad (8)$$

where x_j and x_k are the values of data pairs at times j and k .

($j > k$), respectively, $i = 1, 2, \dots, N$. The median of Sen's slope estimator is computed as

$$Q_{med} = \begin{cases} Q_{[(N+1/2)]} & \text{if } N \text{ is odd} \\ \frac{Q_{[N/2]} + Q_{[(N+2/2)]}}{2} & \text{if } N \text{ is even} \end{cases} \quad (9)$$

The Q_{med} sign reflects the data trend reflection, while its value represents the steepness of the trend [53]. A positive value of Q_i means that there is an increasing trend, while a negative value of Q_i indicates decreasing trend in the time series analysis.

2.2.4. Serial Correlation Effect

In a classical MK test, we assume that the observed time series data are serially independent. However, some significant autocorrelation coefficients may exist in the hydro-meteorological time series data [3,43]. The trend identified by the classical MK test would be increased (decreased) in a time series with positive (negative) autocorrelation coefficients. Generally, lag-1 autocorrelation is used to test for serial correlation in time series data [58]. The lag-1 autocorrelation coefficient is the simple correlation coefficient of the first observations $N-1$, $X_t, t = 1, 2, 3, \dots, N-1$ and the next observations, $X_{t+1}, t = 2, 3, \dots, N$ [59]. The correlation between X_t and X_{t+1} is given as

$$r_1 = \frac{\sum_{t=1}^{N-1} (X_t - \bar{X})(X_{t+1} - \bar{X})}{\sum_{t=1}^N (X_t - \bar{X})^2} \quad (10)$$

where $\bar{X} = \sum_{t=1}^N X_t$ is the overall mean.

Coefficient r_1 is tested for its significance. The probability limits on the correlogram of an independent series of the two tailed test is given below [59].

$$r_1(95\%) = \frac{-1 \pm \sqrt{N-k-1}}{N-k} \quad (11)$$

where N is the sample size and k is the lag.

If the value of r_1 is outside the confidence interval given above, the data are assumed to be serially correlated otherwise the sample data are considered to be serially independent [59]. In this study, the autocorrelation function (ACF) plot implemented in Python was used to explore the significant autocorrelation coefficients with varying lagged values (confidence level of 0.05).

2.2.5. The Revised Mann-Kendall Test

In this study, the revised Mann-Kendall test (RMK) proposed by Hamed and Rao [47] was employed to address serial autocorrelation issues in rainfall time series analysis. This modified MK test uses a variance correction approach to improve trend analysis. All significant lags in time series

data are considered in the RMK test. Detailed information and calculation methods can be found in previous research [3,8].

3. Results and Discussion

3.1. Statistical Characteristics of the Rainfall Time Series

The basic monthly rainfall statistics of Shanxi province at 18 meteorological stations during the period from 1957 to 2019, such as the maximum, mean, standard deviation (SD), and coefficient of variation (CV), were analyzed and presented in Table 2. The maximum and mean of the long-term monthly rainfall at 18 meteorological stations in the study area varied from 264.70 mm to 468.60 mm and 31.93 mm to 64.27 mm, respectively. The SD ranged from 38.45 to 70.03 and CV ranged from 109% to 135%, which indicates that there is a great temporal variation for the long-term monthly rainfall for the whole period of 63 years (1957–2019) in Shanxi province. The highest mean value was found at Wutai Shan station, whereas the CV here was lowest among the meteorological stations. These values indicate that the regions covered by Wutai Shan station with greater rainfall had less variability than the regions with relatively lower rainfall. This finding is consistent with the results of Gajbhiye et al. [4].

Table 2. Basic statistics of monthly rainfall at 18 meteorological stations during the period from 1957 to 2019.

Station	Min (mm)	Max (mm)	Mean (mm)	SD	CV (%)
Youyu	0	264.70	35.82	44.40	124
Datong	0	231.80	31.93	38.45	120
Hequ	0	339.40	34.74	46.74	135
Wutai Shan	0	403.10	64.27	70.03	109
Wuzhai	0	348.40	39.84	48.13	121
Xingxian	0	349.30	41.38	50.81	123
Yuanping	0	391.70	35.65	48.83	137
Lishi	0	321.90	41.44	51.85	125
Taiyuan	0	360.00	36.63	47.29	129
Yangquan	0	427.40	45.06	58.66	130
Yushe	0	351.60	45.16	55.96	124
Xixian	0	403.30	43.33	51.69	119
Jiexiu	0	298.90	38.48	47.05	122
Linfen	0	287.90	39.96	49.00	123
Changzhi	0	345.70	46.62	53.99	116
Yuncheng	0	287.40	43.91	48.10	110
Houma	0	305.90	42.48	48.82	115
Yangcheng	0	468.60	49.80	58.13	117

SD means standard deviation; CV indicates coefficient of variation.

The basic statistics of seasonal (spring, summer, autumn, and winter) and annual rainfall in the study period of 1957–2019, such as the mean, SD, and CV, were also analyzed, and are shown in Table 3. The mean and SD of annual rainfall at different stations varied from 427.82 mm to 771.28 mm and from 84.27 to 205.95, respectively. There was a low CV at the annual scale, which indicates a less inter-annual variability with varied meteorological stations. In terms of seasonal rainfall, the mean and SD of spring rainfall varied from 59.90 mm to 125.12 mm and from 28.08 to 49.11; summer rainfall varied from 230.87 mm to 458.38 mm and from 68.92 to 145.90; autumn rainfall varied from 84.68 mm to 158.28 mm and from 36.50 to 75.58; and winter rainfall varied from 7.42 mm to 34.69 mm and from 4.5 to 22.44 over the period from 1957 to 2019. Summer had the highest mean rainfall and lowest CV, while winter had the lowest mean rainfall and highest CV. These findings indicate that the regions with greater rainfall have less variability than the regions with relatively lower rainfall. This finding is similar to the results of Gajbhiye et al. [4,11].

Table 3. Basic statistics of seasonal and annual rainfall at 18 meteorological stations during the period 1957 to 2019.

Station	Spring			Summer			Autumn			Winter			Annual		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
Youyu	66.38	31.68	48	267.87	75.36	28	87.17	40.59	47	8.40	4.50	54	429.82	98.65	23
Datong	59.90	28.20	47	230.87	68.92	30	84.68	36.50	43	7.68	4.84	63	383.13	84.27	22
Hequ	60.71	30.30	50	258.56	101.23	39	88.63	43.76	49	9.03	5.61	62	416.93	127.93	31
Wutai Shan	125.12	49.11	39	458.38	145.90	32	153.10	54.59	36	34.69	22.44	65	771.28	205.95	27
Wuzhai	73.07	28.08	38	289.05	85.28	30	103.57	42.06	41	12.40	6.44	52	478.10	105.34	22
Xingxian	73.91	29.85	40	293.12	102.59	35	115.99	50.19	43	13.56	7.27	54	496.58	129.82	26
Yuanping	57.22	28.40	50	272.62	107.67	39	90.56	44.31	49	7.42	5.32	72	427.82	118.11	28
Lishi	74.57	33.62	45	284.81	102.68	36	126.81	58.00	46	11.71	7.34	63	497.27	123.34	25
Taiyuan	66.10	37.00	56	259.95	93.21	36	102.37	51.38	50	11.08	7.58	68	439.50	112.40	26
Yangquan	79.81	43.94	55	334.03	117.84	35	113.08	53.73	48	13.84	9.57	69	540.76	143.37	27
Yushe	76.98	34.30	45	328.15	108.20	33	121.13	53.19	44	15.67	9.16	58	541.94	123.64	23
Xixian	81.33	38.25	47	290.86	99.78	34	132.18	61.40	46	15.59	9.30	60	519.96	123.47	24
Jiexiu	73.94	34.22	46	259.40	88.56	34	115.60	55.33	48	12.81	7.83	61	461.75	108.35	23
Linfen	82.56	38.08	46	262.40	97.39	37	121.33	59.00	49	13.29	8.67	65	479.58	113.68	24
Changzhi	96.40	35.98	37	322.45	100.33	31	119.45	56.17	47	21.14	11.61	55	559.45	112.13	20
Yuncheng	107.75	43.33	40	244.73	89.35	37	158.28	75.58	48	16.12	11.34	70	526.89	121.58	23
Houma	99.45	43.58	44	253.20	99.08	39	137.76	60.23	44	19.36	12.02	62	509.77	121.57	24
Yangcheng	107.22	42.13	39	321.91	115.45	36	143.93	65.82	46	24.57	15.26	62	597.62	134.60	23

3.2. Autocorrelation Analysis

In this study, a total of 306 time series (each station contains 12 monthly, four seasonal, and one annual series) generated from 18 meteorological stations were employed to investigate the serial correlation by using the ACF plot in Python. The results of the ACF plot demonstrated that most of the observed series were serially independent. For instance, the time series of rainfall in March at Changzhi and Yuanping stations, in June at Xingxian station, and in September at Yangquan station show slight autocorrelation (Figure 2), which were not expected to influence the results of the trend analysis when using the MK test. Detailed information can be found in the following sections. Statistically significant autocorrelation coefficients were identified in February (first and third lags) and winter (first and second lags) at Wutai Shan station (Figure 3), which resulted in a disproportionate result using a classical MK test [60].

Figure 2. Autocorrelation Function (ACF) plot in March at Changzhi and Yuanping stations, in June at Xingxian station, and in September at Yangquan station.

Figure 3. ACF plot in February and winter at Wutai Shan station.

3.3. Monthly, Seasonal, and Annual Rainfall Trend

The results of the Mann–Kendall (MK) test and Spearman's Rho (SR) test without considering the effect of serial correlation for monthly rainfall series at each station in Shanxi province during the period from 1957 to 2019 are presented in Table 4. The significance level of 10%, 5%, and 1% were considered at each station for Z-statistics of the MK and correlation coefficient of SR. Both positive and negative trends (either statistically significant or non-significant) depending on the stations, were identified using MK and SR tests for monthly rainfall series at 10%, 5%, and 1% levels of significance. However, negative trends dominated at the monthly time scale. As can be seen from Table 4, there was no significant trend detected in June or September for all meteorological stations. Neither significant nor non-significant trends were detected at the monthly scale using the MK and SR tests at 10%, 5%, and 1% significance levels at Youyu, Datong, Xingxian, Yuanping, Lishi, and Taiyuan stations. There was a significant increasing trend in May at Hequ and Wuzhai stations and a significant decreasing trend in March at Yuncheng and Yangcheng stations at the 10% level using MK and SR, and a significant decreasing trend in March at Yushe and Chagnzhi at the 10% level using MK and 5% level using SR. The Wutai Shan station showed significant decreasing trends in January, February, March, April, November, and December at the 1% level using MK and SR. For the remaining months at Wutai Shan station, non-significant decreasing trends were identified by MK and SR (Table 4). Two stations, Wuzhai and Changzhi, experienced significant increasing trends in February at the 5% level. Except for Yangquan and Yushe stations, neither significant positive nor negative trends were detected in August using the MK and SR tests. In July, only Yuncheng station experienced a significant decreasing trend at the 5% level, while the other stations showed non-significant decreasing trends. These findings are consistent with the findings of Gajbhiye et al. [4], which demonstrated that July in the Sindh Basin (1901–2002) experienced a decreasing trend (significant or non-significant at the 10% level). The results of precipitation trends in Jiangxi province during 1960–2008 indicated that June, July, and August showed upward trends as detected by the MK test, which present a contrasting result compared with our study in Shanxi province [2]. The largest number of stations showing decreasing trends occurred in March with 10 out of 18 stations at the 10%, 5%, and 1% levels. Overall, most stations experienced a decreasing trend (significant or non-significant) for the monthly rainfall series, as assessed using the MK and SR tests, during the period from 1957 to 2019, especially Wutai Shan station.

The results of the MK test and SR test, without considering the effect of serial correlation for seasonal and annual rainfall series at each station in Shanxi province over the period 1957–2019, are provided in Table 5. Across the four seasons, only Wutai Shan station showed significantly decreasing trends at the 10%, 5%, and 1% levels; the other stations did not have significant trends. In summer, all stations exhibited decreasing trends, except Lishi, based on the MK and SR tests. Ye [61] investigated the trend of China's summer precipitation; they showed a significant increasing trend in south China and a decreasing trend in north China. However, no significant trends were identified in the west and China overall. The trend in summer in Shanxi province is consistent with that of north China. In autumn, non-significant upward trends were observed at most stations (13 stations). Trends in spring and winter depended on stations. On the annual scale, only Wutai Shan and Yangcheng stations showed significant decreasing trends at the 1% and 10% levels, respectively. Similarly, Sanikhani et al. [3] reported that most stations in central India during 1901–2010 had decreasing trends on an annual time scale. Sharma and Singh [59] also found that the annual rainfall series over the state of Jharkhand, India, experienced a significant downward trend with a decrease of 14.11%. Wu and Qian [25] reported that annual rainfall shows a significant downward trend in the Wei River Basin and north of the Loess Plateau, where spring rainfall is the major contributor to the decline in annual rainfall.

Table 4. Results of Mann–Kendall (MK) test and Spearman’s Rho (SR) test without considering the effect of serial correlation for monthly rainfall series at 18 meteorological stations during the period from 1957 to 2019.

Station	Test	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Youyu	MK	−1.106	1.181	−0.795	0.605	1.418	0.243	−1.269	−1.103	0.540	0.771	−0.475	0.916
	SR	−0.137	0.147	−0.109	0.098	0.192	0.037	−0.152	−0.146	0.077	0.105	−0.054	0.101
Datong	MK	−1.500	0.944	−0.676	0.475	1.026	1.596	−1.026	−1.180	1.180	0.664	−0.184	−0.312
	SR	−0.189	0.114	−0.088	0.076	0.117	0.196	−0.111	−0.161	0.163	0.072	−0.018	−0.052
Hequ	MK	−1.378	0.083	−1.365	−0.231	1.738	1.566	−0.617	−0.664	0.136	−0.249	−0.244	−0.180
	SR	−0.187	0.028	−0.185	−0.026	0.248	0.211	−0.074	−0.088	0.016	−0.021	−0.026	−0.023
Wutai Shan	MK	−3.441 **	−1.590	−3.547 **	−2.912 **	−0.617	−1.145	−1.649	−1.655	−1.340	−1.655	−2.758 **	−3.797 **
	SR	−0.422 **	−0.199	−0.435 **	−0.377 **	−0.077	−0.162	−0.213	−0.219	−0.155	−0.163	−0.341 **	−0.474 **
Wuzhai	MK	0.160	2.053 *	−1.163	0.884	1.756	0.504	−0.065	0.267	0.338	0.712	−0.279	−0.214
	SR	0.034	0.262 *	−0.153	0.113	0.222	0.075	−0.026	0.018	0.029	0.091	−0.037	−0.034
Xingxian	MK	−0.766	0.071	−1.346	0.184	1.192	1.418	−0.813	0.089	0.077	−1.068	0.018	−0.125
	SR	−0.104	0.008	−0.167	0.040	0.157	0.195	−0.102	0.000	−0.003	−0.111	0.012	−0.031
Yuanping	MK	−0.904	0.226	−0.059	0.937	1.429	1.157	−0.474	−0.854	0.338	0.142	−0.791	−0.348
	SR	−0.107	0.013	−0.007	0.103	0.192	0.153	−0.044	−0.115	0.040	0.031	−0.115	−0.060
Lishi	MK	−0.715	1.121	−0.611	0.202	0.409	0.415	−0.344	0.261	0.261	−0.154	−0.706	0.209
	SR	−0.107	0.134	−0.075	0.030	0.043	0.068	−0.023	0.025	0.039	−0.013	−0.084	0.026
Taiyuan	MK	−0.814	0.552	−1.341	0.154	−0.065	0.510	−0.593	−0.071	0.741	0.261	−1.283	−0.043
	SR	−0.115	0.077	−0.177	0.010	−0.003	0.076	−0.091	−0.030	0.091	0.040	−0.169	−0.029
Yangquan	MK	−1.006	−0.059	−2.177 *	1.210	1.038	0.902	−0.611	−2.260 *	0.047	0.297	−1.501	−0.206
	SR	−0.129	0.002	−0.284 *	0.141	0.149	0.133	−0.089	−0.284 *	0.008	0.038	−0.181	−0.043
Yushe	MK	−0.530	0.718	−1.940	0.718	0.872	0.896	−1.062	−2.461 **	0.463	−0.409	−1.187	0.228
	SR	−0.070	0.078	−0.260 *	0.090	0.134	0.139	−0.119	−0.320 *	0.052	−0.050	−0.148	0.014
Xixian	MK	−1.044	0.671	−2.581 **	0.297	0.374	−0.795	−1.619	−0.599	−0.243	0.047	−1.205	0.168
	SR	−0.123	0.075	−0.309 *	0.036	0.069	−0.096	−0.229	−0.067	−0.020	0.004	−0.159	0.013
Jiexiu	MK	0.280	1.449	−1.804	0.718	−0.166	−0.534	−1.145	0.047	0.225	−0.273	−1.721	−0.243
	SR	0.043	0.184	−0.238	0.094	−0.010	−0.073	−0.132	0.013	0.049	−0.026	−0.198	−0.043
Linfen	MK	−0.006	1.295	−2.058 *	0.504	1.222	0.231	−1.382	−0.878	0.516	−0.024	−1.275	0.114
	SR	−0.003	0.163	−0.273 *	0.059	0.175	0.011	−0.175	−0.115	0.056	0.002	−0.167	0.019
Changzhi	MK	0.460	2.202 *	−1.816	1.339	1.623	0.807	−0.220	−1.229	−0.275	−0.440	0.761	−0.175
	SR	0.077	0.322 *	−0.309 *	0.189	0.253	0.116	−0.028	−0.195	−0.032	−0.071	0.112	−0.026
Yuncheng	MK	−0.536	1.460	−1.821	−0.736	0.071	−0.095	−2.076 *	0.166	0.053	−0.047	−1.299	−0.533
	SR	−0.072	0.209	−0.230	−0.107	0.020	−0.023	−0.250 *	0.034	0.006	−0.010	−0.159	−0.081
Houma	MK	0.173	0.979	−2.325 *	0.985	0.647	0.196	−0.344	−1.103	0.089	0.231	−1.127	−0.379
	SR	0.029	0.119	−0.289 *	−0.137	0.104	0.027	0.051	−0.133	0.025	0.013	−0.156	−0.049
Yangcheng	MK	0.030	1.537	−1.869	−0.320	0.937	0.136	−1.382	−1.441	0.172	−0.113	−1.240	−0.892
	SR	0.006	0.205	−0.247	−0.056	0.130	0.008	−0.176	−0.190	0.022	−0.026	−0.178	−0.108

Numbers in bold indicate significant values at the 10% level, * Significant at the 5% level, ** Significant at the 1% level.

Table 5. Results of Mann–Kendall (MK) test and Spearman’s Rho (SR) test without considering the effect of serial correlation for seasonal and annual rainfall series at 18 meteorological stations during the period from 1957 to 2019.

Station	Test	Spring	Summer	Autumn	Winter	Annual	Station	Test	Spring	Summer	Autumn	Winter	Annual
Youyu	MK	1.269	−1.162	1.085	0.338	0.261	Yangquan	MK	0.516	−1.447	0.083	−1.032	−1.168
	SR	0.208	−0.151	0.134	0.054	0.038		SR	0.083	−0.189	0.005	−0.124	−0.166
Datong	MK	0.955	−0.985	1.317	−0.528	0.783	Yushe	MK	0.824	−1.412	0.125	0.19	−1.506
	SR	0.114	−0.106	0.183	−0.07	0.072		SR	0.108	−0.19	0.003	0.024	−0.204
Hequ	MK	1.038	−0.635	0.522	−0.997	−0.178	Xixian	MK	−0.225	−1.4	−0.154	−0.356	−1.578
	SR	0.138	−0.063	0.069	−0.128	−0.027		SR	−0.036	−0.196	−0.015	−0.042	−0.204
Wutai Shan	MK	−3.203 **	−2.372 **	−1.827	−3.47 **	−3.369 **	Jiexiu	MK	−0.35	−0.51	0.095	0.652	−0.694
	SR	−0.405 **	−0.301 *	−0.232	−0.465 **	−0.439 **		SR	−0.038	−0.065	0.012	0.106	−0.091
Wuzhai	MK	1.435	−0.136	1.684	1.103	0.700	Linfen	MK	0.641	−0.866	−0.249	0.641	−1.269
	SR	0.181	−0.026	0.193	0.139	0.088		SR	0.081	−0.118	−0.025	0.094	−0.164
Xingxian	MK	0.813	−0.231	0.32	−0.475	0.415	Changzhi	MK	1.266	−0.514	0.028	1.036	0.037
	SR	0.092	−0.026	0.038	−0.061	0.042		SR	0.182	−0.055	−0.005	0.165	0.024
Yuanping	MK	1.566	−0.356	0.819	−0.386	0.059	Yuncheng	MK	−1.376	−1.56	−0.225	0.32	−1.75
	SR	0.167	−0.049	0.095	−0.041	−0.006		SR	−0.18	−0.208	−0.033	0.05	−0.226
Lishi	MK	−0.119	0.231	0.676	0.166	0.083	Houma	MK	−0.824	−0.985	0.142	0.765	−1.032
	SR	−0.026	0.028	0.076	0.02	−0.004		SR	−0.109	−0.112	0.01	0.118	−0.129
Taiyuan	MK	−0.273	−0.13	0.617	−0.219	−0.629	Yangcheng	MK	−0.083	−1.85	−0.457	0.783	−1.779
	SR	−0.036	−0.034	0.088	−0.025	−0.083		SR	−0.012	−0.227	−0.065	0.099	−0.213

Numbers in bold indicate significant values at the 10% level, * Significant at the 5% level, ** Significant at the 1% level.

From the trend analysis of the monthly, seasonal, and annual rainfall series above, we can conclude that MK and SR have similar power for detecting the trend of rainfall time series data. This result agrees with the finding of Yue et al. [55]. They demonstrated that these two tests have similar power in detecting monotonic trends in hydrological series.

The Revised Mann–Kendall (RMK) test was used to improve the trend analysis by considering the autocorrelation effect on rainfall time series data over the period of 1957–2019. The results of the RMK test for monthly rainfall series at each station are shown in Table 6. The number of significant trends for all stations have changed when using the RMK instead of the MK test. For instance, the Z-statistic value of Wutai Shan station in February and Datong station in June changed from -1.590 (MK) to -1.722 (RMK) and from 1.596 (MK) to 1.724 (RMK), respectively, which indicates that there is a significant trend at a significance level of 10% when using the RMK test. This is mainly contributed to the variance correction method for eliminating the effect of autocorrelation in rainfall time series. February at Wuzhai station showed a significant upward trend at level of 5% based on MK result, while the Z-statistic value of the RMK test indicated a significant increasing trend at the level of 1%. The Yuncheng station in July experienced a similar change; the Z-statistic value changed from -2.076 (MK test at significance level of 5%) to -2.974 (RMK test at a significance level of 1%). In addition, the values of the Z-statistic in August at Yushe station, in July at Xixian station, and in December at Hequ and Houma stations also changed when using the RMK instead of the MK test. This indicates that decreasing trends occurred more frequently in March, while increasing trends occurred more often in February (Tables 4 and 6).

The results of the RMK test, considering the effect of serial correlation for seasonal and annual rainfall series over the period of 1957–2019 are shown in Table 7. The trend in winter at Wutai Shan station was decreasing at a significance level of 5% when considering the serial correlation effect using the RMK test, while the MK test presented a downward trend at the level of 1%. The values of the Z-statistic based on MK test were -1.376 , -1.56 , and -1.75 , for spring, summer, and annual at Yuncheng station, respectively, while the values of Z-statistic using RMK test were -2.301 , -2.285 , and -2.391 , respectively (Tables 5 and 7). On the seasonal scale, summer for all stations showed a decreasing trend (significant or non-significant). There was no significant trend at the annual scale, except for Wutai Shan, Yushe, Yuncheng, and Yangcheng stations.

It should be noted that the Z-statistic value of Hequ station in December changed dramatically from -0.18 (MK) to -4.289 (RMK; Table 6). In winter, Jiexiu station presented an unreasonable Z-statistic value (10.179) when using the RMK test, which is not consistent with actual trend of the rainfall time series in winter (Table 7). The $Var(s)$ of MK in December at Hequ station and in winter at Jiexiu station was 27,813.667 and 28,423, respectively, while the RMK was only 48.92 and 116.79, respectively. Although similar trends and slopes obtained from monthly, seasonal, and annual rainfall series in Shanxi province over the period 1957–2019 were found using RMK test, mismatched results were also generated. Therefore, the RMK test may not be suitable for detecting monotonic trend in some cases. More trend identification methods should be considered, as suggested by Patakamuri et al. [52], to obtain accurate trend in hydro-meteorological variables.

Table 6. Results of the Revised Mann–Kendall (RMK) test with considering the effect of serial correlation for monthly rainfall series at 18 meteorological stations during the period from 1957 to 2019.

Station	Jan	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Youyu	−1.106	1.181	−0.671	0.823	1.328	0.343	−1.180	−1.103	0.700	0.669	−1.306	0.916
Datong	−1.500	0.944	−0.586	0.517	1.026	1.724	−1.258	−1.403	1.180	0.664	−0.223	−0.365
Hequ	−1.442	0.083	−1.866	−0.231	1.253	1.566	−0.617	−1.040	0.141	−0.249	−0.344	−4.289 **
Wutai Shan	−4.407 **	−1.722	−4.691 **	−2.912 **	−0.750	−1.145	−1.649	−1.546	−1.340	−1.655	−3.805 **	−3.058 **
Wuzhai	0.226	5.761 **	−1.163	1.476	1.756	0.496	−0.065	0.279	0.338	0.712	−0.324	−0.253
Xingxian	−0.766	0.071	−1.346	0.163	1.011	1.636	−0.813	0.094	0.077	−1.068	0.025	−0.159
Yuanping	−0.904	0.226	−0.138	0.937	1.164	1.356	−0.474	−0.854	0.338	0.142	−0.741	−0.775
Lishi	−0.715	1.121	−0.611	0.202	0.702	0.588	−0.344	0.261	0.297	−0.154	−0.752	0.537
Taiyuan	−0.814	0.552	−1.341	0.194	−0.077	0.994	−0.593	−0.071	0.741	0.261	−1.480	−0.069
Yangquan	−1.402	−0.059	−2.841 **	1.210	1.038	0.286	−0.671	−2.260 *	0.047	0.297	−1.672	−0.220
Yushe	−0.530	0.718	−2.840 **	0.872	0.872	1.189	−1.062	−2.133 *	0.463	−0.409	−1.480	0.653
Xixian	−1.044	0.671	−2.581 **	0.297	0.470	−1.470	−1.925	−0.768	−0.243	0.047	−1.345	0.330
Jiexiu	0.280	1.449	−1.804	0.718	−0.166	−0.534	−1.145	0.047	0.225	−0.383	−1.606	−0.873
Linfen	−0.006	1.295	−4.164 **	0.504	1.222	0.289	−1.382	−0.878	0.389	−0.024	−1.185	0.408
Changzhi	0.460	2.160 *	−2.144 *	1.837	1.467	0.807	−0.273	−1.229	−0.275	−0.383	0.729	−0.197
Yuncheng	−0.517	1.460	−2.319 *	−0.967	0.071	−0.107	−2.974 **	0.166	0.053	−0.047	−1.494	−1.136
Houma	0.173	0.761	−2.325 *	−0.985	0.604	0.196	−0.300	−0.990	0.094	0.308	−0.956	−1.829
Yangcheng	0.030	1.537	−1.869	−0.221	1.048	0.177	−1.382	−1.624	0.146	−0.113	−1.192	−0.892

Numbers in bold indicate significant values at the 10% level, * Significant at the 5% level, ** Significant at the 1% level.

Table 7. Results of the Revised Mann–Kendall (RMK) test with considering the effect of serial correlation for seasonal and annual rainfall series at 18 meteorological stations during the period from 1957 to 2019.

Station	Spring	Summer	Autumn	Winter	Annual	Station	Spring	Summer	Autumn	Winter	Annual
Youyu	1.269	−1.892	1.085	0.338	0.23	Yangquan	0.516	−1.447	0.069	−1.285	−1.168
Datong	0.955	−1.16	1.317	−0.528	0.959	Yushe	0.824	−1.412	0.125	0.356	−1.692
Hequ	1.038	−0.635	0.522	−0.997	−0.178	Xixian	−0.225	−1.378	−0.154	−0.498	−1.578
Wutai Shan	−3.203 **	−2.372 **	−1.827	−2.011 *	−3.369 **	Jiexiu	−0.415	−0.51	0.093	10.179 **	−0.694
Wuzhai	1.435	−0.136	1.684	2.565 **	0.700	Linfen	0.872	−0.866	−0.249	0.833	−1.269
Xingxian	0.813	−0.231	0.32	−0.577	0.415	Changzhi	1.266	−0.514	0.028	1.036	0.037
Yuanping	1.786	−0.392	0.819	−0.386	0.059	Yuncheng	−2.301 *	−2.285 *	−0.225	0.759	−2.391 **
Lishi	−0.113	0.252	0.481	0.28	0.091	Houma	−1.543	−0.985	0.142	0.804	−1.032
Taiyuan	−0.25	−0.192	0.454	−0.219	−0.925	Yangcheng	−0.093	−1.85	−0.457	1.904	−1.779

Numbers in bold indicate significant values at the 10% level, * Significant at the 5% level, ** Significant at the 1% level.

As indicated by the above analysis, early spring (March) experienced a decreasing (significant or non-significant) trend at most stations. This indicated that the climate of Shanxi province will be drier in the future. March is the beginning of spring plowing in Shanxi province, so a negative influence on agricultural activities, the water supply, the natural environment, public health, and socioeconomic development can be expected. Stations with significant decreasing trends at the 10%, 5%, and 1% level are mainly distributed in the east, south, and south-east of Shanxi province. In the north-east of Shanxi province, only Wutai Shan station showed a significant decreasing trend at the 1% level in March. However, stations distributed in the west and north-west of Shanxi province presented non-significant decreasing trends. Therefore, adaptation pathways for changes of rainfall in Shanxi province should be formulated based on the sensitive regions and time period, such as optimizing the planting structure, building agricultural irrigation projects, and constructing water conservancy projects, and these should be flexible in order to respond to future knowledge of climate change to guards against the potential risks [62,63].

3.4. Magnitude of Trend

The magnitudes of the trends for the monthly, seasonal, and annual rainfall series over the period from 1957 to 2019 in the study area were calculated using Sen's slope estimator, and are provided in Table 8. In January, 6 out of 18 stations had no trend, while other stations had slight negative slopes (close to zero). Most of stations in February showed a positive slope or no trend, except Wutai Shan station (-0.104 mm/year), while all stations in March presented a negative slope, especially Wutai Shan station (-0.494 mm/year). There was an increasing slope of the rainfall trend in the monthly series (April to June, September) for most stations. The values of Sen's slope in Table 8 indicate that the falling slope of the rainfall trend existed in July, August, October, and November. There was no significant trend slope identified in December. A negative trend of rainfall slope was observed for all stations in summer. This finding is not consistent with the results of Gajbhiye et al. [4], who concluded that all stations in the Sindh River Basin in India had positive trend slope for the summer season. Huang et al. [2] applied the MK test to detect rainfall trends at the monthly, seasonal, and annual scale during 1960–2008 in Jiangxi province, south-east China. They found that significant increasing trends existed in January, August, winter, and summer.

Table 8. The magnitudes of trend slope for monthly, seasonal, and annual rainfall time series at each station over the period from 1957 to 2019.

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Spring	Summer	Autumn	Winter	Annual
Youyu	−0.010	0.025	−0.030	0.057	0.194	0.050	−0.421	−0.464	0.131	0.100	−0.008	0.005	0.241	−0.617	0.335	0.012	0.152
Datong	−0.010	0.017	−0.022	0.048	0.118	0.229	−0.326	−0.322	0.268	0.064	0.000	0.000	0.159	−0.594	0.388	−0.017	0.539
Hequ	−0.011	0.000	−0.067	−0.030	0.254	0.282	−0.312	−0.296	0.035	−0.029	0.000	0.000	0.182	−0.573	0.185	−0.044	−0.214
Wutaishan	−0.135	−0.104	−0.494	−0.420	−0.109	−0.312	−0.963	−1.040	−0.429	−0.279	−0.333	−0.180	−1.067	−2.263	−0.740	−0.428	−4.224
Wuzhai	0.000	0.062	−0.053	0.094	0.241	0.083	−0.028	0.120	0.083	0.059	−0.017	−0.003	0.294	−0.080	0.467	0.056	0.485
Xingxian	−0.011	0.000	−0.071	0.030	0.204	0.345	−0.351	0.071	0.029	−0.133	0.000	0.000	0.155	−0.157	0.126	−0.025	0.439
Yuanping	0.000	0.000	0.000	0.091	0.220	0.236	−0.190	−0.430	0.107	0.013	−0.028	0.000	0.348	−0.238	0.238	−0.013	0.035
Lishi	−0.007	0.029	−0.043	0.027	0.068	0.065	−0.160	0.072	0.069	−0.021	−0.054	0.000	−0.019	0.179	0.258	0.007	0.075
Taiyuan	−0.002	0.011	−0.066	0.026	−0.009	0.133	−0.277	−0.011	0.203	0.032	−0.059	0.000	−0.071	−0.066	0.200	−0.009	−0.461
Yangquan	−0.012	0.000	−0.119	0.142	0.193	0.205	−0.352	−0.921	0.016	0.043	−0.084	0.000	0.132	−1.236	0.029	−0.050	−1.227
Yushe	−0.003	0.023	−0.114	0.103	0.150	0.226	−0.493	−1.103	0.127	−0.054	−0.083	0.000	0.200	−1.173	0.038	0.016	−1.205
Xixian	−0.012	0.018	−0.180	0.036	0.066	−0.175	−0.693	−0.281	−0.089	0.006	−0.085	0.000	−0.071	−1.067	−0.096	−0.020	−1.659
Jiexiu	0.000	0.042	−0.112	0.093	−0.033	−0.074	−0.450	0.011	0.068	−0.042	−0.107	0.000	−0.087	−0.323	0.052	0.050	−0.500
Linfen	0.000	0.038	−0.147	0.071	0.226	0.050	−0.606	−0.333	0.148	−0.005	−0.090	0.000	0.136	−0.640	−0.094	0.036	−1.083
Changzhi	0.010	0.170	−0.207	0.246	0.564	0.419	−0.150	−0.577	−0.124	−0.100	0.077	0.000	0.500	−0.450	0.020	0.129	0.093
Yuncheng	−0.003	0.056	−0.159	−0.112	0.013	−0.022	−0.850	0.067	0.028	−0.009	−0.144	0.000	−0.365	−0.987	−0.105	0.024	−1.433
Houma	0.000	0.041	−0.221	−0.146	0.109	0.044	−0.176	−0.417	0.032	0.062	−0.114	0.000	−0.237	−0.586	0.041	0.052	−0.878
Yangcheng	0.000	0.097	−0.157	−0.037	0.179	0.047	−0.800	−0.576	0.055	−0.028	−0.138	−0.004	−0.015	−1.586	−0.225	0.078	−1.718

3.5. Impacts of ENSO on Rainfall in Shanxi Province

Previous studies have demonstrated that atmospheric circulation patterns (e.g., ENSO) have an influence on global and regional precipitation [64–70]. In order to better understand the impacts of extreme climate events on rainfall in Shanxi province, seasonal and annual rainfall anomalies in the years of El Niño and La Niña were analyzed based on the average rainfall over the period of 1981–2010. As indicated by the National Oceanic and Atmospheric Administration (NOAA), El Niño and La Niña events can be identified by using Oceanic Niño Index (ONI), which is the running 3-month mean sea surface temperature (SST) anomaly for the Niño 3.4 region. According to the results of ONI, very strong El Niño patterns occurred in 1982–1983, 1997–1998 and 2015–2016, strong El Niño patterns presented in 1957–1958, 1965–1966, 1972–1973, 1987–1988, and 1991–1992, and strong La Niña patterns were observed in 1973–1974, 1975–1976, 1988–1989, 1998–1999, 1999–2000, 2007–2008 and 2010–2011 (<https://ggweather.com/enso/oni.htm>). Rainfall anomalies in seasonal and annual rainfall in the specific El Niño and La Niña years were calculated and are presented in Table 9. As it can be seen from Table 9, both El Niño and La Niña have different degrees of impacts on rainfall. In general, negative annual rainfall anomalies occurred in El Niño years (e.g., 1997, 2015, 1957, 1965, 1972, 1987, and 1991), while positive annual rainfall anomalies presented in La Niña years, excluding 1974, 1999, 2000, 2008, and 2010. From the analysis of ENSO and annual rainfall anomalies, rainfall showed a reduction in El Niño years, and is mainly increased in La Niña years. This is consistent with the statistical analysis of Li et al. [71], which showed that there are many years with reduced annual precipitation in El Niño years, and the probability of negative anomalies is 58.8%, while many years with increased annual precipitation were La Niña years, with a probability of positive anomalies of 56.5%. However, annual rainfall increased in other El Niño years (Table 9), which is in line with results of Li et al. [71].

Table 9. Rainfall anomaly in seasonal and annual rainfall based on the average rainfall during the period (1981–2010).

Very Strong El Niño	Rainfall Anomaly				
	Spring	Summer	Autumn	Winter	Annual
1982	−11.03	49.79	−14.12	−1.14	23.50
1983	58.57	−38.97	58.46	−8.52	69.53
1997	−11.11	−125.70	−23.65	−2.07	−162.53
1998	54.56	13.06	−62.31	−3.45	1.86
2015	−0.87	−94.14	62.54	6.51	−25.96
2016	0.83	96.02	17.32	4.50	118.66
Strong El Niño	Rainfall anomaly				
	Spring	Summer	Autumn	Winter	Annual
1957	5.8551	−6.6057	−50.835	5.1837	−46.402
1958	31.237	134.694	9.359	5.0073	180.298
1965	2.8963	−115.08	−51.294	−7.557	−171.04
1966	−7.621	149.406	−24.753	−3.057	113.975
1972	−44.92	−93.712	−14.294	9.9367	−142.99
1973	−24.3	115.241	55.03	−3.269	142.698
1987	7.7786	−13.012	2.1708	−3.31	−6.3725
1988	10.667	175.177	−50.812	−2.481	132.551
1991	60.902	−102.66	−18.2	4.1484	−55.814
1992	−2.715	36.859	−1.0527	−11.73	21.3627
Strong La Niña	Rainfall anomaly				
	Spring	Summer	Autumn	Winter	Annual
1973	−24.3	115.241	55.03	−3.269	142.698
1974	−24.19	−60.335	8.8531	10.095	−65.573
1975	−14.58	8.9002	44.83	0.2367	39.3863
1976	−9.833	86.4355	−4.3763	14.554	86.7804
1988	10.667	175.177	−50.812	−2.481	132.551
1989	−23.6	23.459	2.7237	13.86	16.4451
1998	54.555	13.059	−62.312	−3.446	1.85686
1999	−6.457	−73.617	−9.3763	−12.35	−101.8
2000	−42.15	5.27078	8.7649	1.672	−26.443
2007	6.161	26.1237	32.347	2.0014	66.6333
2008	10.949	−40.906	13.3	0.4778	−16.178
2010	6.0316	−30.706	0.5884	−2.181	−26.267
2011	−15.12	−4.9469	88.065	1.1955	69.198

On the seasonal scale, generally, summer rainfall decreased in most El Niño years (e.g., 1957, 1965, 1972, 1987, 1991, 1997 and 2015), while summer rainfall increased in most La Niña years (e.g., 1973, 1975, 1976, 1988, 1998 and 2007) and the following El Niño years (e.g., 1958, 1966, 1973, 1988, 1992, 1998 and 2016). Overall, different intensities of ENSO events have positive and negative impacts on seasonal and annual precipitation in Shanxi province, and the direction of the increase or decrease is uncertain. However, the response of annual precipitation to El Niño years is mainly decreased, while it is increased in the following El Niño years. For La Niña years, increases are typically seen. Summer rainfall responds significantly to El Niño and La Niña years.

4. Conclusions

In this study, the trends and magnitudes of slope for monthly, seasonal, and annual rainfall series at 18 meteorological stations in Shanxi province during the period from 1957 to 2019 were investigated using three trend identification methods (MK/SR and RMK tests) and Sen's slope estimator. Both positive and negative trends (significant or non-significant at the significance levels of 10%, 5%, and 1%), depending on stations, were identified in the study area. Similar trends are generally obtained for monthly, seasonal, and annual rainfall series from the MK/SR and RMK tests. In some cases, however, there were some unreasonable results (e.g., monthly rainfall in December at Hequn station and seasonal rainfall in winter at Jiexiu station) provided by the RMK test instead of the MK/SR test. The main findings of this study are summarized as follows.

1. The months June and September showed no significant trends for all stations according to the MK/SR, while only September showed no significant trend using the RMK test. March experienced significant decreasing trends for most stations (Wutai shan, Yangquan, Yushe, Xixian, Jiexiu, Linfen, Changzhi, Yuncheng, Houma, and Yangcheng) at the significance levels of 10%, 5%, and 1% identified by the MK/SR and RMK tests. Only Wutai Shan station showed a significant downward trend in January, March, April, November, and December at the levels of 1% and 5% by the application of the MK/SR and RMK tests. For remaining stations, significant increasing or decreasing trends were observed in February (Wuzhai and Changzhi), April (Changzhi), May (Wuzhai), June (Datong), July (Xixian and Yuncheng), August (Yangquan and Yushe), and December (Houma).
2. On the seasonal scale, similar results were obtained by using the MK/SR and RMK tests. However, the number of significant trends was increased by the application of RMK test. The values of the Z-statistic in summer at Youyu, Yuncheng, and Yangcheng stations using the RMK test showed a significant decreasing trend at the level of 10%, while those using the MK/SR test showed no significant trends. In addition, spring, summer and winter at Yuanping, Yuncheng, and Yangcheng, experienced similar changes when using the RMK test instead of the MK/SR test. Over the four seasons, both the MK/SR and RMK tests indicated that Wutai Shan station showed a significant decreasing trend at a significance level of 1% (spring, summer, and winter) and 10% (autumn). On the annual scale, most stations showed non-significant trends, except Wutai Shan, Yushe, Yuncheng, and Yangcheng, with the application of the RMK test.
3. Summer showed a negative slope magnitudes for all stations. The Wutai Shan station showed the highest negative slope magnitude in the annual series (-4.224 mm/year), followed by the summer (-2.263 mm/year). Spring ranked third, with a decreasing rate of -1.067 mm/year. The magnitudes of the trend slope in January, February, and December for all stations were no trend or slightly increasing (decreasing; close to zero). A falling slope of the rainfall trend existed in July, August, October, and November.
4. Both MK and SR have similar power for detecting monotonic trend in rainfall time series data. Overall, the RMK test proposed by Hamed and Rao [38] can improve the trend analysis of rainfall series by considering the autocorrelation effect at significant lags.

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