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Articles

Analysis on the evolution of precipitation and Runoff characteristics in the east Pi River Basin, China

Análisis de la evolución de las características de la escorrentía y de las precipitaciones en la cuenca este del río Pi, China

Hanjiang Nie[1], ORCID: https://orcid.org/0000-0003-1712-1450
Zhenqian Shen[2]
Tianling Qin[3]
Xinfeng Gong[4]
Yinghou Huang[5]

[1]State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing, China / Key Laboratory for Geographical Process Analysis & Simulation of Hubei Province, School of Urban and Environmental Sciences, Central China Normal University, Wuhan, China, nhj199008@163.com

[2]Guangzhou Water Science Research Institute, Guangzhou, China, shenzqbin@163.com

[3]State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing, China, qintl@iwhr.com

[4]College of Water Conservancy Engineering, Zhengzhou University, Zhengzhou, China, gxf199502@163.com

[5]College of Hydrology and Water Resources, Hohai University, Nanjing, Jiangsu, China, huangyinghou123@163.com

Corresponding author: Tianling Qin, qintl@iwhr.com

Abstract

The natural hydrologic cycle is greatly influenced by climate change. In particular, substantial spatiotemporal variations in precipitation can occur in some mountainous areas, and thus it is very important to identify hydrological processes in watershed with high resolution. To analyze the problem above, the Mann-Kendall test, the moving T-test, Sen's slope estimator and Spearman rank correlation test combined with the spatial interpolation function of ArcGIS, are used to analyze and discuss the evolution of the spatiotemporal distribution characteristics of precipitation and Runoff in a typical small watershed of mountainous areas. The result is precipitation showed a downward trend from south to north and from high-altitude to low-altitude regions. And the difference mainly occurred in the western part of the basin. And the conclusions show the following: 1) An abrupt change in both precipitation and Runoff sequences occurred in 1991; 2) the extreme value of the precipitation trend shifted from the central region to the western region; 3) for the ratio of Runoff in the flood season to annual Runoff, the sequence showed a significant upward trend (95 % confidence level), indicating that the uneven distribution of Runoff has significantly increased since the 1960s.

Keywords: Trend and significance, abrupt change, spatiotemporal analysis, high resolution.

Resumen

El ciclo hidrológico natural se ve muy afectado por el cambio climático. En particular, en algunas zonas montañosas, las precipitaciones pueden variar significativamente en el tiempo y el espacio, por lo que es muy importante identificar los procesos hidrológicos de las cuencas hidrográficas con alta resolución. Para analizar estos problemas, la prueba Mann-Kendall, la prueba T móvil, el estimador de pendiente Sen y la prueba de correlación de rango Spearman se combinan con la función de interpolación espacial ArcGIS. Se analiza y discute la evolución de las características de distribución espacial y temporal de las precipitaciones y la escorrentía en las cuencas montañosas típicas. Los resultados muestran que las precipitaciones disminuyen de sur a norte, de alta

altitud a baja altitud. Esta diferencia se produce principalmente en el oeste de la cuenca. Las conclusiones son las siguientes: 1) la serie de precipitaciones y escorrentías cambió repentinamente en 1991; 2) el valor extremo de la tendencia de las precipitaciones se mueve del centro al oeste; 3) para la relación entre la escorrentía de la temporada de inundaciones y la escorrentía anual, la serie muestra una tendencia ascendente significativa (nivel de confianza del 95 %), lo que indica que la distribución desigual de la escorrentía ha aumentado de forma notable desde la década de 1960.
Palabras clave: tendencia y significado, cambio abrupto, análisis espacio-temporal, alta resolución.

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Introduction

Under the background of global warming and human activities, significant changes have occurred in the precipitation characteristics of global and local regions. Precipitation is the main controlling factor of the spatiotemporal variability of water resources, and significant changes in the spatiotemporal distribution characteristics of precipitation in local areas will bring about transformations in regional Runoff (Zhang & Zhang, 2000; Xia & Ge, 2002; Liu, 2004). Therefore, analysis of the evolution of spatial and temporal characteristics in regional precipitation and Runoff has become one of the primary research directions in regional water cycle and water resources studies under the background of climate change (Trenberth, Dai, Rasmussen, & Parsons, 2010; IPCC, 2013; Yao, Wu, & Guan, 2013; Ren *et al*., 2015).

In recent decades, especially in the past 20 years, many studies have been performed on the trends of precipitation and Runoff and on the relationship between precipitation and Runoff, such as the spatiotemporal characteristics of extreme precipitation events (Xia, She, Zhang, & Du, 2012; Du, Xia, & Zeng, 2014), the spatiotemporal patterns of the dry and wet conditions (He, Ye, & Yang, 2015), the correlation between rainfall and Runoff (Huang, Huang, Chang, Leng, & Yutong, 2016; Xie *et al*., 2018), and the impact of climate change and human activities on Runoff (Ma *et al*., 2014; Wu *et al*., 2017; Zhai & Tao, 2017). Zhang, Zheng, Wang, and Yao (2015a) indicated that abrupt changes in precipitation in East China were recorded mainly in the mid and late 1970s, from the late 1980s to the early 1990s and in the early 21st century. The Huai River Basin is a transitional zone between the northern and southern climate zones in China that is sensitive to climate change and a frequent area of extreme precipitation events. According to statistical analysis, 131 floods and 97 droughts occurred over 530 years (Zhang *et al*., 2015b) and caused substantial losses for the local society, such as economic and property losses and human casualties. Precipitation is closely related to Runoff in the Huai River Basin; namely, variable precipitation is still the main factor affecting water resource changes in the future (Zhang *et al*., 2016).

Notably, the temporal and spatial distribution of precipitation has considerable variability, and detecting patterns of spatiotemporal changes is easier on large scales than small scales (Shi, Ma, Chen, Qu, & Zhang, 2013). However, observations of sufficient spatial and temporal resolution are crucial to the detection of patterns in hydrological series, especially in the Huai River Basin, which is characterized by a large spatiotemporal variability in precipitation (He *et al*., 2015). In addition, the majority of previous studies on spatiotemporal patterns of precipitation in the Huai River Basin were based on sparsely distributed climate observations (Shi *et al*., 2013). Therefore, precipitation that occurs on a suitable regional scale (< 50 000 km^2) is of considerable importance for flood mitigation, water supply and water resource management (Zhang *et al*., 2016).

In this study, the East Pi River Basin was selected as the study area. The research steps of this study are as follows: 1) break point analysis: The Mann-Kendall (M-K) test and the moving T-test were used to determine the breaking point of annual precipitation and annual Runoff series; 2) trend and significance analysis: Sen's slope estimator was used to analyze the trend magnitude of rainfall and Runoff before and after the breaking point, and the M-K trend analysis was used to test the significance level of trend; 3) correlation analysis: Spearman rank correlation test was used to determine the relationship between precipitation and elevation as well as between precipitation and Runoff. The purpose of this study is to identify the temporal and spatial variation trend characteristics of rainfall and Runoff in flood season and annual scale, which can provide technical support for watershed managers to formulate more detailed and scientific flood control and water use strategies.

Materials and methods

Study area

The East Pi River Basin, the catchment above the Foziling Reservoir, is situated between 115° 50′E~116° 30′ E and 30° 55′ N~31° 23′ N, covering a total area of 1 811 km^2 (Figure 1). Topographically, the basin is fluctuant and vertical, and the elevation decreases from the central and southern mountains to the surrounding areas. The elevation of the whole basin decreases from south to north with an elevation difference of greater than 1 600 m. The soil types are mainly rhogosol and brunisolic soil and dark-yellow-brown soil. The Foziling Provincial Nature Reserve in the basin provides good vegetation protection, with a vegetation coverage rate of 77.3 % and is dominated by coniferous forests and shrubs. Situated in a subtropical humid monsoon climate zone, the annual average temperature of the basin is 15.1 °C with 2 084 h annual average sunshine hours. The annual precipitation of the basin is nearly 1 496.8 mm, and the flood season (from June to September) includes approximately 54 % of the annual precipitation. Historically, the Pi River

Basin has suffered frequent floods. Since 1954, 236 major floods have occurred and threaten sustainable socioeconomic development in the basin. Therefore, studying precipitation and Runoff under the context of a changing climate is important.

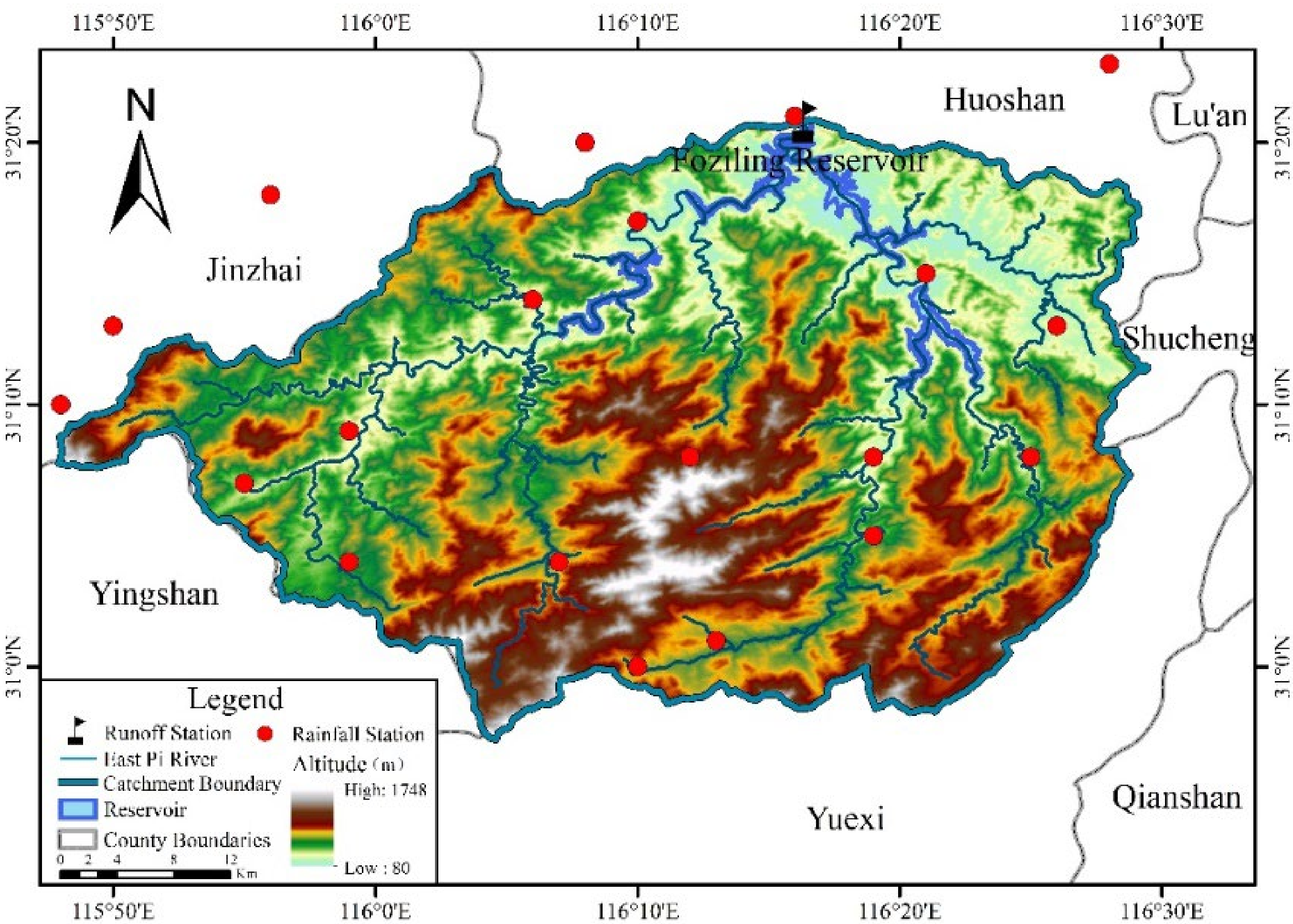

Figure 1. The East Pi River Basin.

Study data

The hydrological data of the East Pi River Basin are from the Huaihe River Conservancy Commission and include daily precipitation data from 20 rainfall stations and daily Runoff data from the Foziling Reservoir Station. The chronological series is from 1960 to 2015. Additionally, the double-mass curve method (Xie *et al.*, 2018) was adopted to validate the consistency of these data, and the results indicated that the data used in the paper are consistent and reliable.

Methodologies

Abrupt change analysis

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The M-K test is a widely used non-parametric order test method that does not require samples to follow a certain distribution, is not subject to interference from a few outliers, and has been widely used in hydrological sequence analysis (Song *et al*., 2015a; Song, Zhang, Liu, & Yang, 2015; Wu, Huang, Yu, Chen, & Ma, 2015). In addition, the moving t-test is used in this article to test the abrupt change points in the precipitation and Runoff sequences. The specific methods of the M-K test and the moving t-test can be found in the literature (Wei, 2007).

Trend analysis and significance test

Generally, a strong or weak trend occurs in hydrological sequences (Wu *et al*., 2015; Tian *et al*., 2017). Sen's slope estimator (Sen, 1968) is a suitable method for sequence trend prediction. This method can effectively avoid the interference of an individual abnormity on sequence trends and is widely used in hydrological analysis (Wu *et al*., 2015; Nie *et al*., 2019). In addition, the M-K trend analysis method is a nonparametric method for trend detection and is used to assess the significance of trends in hydrological sequences. The detailed steps of this method are described in a previous article (Song *et al*., 2015). The strength of statistically

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significant trends is determined as follows (p is the tested significance level, and Z is the test statistic):

Very strong trends: $p \leq 0.025$ ($|Z| \geq 1.96$). Strong trends: $0.025 < p \leq 0.05$ ($1.96 > |Z| \geq 1.645$). Weak trends: $0.05 < p \leq 0.1$ ($1.645 > |Z| \geq 1.28$). Insignificant trends: $p > 0.1$ ($1.28 > |Z|$).

Correlation analysis

In this paper, the correlation of sequences is tested by the Spearman rank correlation test. This method is a nonparametric test method that does not require the distribution of original variables and is widely applicable to reflect the close relationship between two groups of variables (Zhang, Zhang, & Ru, 2005).

The calculation formula of the Spearman correlation coefficient is given as follows:

$$\rho_s = 1 - \frac{6\Sigma d_i^2}{n(n^2-1)} \quad (1)$$

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where d_i is the difference in the rank, n is the number of data points, ρ_s and is the Spearman correlation coefficient. The calculation process is as follows: first, the two sets of data (X, Y) to be analyzed are sorted from large to small and the value of the position of the sorted data, (X', Y'), is recorded as the rank.

In general, the value of ρ_s is between -1 and 1. When ρ_s is greater than zero, the sequence is positively correlated; when ρ_s is less than zero a negative correlation exists, and a ρ_s value equal to zero indicates no correlation exists. Moreover, when the absolute value of ρ_s is 0.8~1.0, 0.6~0.8, 0.4~0.6, 0.2~0.4, and 0.0~0.2, the correlation between the variables is very strong, strong, moderate, weak, and weak or absent, respectively (Qiu, 2009).

Results

Identification of abrupt change in the precipitation and Runoff in the East Pi River Basin

Figure 2 and Table 1 show the abrupt analysis of annual precipitation in the study area using the M-K test and moving t-test methods. According to the UF and UB statistical curves, many intersections can be preliminarily determined in the annual precipitation series under different sequence lengths (1960-2015, 1960-2010, 1965-2010), and the intersections are concentrated in the 1990s. The UF curves show that the annual precipitation series had an upward trend in the early 1970s, but the trend did not reach a significance level of 0.05 and decreased with the time series fluctuation. The moving T-test results of annual precipitation under different sub-sequences (*n* = 10, 11, 12) showed that the maximum value of the t statistics appeared in 1991. In summary, the year of the detected abrupt change in the annual precipitation series obtained by the M-K test and the moving T-test was 1991.

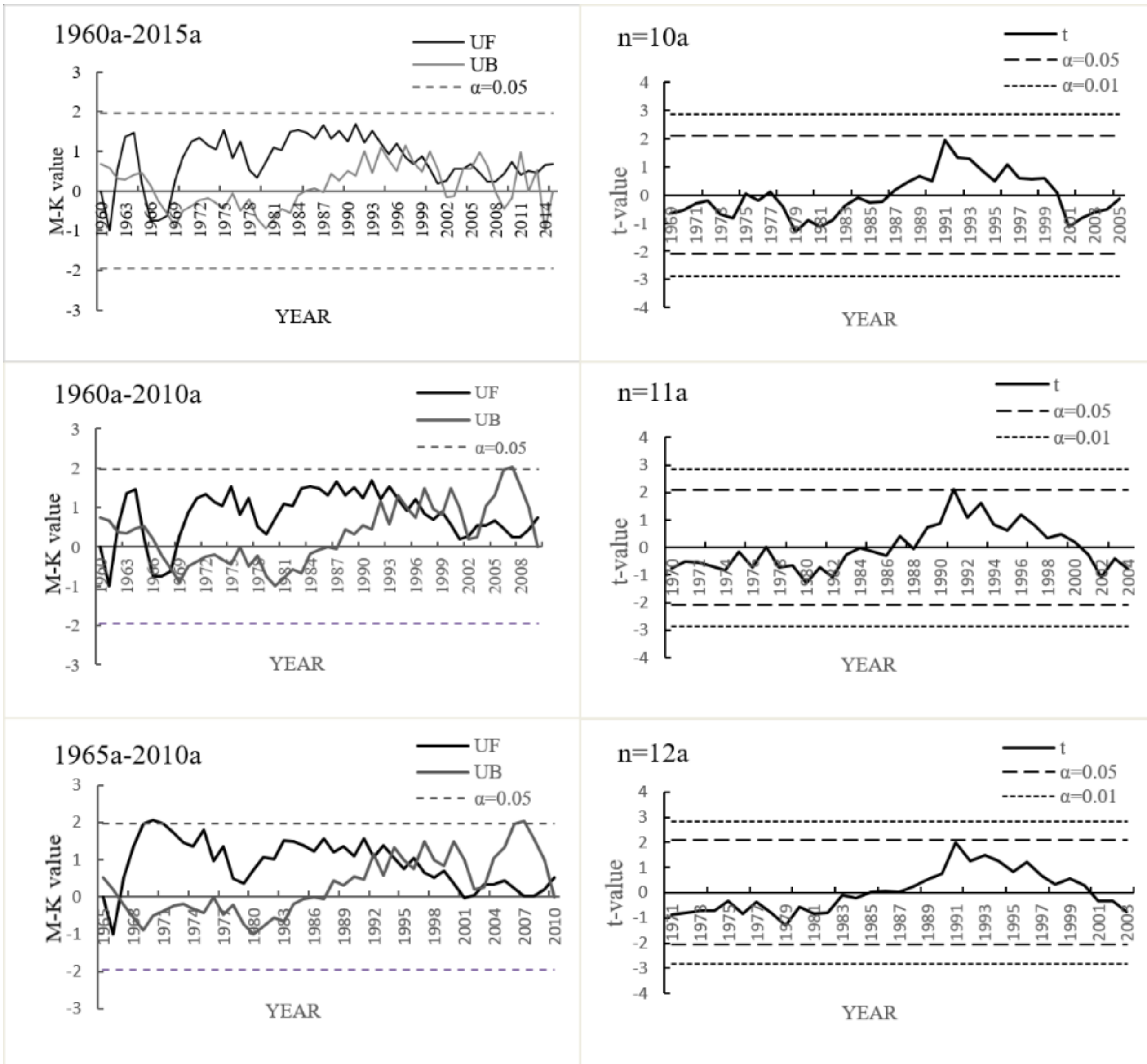

Figure 2. Detected abrupt change results for the annual precipitation in the East Pi River Basin.

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Table 1. Analysis of the abrupt change in the annual precipitation in the East Pi River Basin.

Objective	Methods	Time Series	Results	Significance
Annual precipitation	M-K test	1960a~2015a	1965, 1968, 1997-2013	*
		1960a~2010a	1965, 1969, 1992, 1994-2004	*
		1965a~2010a	1967, 1992, 1994, 1996, 2003	*
	T-test	n=10a	1991	/
		n=11a	1991	*
		n=12a	1991	*

* Significant at the 0.05 level. / Insignificant.

The abrupt change analysis of the annual Runoff series of the Foziling Reservoir Station is shown in Figure 3 and Table 2. For the different time series (1960-2015, 1960-2010, 1965-2010), the UF and UB intersections of the Runoff series appeared in the early 1990s. The UF curve also shows that the annual Runoff series had an upward trend from the early 1970s to the mid-to-late 1990s, while the trend intensity did not reach a significance level of 0.05. Then, the Runoff series showed a downward trend. The results of the moving T-test for annual Runoff series with different sub-sequences (n = 10, 11, 12) showed that the maximum value of the t statistics appeared in 1991, indicating that the year of the detected abrupt change in the annual Runoff series was 1991 and reached a significance level of 0.01.

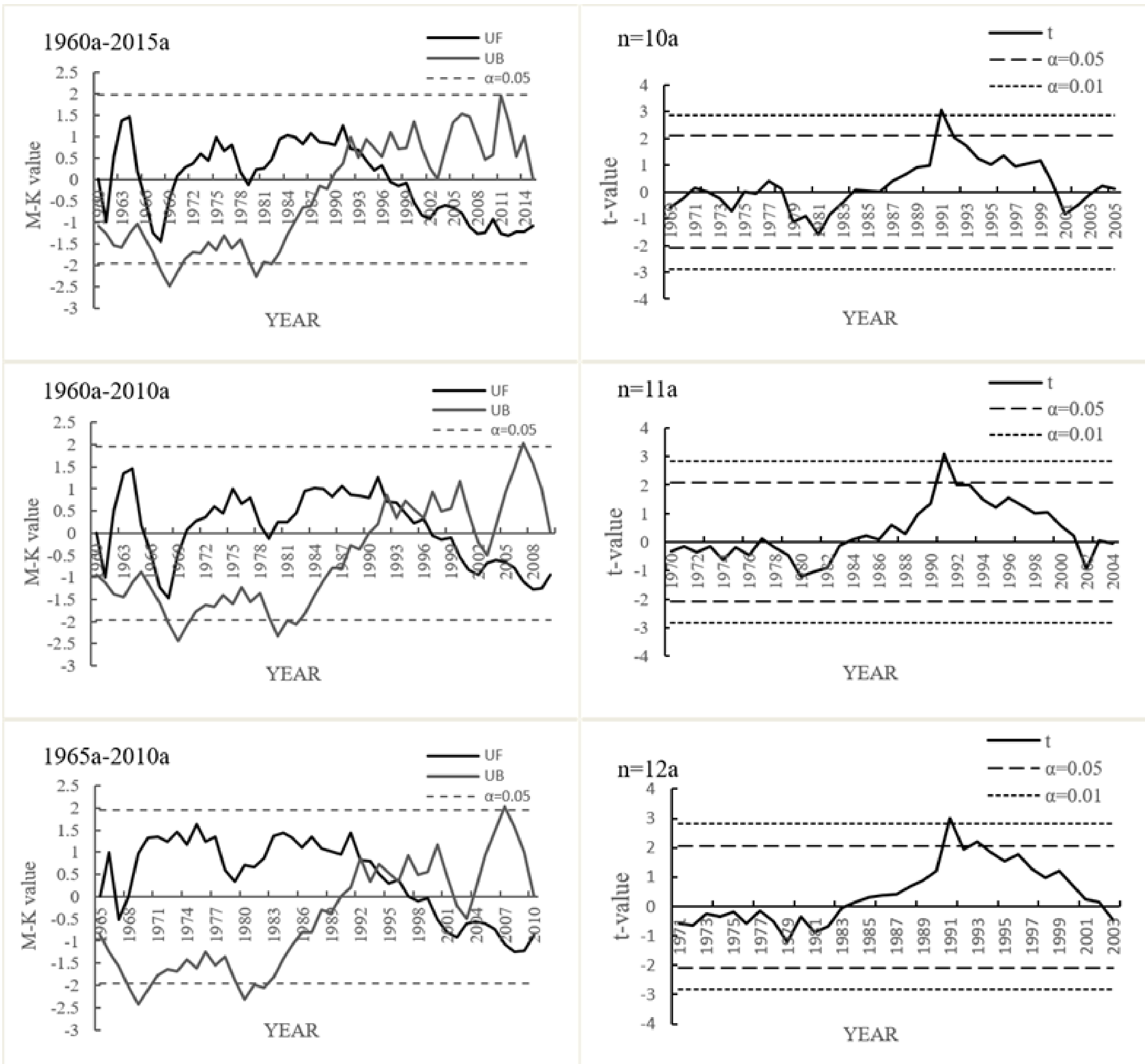

Figure 3. Detected abrupt change results of the annual Runoff of the Foziling Reservoir Runoff station.

Table 2. Analysis of the abrupt change in the annual Runoff.

Objective	Methods	Time series	Results	Significance
Annual Runoff	M-K test	1960a~2015a	1992, 1993	*
		1960a~2010a	1992, 1993	*
		1965a~2010a	1992, 1993	*
	T-test	*n* = 10a	1991	**
		n = 11a	1991	**
		n = 12a	1991	**

* Significant at the 0.05 level.

** Significant at the 0.01 level.

In summary, the abrupt change points in both annual precipitation and Runoff in the basin were located in the early 1990s. A moving T-test indicates the specific time of the abrupt change occurrence: 1991. According to this result, the data from each rainfall station and the Foziling Reservoir Runoff station are divided into two sections based on the abrupt change point: 1960-1991 (before the abrupt change point) and 1992-2015 (after the abrupt change point). Then, the variation trend and characteristics of the precipitation and Runoff series in the study area are determined by analyzing the precipitation and Runoff data in the above two periods.

To intuitively present the changing characteristics of precipitation in the East Pi River Basin, spatial interpolation was carried out according to the precipitation data of the above 20 rain stations.

Temporal and spatial distributions of precipitation

Figure 4 shows the spatial distribution of annual precipitation in the basin before and after the abrupt change. Overall, the annual precipitation decreases from south to north in the basin. Before the abrupt change, the average annual precipitation in the central, southern, and western regions of the basin was relatively high (≥ 1 530 mm), while the annual average precipitation was relatively low (≤ 1 470 mm) in the northern and eastern parts of the basin, with a minimum of 1 410 mm. However, the average annual precipitation of the basin decreased significantly after the abrupt change, and the annual precipitation in most areas decreased by up to 30 mm. Specifically, the precipitation in the central and southern parts of the basin was relatively high (≥ 1 500 mm), while the precipitation in the northwestern part of the basin was relatively low (≤ 1 470 mm). Moreover, based on the difference value of the average annual precipitation before and after the abrupt change, the decrease in the average annual precipitation after the abrupt change mainly occurred in the western part of the basin (decrease of 60~110 mm), and a decrease in the average annual precipitation in some southeastern parts of the basin was not obvious (a decrease of -10~20 mm).

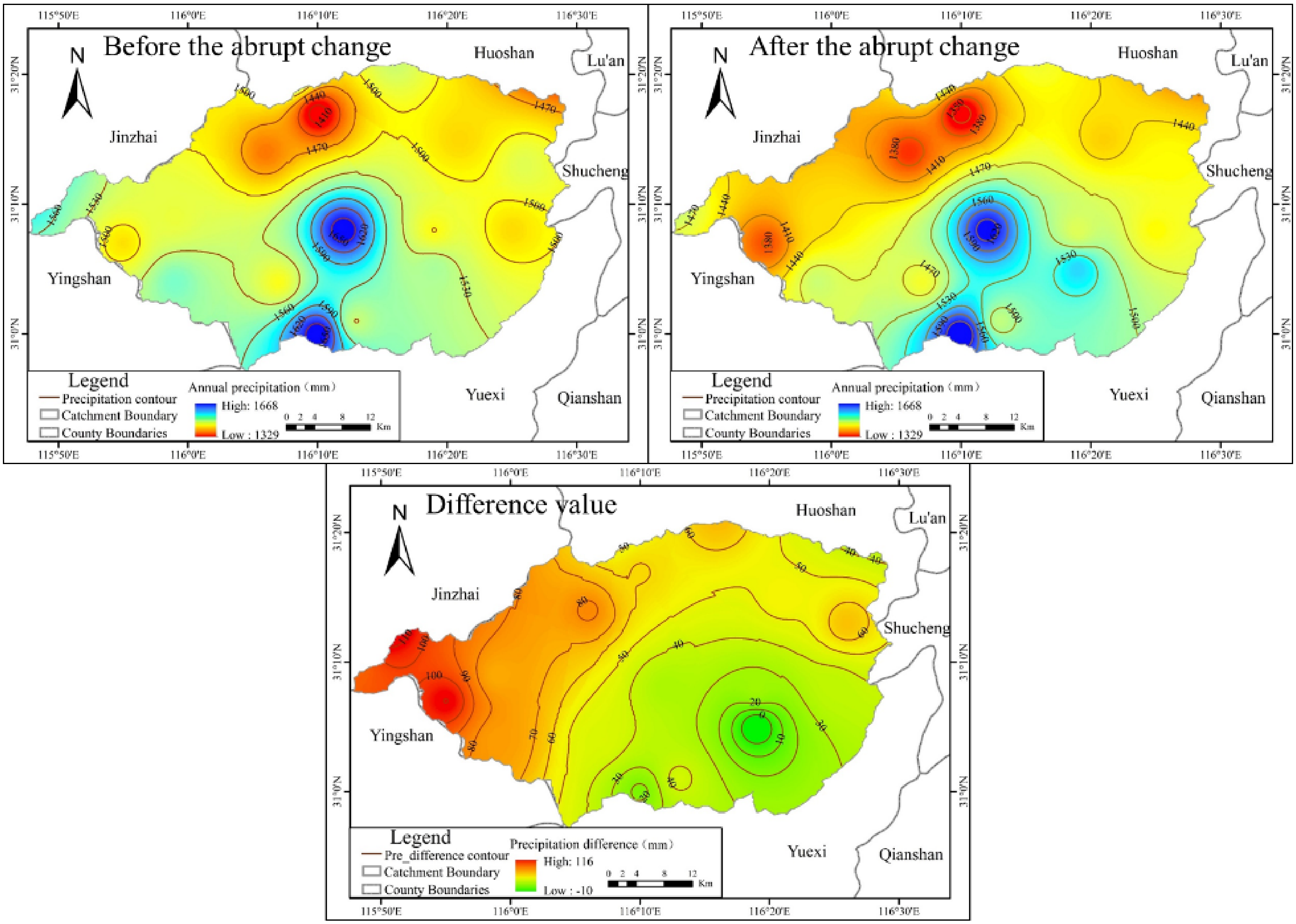

Figure 4. Spatial distribution of annual precipitation in the East Pi River Basin.

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Figure 5, similar to Figure 4, portrays the spatial distribution of precipitation in the flood season before and after the abrupt change. Overall, precipitation in the flood season shows a downward trend from south to north in the basin. Before the abrupt change, precipitation (≥ 820 mm) is mainly concentrated in the western and south-central parts of the basin, but after the abrupt change, precipitation is mainly concentrated in the central and southern parts of the basin. The difference value of the average precipitation in the flood season before and after the abrupt change shows that the decrease in average precipitation after the abrupt change is still mainly in the western part of the basin, and the maximum value reached up to 60 mm. In addition, the difference value in some southeastern parts of the basin is less than zero (-25 to 0 mm), indicating that precipitation does not decrease after the abrupt change.

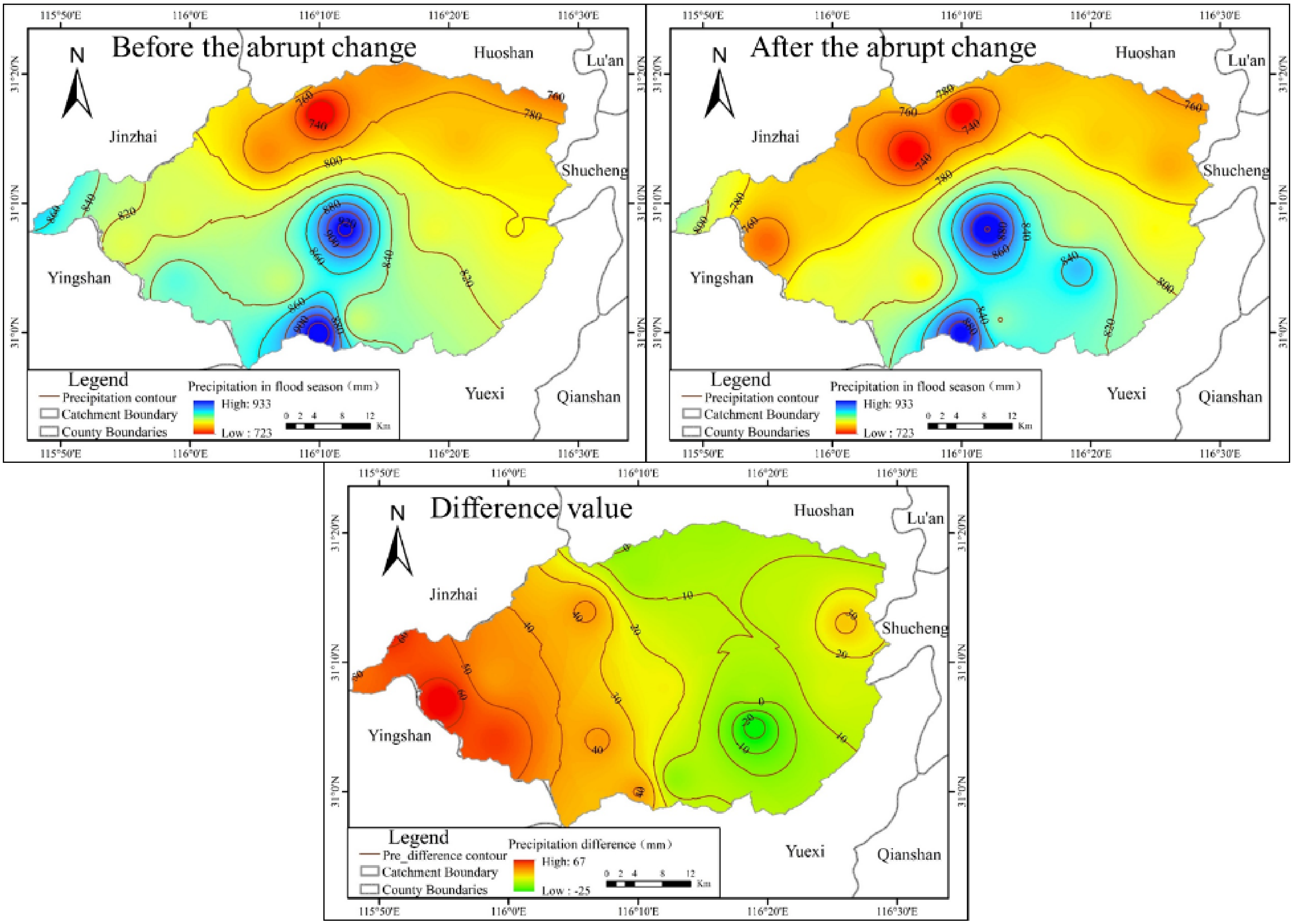

Figure 5. Spatial distribution of precipitation in the flood season.

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The correlation coefficients between the ground elevation and annual precipitation or precipitation in the flood season are 0.68 (a strong correlation) and 0.82 (a very strong correlation), respectively. These results imply that elevation is one of the main factors affecting local precipitation, especially for precipitation in flood seasons.

Figure 4 and Figure 5 show that the spatial distributions of the annual precipitation and the precipitation in the flood season are basically similar, decreasing from south to north and having a high correlation with altitude. In addition, the difference in precipitation before and after the abrupt change shows a downward trend from the western part of the basin to the eastern part, indicating that the decrease in precipitation after the abrupt change mainly occurs in the western part of the basin (the annual average decrease is ≥ 60 mm, and the average decrease in the flood season is ≥ 30 mm), and a substantial decrease does not occur in the southeastern part of the basin.

Precipitation trend analysis and significance

The trends in annual precipitation were different in different periods. From 1960 to 1991, the annual precipitation in the whole basin shows an upward trend. The central and southern regions have a large trend, ranging from 100 mm/10a to 200 mm/10a, while the northern part of the basin has a smaller trend, ranging from 42 mm/10a to 100 mm/10a. The spatial distribution features of the significance of the trends are similar to those of the trends. Specifically, there is a strong significance in the south-central and some eastern regions of the basin, and the trend in the northern part of the basin is insignificant. From 1992 to 2015, the annual precipitation still shows an upward trend, and the trend of the east-central and western parts of the basin is larger, ranging from 100 mm/10a to 135 mm/10a, while the trend of the northwestern and southern regions is smaller, ranging from 36 mm/10a to 80 mm/10a. However, the trends in most areas of the basin are insignificant, except for the eastern part of the basin.

Comparing the spatial distribution of the annual precipitation trend and its significance in different periods (Figure 6) shows that the regions with extreme values in the trend have changed from the central region of the basin to the eastern and western regions. The distribution of the trend of the whole basin became more uniform after the abrupt change, and the significance level decreased to insignificant in most parts of the basin.

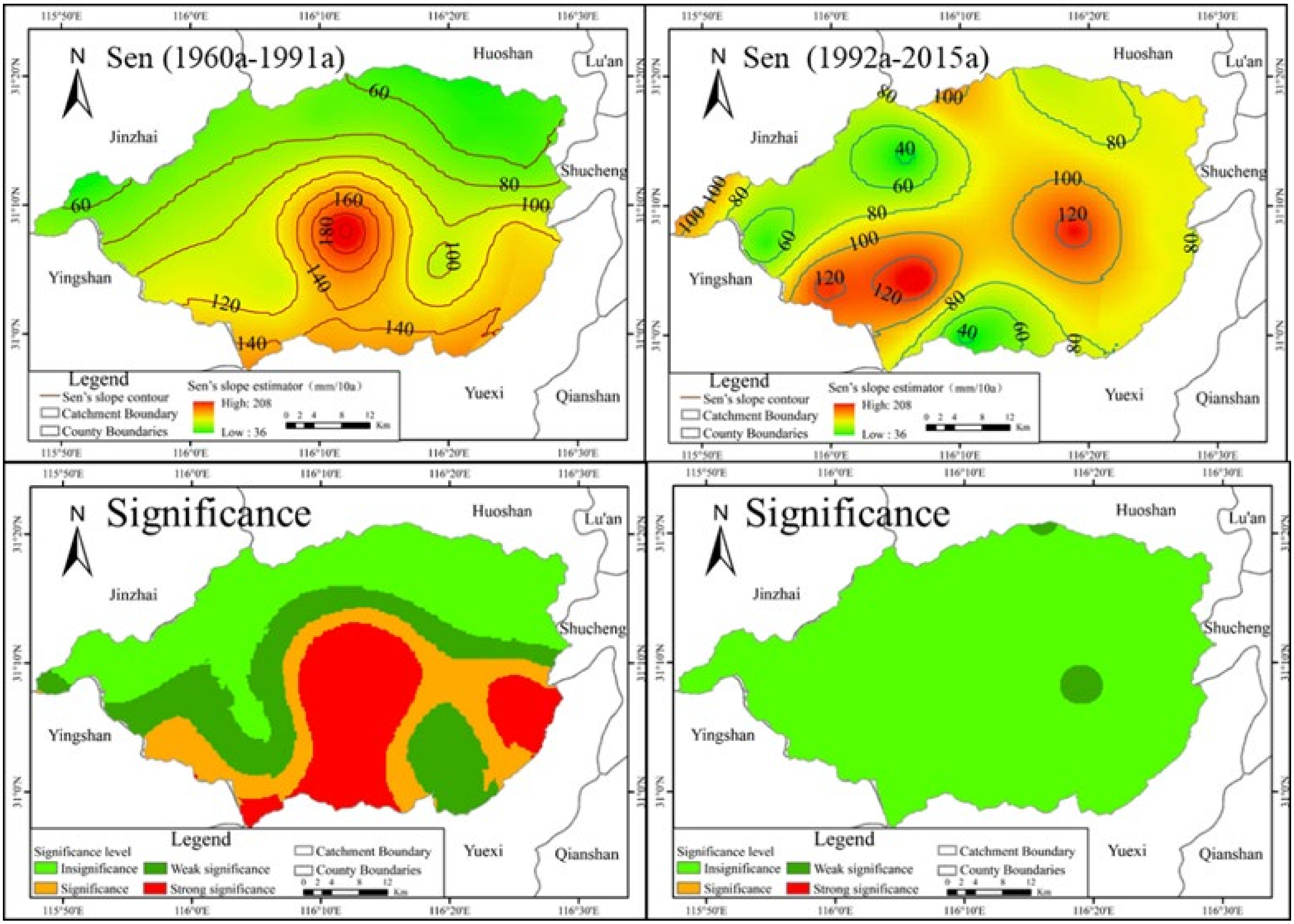

Figure 6. Annual precipitation trend and significance in the East Pi River Basin.

In addition to the trends and their significance in annual precipitation, precipitation in the flood season is also important (Figure 7). From 1960 to 1991, similar to the annual precipitation mentioned above, the summer rainfall of the whole basin showed an upward trend, where the trend of the central and southern regions is larger, ranging from 90 mm/10a to 137 mm/10a, while the trend of the northern region is smaller, between 45 mm/10a and 75 mm/10a. In addition, the spatial distribution of the significance of the trend is related to the spatial distribution of the trend; if the trend is greater than 90 mm/10a, there is at least a weak significance, and if the trend of the regions is greater than 130 mm/10a, there is a strong significance. The upward trend in the northern and western regions of the basin does not reach the level of significance. During the period from 1992 to 2015, although the precipitation in the flood season still showed an upward trend, the spatial distribution of the trend is quite different from that of the period from 1960 to 1991. Therefore, except for the trends of the southeastern and southwestern parts of the basin, which are greater than 105 mm/10a, the trends of the majority of the basin are between 75 mm/10a and 105 mm/10a. From the perspective of significance, while the trends of some regions in the northwestern and southern parts of the basin did not reach the level of significance, the trends of some regions in the central and southeastern parts of the basin reached the level of significance, and precipitation in the flood season in most regions had a weakly significant upward trend.

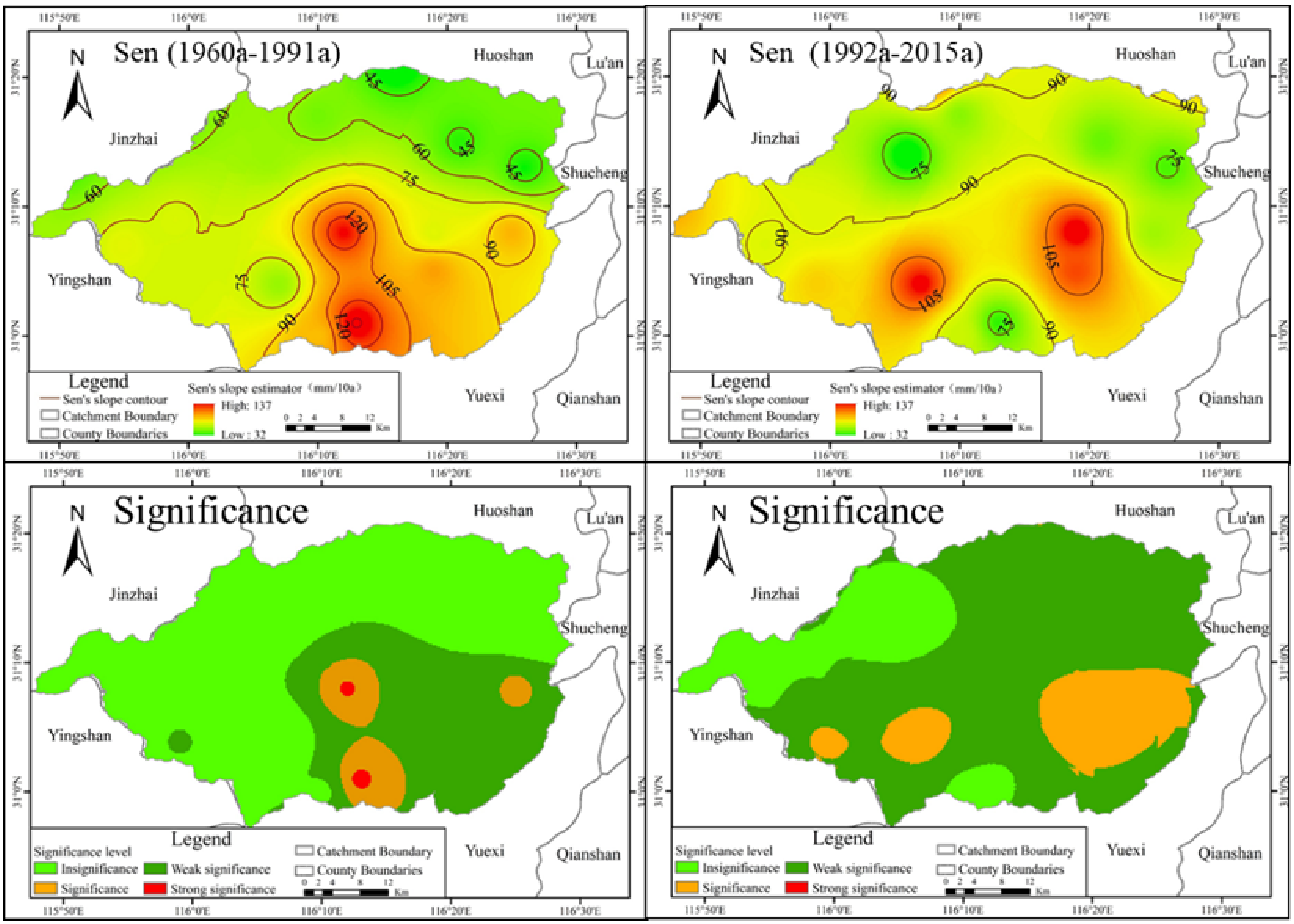

Figure 7. Precipitation trend in the flood season and its significance.

The comparison of the precipitation trends and their significance in the flood season in different periods (Figure 7) shows that the extreme value of precipitation trends shifted from high-altitude areas in the central and southern regions of the basin to the eastern and western regions. Except for precipitation in the northwestern and southern parts of the basin that did not have a significant trend, precipitation in the flood season in other regions had a weakly significant trend (and even a significant trend). The precipitation trend is more homogeneous after the abrupt change.

Overall, the annual precipitation and precipitation in the flood season in the East Pi River Basin showed an upward trend in different time periods, while the spatial distributions of the precipitation trend and significance are quite different. Especially for the period from 1992 to 2015, the annual precipitation has an insignificant upward trend, but the flood season precipitation shows a weakly significant upward trend, indicating that the distribution of precipitation in the basin during the year may be uneven.

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Analysis of Runoff characteristics in the East Pi River Basin

Analysis of basic characteristics in Runoff

Through the normal statistics method, the basic characteristics of the Runoff sequence are calculated, and the results are illustrated in Table 3. Table 3 clearly shows that the mean values of annual Runoff and Runoff in the flood season during 1960-2015 are $14.7\times10^8 m^3$ and $8.11\times10^8 m^3$, respectively. The coefficients of variation (Cv) are 0.35 and 0.51, respectively, indicating that the variation in annual Runoff in the tested 56 years is relatively small, while the variation in Runoff in the flood season is relatively large. In addition, the coefficients of skew (Cs) are 0.97 and 1.85, respectively, showing that the probability of the Runoff series being less than the mean is higher. For the ratio of Runoff in the flood season to annual Runoff, the Cv value is 0.24, which is less than 0.35 or 0.51, indicating that the ratio sequence is more stable than that of the Runoff series. Second, the mean values of annual Runoff and Runoff in the flood season during 1960-1991 are $16.11\times10^8 m^3$ and $8.67\times10^8 m^3$, while the mean values during 1992-2015 are $12.82\times10^8 m^3$ and $7.37\times10^8 m^3$, with a significant decrease of $3.29\times10^8 m^3$ and $1.3\times10^8 m^3$, respectively. Based on the Cs, the values of annual Runoff and Runoff in the flood season during 1960-1991 are greater than zero (0.82 and 1.82, respectively), while the values during 1992-2015 are less than 0 (-0.08 and -0.08, respectively), indicating the probability that the actual Runoff in the year or flood season is greater than the mean of the Runoff series after the abrupt change; that is, the risk of flooding in the basin increased after the abrupt change. Additionally, for the series of the ratio of Runoff in the flood season to annual Runoff, the mean of the ratio during 1960 to 1991 is smaller than the mean during 1992 to 2015, showing that the Runoff has become more concentrated during the flood season since 1992. In addition, the values of Cv and Cs for the ratio mentioned above clearly show that the variation range of the ratio decreases, and the probability of the actual ratio being greater than its mean increases after the abrupt change; namely, the probability of a flood disaster increases.

Table 3. Variation characteristics of Runoff in the East Pi River Basin in 1960a-2015a.

Proposed target	Period	Min	Max	Mean	Std	Cv	Cs
Runoff (annual)	1960-2015	6.38	33.58	14.7	5.12	0.35	0.97
	1960-1991	7.11	33.58	16.11	5.69	0.35	0.82
	1992-2015	6.38	19.25	12.82	3.54	0.28	-0.08
Runoff (flood season)	1960-2015	1.87	26.4	8.11	4.12	0.51	1.85
	1960-1991	2.43	26.4	8.67	4.84	0.56	1.82
	1992-2015	1.87	13.02	7.37	2.84	0.38	-0.08
P	1960-2015	0.29	0.79	0.54	0.13	0.24	-0.15
	1960-1991	0.29	0.79	0.52	0.13	0.25	-0.11
	1992-2015	0.29	0.76	0.56	0.12	0.22	-0.13

P represents the ratio of Runoff in the flood season to annual Runoff; And the unit of Runoff series is 10^8 m^3.

Trends and their significance in Runoff from 1960 to 2015

The trends and significance of the Runoff sequences are shown in Table 4. For the annual Runoff series, a slight upward trend occurs before (from 1960 to 1991) and after (from 1992 to 2015) the abrupt change, while the whole sequence (from 1960 to 2015) shows an insignificant downward trend. This result may occur because the average annual Runoff decreases significantly after the abrupt change. For the Runoff series in

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the flood season, the Runoff series from 1960 to 1991 shows a strong significant upward trend (97.5 % confidence level), while the sequences from 1992 to 2015 show an insignificant upward trend, indicating that the sequences after the abrupt change have not only a significant decrease in the mean but also a gentle trend. For the ratio of Runoff in the flood season to annual Runoff, the sequence from 1960 to 2015 shows a significant upward trend (95 % confidence level), indicating that the proportion of Runoff in the flood season to annual Runoff increases and that the uneven distribution of Runoff during the year increases significantly.

Table 4. Annual Runoff and Runoff trends and significance in the flood season in the East Pi River Basin.

Proposed target	Period	Sen's slope	M-K Trend Analysis	
			Zc	Significance
Runoff (annual)	1960-2015	-0.042	1.081	/
	1960-1991	0.149	1.249	/
	1992-2015	0.102	0.967	/
Runoff (flood season)	1960-2015	0.015	0.558	/
	1960-1991	0.138	2.092	***
	1992-2015	0.069	0.719	/
P	1960-2015	0.002	1.859	**
	1960-1991	0.004	1.703	**
	1992-2015	0.005	1.116	/

** Strong significance

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*** Very strong significance; / Insignificant

And P represents the ratio of Runoff in flood season to annual Runoff.

Correlation between precipitation and Runoff

In this section, the Spearman rank correlation test was used to demonstrate the correlation between precipitation and Runoff. The test results showed that the Spearman rank correlation coefficient of the annual Runoff of the Foziling Reservoir Station and the basin surface precipitation is 0.845 (a very strong correlation), and the correlation coefficient of the Runoff and precipitation in the flood season is 0.811 (a very strong correlation). This result illustrates that precipitation has a strong correlation with Runoff, and precipitation is still the most important factor affecting Runoff.

Discussion and conclusions

Compared with previous studies (Tao *et al*., 2014; Wang & Zhang, 2015; Wang, Chen, & Yan, 2015), the study, based on the data of rainfall stations with higher density, analyzed the characteristics of modern precipitation climate distribution in typical small watershed (taking the East Pi River Basin as an example). And the results are similar to those of previous studies, but some new phenomena and characteristics have also been found. Wang *et al*. (2015) showed that annual rainfall (1960-2010) in the Jianghuai region (the East Pi River Basin belongs to the region) showed an increasing trend, and the abrupt changes in rainfall mainly occurred in the mid-late 1970s, from the late 1980s to the early 1990s and the early 21st Century. And there has been more precipitation in the area since the early 21st century. In this study, annual rainfall also showed an increasing trend, and the most significant abrupt point (1991a) were obtained by combining the M-K test and the moving T-test methods. In addition, due to the uneven distribution of rainfall within the year in China, the rainfall in flood season and annual scale were analyzed respectively. The results showed that the uneven distribution of rainfall in the study area would further increase, which would be conducive to further analysis of the trend of extreme rainfall events in flood season and make positive response. For the Runoff evolution in the area, this study revealed that the annual Runoff (1960-2015) showed decreasing trend, which was similar to the research results of Wang and Zhang (2015) on the Runoff data of two hydrological stations in the main stream of the Huaihe River Basin. At the same time, the flood season Runoff showed increasing trend. Precipitation is the main influencing factor of Runoff change (Li *et al.*, 2021; Zhao, Wang, Dong, Yang, & Govers, 2022), which indicated that the flood season Runoff showed an increasing trend due to the increase in flood season rainfall. Based on the analysis of flood season and annual scale, this study further clarified that changes in rainfall and Runoff were caused by changes in flood season, which will provide technical support for managers to formulate more detailed and scientific flood control and water use strategies. The primary conclusions are as follows:

1. Abrupt changes in the precipitation and Runoff sequences occurred in 1991, and the mean values of the sequences before and after the abrupt changes were significantly different.
2. Precipitation decreases from south to north and from the high-altitude mountainous area to the low-altitude area. However, the difference values, calculated by the average precipitation sequences before and after the breakpoint, are high in the western region of the basin and low in the eastern region. In some southeastern parts of the basin, the difference values are less than

zero, indicating that precipitation increased in these areas after the abrupt change.

3. Precipitation showed an upward trend during the two periods bounded by the abrupt change. After the abrupt change, the distribution trend of precipitation in the basin became more uniform, and the extreme value of the trend shifted from the central region to the western region. In terms of the significance of the trend, the annual precipitation in the central and southern regions during 1960-1991 showed a significant upward trend, while the trend of the whole basin after the breakpoint was insignificant. The precipitation sequences in the flood season have obvious differences, and most of the regions reached a weakly significant upward trend after the breakpoint, indicating that the annual precipitation distribution may have been more uneven since 1992.
4. Similar to the precipitation sequences, the Runoff series also showed an upward trend during the two periods bounded by the abrupt change. Moreover, the average annual Runoff and Runoff in the flood season after the breakpoint decreased by $3.29\times10^{8}m^{3}$ and $1.30\times10^{8}m^{3}$, respectively, compared with the Runoff series before the abrupt change. Regarding the ratio of Runoff in the flood season to annual Runoff, the ratio sequences are more stable than those of the actual Runoff sequences, showing a significant upward trend. This result indicates that the Runoff series is more

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concentrated during the flood season and that the unevenness of the Runoff distribution during the year has increased significantly in the flood season since the 1960s. Therefore, increased vigilance and protection against floods are necessary.

5. High correlations between precipitation and Runoff variability, especially during the flood season, imply that precipitation variability is still the major factor affecting Runoff variability.

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