Trend Analysis of Precipitation in the Jinsha River Basin in China

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ABSTRACT

According to the mean seasonal and annual precipitation from 30 meteorological stations in the periods of 1961–2008, the precipitation trends are analyzed by using the Mann–Kendall (MK) test in the Jinsha River basin (JRB). Both the temporal and spatial distribution characteristics of precipitation trends in different regions in the JRB are studied for the first time in this paper. There is a slight and insignificant increasing trend in seasonal and annual precipitation except for autumn precipitation, and the annual precipitation has increased by 0.7634 mm yr\(^{-1}\) during the last 48 years. The increasing precipitation trends in spring seem more significant than those in the other three seasons, and autumn is the only season showing a slight and insignificant decreasing precipitation trend. There are more than 80% of stations exhibiting increasing trends for annual precipitation, and it goes to 90% for spring precipitation. The increasing precipitation trends in the headwater and the middle reaches are more dominant than those in the upper and lower reaches. The largest increase magnitude occurred in the less precipitation area, while the largest decrease magnitude occurred in the more precipitation area. The increasing trend of minimum precipitation series and decreasing trend of maximum precipitation series could result in a decreasing trend for the range series in the JRB. In general, the increasing trends of precipitation in the tributary (the Yalong River) are more significant than those in the mainstream (the Jinsha River). The results of this study will provide further knowledge for understanding on the climate change in the JRB.

1. Introduction

As a result of global warming, climate change has had an increasing impact on the environment, water resources, industrial production, agricultural activities, and human lives (Shi and Xu 2008). The detection of changes in precipitation is an important and difficult issue that is of increasing interest because of its fundamental role in the planning of future water resources and flood protection. According to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC), on average, global land precipitation has increased by approximately 2% in the twentieth century (Houghton et al. 2001). Global annual precipitation shows a gradual increase from 1900 to the late 1950s, this was followed by a decrease to 1970, higher amounts of precipitation in the 1970s, and a decrease since 1980. Precipitation amounts have increased in high northern latitudes but have decreased slightly in the subtopics of the Southern and Northern Hemispheres, and have shown marked decreases in areas such as the Sahel of Africa (Houghton et al. 1996; Jones and Hulme 1996). However, such changes at the global scale may not reflect the variations on a regional scale, and more so at the local scale. Therefore, many investigations have been conducted to explore whether precipitation records exhibit trends at the local scale. For example, James et al. (2001) observed precipitation data showed increasing trends in the Kejimkujik, Long Point, Niagara Escarpment, and Waterton Lakes...
areas with no long-term trend in the Riding Mountain area in Canada by using least squares regression analysis and $t$ test. Cannarozzo et al. (2006) applied the Mann–Kendall rank correlation method to verify the existence of trend in monthly, seasonal, and annual rainfall and the distribution of the rainfall in Sicily during 1921–2000. According to the results by statistical tests, such as cumulative deviations, Mann–Whitney–Pettit statistics, and the Kruskal–Wallis test, Paoshan et al. (2006) determined rainfall in northern and eastern Taiwan increased on various time scales, but decreased in central and southern Taiwan. Kampata et al. (2008) found there was no evidence of significant trends in the annual rainfall in the headwater of the Zambezi River basin in Zambia by using the cumulative summation and rank-sum tests. Millett et al. (2009) determined that precipitation averaged across the Prairie Pothole Region in North America increased during the past century by using simple linear regression, despite a precipitation decrease in the western Canadian prairies. Zhong and Li (2009) found that annual precipitation in Mianyang of Sichuan in China also had a declined tendency by using empirical orthogonal function and continuous power spectrum method. Vijay and Sharad (2010) analyzed seasonal and annual rainfall at five stations to decipher rainfall trends over the Kashmir Valley in India by using the Mann–Kendall (MK) test. Xu et al. (2010) identified mean annual precipitation experienced an increasing trend for the Tarim River basin during the period of 1960–2007 by using the MK test. Dos Santos et al. (2011) found the precipitation showed a large variation throughout Utah in the United States during the period from 1930 to 2006 by using the RClimdex 1.0 software, and, in general, with few statistically significant trends. Both parametric and nonparametric trend tests were used in previous studies. In this study, nonparametric method was applied to detect the precipitation trends in the Jinsha River basin (JRB).

The JRB is the main part of the upper reaches of the Yangtze River. Most of the previous studies focused on regional precipitation changes in the Yangtze River basin (Gong and He 2006; Zhang et al. 2006; Su et al. 2007; Su and Jiang 2008; Zeng et al. 2008). However, a few studies have been done on the precipitation tendencies in the JRB, except for analysis of precipitation characteristics including temporal distribution and period features (Chen et al. 2010; Liao and Ni 2011; Zhang et al. 2011). In previous studies, the temporal distribution characteristics of the JRB were analyzed by using time series analysis method (Chen et al. 2010; Liao and Ni 2011; Zhang et al. 2011). At present, there is still no research about spatial distribution characteristics of precipitation trends in different regions in the JRB. In addition, the JRB is the “water source” of the Yangtze River basin, in which climate changes have been paid more attention to by researchers in recent years. Therefore, it is necessary to study the climate changes in the JRB, especially precipitation trends—one of the most important climate factors.

In this study, we analyzed mean seasonal and annual precipitation from 30 main meteorological stations during the period of 1961–2008 in the JRB. The long-term trends of precipitation on seasonal and annual time scale are investigated, which advance our understanding on the climate change in the JRB. At the same time, both the temporal and spatial distribution characteristics of precipitation trends in different regions in the JRB are studied for the first time in this paper. Moreover, precipitation change analysis is the base of water resources management (Cheng et al. 2002, 2008; Wang et al. 2009; Chau et al. 2005)—the results of this study can potentially provide important information for the planning of future water resources and flood protection in the JRB (Lin et al. 2006; Wu et al. 2009).

2. Study area

Shown in Fig. 1, the JRB is located between 24°36′–35°44′N and 90°30′–105°15′E in southwestern China. The drainage area of the JRB is 473.2 × 10^5 km², which is about 26% of the total drainage area of the Yangtze River basin. The JRB covers three provinces including Qinghai, Yunnan, Sichuan, and Tibet Autonomous Region in China. The Jinsha River is the mainstream of the JRB, and the Yangtze River is the biggest tributary of the JRB (Fig. 2). “JinSha” literally means “gold sand” or “golden sands.” The Jinsha River is 3464 km long and its mean annual runoff is about 152 × 10^6 m³. The discharge of the JRB significantly increases as the Yangtze River merges into the Jinsha River at Panzhihua City of Sichuan Province. The Jinsha River is the westernmost of the major headwater streams of the Yangtze River. It flushes from the north to the south and forms the deepest gorge in the world.

The JRB has plentiful hydropower resources. The total exploitable installed capacity for power generation is 59 080 MW, which is about 40% of the Yangtze River and about one-sixth of that of China. According to the China’s state power planning, four large hydropower stations—namely Xiangjiaba (6.00 × 10^6 kW of installed capacity for power generation), Xiluodu (12.6 × 10^6 kW of installed capacity for power generation), Baihetan (12.5 × 10^6 kW of installed capacity for power generation), and Wudongde (7.40 × 10^6 kW of installed
capacity for power generation)—are located in the JRB, which is more than double capacity of the Three Gorges hydropower station. Among them, the Xiangjiaba and Xiluodu hydropower stations are under construction and will be completed in 2015. In addition, the JRB is one of the water sources in the South–North Water Transfer Project (SNWTP). A total of $1.5 \times 10^9$ m$^3$ of water is to be transferred to the northern part of China from the
upper reaches of the Yalong River in the first phase according to the western route of the SNWTP. The JRB also contributes to irrigation, water supply, flood control, wood drift, and tourism. Overall, the JRB plays a very important role in regional and national economic development.

3. Data

The precipitation data used in this study were obtained from the National Meteorological Observatory (NMO) stations in the JRB administrated by the China Meteorological Administration (CMA), which have been checked by primary quality control. Among 88 meteorological stations in or around the JRB, 30 stations that have continuous data series from 1961 to 2008 were selected including 22 stations in the Jinsha River and eight stations in the Yalong River. The mean seasonal and annual precipitation time series were constructed according to monthly precipitation over the 30 meteorological stations. For seasonal analysis, each year was divided into four seasons—namely spring (March to...
May), summer (June to August), autumn (September to November), and winter (December through February the following year). For the time series of each season, the data of mean precipitation is the average of 3 months’ value.

The information of meteorological stations used in this study in the JRB is listed in Table 1, and their location is shown in Fig. 2. Both the temporal and spatial distribution characteristics of precipitation trends in different regions in the JRB are studied for the first time in this paper. The distribution of subbasins in the JRB is shown in Fig. 3.

4. Methodology

To identify the trend in climatic variables, the MK test has been employed in previous studies (Mann 1945; Kendall 1970; Vijay and Sharad 2010). The rank-based non-parametric MK test has been commonly used to assess the significance of monotonic trends in hydrometeorological time series, such as water quality, runoff, temperature, and precipitation in different regions across the world (Hirsch et al. 1982; Lettenmaier et al. 1994; Gan 1998; Lins and Slack 1999; Fu et al. 2004; Domroes and El-Tantawi 2005; Jaagus 2006; Xu et al. 2007; Burn 2008; Wu et al. 2008; Zhang and Du 2008; Wang 2009). The advantages of this method include that 1) it can handle nonnormality, censoring or data reported as values “less than,” missing values, or seasonally and 2) it has a high asymptotic efficiency (Gan 1998; Fu et al. 2004, 2009; Xu et al. 2010). Therefore, The MK test was used in this study to detect long-term trend of precipitation in the JRB.

The MK test statistic $Z$ is estimated by the following formula as (Hirsch et al. 1982; Gan 1998):

$$Z = \begin{cases} \frac{S - 1}{\delta}, & S > 0 \\ 0, & S = 0 \\ \frac{S + 1}{\delta}, & S < 0 \end{cases}$$

where

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \text{sgn}(x_k - x_i),$$

$\text{sgn}(\theta) = \begin{cases} 1, & \theta > 0 \\ 0, & \theta = 0 \text{, and} \\ -1, & \theta < 0 \end{cases}$

$$\delta^2 = \left[ \frac{n(n-1)(2n+5) - \sum_{j=1}^{m} t_j(t_j - 1)(2t_j + 5)}{18} \right].$$

Here $m$ is the number of tied groups and $t_j$ is the number of data values in the $j$th group. A positive (negative) value of $Z$ indicates an upward (downward) monotone trend for the test time series. The time series shows a significant trend at a particular

Table 2. Statistics for precipitation series from 1961 to 2008 in the JRB.

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean (mm)</th>
<th>Variance</th>
<th>Standard Deviation</th>
<th>Coefficient of skew</th>
<th>Coefficient of kurtosis</th>
<th>Maximum value (mm)</th>
<th>Minimum value (mm)</th>
<th>Range (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>105.90</td>
<td>694.71</td>
<td>26.36</td>
<td>0.03</td>
<td>-0.29</td>
<td>162.97</td>
<td>46.57</td>
<td>116.40</td>
</tr>
<tr>
<td>Summer</td>
<td>442.78</td>
<td>2407.07</td>
<td>49.06</td>
<td>0.67</td>
<td>1.74</td>
<td>610.13</td>
<td>344.53</td>
<td>265.60</td>
</tr>
<tr>
<td>Autumn</td>
<td>170.49</td>
<td>640.06</td>
<td>25.30</td>
<td>-0.53</td>
<td>0.30</td>
<td>216.36</td>
<td>106.65</td>
<td>109.70</td>
</tr>
<tr>
<td>Winter</td>
<td>18.58</td>
<td>31.79</td>
<td>5.64</td>
<td>0.27</td>
<td>-0.19</td>
<td>31.69</td>
<td>8.51</td>
<td>23.18</td>
</tr>
<tr>
<td>Annual</td>
<td>743.05</td>
<td>3131.30</td>
<td>55.96</td>
<td>0.40</td>
<td>-0.30</td>
<td>869.12</td>
<td>646.71</td>
<td>222.41</td>
</tr>
</tbody>
</table>
significance level $\alpha$ if the absolute value of $Z$ is greater than $z_{1{-}\alpha/2}$, where $z_{1{-}\alpha/2}$ is obtained from the standard normal cumulative distribution tables (Gan 1998; Fu et al. 2009; Xu et al. 2010).

The magnitude of the trend was estimated by a slope estimator $\beta$, which was extended by Hirsch et al. (1982) from that proposed by Sen (1968), defined as

$$\beta = \text{median} \left( \frac{x_i - x_k}{i - k} \right) \quad \forall \ k < i.$$  

5. Results and discussion

a. General characteristics of precipitation in the JRB

The basic statistics for mean seasonal and annual precipitation time series from 1961 to 2008 in the JRB including average, variance, standard deviation, coefficient of skew, coefficient of kurtosis, maxima, minima, and range (the difference between maximum precipitation and minimum precipitation) are listed in Table 2. The mean annual precipitation is 743.05 mm in the JRB. Analytical results indicate that the precipitation in the study area is not uniformly distributed over time and space. The study area experiences a precipitation regime in a year from June to September with a peak in July, and 74.25% of the total annual precipitation is recorded in this period. There is very little or no rainfall at all from November to March next year. If one examines the amount of mean precipitation in different seasons, it is evident that the annual precipitation period is dominant in summer (Fig. 4), and 59.59% of the total annual precipitation occurred in this season. However, only 2.50% of the total annual precipitation occurred in winter. In particular, the precipitation variation (265.60 mm) is the biggest in summer, and its mean precipitation (442.78 mm) is the largest. By contrast, the winter season has the lowest mean precipitation (18.58 mm) and the smallest change range (23.18 mm). Figure 5 shows the plots of the mean annual precipitation over 30 stations selected in this study during 1961–2008 in the JRB. To make it clear, the 5-yr moving average time series are also superimposed in Fig. 5. It clearly reveals that the mean annual precipitation has increased unsteadily since 1961 and reached to the peak in 1998. As we all know, the flood of the Yangtze River in 1998 was the biggest flood in the entire basin since 1954.

The mean seasonal and annual precipitation for each decade (1961–69, 1970–79, 1980–89, 1990–99, and 2000–08) were calculated. The results were shown in Table 3. According to Table 3, there are no obvious change trends during the decades, except for the less precipitation for spring in 1960s.

b. Spatial variations of precipitation in the JRB

On the basis of the observed data in the JRB, the mean annual maximum precipitation was 1607.10 mm in Huidong in 1991, and the mean annual minimum precipitation was 136.30 mm in Wudaoliang in 1984. Seasonally, the spring maximum precipitation was 427.30 mm in Weixin in 1972, and the spring minimum precipitation was 1.4 mm in Yuanmou in 1963. The summer maximum precipitation was 1144.40 mm in Huaping in 1998, and the summer minimum precipitation was 79.70 mm in Wudaoliang in 1978. The autumn maximum precipitation was 509.40 mm in Huaping in 1986, and the autumn minimum precipitation was 0 in Qumalai in 1962. The winter maximum precipitation was 107.1 mm in Weixin in 1970, and the winter minimum precipitation was 0 in

| Table 3. Decadal variations of mean seasonal and annual precipitation in the JRB (mm). |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Spring | 46.57   | 109.78  | 101.59  | 105.89  | 124.17  |
| Summer | 443.20  | 422.97  | 436.23  | 459.10  | 437.57  |
| Autumn | 148.45  | 170.66  | 176.43  | 169.83  | 164.25  |
| Winter | 12.69   | 17.41   | 18.33   | 22.22   | 18.93   |
| Annual | 652.33  | 726.34  | 737.95  | 761.58  | 750.02  |

FIG. 4. Temporal distribution of mean monthly and seasonal precipitation from 1961 to 2008 in the JRB.

FIG. 5. Time series of mean annual precipitation from 1961 to 2008 in the JRB.

Figure 6 shows the spatial distribution of mean seasonal and annual precipitation over 30 stations in the JRB. The seasonal and annual precipitation generally occurred in the middle and lower reaches (the gorge district between Yunnan–Guizhou Plateau and Hengduan...
Mountains, and also the southeastern Tibetan Plateau), while there is little precipitation in the headwater. On the seasonal scale, 25 out of 30 stations are 50–200-mm average precipitation in spring; however, only 2 out of 30 stations are 200–400-mm average precipitation and 3 out of 30 stations are less than 50-mm average precipitation. In summer, the precipitation is more than 150 mm for all stations, and the minimum precipitation is 193.79 mm in Wudaoliang. Sixteen out of 30 stations are 400–800 mm and 13 out of 30 stations are 200–400 mm. In autumn, 26 out of 30 stations have 100–400-mm average precipitation, and only 4 out of 30 stations have 50–100 mm. The precipitation is exiguous in winter, and only 2 out of 30 stations are 50–100 mm but 22 out of 30 stations are less than 25 mm. Because nearly 60% of annual precipitation concentrates in summer, the annual precipitation has similar spatial distribution as summer precipitation. The annual maximum precipitation occurred in Mianning (1104.51 mm), and Yibin (1103.93 mm), Huidong (1078.94 mm), Huaping (1076.73 mm), Weixin (1048.71 mm), Xichang (1018.42 mm), and Kunming (1001.69 mm) followed.

c. Trends of precipitation in the JRB

The results of the MK test for precipitation in the JRB are shown in Fig. 7. The mean seasonal and annual precipitation time series show a positive trend, except for a negative trend in autumn. The Fig. 7 shows the trends in the spring series seem more significant than those in all the series, and spring time series is the only series being statistically significant increasing trend at the $\alpha = 0.05$ level. Overall, the mean annual precipitation have increased by 0.7634 mm yr$^{-1}$. The magnitudes of trend for spring, summer, autumn, and winter are 0.6235, 0.0252, −0.1313, and 0.1064 mm yr$^{-1}$, respectively. The largest seasonal magnitudes of the increase in precipitation occurred in spring.

The trend analysis for mean seasonal and annual precipitation at each station from 1961 to 2008 indicates that most stations have positive trend in the JRB, but a few stations have statistically significant increasing trends at the $\alpha = 0.05$ level. Twenty-four out of 30 stations exhibited an increasing annual precipitation trend while three of them were statistically significant at the level of $\alpha = 0.05$. By contrast, 6 out of 30 stations exhibited a decreasing annual precipitation trend and only 2 of them were statistically significant at the level of $\alpha = 0.05$ (Table 4). The percentage of stations with increasing trend for the annual series goes to 80.00%, and 12.50% of them are statistically significant at the level of $\alpha = 0.05$. On the seasonal scale, there are more than 50% of the stations with increasing trend; especially, the percentage goes to 80% and 90% for winter and spring series, respectively. There are nearly half of the stations (14 stations) with decreasing trend for autumn series, but only one of them was statistically significant at the level of $\alpha = 0.05$ (Table 4). The observation stations mainly exhibited increasing trends, which may result in precipitation increasing in the entire basin for the 1961–2008 periods.

Figure 8 shows the spatial distribution of the MK test trends for mean seasonal and annual precipitation time series. The stations with negative trend mainly center in the upper and lower reaches.

For mean annual precipitation, the two stations— including Yibin and Zhaotong—with statistically significant decreasing trends at the level of $\alpha = 0.05$ are located in the lower reaches. The three stations— including Yushu, Qingshuinhe, and Shiqu—with decreasing trend are located in the upper reaches. The three stations

<table>
<thead>
<tr>
<th>Time</th>
<th>Number of stations</th>
<th>Percentage</th>
<th>Number of stations</th>
<th>Percentage</th>
<th>Number of stations</th>
<th>Percentage</th>
<th>Number of stations</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>27</td>
<td>90.00%</td>
<td>13</td>
<td>43.33%</td>
<td>3</td>
<td>10.00%</td>
<td>1</td>
<td>3.33%</td>
</tr>
<tr>
<td>Summer</td>
<td>17</td>
<td>56.67%</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>43.33%</td>
<td>3</td>
<td>10.00%</td>
</tr>
<tr>
<td>Autumn</td>
<td>16</td>
<td>53.33%</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>46.67%</td>
<td>1</td>
<td>3.33%</td>
</tr>
<tr>
<td>Winter</td>
<td>24</td>
<td>80.00%</td>
<td>4</td>
<td>13.33%</td>
<td>6</td>
<td>20.00%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Annual</td>
<td>24</td>
<td>80.00%</td>
<td>3</td>
<td>10.00%</td>
<td>6</td>
<td>20.00%</td>
<td>2</td>
<td>6.67%</td>
</tr>
</tbody>
</table>
with statistically significant increasing trends at the level of \( \alpha = 0.05 \) are Wudaoliang, Yajiang, and Chuxiong.

On the seasonal scale, 10 out of 14 stations with statistically significant increasing trends at the level of \( \alpha = 0.05 \) mainly center in the middle reaches and the other 4 stations are located in the headwater, and 3 out of 30 stations with negative trends are located in the headwater (Qumalai) and the lower reaches (Yibin and Zhaotong) in spring. In summer, 13 out of 30 stations with negative trends are distributed in the entire basin especially in the lower reaches, but the all stations in the headwater show positive trends. In autumn, the stations with decreasing trends are distributed mainly in the middle and lower reaches. Six out of 30 stations
with negative trends are distributed in the middle and lower reaches of the Yalong River and the lower reaches of the Jinsha River in winter.

There was not obvious change for the mean seasonal and annual precipitation trend magnitudes in the JRB, and the absolute values of trend magnitudes are less than 10 mm yr\(^{-1}\) (Table 5). The seasonal and annual precipitation trend magnitudes are less than 1 mm yr\(^{-1}\) or more than −1 mm yr\(^{-1}\) and less than 0 for most of the stations in the JRB. Only for a few stations, the seasonal and annual precipitation trend magnitudes are more than 1 mm yr\(^{-1}\) or less than −1 mm yr\(^{-1}\). Table 5 shows that the maximum and minimum of seasonal and annual precipitation trend magnitude are 3.4083 and −6.3000 mm yr\(^{-1}\), respectively.

Figure 9 shows the spatial distribution of mean seasonal and annual precipitation trend magnitudes for stations. According to Fig. 9, the largest decrease magnitude occurred in the lower reaches and the largest increase magnitude mainly centered in the middle reaches. Spring has relatively larger magnitudes of increase. As a whole, the increasing or decreasing situation in the middle and lower reaches are more dominant than those in the headwater and the upper reaches.

According to Figs. 6 and 9, the less seasonal or annual precipitation is, the more the decrease trend magnitude will be; instead, the more seasonal or annual precipitation is, the more the decrease trend magnitude will be. For example, Yibin with plenty of rainfall has the maximum seasonal and annual decreasing trend magnitude.

d. **Trends of extreme precipitation in the JRB**

To clearly identify the trend changes of precipitation in the JRB, the seasonal and annual extreme precipitation series—including maximum, minimum, and range time series—are tested by the MK test. The results were shown in Table 6.

For maximum precipitation time series, spring and summer is the two seasons showing a slight and insignificant increasing trend, and the other two seasonal series and the annual series exhibit a slight and insignificant decreasing trend. The magnitude of decreasing trend for annual maximum temperature time series is −0.7711 mm yr\(^{-1}\). The largest magnitudes of decrease for the maximum precipitation time series occurred in autumn, while the largest magnitudes of increase for the maximum precipitation time series occurred in spring.

All the time series showed an increasing trend, and the increasing trend for spring and annual series were statistically significant at the level of \(\alpha = 0.1\) (it is 0.01 for the spring series) for the minimum precipitation time series. The annual increasing trend magnitude for the minimum precipitation time series is 0.9436 mm yr\(^{-1}\). The order from small to large for seasonal trend magnitude were winter, autumn, summer, and spring for the minimum precipitation time series.

For range time series, the decreasing trends are mainly characterized. Spring is the only season exhibiting a slight and insignificant increasing trend. The largest seasonal trend magnitude of the range series occurred in autumn decreasing by 0.9070 mm yr\(^{-1}\), followed by summer and winter, respectively. The annual decreasing trend magnitude for the range time series is 1.6140 mm yr\(^{-1}\), while the spring increasing trend magnitude for the range time series is 0.0235 mm yr\(^{-1}\).

e. **Trends of precipitation in the Jinsha River and Yalong River**

Since the Jinsha River and Yalong River formed the JRB, it is of interest to analyze the trend test for the Jinsha River and Yalong River. The results by using the MK test are shown in Table 7.

For the annual precipitation, there is a slight and insignificant increasing trend both in the Jinsha River and in the Yalong River, but the increasing trend magnitude in the Jinsha River (0.4983 mm yr\(^{-1}\)) is larger than that in the Yalong River (0.0602 mm yr\(^{-1}\)). On the season scale, there is an increasing trend both in the Jinsha River and in the Yalong River, and the increasing trend in the Jinsha River is statistically significant at the level of \(\alpha = 0.05\) in spring. However, the other seasons—including summer, autumn, and winter—changed in the opposite tendency. For example, there is a slight and insignificant decreasing trend in the Jinsha River, but there is a statistically significant increasing trend at the level of \(\alpha = 0.05\) in the Yalong River in summer. Winter is the only season with a slight and insignificant decreasing trend in the Yalong River, while both summer and autumn in the Jinsha River show a slight and insignificant decreasing trend. As a whole, the increasing trends in the Yalong River are more significant than those in the Jinsha River.

### Table 5. Extreme values of trend magnitude over the 30 meteorological stations from 1961 to 2008 in the JRB.

<table>
<thead>
<tr>
<th>Time series</th>
<th>(\beta_{\text{max}}) (mm yr(^{-1}))</th>
<th>Station of (\beta_{\text{max}})</th>
<th>(\beta_{\text{min}}) (mm yr(^{-1}))</th>
<th>Station of (\beta_{\text{min}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>1.2643</td>
<td>Yuanmou</td>
<td>−1.3156</td>
<td>Yibin</td>
</tr>
<tr>
<td>Summer</td>
<td>1.2564</td>
<td>Chuxiong</td>
<td>−2.7714</td>
<td>Yibin</td>
</tr>
<tr>
<td>Autumn</td>
<td>0.8025</td>
<td>Yajiang</td>
<td>−1.5769</td>
<td>Yibin</td>
</tr>
<tr>
<td>Winter</td>
<td>0.3333</td>
<td>Huidong</td>
<td>−0.2609</td>
<td>Yibin</td>
</tr>
<tr>
<td>Annual</td>
<td>3.4083</td>
<td>Yajiang</td>
<td>−6.3000</td>
<td>Yibin</td>
</tr>
</tbody>
</table>

6. **Conclusions**

This work studied precipitation trend and its spatial distribution in the JRB. Both the temporal and the spatial distribution characteristics of precipitation
Trends in different regions in the JRB were studied for the first time in this paper. Precipitation trend analyses will provide further knowledge for our understanding on the climate change in the JRB. The results would be helpful for future planning and management to maintain the water resources safety of the JRB, especially under the background of global warming.

The results of this study indicate a slight and insignificant increasing precipitation during 1961–2008 in the JRB. Although the trends are not significant, the precipitation is generally increasing as evident from the positive values of the MK trend magnitude, $\beta$. Twenty-four out of 30 stations exhibited an increasing trend and 3 of them were statistically significant at the level of...
The conclusions in this study are necessary to do further study combining atmospheric circulation, other meteorological factors, and others to find the causative reasons. In addition, only the MK test is used to trend analysis in this investigation. It is necessary to verify the conclusions in this research by using more other trend analysis methods. On the other hand, only 30 meteorological stations with 48-yr-long records are used in this paper. If all the 88 meteorological stations are averaged, it could result in a decreasing trend for the range. It is unclear whether it also causes the number of rainy days change for the heavy rain and light rain, which need to have further investigation according to the daily precipitation.

The increasing trends in spring seem more significant than those in the other three seasons, and 27 out of 30 stations exhibited an increasing trend and 13 of them were statistically significant at the level of $\alpha = 0.05$ in spring. The greatest magnitudes of the increase in precipitation occurred in spring, and the greatest magnitudes of the decrease in precipitation occurred in summer. Autumn is the only season exhibiting a slight and insignificant decreasing trend.

Although the annual precipitation increasing trend is insignificant, great attention should be paid to seasonal change trends. For instance, because of the increase of precipitation in spring and summer, there may be more floods and geological disasters such as earthquake disaster, landslide, debris flow, collapse, and so on. On the other hand, the influence of autumn drought to agricultural production in the JRB should become more and more serious because of the decrease of precipitation in autumn, especially in the dry–hot valley of the Jinsha River. The increasing trend of minimum precipitation and decreasing trend of maximum precipitation could result in a decreasing trend for the range. It is unclear whether it also causes the number of rainy days change for the heavy rain and light rain, which need to have further investigation according to the daily precipitation.

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