Spatial–temporal variation of precipitation concentration
and structure in the Wei River Basin, China

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Abstract  It is of significant importance to investigate precipitation structure and precipitation concentration due to their great impact on droughts, floods, soil erosion, as well as water resources management. A complete investigation of precipitation structure and its distribution pattern in the Wei River Basin was performed based on recorded daily precipitation data in this study. Two indicators were used: concentration index based on daily precipitation (CID), to assess the distribution of rainy days, and concentration index based on monthly precipitation (CIM), to estimate the seasonality of the precipitation. Besides, the modified Mann–Kendall trend test method was employed to capture the variation trends of CID and CIM. The results indicate that: (1) the 1–3-day events are the predominant precipitation events in terms of the occurrence and fractional contribution; (2) the obvious differences in the CID of various areas are found in the Wei River Basin, and the high CID values mainly concentrate in the northern basin, conversely, the southern basin has a relatively low CID value; (3) high CIM values are primarily in the western and northern basin, reflecting a remarkable seasonality of precipitation in these regions; and (4) all of the stations show a downward trend of CIM, which indicates that the monthly precipitation distribution tends to be more uniform.

1 Introduction

Under the background of global warming and climate changes, extreme climate events like droughts and floods have great effects on society, environment, and even polity (Milly et al. 2002; Min et al. 2011). Enormous attention has been drawn to the changing characteristics, causes, and the regimes of extreme climate events on various scales due to their heavily catastrophic nature (Milly et al. 2002; Min et al. 2011; Zhang et al. 2010a, b, 2011; Mladjic et al. 2011). One of the important parts of climate changes needing thoroughgoing research is the spatial and temporal distribution of precipitation and its historical changes. Precipitation is a critically important climate variable due to the disastrous weather such as floods and droughts mainly caused by its abnormity. Therefore, investigation of the changes in precipitation will help to further understand the hydrological response to climate changes.

To date, precipitation variability on various temporal scales were performed by numerous researchers (Gong et al. 2004; Cannarozzo et al. 2006; Liang et al. 2011; Chen et al. 2011; Oguntunde et al. 2011; Zhang et al. 2012a; Brunetti et al. 2012). Moreover, long-precipitation historical records were studied in Northern and Central Italy (Montanari et al. 1996; Brunetti et al. 2006a) and in Southern Italy (Palmieri et al. 1991; Cotecchia et al. 2004; Brunetti et al. 2004, 2006b). Many previous researches concerning precipitation variability indicated that a significant decrease in precipitation duration and an increase in precipitation intensity had been detected during extreme climate events over the last few decades (Ren et al. 2000). Although the observed extreme climate events occur in a low-frequency, heavy precipitation with only a few days has a high proportion of the total annual precipitation and tends to cause soil erosion and flooding (Zhang et al. 2009).
A better way to describe the different involvement of daily precipitation is to compute the contribution of rainy days with the largest amount of precipitation to the total amount of precipitation. The concept, called as the concentration index based on daily precipitation (CID), is introduced to characterize the statistical features of daily precipitation and to assess anomalies in precipitation distribution (Alijani et al. 2008; Zhang et al. 2009; Li et al. 2011; Coscarelli and Caloiero 2012). Li et al. (2010) computed CID values for the Kaidu River basin and individuated a region of Southern Xinjiang characterized by the highest values of CID. Alijani et al. (2008) confirmed the anamnestic nature of daily precipitation across Iran by analyzing CID. Their study indicated that at least 20 % of the country is subject to a risk of extreme precipitation.

A higher CID value reflects a more heterogeneous precipitation distribution and is more prone to cause droughts and floods. Consequently, the high precipitation intensity is likely to increase slope instability and make the soil more vulnerable to erosion, thus resulting in the variation of land use, agricultural practices, and growth conditions of plants and even leading to economic and life losses (Scholz et al. 2008). Therefore, it is of great significance to investigate the precipitation concentration and structure based on daily precipitation data.

Apart from investigating the changing weight of daily precipitation, the seasonal heterogeneity of precipitation amounts was also analyzed in this study, which can quantitatively estimate the distribution of precipitation patterns and the seasonality of the precipitation. Michiels et al. (1992) had analyzed the precipitation data from meteorological stations located in a central transect of Spain and concluded that the concentration of historical precipitation data had a temporal effect (bounded to the unreliable, unpredictable character of precipitation) rather than a seasonal effect (not strongly confined by a typical wet or dry period). Cannarozzo et al. (2006) had applied the Mann–Kendall trend test method in concentration index based on monthly precipitation (CIM) values of the Sicily territory and found a stable situation where the temporal distribution of precipitation during the year did not change.

The Wei River, the biggest tributary of the Yellow River in China, is located in the middle reaches of the Yellow River with a total area of 135,000 km². The Wei River Basin is an important region for China, especially after the establishment of the Guanzhong-Tianshui Economic Zone, which acts as an important role in the rapid economic development of the whole western region. Fully understanding the spatial–temporal changes in CID, CIM and precipitation structure in the basin is a key to further comprehend the hydrological response, particularly under the background of climate changes and human activities. However, as far as we know, few studies have investigated the contribution of anomalous precipitation to the basin precipitation distribution or the statistical precipitation structures over the last several decades. Investigating CID and CIM in the Wei River Basin can offer a firm foundation for further understanding the water resources variability response to climate changes in the watershed. Furthermore, the research will help to take scientific decisions to alleviate damages of natural disaster and to promote human adaptation to increasing risks induced by natural disaster.

Therefore, the main objectives of this study are: (i) to explore spatial–temporal change characteristics of CID on annual and seasonal scales from 1960 to 2005 under climate change in the Wei River Basin; (ii) to quantitatively estimate the seasonal heterogeneity of precipitation amounts using CIM; and (iii) to investigate the precipitation structure in terms of precipitation duration, amount, and intensity in both time and space across the Wei River Basin.

2 Study area and data

2.1 Introduction of the Wei River Basin

The Wei River Basin, as shown in Fig. 1, is selected in this research. The Wei River lies between 103.5°–110.5° E and 33.5°–37.5° N. Located in the continental monsoon climate zone, the Wei River Basin is characterized by abundant precipitation and high temperature in summer but by sparse precipitation and low temperature in winter. The annual precipitation of the basin is approximately 559 mm (Zhang et al. 2008). Additionally, the precipitation varies monthly and annually, which in flood season (from June to September) accounts for approximately 60 % of the total annual precipitation. The annual precipitation also varies greatly due to the unstable features of the intensity, duration and influencing area of the subtropical high pressure belt over the northern Pacific (Huang et al. 2014a). For instance, the annual precipitation is more than 800 mm in wet years, whilst it is less than 370 mm in drought years, which is likely to result in highly frequent droughts and floods. Topographically, the altitude decreases from the highest northwest mountainous areas to the lowest Guanzhong Plain situated in the southeast and south portion of the basin. However, in recent decades, the precipitation of the basin has a remarkably decreasing trend (Huang et al. 2014a), resulting in failing to satisfy the water demand for socioeconomic development and eco-environment in the basin. Furthermore, the serious water pollution makes the water resources availability further deteriorated. In view of the significance of water security in the basin, a further investigation is needed to further understand the spatial–temporal variations of CID, CIM and precipitation structure in the Wei River Basin, which is of great significance to the conservation of water and soil, local water resources management, and agricultural practices under the backdrop of global climate change.
2.2 Study data

Daily precipitation data collected from 21 meteorological stations in the Wei River Basin were utilized in this study, whose locations are presented in Fig. 1. Each station has daily precipitation data covering 1 January 1960∼31 December 2005, which were acquired from the National Climate Center (NCC) of the China Meteorological Administration (CMA). The data quality was strictly controlled during their release. Amongst the 21 stations, two of them have some missing values. However, the total lost data are less than 0.01%. The missing data were reconstructed by calculating the average value of their neighboring stations. In addition, the double-mass curve method was used to check the data consistency, and the results indicate that all daily precipitation data used in the paper are consistent.

3 Methodology

3.1 The modified Mann–Kendall trend test method

The modified Mann–Kendall trend test (MMK) method (Mann 1945; Kendall 1955; Hamed and Rao 1998) was employed to capture the trend of the meteorological variables in Wei River Basin. The initial Mann–Kendall (MK) test recommended by the World Meteorological Organization is a nonparametric approach. However, the MK test results are affected by the persistence of the hydro-meteorological series. Therefore, Hamed and Rao (1998) improved the MK test by taking into account the lag-i autocorrelation to remove the persistence of the hydro-meteorological series. Hamed and Rao (1998) and Daufresne et al. (2009) concluded that the MMK test is robust for the trends in hydro-meteorological series. Considering the completeness of this study, the MMK test was used (Daufresne et al. 2009).

For a time series of \( n \) observations \( X=x_1, x_2, \ldots, x_n \), the MK trend statistic \( S \) is computed as follows:

\[
S = \sum_{i < j} \text{sgn}(x_j - x_i)
\]  

(1)

where

\[
\text{sgn}(x_j - x_i) = \begin{cases} 
1 & x_j > x_i \\
0 & x_j = x_i \\
-1 & x_j < x_i 
\end{cases}
\]  

(2)

The variance of \( S \) is proposed by Kendall (1955):

\[
\text{Var}(S) = \frac{n(n-1)(2n+5)}{18} 
\]  

(3)

Then, the standardized test statistic \( Z = \frac{S}{\sqrt{\text{Var}(S)}} \) with the standard normal variable under the desired significance level.
is calculated to test the significance of the time series trend. Hamed and Rao (1998) indicated that the significant temporal autocorrelations of a time series disturbed the evaluation of the variance of S. For removing the persistence influences, Hamed and Rao (1998) suggested extracting a nonparametric autocorrelation coefficients of the new time series. Autocorrelation coefficients (\(\rho_i\)) at lag (\(i\)) which are significantly different from zero at the 5 % confidence level are then used to estimate the modified variance of \(S\), \(\nu^*(S)\) as follows:

\[
\nu^*(S) = \text{Var}(S)\text{Cor}
\]

where \(\text{Cor}\) is a correction due to the autocorrelation of the time series, which is calculated as follows:

\[
\text{Cor} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-1)(n-i-1)(n-i-2)\rho_i(i)
\]

### 3.2 Concentration index based on daily precipitation

To assess the contribution of the various daily precipitation classes to the total precipitation, especially the highest frequent daily precipitation, the cumulative percentage of precipitation corresponding to the cumulative percentage of rainy days were computed (Olascoaga 1950; Li et al. 2011). A limit of 1 mm/day precipitation amount was used to distinguish the wet day and a limit of 1 mm/day was employed to classify precipitation values. Anomalies of precipitation distribution are determined by the various proportion of the total precipitation corresponding to different precipitation durations. If rainy events are ranked in a descending order and \(X_i\) denotes the \(i\)th highest event, \(Y_i\) is the fractional contribution of the total precipitation offered by the highest events from the first to the \(i\)th which is corresponding to \(X_i\). It is worth mentioning that both the \(X\) events and their corresponding \(Y\) are expressed as percentiles. The relationship between \(X\) and \(Y\) exhibits a remarkable exponential distribution curve and can be expressed as follows (Olascoaga 1950):

\[
Y = aX\exp(bX)
\]

where both \(a\) and \(b\) are constants computed by the method of least squares. In general, this curve is known as the Lorenz curve or concentration curve (Shaw and Wheeler 1994), which was initially used in financial field by economists (Lorenz 1905). Under an ideal circumstance, the precipitation follows an equal distribution and the relationship between \(X\) and \(Y\) can be described as \(Y=X\). In fact, the precipitation exhibits an irregular distribution and the Lorenz curve is always under the line of equation, \(Y=X\). The area enclosed by the concentration curve and the bisector of the quadrant is represented as \(A\). The daily precipitation concentration index is expressed as:

\[
\text{CID} = A/5000
\]

The enclosed area \(A\) is calculated as:

\[
A = 5000 - \int_0^{100} ax\exp(bx)\,dx
\]

A higher CID value reflects that the precipitation is more concentrated in a few rainy days during the year for a specific meteorological station. Therefore, the CID is used to assess the anomalies of precipitation distribution.

### 3.3 Concentration index based on monthly precipitation

In addition to analyzing the changing weight of daily precipitation, it is also essential to investigate seasonal heterogeneity of precipitation amounts by means of a modified version of Oliver’s (1980) CIM (De Luis et al. 1997). The index is computed as follows:

\[
\text{CIM} = 100 \left( \sum_{i=1}^{12} \frac{P_i^2}{\bar{P}_i} \right)^{2/3}
\]

where \(P_i\) denotes the precipitation amount of the \(i\)th month, computed for every meteorological station and for each year during the observation period. According to Oliver (1980), CIM values that are less than 10 mean a uniform seasonal precipitation distribution during this year, whilst the values between 11 and 20 represent a certain seasonality of precipitation distribution. Values greater than 20 denote tremendous seasonality in precipitation amounts responding to climate changes.

### 4 Results and discussions

#### 4.1 Occurrence and fractional contribution of precipitation durations

The occurrence and fractional contribution of various precipitation durations are presented in Fig. 2. It can be obviously observed that the occurrence of precipitation durations exhibits a positive exponential distribution curve with decreasing durations of wet periods. The highest occurrence of wet periods is in 1-day event, accounting for approximately 48.3 % of all the occurrences, whilst that of \(\geq\)12-day events
is only 0.4 %. With regard to the fractional contribution of different precipitation durations to the total amount, the highest proportion is in the 2-day events, being responsible of nearly 25.6 % of the total annual precipitation amount, whereas the rate of contribution of ≥12-day events reaches to 3.1 % of total annual precipitation amount. The rate of contribution of 1- and 2-day events is about 43 %. In general, the precipitation durations of 1–3-day events are the primary precipitation events due to its largest rate of contribution to the total annual precipitation amount, accounting for approximately 60.7 %.

4.2 Temporal evolutions of fractional contribution and occurrence of various precipitation durations

The temporal evolutions of normalized fractional contribution and occurrence derived from all meteorological stations across the whole Wei River Basin are illustrated in Fig. 3a, b, respectively, which are smoothed by a 5-year moving mean (the specific procedures can refer to Zolina et al. 2010).

The Fig. 3a indicates that the patterns of the fractional contribution of different precipitation durations are obvious. Overall, the high fractional contribution of 1–4-day events can be identified throughout the entire period, whilst the low fractional contribution of ≥7-day events can also be detected. The highest fractional contribution of different durations always belongs to the 1–3-day events, which indicates that short-precipitation durations are the major parts of the precipitation in the Wei River Basin. In contrast, the lowest fractional contribution of different durations always belongs to ≥7-day events. The primary reason for the findings is that the Wei River Basin is located in inland and far away from sea, therefore, the water vapor across the basin is low and the precipitation is characterized by short durations. Ma et al. (2012) and Huang et al. (2014a) also reported that the Wei River Basin is located in the east edge of the northwest inland of China where is relatively far from sea, and it has been plagued by droughts for a long time. Note that a little variability of the normalized fractional contribution is detected. On the whole, the contribution of the 4–6- and ≥7-day events has a slowly decreasing trend and that of the 1–3-day events has a slightly increasing trend, implying that the precipitation has a concentrated trend in the whole basin.

The temporal evolution of the occurrence of different precipitation durations exhibits a similar change characteristic compared with the fractional contribution of various precipitation durations (see Fig. 3b). In general, a high occurrence of 1–4-day events can be detected during the entire period, whereas a relatively low occurrence of ≥7-day events can be identified. Similarly, the highest occurrence of various durations belongs to 1–3-day events, whilst ≥7-day events have the lowest occurrence, indicating that 1–3-day events are the predominant precipitations both in occurrence and fractional contribution. The result is similar to Zhang et al. (2012b), who found that wet periods with shorter durations had an increasing occurrence and fractional contribution in the Pearl River Basin. Furthermore, a small variability of the normalized occurrence is also identified. Overall, the occurrences of longer precipitation durations have a slightly downward trend, whilst the occurrences of shorter precipitation durations have a slowly upward tendency. The results are extremely opposite to Zolina et al. (2010), who pointed out that the occurrences of longer precipitation durations had an upward trend in Europe. It should be mentioned that the Wei River Basin is located in trade-wind zone, whilst Europe is primarily located in westerly zone. Therefore, the precipitation in the two regions is affected by different atmospheric circulation, and their
hydrologic responses to global climate change are expected to be different. However, the detailed influence of atmospheric circulation on the precipitation structure in the two regions needs to further study.

4.3 Spatial distribution of average annual CID values in the Wei River Basin

The CID values were calculated for all stations across the whole Wei River Basin from 1960 to 2005. Table 1 shows the values as follows: (1) fitted parameters, $a$ and $b$, which were computed through the least squares method, are the constants of the exponential function, and (2) CID values, which were calculated according to section 3.2 in this paper.

The CID values vary from 0.396 to 0.688 and those of nearly half of all stations are more than 0.5. The maximum value of CID belongs to Yan’an meteorological station, implying that the most concentrated precipitation is in Yan’an, which is situated in the loess plateau area. It should be noted that the soil and water loss easily occur in the loess plateau, and the ecology of this area is extremely fragile. According to Chen et al. (2008), for the loess plateau, its soil is highly loose and rainstorm is very concentrated, indicating that the intensity of precipitation is large, which can easily trigger soil loss and even poses a threat to the security of the ecological environment. Therefore, local government should draw high attention to the precipitation changes and take some relevant mitigation measures in advance.

The daily CID during the study period (1960–2005) of all meteorological stations are spatially interpolated using smoothing thin splines interpolation throughout the whole Wei River Basin, and the spatial distribution of annual average CID is presented in Fig. 4. Overall, the high CID values mainly concentrate on the northeast part of the basin, especially for Wuqi and Luochuan stations. In these areas, the anomalies of precipitation amount are noticeable due to their high proportion of a little precipitation amounts where more than 70% of the total precipitation amount concentrates on only 25% of the rainy day. High precipitation intensity identified over the northeast part of the basin is consistent with high precipitation concentration recorded in these regions. Besides, the average CID value of the region around Shangzhou station is 0.42, which is located in the middle reaches of the Wei River, implying the precipitation distribution in this region is more uniform than other parts of the basin. As shown in Fig. 1, the
elevation of the Wei River basin generally decreases from the west to the east and from north to the south. A part of the Loess Plateau with a high elevation is located in the northern basin. Some reasons may account for the differences in the CID values of various areas in the Wei River Basin. High mountains can block atmospheric circulation, and its windward slope tends to be rainy, however, for its leeward slope, the precipitation tends to be sparse (Thomas et al. 1986). Hence, the topography may play an important role in influencing the precipitation amount and its distribution across the basin. This detailed influence needs to further study.

Additionally, the southeast monsoon coming from the western Pacific has a great impact on the precipitation in this basin, and it increasingly weakens from south to north (Huang et al. 2014b). Generally, the southern basin has a long period of precipitation with a relatively uniform amount, which is mainly influenced by strong southeast monsoon, thus its CID value is low. Conversely, the northern basin has a relatively short period of precipitation, which is primarily impacted by weak southeast monsoon. Hence, the precipitation in the northern basin is concentrated, and its CID value is higher than that in the southern basin. Therefore, the influences of various elevations and the southeast monsoon may be the primary reasons of the discrepancy in CID values in the Wei River Basin. In fact, in addition to various elevations and the southeast monsoon, there are some other factors such as different vegetation covers (Collow et al. 2014), zones of atmospheric pressure (He et al. 2014), and heat distributions (Wang et al. 2014) which can also affect precipitation, thereby influencing the distribution of CID values. However, the major motivation of this paper is to reveal the spatial–temporal variation characteristic of precipitation concentration and structure in the Wei River Basin. Therefore, the comprehensive analysis of the reasons of the discrepancy in CID values will be performed in future study.

### 4.4 Spatial distribution of CIM in four seasons

Distinctly dry and rainy seasons are the major characteristics in the Wei River Basin. The complex spatial patterns of CIM at seasonal scale over the whole Wei River Basin are exhibited in Fig. 5.

Precipitation is regularly distributed within spring months except the western basin with high CIM values (see Fig. 5a), whereas higher CIM values are identified within summer months, especially in the northern basin, which is slightly similar to the annual pattern with a low CIM values (see Fig. 5b). The relatively high CIM values are observed in the western and northern basin in autumn months, which is also similar to the annual pattern (see Fig. 5c). Moreover, most of the basin exhibits a relatively high CIM values in winter months, which is generally similar to the annual pattern but with higher CIM values; the largest CIM values are observed in the western and northern basin (see Fig. 5d). All of summer, autumn, and winter greatly affect the annual precipitation distribution patterns, especially summer and winter which make the highest contributions to the anomaly of the annual precipitation distribution.

### 4.5 Spatial distribution of average annual CIM

The seasonal precipitation distribution pattern throughout the year also has been investigated based on CIM. The average annual CIM values of each meteorological station are

| Station | a     | b     | $R^2$ | CID  |
|---------|-------|-------|-------|------|
| Lintao  | 0.073 | 0.036 | 0.997 | 0.628|
| Minxian | 0.065 | 0.031 | 0.995 | 0.508|
| Huajialing | 0.062 | 0.028 | 0.996 | 0.566|
| Xiji    | 0.054 | 0.025 | 0.998 | 0.544|
| Tianshui| 0.049 | 0.033 | 0.997 | 0.478|
| Guyuan  | 0.071 | 0.031 | 0.995 | 0.584|
| Pingliang| 0.055 | 0.027 | 0.998 | 0.478|
| Baoji   | 0.049 | 0.041 | 0.997 | 0.414|
| Huanxian| 0.072 | 0.024 | 0.998 | 0.651|
| Xifengzhen| 0.081 | 0.019 | 0.995 | 0.412|
| Changwu | 0.077 | 0.028 | 0.996 | 0.426|
| Foping  | 0.059 | 0.032 | 0.995 | 0.48  |
| Wuqi    | 0.068 | 0.033 | 0.998 | 0.676|
| Wugong  | 0.075 | 0.027 | 0.994 | 0.5   |
| Xi’an   | 0.065 | 0.025 | 0.998 | 0.486|
| Tongchuan| 0.059 | 0.031 | 0.994 | 0.543|
| Zhen’ an| 0.072 | 0.029 | 0.997 | 0.48  |
| Yan’an  | 0.068 | 0.034 | 0.996 | 0.688|
| Luochuan| 0.073 | 0.025 | 0.997 | 0.622|
| Shangzhou| 0.081 | 0.023 | 0.994 | 0.396|
| Huashan | 0.079 | 0.022 | 0.995 | 0.508|
computed from precipitation data of each single year and then calculated the average values of the entire study period. Their spatial distribution is shown in Fig. 6. The values range from the minimum of 11.47 to the maximum of 17.08, showing an obvious seasonality of the precipitation distribution. The average annual CIM (approximately 13.8) in Wei River Basin is less than that of Calabria region (approximately 16.9) (Coscarelli and Caloiero 2012). In general, the spatial distribution of the CIM values is irregular over the whole basin. The noticeable seasonality is detected in western and northern basin, particularly for the western basin which has the highest CIM value.

Comparatively, the middle reaches of the basin and the southern watershed have lower CIM values, especially for the southern basin, whose average CIM value is less than 13, implying that the southern basin has a more uniform precipitation distribution than the other parts of the basin. The reasons for the differences in CIM values of the various areas in the Wei River Basin are similar to that in CID values of the various areas in this basin outlined in Sect. 4.3.

4.6 Temporal change trend of CID and CIM

The modified Mann–Kendall trend test method was employed to capture the temporal changing characteristics of the CID and CIM. The CID values shows a nonsignificantly changing temporal trend, which can be described by the spatially heterogeneous amongst all of the meteorological stations (see Fig. 7). It can be observed from Fig. 7 that more than 50 % of the stations show a slightly upward trend, whilst the others exhibit a slightly downward trend. Most of the trends are not significant at the 95 % confidence level, except that Huashan meteorological station has a statistically significantly positive trend at the 95 % confidence level and Guyuan station has a statistically significantly negative trend at the 99 % confidence level. The number of stations with an upward trend is more than that with a downward trend. The distribution of the trend of CID shows that the stations with negative
trends primarily concentrate on the northern and western basin, which is characterized by high CID values. Therefore, the areas with high CID values have a negative trend in precipitation concentrations, whilst areas with low CID values tend to have a positive trend.

The temporal change trend of the CIM is exhibited in Fig. 8. It can be obviously observed that all the CIM values of each station in the Wei River Basin have a negative tendency, indicating that the whole basin exhibits a decreasing trend of the CIM. Four meteorological stations have a statistically significantly downward tendency at the 95 % confidence level, whilst 11 stations exhibit a statistically significantly decreasing trend at the 99 % confidence level, implying that the seasonal precipitation distribution tends to be more uniform. Through the comparison analysis between Figs. 7 and 8, we can find that the temporal change characteristic of precipitation concentration exhibits a striking discrepancy on different time scales. On a daily scale, there exists increasing and decreasing trends in precipitation concentration in the Wei River Basin. However, on monthly scale, there only exists decreasing trend in precipitation concentration.

5 Conclusions

It is of importance to investigate the precipitation concentration and structure due to their strong effects on droughts, floods, soil erosion and water resources management. A complete investigation of precipitation structure and its distribution pattern in the Wei River Basin was performed based on the recorded daily precipitation data in this study. Two indicators were used: the concentration index based on daily precipitation (CID), to assess the distribution of rainy days, and the CIM, to estimate the seasonality of the precipitation. Furthermore, the modified Mann–Kendall trend test method was used to capture the temporal trends of CID and CIM.

Through the analysis in this paper, the main conclusions are as follows:

In terms of the precipitation structure, the occurrence of different precipitation durations exhibits a positive exponential curve with the decrease in precipitation duration. With regard to the fractional contribution of various precipitation durations to the total amount, 1–3-day events are the predominant precipitation events due to its largest proportion of the total amount, approximately accounting for 60.7 %. Therefore, the precipitation with a short duration is the major precipitation event in the basin. Furthermore, the occurrence and fractional contribution of precipitation with a short duration has a slightly positive trend, whilst that with a long duration has a negative trend, indicating that the precipitation in the Wei River Basin tends to be more concentrated.

The Wei River Basin has an obvious discrepancy in CID values in different areas. The high CID values mainly concentrate in the northern basin, which is an ecologically vulnerable area and the highly concentrated precipitation easily triggers water and soil erosion. Conversely, the southern basin has a relatively low CID value. These differences are closely related to the various topographies and the southeast monsoon, and their detailed influences on these differences need to further investigate. Furthermore, the spatial distribution of the CIM values is heterogeneous over the whole basin. The obvious seasonality is identified in the western and northern basin, particularly for the western basin which has the highest CIM value.

Regarding the trend of CID, more than half of the stations have an upward trend of the CID. Most of the trends are not significant at the 95 % confidence level, except for Huashan station with a statistically significantly positive trend at 95 % significance level and Guyuan station with a statistically
significantly positive trend at 99% significance level. As for the trend of CIM, all of the stations exhibit a negative trend, which implies that the seasonal precipitation distribution in this basin is expected to be more uniform.

The investigation of the precipitation structure, CID and CIM confirms the anomaly and irregularity of daily precipitation over the Wei River Basin. The findings will help to improve local water resources management and to relieve the risks derived from droughts, floods, as well as soil erosion.

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