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# Relationship between meteorological and hydrological drought in the mountain areas: a study in the upper reaches of Ying River, China

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**ABSTRACT**

This study attempts to probe into the relationship between meteorological droughts and hydrological droughts by analyzing the trends and the co-variability of precipitation and runoff data in an area with little human activity. In this study, the standardized precipitation index (SPI), modified Mann–Kendall (MMK) trend test and cross-wavelet analysis are used to study the relationship between meteorological droughts and hydrological droughts, including the various trends and correlations. It is found that: (1) the shorter the duration of hydrological drought, the higher its correlation with the meteorological droughts; (2) regardless of the time scale of standardized runoff index (SRI), SPI/SPEI on a longer time scale produces greater influence on SRI; (4) there are dry trends under both the hydrological and meteorological conditions in the upper reaches of Ying River, with the hydrological ones less obvious; (5) the periodicity of meteorological and hydrologic droughts follows different patterns with the increase of accumulation time. As the duration of meteorological droughts increases, the number of hydrological drought cycles decreases and the correlation between meteorological droughts and hydrologic droughts weakens. While the time scale of hydrologic droughts increases, the number of hydrological drought cycles remains unchanged. This demonstrates that the short time scale of hydrological droughts is attributed to the superposition of multiple periodic meteorological droughts; (6) this study also shows that SPEI is a better measure than SPI for short-time scale hydrological drought evaluation or forecast in the arid regions, and the 9 month time scale SPEI is more suitable for the characterization of hydrological droughts.

*Keywords:* Standardized precipitation index; Standardized rainfall index; Meteorological drought; Hydrological drought; Upper reaches of Ying River

## 1. Introduction

Even though surface runoff accounts for only 10% of the total water resources around the world [1], it is one of the most important resources to support global economic and social development, as well as to maintain regional stability [2]. Global surface water resources are inevitably influenced by increasing climatic variability and uncertainty, which could further place an impact on the sustainable development of human society [3–5]. In recent years, the change trend of temperature in the northern hemisphere is obvious [6], which has directly influenced the regional atmospheric circulation, intensified the variability of hydrologic cycles, triggered the frequent occurrences of extreme precipitation events, the enhanced evaporation, and the increasing intensity and duration of meteorological droughts, resulting in the changes of recharge and discharge process of surface runoff, and leaving an impact on surface

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runoff [7–10]. Therefore, hydrological droughts and meteorological droughts are inextricably related to each other, and it is important to understand the effects of meteorological droughts on hydrological droughts in order to find out the characteristics of change trends of surface runoff. For the river basins that are not heavily influenced by human activities, precipitation is an important factor affecting regional surface runoff [11]. In general, the peak of surface runoff tends to lag behind that of precipitation, but it is not clear to what extent this lagging contributes to the greatest cumulative impact. In addition, most of the current research focuses on the areas heavily influenced by human activities, and the characteristics of meteorological and hydrological evolution in the upper reaches of Mountain Rivers are often ignored.

Standardized precipitation index (SPI) is an indicator that reflects the changes of precipitation cycles, including the accumulated deficits and surpluses of precipitation [12,13]. In fact, SPI has been widely used in the evaluation of drought and flood events. A number of studies have shown that the 12 months scale of SPI is closely related with the surface runoff, and has been widely applied by researchers to assess the hydrological droughts or flood conditions of rivers [14–16]. However, this theory is based on the relationship between the cumulative change characteristics of precipitation and the instantaneous status of surface runoff. Like precipitation, the instantaneous runoff amount may not be enough to assess the extent of its abundance for human use, while its cumulative deficits could reflect well the water availability in terms of human use. Therefore, we can borrow the theory of SPI to study the characteristics of the surface runoff accumulation.

In general, as the formation of surface runoff is slower than that of precipitation, the time when surface runoff reaches the peak usually lags behind the rainfall. Compared with the original surface runoff, new characteristic appears as a result of the cumulative effect. Therefore, the characteristics of surface runoff under the influence of cumulative effect are more complex. Therefore, it is of significance to discover and interpret these characteristics. In order to solve the above-mentioned problems, this study chooses a river basin in the upstream areas which is little affected by human activities and conducts an analysis on meteorological droughts, the diurnal variation of the hydrological droughts, and the characteristics of cumulative changes, to further reveal the accumulation of hydrological drought variation characteristics and its relationship with meteorological droughts.

Specifically, the objectives of this study are as follows: (1) to reveal the relationship between precipitation and surface runoff based on the analysis of monitored precipitation data and runoff data of the upper reaches of Ying River; (2) to analyze the characteristics of the meteorological drought index and surface runoff; (3) to discuss the variation trends of meteorological droughts and hydrological droughts under different time scale and their change trends by using the SPI, the standardized runoff index (SRI), and the modified Mann–Kendall (MMK) trend test; (4) to study the relationship between the change cycles of regional meteorological droughts and hydrological droughts by using cross-wavelet analysis method.

## 2. Study area and data sources

### *2.1. Overview of study area*

Ying River is the largest tributary of the Huai River, the sixth-longest river in China, which has a total length of 620 km and covers a basin area of 36,728 km$^2$. The area studied is located in the upstream of Ying River, the geographical coordinates of which range from 34°35′ to 34°15′N and from 112°49′ to113°19′E, with a total area of 1,219 km$^2$. The terrain of the study area features mountains. The basin area is surrounded by mountains in the south and north and has a valley area down in the middle. In terms of geographical features, the region can be roughly divided into four parts: the remote mountains, shallow mountains, hills, and flatlands, the areas of which account for 17%, 30%, 36%, and 30%, respectively, of the total area of the basin. The surface runoff of the basin is controlled by two stations located at the export of the Ying River of the study area, which is named as Gaocheng and Baisha Hydrological Stations, respectively.

This area is characterized by the warm temperate continental monsoon climate, with an average annual temperature of 14.2°C. The average annual precipitation in the study area is 661 mm and is unevenly distributed in different years. Its maximum precipitation is about 3 times the minimum. The regional precipitation is concentrated during the flood season. While the precipitation from July to September accounts for about 62% of the annual precipitation, the precipitation from December to March accounts for about 6% of the annual precipitation. The level of precipitation in the study area is weakly correlated with the heights, with the largest average annual precipitation taking place in Xibaiping (741 mm), the smallest average annual precipitation taking place in Dengfeng (605 mm), and those of other stations ranging from 611 to 674 mm. There are only three small rivers that originate from the area researched: the Shaoxi River, the Shuyuan River, and the Wudu River. The surface water resources per year and per unit area are 150 million m$^3$ and 123 thousand m$^3$ km$^{-2}$/y. Water in the study area is mainly derived from groundwater, and only 14% is supplied by the local surface water resource. According to the water resources bulletin of Zhengzhou City (1997–2017), the local surface water resource volume was about 43 million m$^3$/y, while the consumption of surface water resource, before the construction of the Gaocheng Station Control Section, was only 1.6 million m$^3$, accounting for just 3.7% of the total surface water resources. Therefore, the use of local water resources has limited impact on natural surface runoff.

### *2.2. Data sources*

The precipitation data used in this study is originated from the daily monitoring data between the year of 2002 and 2019 collected at the weather stations in Gaocheng (GC), Dengfeng (DF), Ludian (LD), Daye (DY), Xibaiping (XBP), Dajindian (DJD), Shidao (SD), Qianling (QL), and Xigou (XG), all of which are located in Dengfeng City. The locations of the 9 weather stations are shown in Fig. 1. The design and construction of these stations have taken into consideration elements of the terrain, landscape, and meteorology. Each

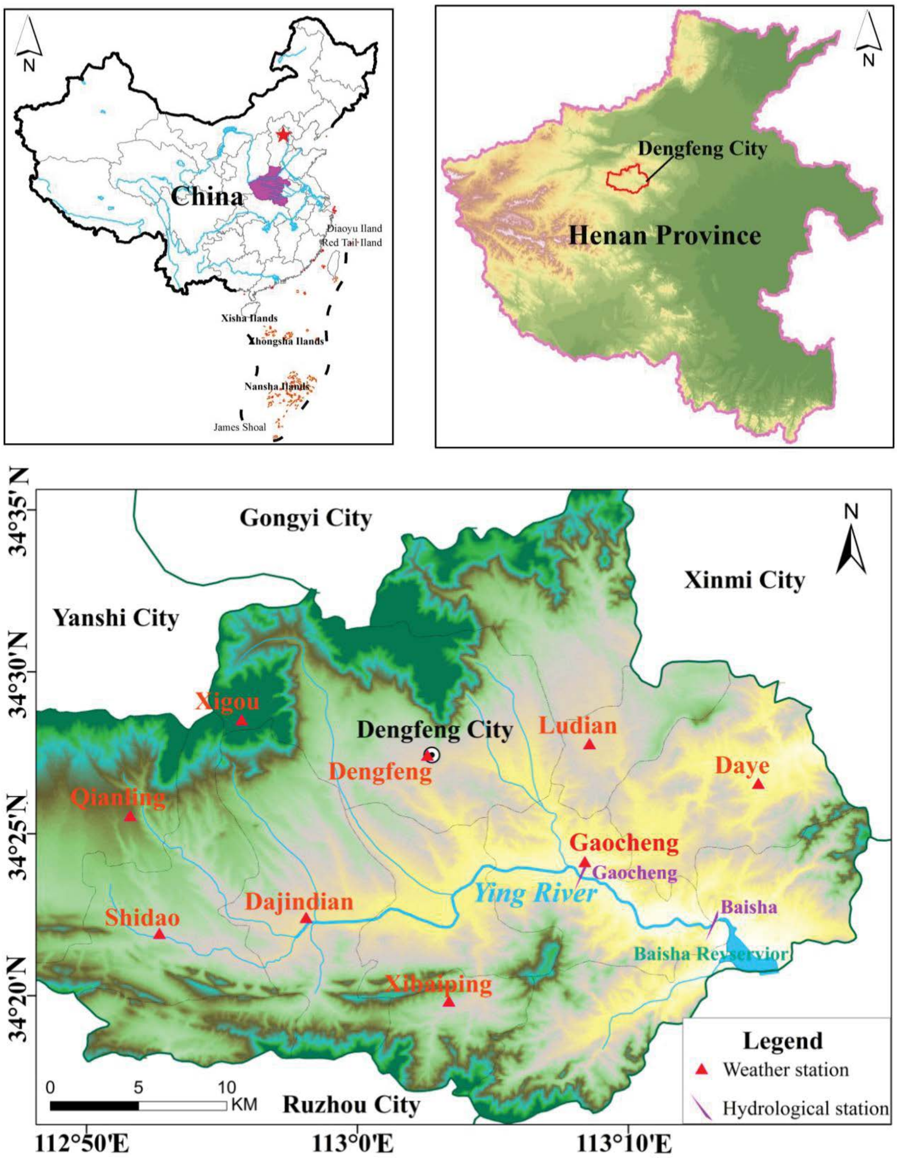


Fig. 1. Location of the study area and the distributions of the weather stations and hydrological stations.

of the above-mentioned station covers an area of 30 km$^2$ area. Therefore, these stations are representative enough to characterize the main precipitation characteristics in the upper reaches of Ying River.

Likewise, the surface runoff series used in this study comes from daily monitoring data between 2002 and 2019 collected from two hydrological stations named Gaocheng Station and Baisha Station (shown in Fig. 1).

## 3. Research methodology

The technical route of this study is described as follows: (1) prepare watershed data. The precipitation data of meteorological stations and the runoff data of hydrological control stations were collected in mountainous areas with low impact on human activities. (2) Calculate drought index. Based on precipitation and surface runoff, the meteorological drought index and hydrological drought index on different time scales were calculated. (3) The correlation, trend, and periodicity of meteorological drought index and hydrological drought index were analyzed, so as to reveal the relationship between meteorological droughts and hydrological droughts on different time scales. (4) Combined with the data of precipitation, evaporation, and topography of the basin, the influencing factors of hydrology, and droughts at different scales were analyzed. The specific technology roadmap is shown in Fig. 2.

### 3.1. Standardized precipitation index

SPI is a commonly used meteorological index that was developed and reported by McKee et al. [17]. Different time scales of SPI are used to characterize droughts or floods of different meteorological and hydrological systems [18–21]. For example, SPI on short time scales can reflect the impacts of droughts on agriculture, SPI on mesoscale is closely related to the abundance and depletion of rivers and lakes, while SPI on long time scales can reveal the evolution-related information of groundwater resources [22,23].

### 3.2. MMK trend test

The MK test is often used to test the evolution of a physical process of a time sequence after it was established [24,25]. In recent years, it is often applied in the research of climate change, hydrological evolution as well as other aspects, and has been constantly improved [26–29]. In this study, MMK test is used to compare the correlation between meteorological droughts and hydrological droughts with the evolution trends.

### 3.3. Cross-wavelet analysis

Cross-wavelet analysis is a method that could effectively analyze the correlation between two-time series [30–32]. In this study, this method is applied to analyze the relationship between meteorological droughts and hydrological droughts during the evolution period.

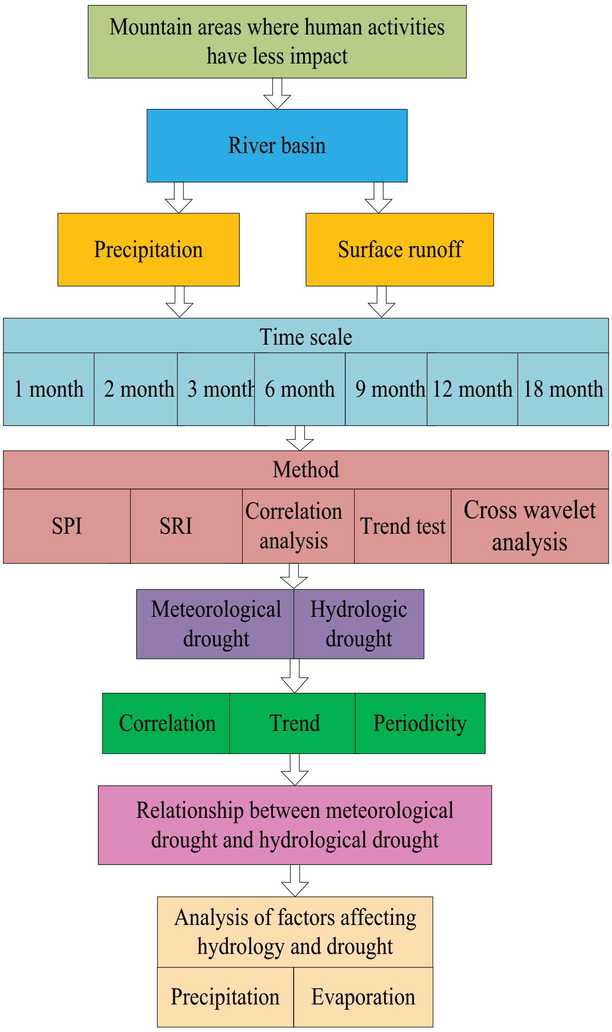


Fig. 2. Technical roadmap of this study.

## 4. Results

### 4.1. Precipitation and runoff characteristics in the upper stream of Ying River Basin

As shown in Fig. 3, the precipitation figures in the upper Ying River during 2003–2004 and 2009–2010 were relatively high, indicating that they were both flood periods. During this period, the runoff of Gaocheng Hydrographic Station and Baisha Hydrographic Station also reached a historic peak. Therefore, precipitation and runoff in the upper stream of Ying River in the flood years were positively correlated. It can also be seen from the figure that, except for flood years, there is no significant difference in the runoff data of other years before 2014. However, after 2014, when the precipitation of the basin showed a downward trend, the runoff data also decreased sharply and remained stable after 2014.

In order to select representative meteorological stations, the precipitation figures of which are typical and suitable for analysis, correlation analysis regarding the precipitation series of 9 rainfall stations was carried out every month for 18 consecutive years (Table 1). The results show that there is a strong correlation among the precipitation series of these 9 stations. Therefore, this paper has chosen one of the representative stations for analysis. As the precipitation level of the Daye Station is close to the average precipitation level of the basin, this station is used again as an example for further rainfall analysis in the following parts of this paper.

### 4.2. Characteristics of meteorological droughts in the upper Ying River Basin

As shown in Figs. 4a1~h1, through the SPI index, droughts demonstrate relatively strong cyclical fluctuations. And in Figs. 4a2~h2, the cycles of droughts represented by SPEI index last longer than those represented by SPI index. By SPI index, there is a significant tail effect on the duration of droughts, that is, as time scale lengthens, the duration of droughts in the second half of the evaluation period becomes longer owing to this cumulative effect, on the SPI curve there are multiple peaks of similar intensity during the dry periods, while on the SPEI curve, the peaks are pushed back in the dry periods.

### 4.3. Characteristics of hydrological droughts in the upper Ying River Basin

Fig. 5 shows the characteristic curves of hydrological droughts in Gaocheng Hydrological Station and Baisha Hydrological Station. Compared with the curves of SPI and SPEI in Fig. 4, the periodic fluctuations of SRI were relatively weak. Gaocheng Hydrological Station has three obvious hydrologic drought cycles, while Baisha Hydrological Station has only two. The reason is as follows: as shown in Fig. 1, in addition to incoming upstream

Table 1
Correlation analysis of precipitation between the 9 weather stations at upstream of the Ying River

| | GC-M | DF-M | LD-M | DY-M | XBP-M | DJD-M | SD-M | QL-M | XG-M |
|---|---|---|---|---|---|---|---|---|---|
| GC-M | 1 | 0.956** | 0.968** | 0.957** | 0.939** | 0.941** | 0.928** | 0.906** | 0.902** |
| DF-M | | 1 | 0.939** | 0.916** | 0.916** | 0.943** | 0.930** | 0.915** | 0.915** |
| LD-M | | | 1 | 0.963** | 0.888** | 0.906** | 0.904** | 0.874** | 0.871** |
| DY-M | | | | 1 | 0.878** | 0.901** | 0.907** | 0.869** | 0.871** |
| XBP-M | | | | | 1 | 0.945** | 0.900** | 0.914** | 0.876** |
| DJD-M | | | | | | 1 | 0.953** | 0.925** | 0.891** |
| SD-M | | | | | | | 1 | 0.927** | 0.899** |
| QL-M | | | | | | | | 1 | 0.926** |
| XG-M | | | | | | | | | 1 |

**indicates extremely significant correlation ($p < 0.01$).

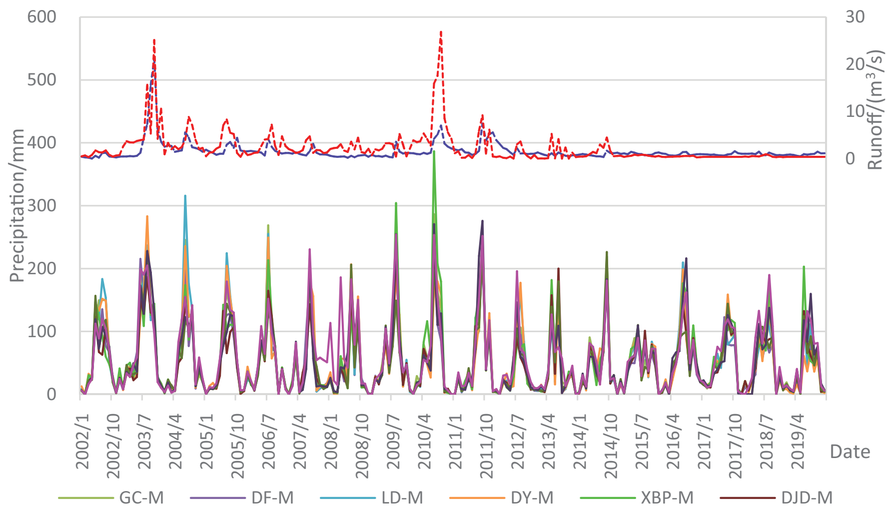


Fig. 3. Runoff at two hydrological stations and precipitation at 9 weather stations located in the upstream of Ying River basin (2002~2019). GC-M, DF-M, LD-M, DY-M, XBP-M, DJD-M, SD-M, QL-M, and XG-M denote Gaocheng, Dengfeng, Ludian, Daye, Xibaiping, Dajindian, Shidao, Qianling, and Xigou Station, respectively. GC-H and BS-H denote Gaocheng and Baisha Hydrographic Station, respectively.

water for Gaocheng Hydrological Station, there was also incoming water from areas between Gaocheng and Baisha Hydrological Station, such as the areas controlled by XBP, LD, and DY Meteorological Stations. As demonstrated in Fig. 3, from December 2007 to August 2009, the precipitation of the three weather stations – XBP, LD, and DY – reached high levels, which were much higher than those of other weather stations. Therefore, the Baisha Hydrological Station had access to abundant water resources during this period. However, the precipitation level of the meteorological station controlled by Gaocheng Hydrological Station from December 2007 to August 2009 was comparatively low, thus resulting in one more dry period than Baisha Hydrological Station.

### *4.4. Trends of meteorology and hydrology droughts in the upper reaches of Ying River*

The meteorological droughts in the upper Ying River basin on different time scales follow a consistent trend and so do the hydrological droughts (Table 2). In terms of the variations of meteorological droughts under different indices, SPEI shows a more intense drought characteristic than SPI. From the perspective of runoff droughts in different hydrological stations, the trend of droughts in Baisha Hydrological Station in the lower reaches is more obvious.

### *4.5. Correlation between meteorological droughts and hydrological droughts in the upper reaches of Ying River*

The cross-network analysis between the SRI result of the Gaocheng Hydrological Station and of the SPI result of the Daye Meteorological Station is shown in Fig. 6. It can be seen that there is a significant and strong periodic correlation between results derived from SPI and SRI methods during positive and inverse phases on a short time scale, especially when SRI is less than 3 months and SPI less than 3 months. With the increase of time scale, the correlation between the two periodic changes weakens.

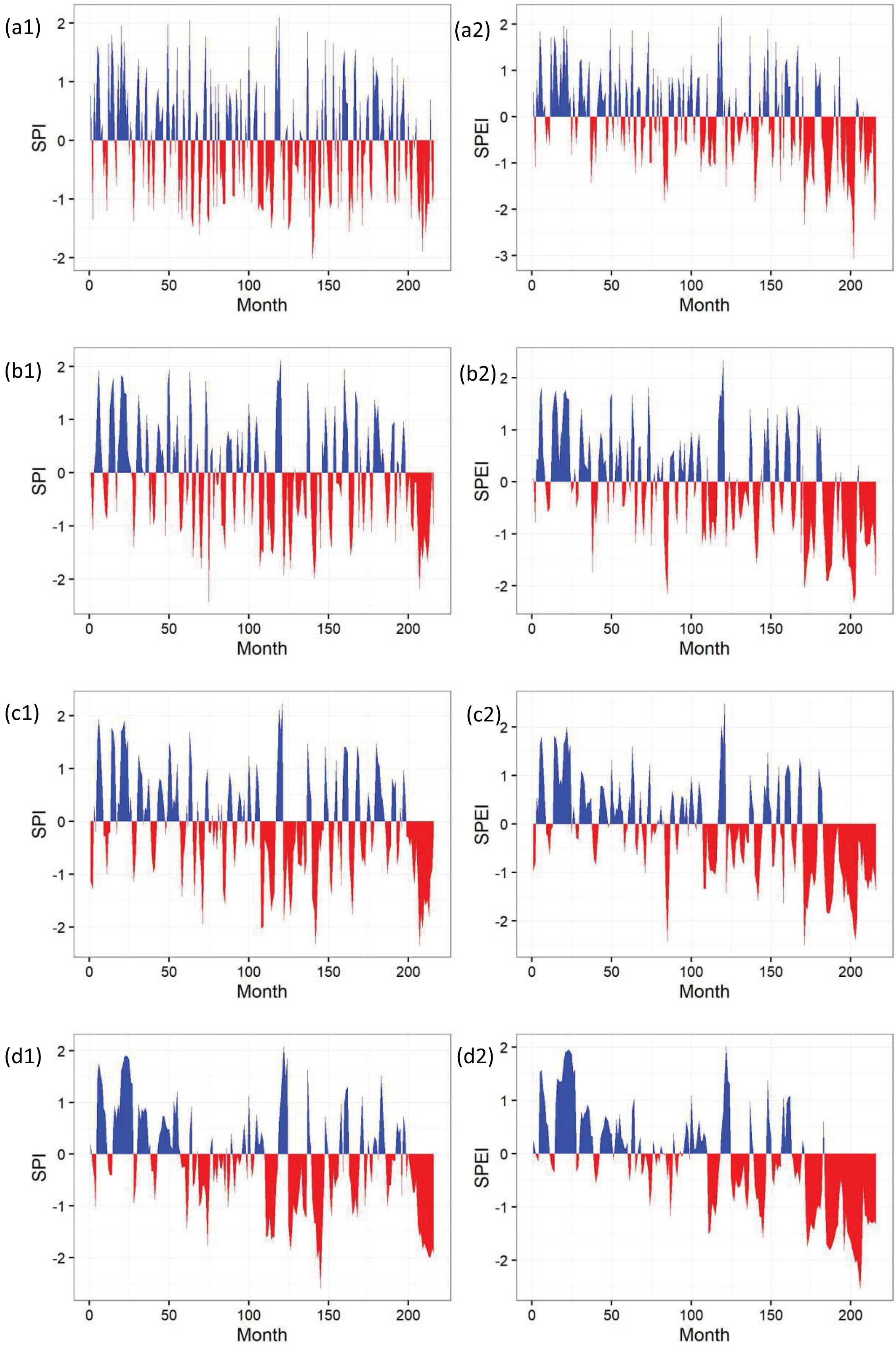


Fig. 4. Continued

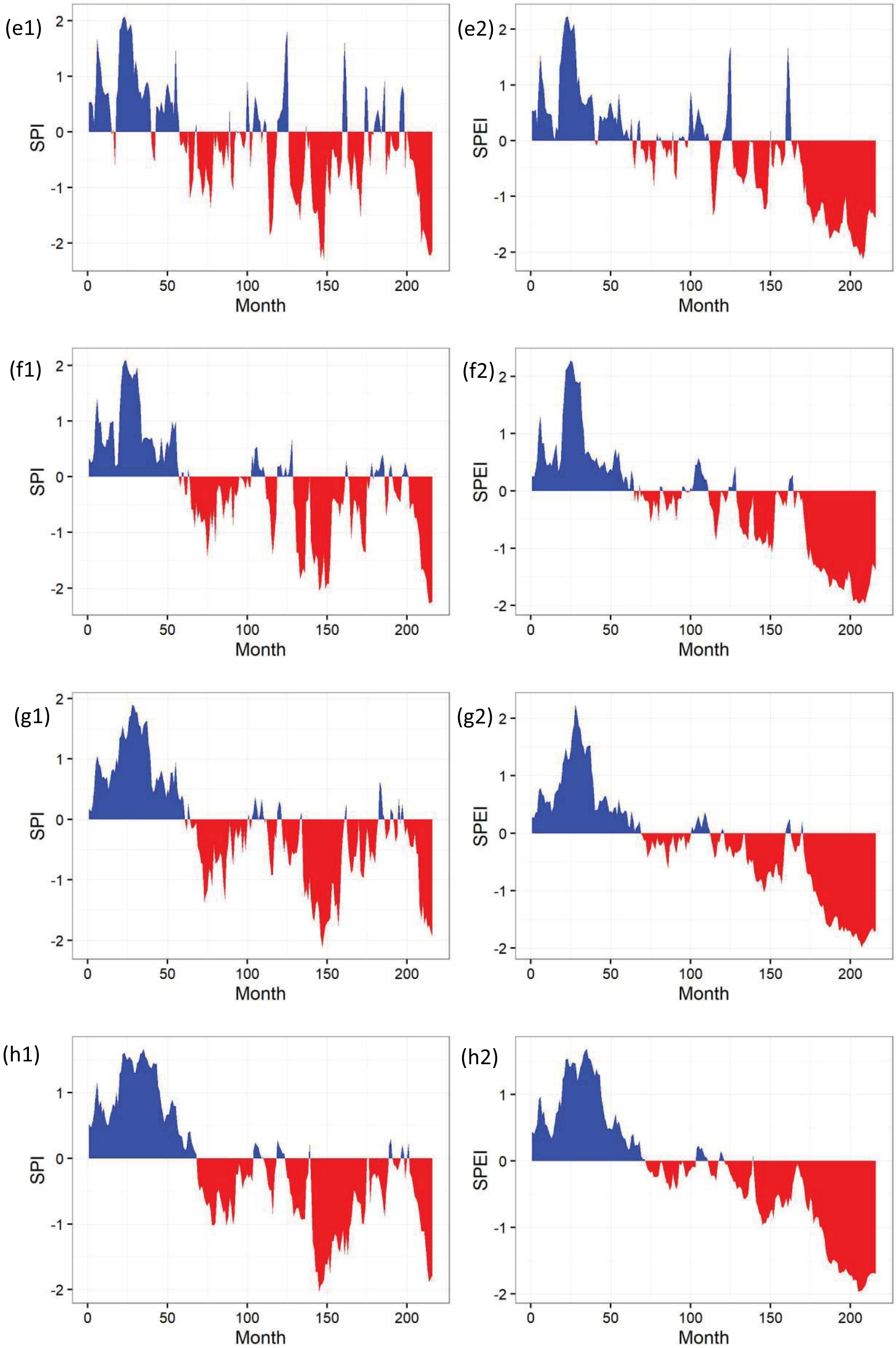


Fig. 4. Different time scales of SPI and SPEI at DY-M: (a1~h1) denote 1, 2, 3, 6, 9, 12, 18, and 24 months in the case of SPI, respectively; (a2~h2) denote 1, 2, 3, 6, 9, 12, 18, and 24 months in the case of SPEI, respectively.

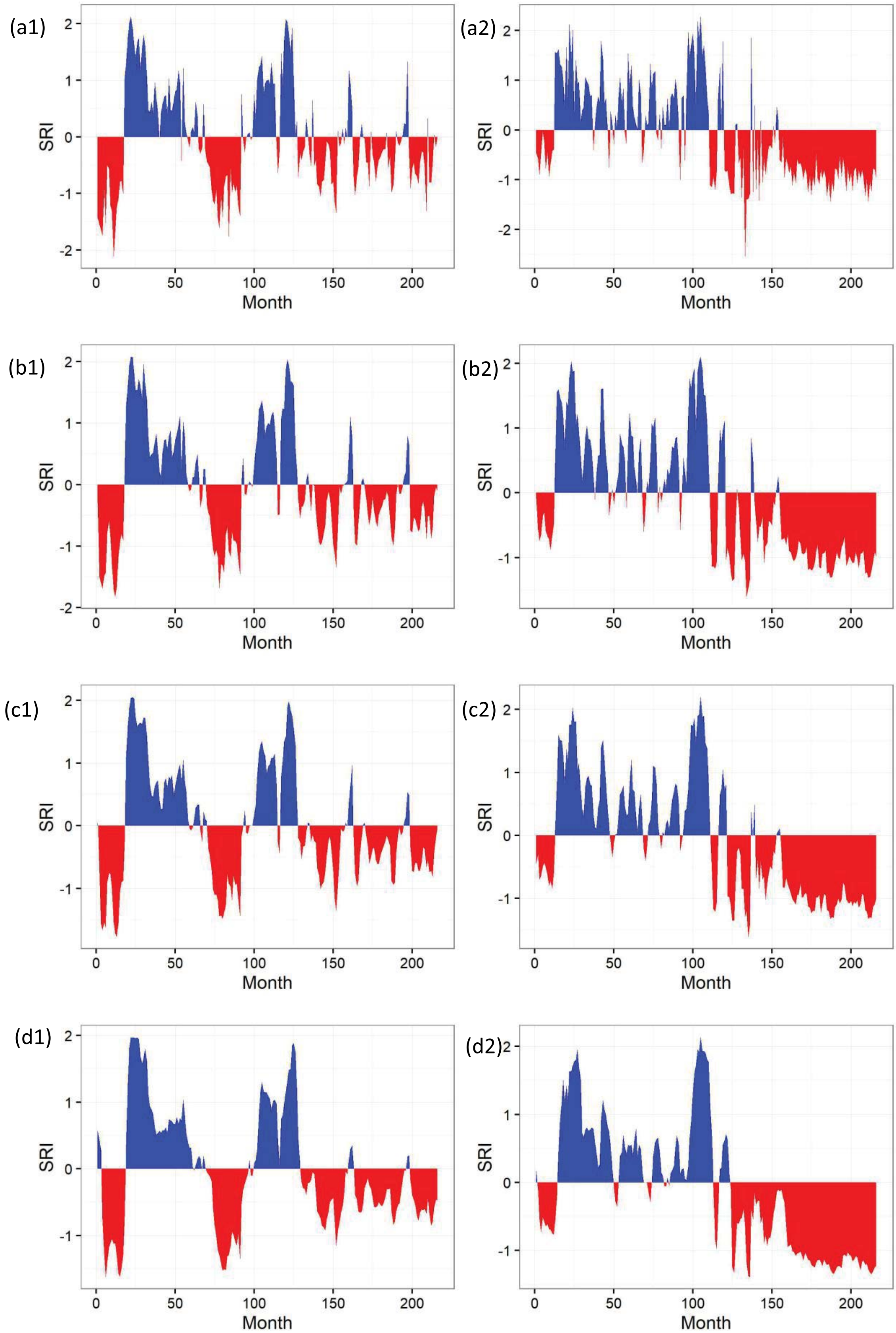


Fig. 5. Continued

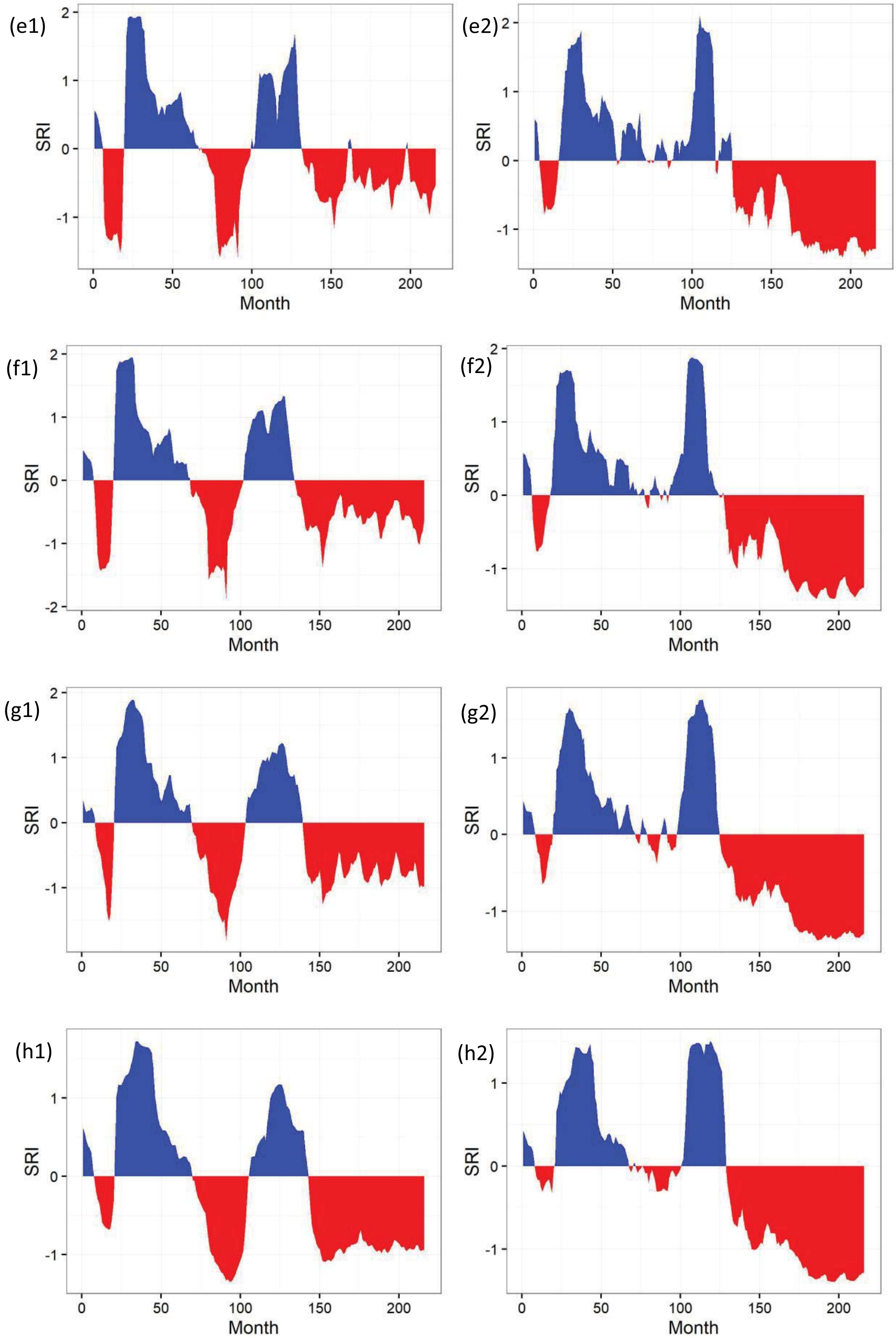


Fig. 5. Different time scales of SRI at Gaocheng and Baisha Hydrological Station: (a1~h1) denote 1, 2, 3, 6, 9, 12, 18, and 24 months of SRI at Gaocheng Hydrological Station, respectively; (a2~h2) denote 1, 2, 3, 6, 9, 12, 18, and 24 months of SRI at Baisha Hydrological Station, respectively.

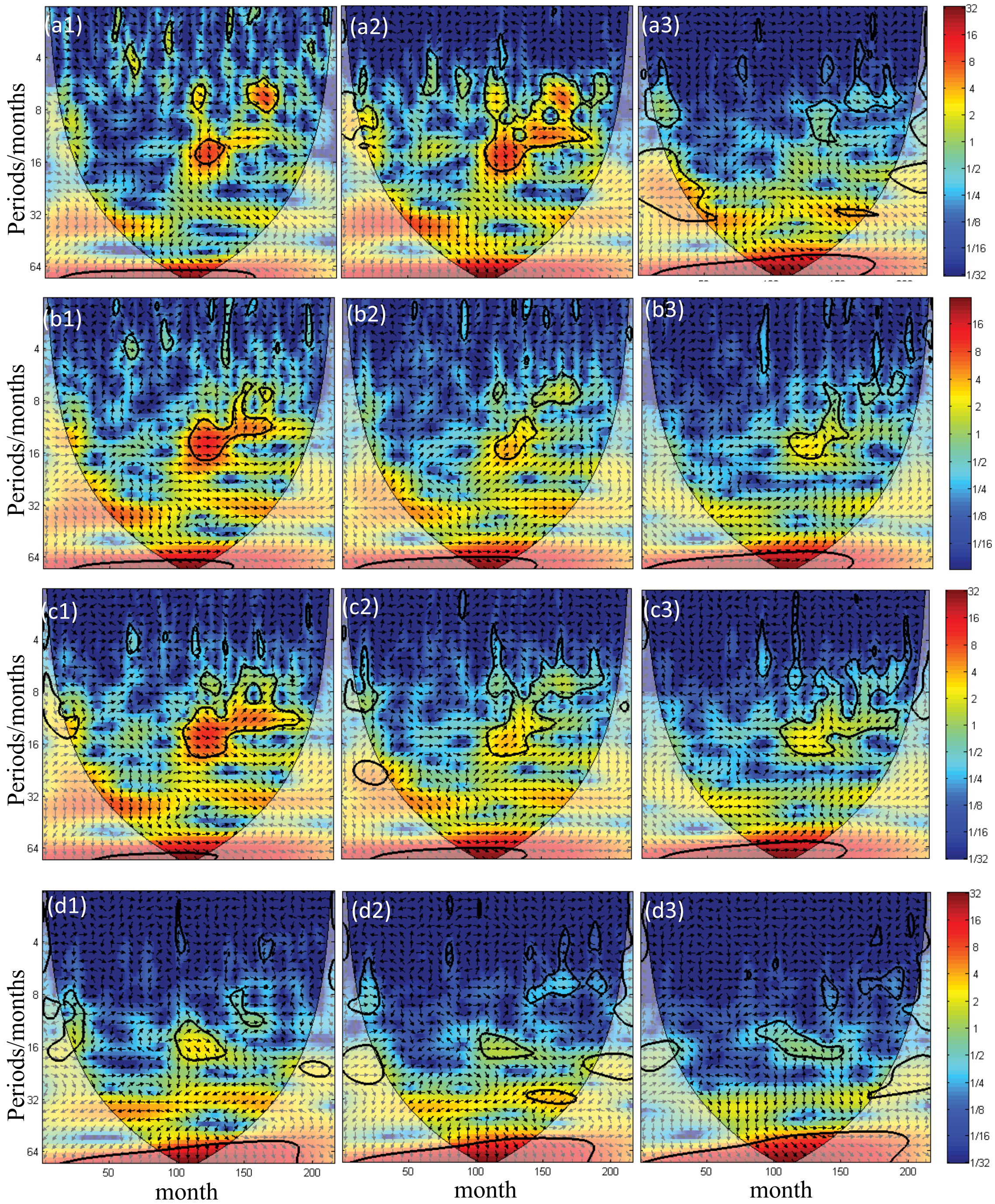


Fig. 6. Cross-wavelet transform between SRI result at Caocheng Hydrological Station and SPI result at DY-M. The 5% confidence level against red noise is exhibited as bolded. (a1) 1 month SPI and 1 month SRI, (a2) 3 month SPI and 3 month SRI, (a3) 12 month SPI and 12 month SRI, (b1) 6 month SPI and 1 month SRI, (b2) 12 month SPI and 1 month SRI, (b3) 24 month SPI and 1 month SRI, (c1) 6 month SPI and 3 month SRI, (c2) 12 month SPI and 3 month SRI, (c3) 24 month SPI and 3 month SRI, (d1) 6 month SPI and 24 month SRI, (d2) 12 month SPI and 24 month SRI, and (d3) 24 month SPI and 24 monthf SRI.

The cross-network analysis between the SRI result of the Baisha Hydrological Station and the SPI result of the Daye Meteorological Station is shown in Fig. 7. It can be seen that the relationship between meteorological droughts and hydrologic droughts in Baisha Hydrological Station is similar to that in Gaocheng Hydrological Station, and with the increase of time scale, the correlation between the periodicity of meteorological droughts and hydrologic droughts weakens. However, it can be seen clearly that the runoff droughts of Baisha Hydrological Station and meteorological droughts in the basin demonstrate a more significant cyclical characteristic.

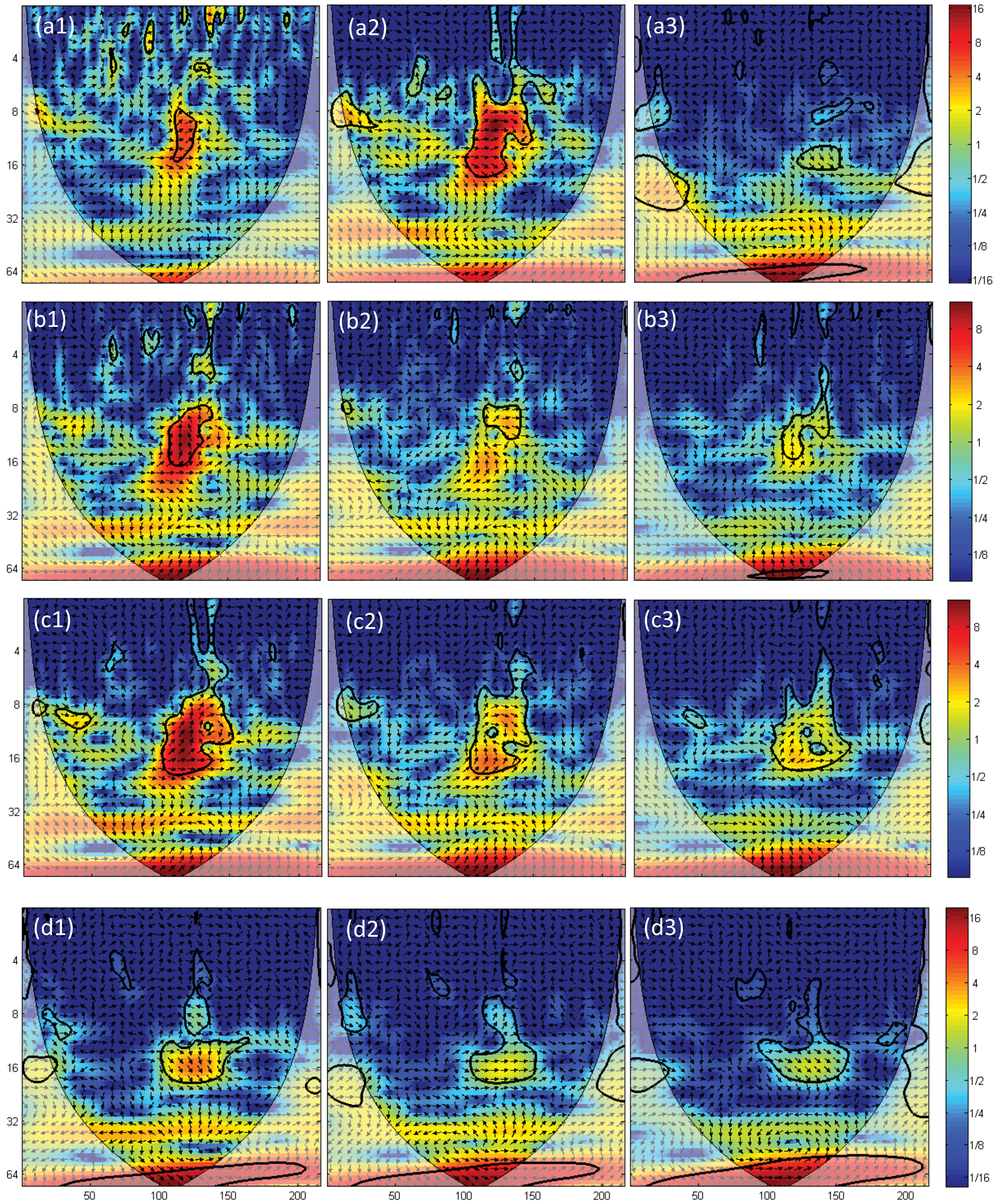


Fig. 7. Cross-wavelet transform between SRI result at Baisha Hydrological Station and SPI result at DY-M. The 5% confidence level against red noise is exhibited as bolded. (a1) 1 month SPI and 1 month SRI, (a2) 3 month SPI and 3 month SRI, (a3) 12 month SPI and 12 month SRI, (b1) 6 month SPI and 1 month SRI, (b2) 12 month SPI and 1 month SRI, (b3) 24 month SPI and 1 month SRI, (c1) 6 month SPI and 3 month SRI, (c2) 12 month SPI and 3 month SRI, (c3) 24 month SPI and 3 month SRI, (d1) 6 month SPI and 24 month SRI, (d2) 12 month SPI and 24 month SRI, and (d3) 24 month SPI and 24 month SRI.

## 5. Discussion

### 5.1. Comparison with other studies

Prior to this paper, many scholars have studied the relationship between precipitation levels and surface runoff on different time scales. Barker et al. [33] studied the relationship between meteorological droughts and hydrological droughts in 121 catchments, whose research showed that meteorological droughts are less spatially correlated than hydrological droughts. In his research, he found that the accumulation of meteorological droughts was closely related to hydrological droughts on the 1 month scale, which has been further confirmed by the research results of this paper. Besides, this paper has further arrived at another conclusion that the smaller the scale of hydrological droughts, the closer its relationship with meteorological drought, an indication that meteorological droughts can be applied to predict hydrological droughts in the short term. Meanwhile, it is also found that the longer the time scale of meteorological droughts, the higher its correlation with hydrological droughts and that the cumulative meteorological droughts over the time scale of 6 months are strongly correlated with hydrological droughts. Therefore, it is better if the time scale of meteorological droughts used for the short-term hydrological drought prediction is set beyond 6 months, and even more so if it is set at 24 months.

### *5.2. Influencing factors for hydrological droughts on different time scales*

Barker et al. [33] and Haslinger et al. [34] analyzed the influences of precipitation, soil water storage capacity, groundwater depth, and topography on hydrology and droughts. Their results show that different factors come into play in different regions. In some regions, hydrological droughts are mainly influenced by precipitation, while in others, soil water storage capacity is the main influencing factor. Their study on hydrological droughts was conducted on a large scale based on multiple basins, while the study of hydrological droughts in this paper was carried out based on a small basin. Owing to the limited research scale, only two hydrological stations were selected, which makes it difficult to analyze the spatial influences of groundwater depth and topography on hydrological droughts, and only the influences of precipitation and evaporation were studied. Correlation analysis showed that SRI results had a higher correlation with SPEI results rather than SPI results (Tables 3~6). Specifically, the shorter the time scale, the higher the correlation was between SRI and SPI (SPEI), with the 9 month SPEI scale most correlated with SRI, which is different from the results of Haslinger et al. [34]. According to their study, it was found that SPEI-4 was a better indicator for hydrological droughts than SPI and this may be attributed to the fact that the study area chosen by Haslinger et al. [34] in his research was relatively wet.

Table 2
Trends of SPI and SRI values in the upstream of Ying River calculated based on the modified Mann–Kendall trend test

| Time scale | SPI | SPEI | SRI[a] | SRI[b] |
|---|---|---|---|---|
| 1 month | –1.27 | –1.92 | –0.98 | –1.88 |
| 2 months | –1.59 | –2.02* | –1.15 | –1.95 |
| 3 months | –1.69 | –2.10* | –1.25 | –2.01* |
| 6 months | –1.81 | –2.20* | –1.52 | –2.14* |
| 9 months | –1.94 | –2.46* | –1.67 | –2.20* |
| 12 months | –1.92 | –2.50* | –1.70 | –2.22* |
| 18 months | –1.85 | –2.55* | –1.61 | –2.26* |
| 24 months | –1.82 | –2.57* | –1.70 | –2.22* |

*represents significance test $p < 0.05$, *a* and *b* denote Gaocheng and Baisha hydrological stations respectively.

### *5.3. Significance of this study*

It is found in this study that while hydrologic droughts are better predicted on short time scales (scale less than 1 month), they are more accurately evaluated by SPEI, the meteorological drought indicator, on a 6–24 month scale. Moreover, this study also found that SPEI is better than SPI at predicting hydrologic droughts, indicating that the influence of evaporation on hydrology and droughts should not be neglected. The study also learns that the meteorological droughts in this region on a 9 month scale are most closely related to hydrology and droughts on a short time scale, which may be attributed to the influences of mountain climate in the study area that could delay the accumulation of hydrology and droughts., an indicator that the time scale of meteorological droughts as an index representing hydrological droughts is different in different regions.

### *5.4. Study to be carried out in the future*

Hydrological forecasting has always been difficult and many relevant problems should be solved step by step.

Table 3
Correlation coefficient between SPI and SRI at Gaocheng Hydrological Station on different time scales in the upstream of Ying River

| | SRI-1 | SRI-2 | SRI-3 | SRI-6 | SRI-9 | SRI-12 | SRI-18 | SRI-24 |
|---|---|---|---|---|---|---|---|---|
| SPI-1 | 0.238** | 0.127 | 0.071 | 0.044 | 0.066 | 0.040 | 0.022 | 0.026 |
| SPI-2 | 0.288** | 0.233** | 0.144* | 0.078 | 0.104 | 0.069 | 0.042 | 0.043 |
| SPI-3 | 0.325** | 0.284** | 0.222** | 0.103 | 0.130 | 0.110 | 0.073 | 0.069 |
| SPI-6 | 0.426** | 0.418** | 0.402** | 0.325** | 0.280** | 0.275** | 0.232** | 0.211** |
| SPI-9 | 0.486** | 0.495** | 0.490** | 0.489** | 0.483** | 0.443** | 0.415** | 0.370** |
| SPI-12 | 0.439** | 0.473** | 0.485** | 0.506** | 0.548** | 0.539** | 0.488** | 0.456** |
| SPI-18 | 0.478** | 0.495** | 0.497** | 0.505** | 0.544** | 0.563** | 0.571** | 0.537** |
| SPI-24 | 0.434** | 0.464** | 0.478** | 0.521** | 0.569** | 0.595** | 0.627** | 0.648** |

* and ** indicate significant correlation ($p < 0.05$) and extremely significant correlation ($p < 0.01$), respectively. The meanings of * and ** are the same below.

Table 4
Correlation coefficient between SPI and SRI at Baisha Hydrological Station on different time scales in the upstream of Ying River

| | SRI-1 | SRI-2 | SRI-3 | SRI-6 | SRI-9 | SRI-12 | SRI-18 | SRI-24 |
|---|---|---|---|---|---|---|---|---|
| SPI-1 | 0.291** | 0.225** | 0.192** | 0.110 | 0.077 | 0.070 | 0.070 | 0.050 |
| SPI-2 | 0.289** | 0.331** | 0.282** | 0.171* | 0.127 | 0.113 | 0.109 | 0.080 |
| SPI-3 | 0.327** | 0.343** | 0.363** | 0.226** | 0.153* | 0.142* | 0.145* | 0.114 |
| SPI-6 | 0.319** | 0.366** | 0.382** | 0.400** | 0.297** | 0.259** | 0.274** | 0.259** |
| SPI-9 | 0.331** | 0.371** | 0.391** | 0.442** | 0.468** | 0.418** | 0.414** | 0.413** |
| SPI-12 | 0.438** | 0.475** | 0.488** | 0.511** | 0.531** | 0.539** | 0.508** | 0.510** |
| SPI-18 | 0.390** | 0.443** | 0.473** | 0.523** | 0.537** | 0.529** | 0.567** | 0.535** |
| SPI-24 | 0.443** | 0.495** | 0.512** | 0.542** | 0.557** | 0.562** | 0.590** | 0.612** |

Table 5
Correlation coefficient between SPEI and SRI at Gaocheng Hydrological Station on different time scales in the upstream of Ying River

| | SRI-1 | SRI-2 | SRI-3 | SRI-6 | SRI-9 | SRI-12 | SRI-18 | SRI-24 |
|---|---|---|---|---|---|---|---|---|
| SPEI-1 | 0.248** | 0.159* | 0.116 | 0.101 | 0.132 | 0.126 | 0.123 | 0.159* |
| SPEI-2 | 0.299** | 0.255** | 0.188** | 0.147* | 0.184** | 0.173* | 0.162* | 0.202** |
| SPEI-3 | 0.345** | 0.316** | 0.273** | 0.188** | 0.227** | 0.228** | 0.213** | 0.248** |
| SPEI-6 | 0.432** | 0.433** | 0.430** | 0.384** | 0.367** | 0.373** | 0.355** | 0.382** |
| SPEI-9 | 0.473** | 0.488** | 0.491** | 0.510** | 0.520** | 0.510** | 0.504** | 0.515** |
| SPEI-12 | 0.430** | 0.460** | 0.478** | 0.516** | 0.567** | 0.580** | 0.571** | 0.578** |
| SPEI-18 | 0.418** | 0.444** | 0.460** | 0.499** | 0.547** | 0.579** | 0.621** | 0.634** |
| SPEI-24 | 0.385** | 0.414** | 0.434** | 0.486** | 0.541** | 0.581** | 0.640** | 0.694** |

Table 6
Correlation coefficient between SPEI and SRI at Baisha Hydrological Station on different time scales in the upstream of Ying River

| | SRI-1 | SRI-2 | SRI-3 | SRI-6 | SRI-9 | SRI-12 | SRI-18 | SRI-24 |
|---|---|---|---|---|---|---|---|---|
| SPEI-1 | 0.438** | 0.386** | 0.361** | 0.294** | 0.276** | 0.275** | 0.270** | 0.248** |
| SPEI-2 | 0.430** | 0.482** | 0.445** | 0.359** | 0.333** | 0.325** | 0.326** | 0.303** |
| SPEI-3 | 0.472** | 0.501** | 0.527** | 0.428** | 0.385** | 0.378** | 0.382** | 0.362** |
| SPEI-6 | 0.508** | 0.574** | 0.598** | 0.633** | 0.567** | 0.539** | 0.536** | 0.523** |
| SPEI-9 | 0.535** | 0.602** | 0.627** | 0.692** | 0.724** | 0.689** | 0.665** | 0.654** |
| SPEI-12 | 0.594** | 0.657** | 0.680** | 0.729** | 0.767** | 0.774** | 0.737** | 0.717** |
| SPEI-18 | 0.557** | 0.627** | 0.658** | 0.728** | 0.766** | 0.772** | 0.783** | 0.748** |
| SPEI-24 | 0.586** | 0.650** | 0.672** | 0.722** | 0.754** | 0.767** | 0.784** | 0.788** |

The applicability of indicators for hydrological drought prediction needs to be verified and improved by studies conducted in different regions. Meanwhile, attention must be paid to the length of time during which the meteorological data series on hydrology and droughts are collected and to how the hydrology and droughts in areas lacking in data are scientifically assessed.

## 6. Conclusions

The study has chosen the basin of the Ying River, a basin not so heavily influenced by human activities, as the research object to explore the relationship between meteorology droughts and hydrological droughts. The primary conclusions are as follows:

- Meteorological droughts and hydrological droughts are positively correlated. For hydrological droughts, a smaller time scale would produce a higher correlation with meteorological droughts, while a longer time scale would bring about a better correlation. In other words, the prediction of hydrology and droughts is more accurate when it is applied on a smaller time scale while the prediction delivers better effects when it is conducted on a longer time scale of meteorological droughts. Therefore, this study suggests that meteorological droughts lasting more than 6 months be used to predict hydrological droughts of less than 1 month.
- While it is noted that there are dry trends under both meteorological and hydrological conditions, the dry trends of the latter were less obvious.

- With an increased length of time, meteorological and hydrologic droughts follow different periodic patterns. When the time scale of meteorological drought increases, the number of hydrological drought cycles decreases. Though there are still a number of cycles, the correlation decreases. When the time scale of the hydrologic droughts increases, the meteorological drought cycles become simpler, demonstrating that the hydrological droughts on a short time scale are the result of the superposition of multiple periodic meteorological droughts.
- This study also shows that SPEI may be more suitable than SPI for identification and characterization of hydrology and drought problems in arid regions and in areas featuring scarce hydrological data, the 9 month time scale SPI is more suitable for the characterization of hydrological droughts.

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