Rainfall and runoff characteristics in a karstic basin of China
Chongxun Mo, Guiyan Mo, Junkai Qin, Ming Zhou, Qing Yang, Ya Huang and Yunchuan Yang

ABSTRACT
This paper examines the rainfall and runoff characteristics in a karstic basin of China. The results indicated that the inner-annual distributions of rainfall and runoff were uneven and slightly different, as the concentration period of rainfall (from April to October) was earlier; there was a delay of about a month before the runoff (from May to September), and the concentrated volume accounted for 87% of annual precipitation or annual streamflow. Interannually, rainfall changed more significantly than runoff, the wet years lasted longer than the dry years (rainfall), while the high and low flow years were equal for runoff. In addition, judging from the value of the Mann-Kendall test, the average annual change of rainfall (−2.36) was more significant than that of runoff (−2.05), and the seasonal pattern of runoff maintained an opposite tendency in autumn and winter before 1990. The changes in runoff were mainly associated with rainfall and the formation conditions in the karstic area, and the reservoir in this basin should be operated with different flood limiting water levels, and the vegetation coverage should be improved.

Key words | displacement theory, karstic basin, Mann-Kendall test method, rainfall and runoff, round analysis

INTRODUCTION
Over the past century, the hydrologic circulation process has been changed by various degrees due to the significant changes in the earth’s climate system and the dramatic impacts of human activities. Therefore, hydrologic circulation and water resources vulnerability under changing environments has been one of the hot topics of hydrological research (Elias et al. 2016; Tong et al. 2016). Focussing on the problems of hydrologic circulation and related resources and environmental issues under a changing environment at different scales (global, regional, watershed, etc.), a series of cooperative projects have been conducted in succession (Liu 2002; Barnett et al. 2005; Zhang & Wang 2007; Liu et al. 2016), including the Intergovernmental Panel on Climate Change (IPCC), the World Climate Research Programme (WCRP), and the Global Water System Project.

Climate warming aggravates the hydrologic circulation process and drives the change of hydrological and meteorological elements. Meanwhile, human activities change the conditions of the underlying surface of the river basin and affect the distribution of runoff so that runoff may increase or decrease by various degrees.
Thus, the change of rainfall and runoff had attracted the attention of many researchers. A succession of Assessment Reports (AR) by the IPCC strengthened the evidence of a global change whose main manifestation was an increase in global temperature. The IPCC (2013) stated that more than half of the global warming was caused by human activities since the 1950s, 93% of the heat of greenhouse gases which came from anthropogenic emissions was absorbed by the sea, and the ocean also absorbed approximately 30% of the anthropogenic emissions of carbon dioxide since 1971, which has caused the pH of sea surface water to decrease by 0.1. On the other hand, based on the model of CMIP5, the future global warming will continue and global average surface temperature at the end of the 21st century will be higher by 0.3–4.8 °C from that of 1986–2005 (Moss et al. 2010; WMO 2013; IPCC 2013; Qin & Stocker 2014).

Aondover & Ming-ko (1998) probed the changes in rainfall characteristics in northern Nigeria, and Blanchet et al. (2016) explored the spatial distribution of trends in extreme daily rainfall in southern France. Cheng et al. (2016a, 2016b) proposed the DPMI method to reflect the system nonlinearities, data uncertainties, and multivariate dependencies in hydrological systems, and it was applied in the Three Gorges Reservoir region to reveal the complexities of hydrological processes. Then, Cheng et al. (2017) developed an ECDoCP framework, for projecting temperature and precipitation in a large unregulated continental river basin in Athabasca, Canada and found that the colder days in the north were fewer, with less precipitation in the upstream areas, and warmer and wetter days in the other regions in the 21st century. Xu et al. (2009a) analyzed the multi-time-scale variability of precipitation in a desert region of northern China, and the other Xu et al. (2009b) studied the runoff variation and its impacting factors in the Nen-jiang river basin during 1956–2006.

Although there are many studies on the changes of rainfall or runoff, there has been little systemic analysis about the various characteristics and their relative contributions, especially in karstic areas where the formation conditions for runoff are complex and variable. Therefore, the main objectives of this study are: (1) to obtain a comprehensive insight into the inner-annual distribution of rainfall and runoff; (2) to identify the inter-annual variation features of them; (3) to examine the trends of them from 1964–2015; and (4) to analyze the relationship among runoff changes, rainfall and the karstic formation conditions. Finally, this study should provide a scientific basis for water resources development in a river basin and ecological environment protection in the karstic area.

**STUDY AREA**

The Chengbihe River, originating from Lingyun County in Guangxi province, China, has a total length of the mainstream of 127 km and a natural drainage area of 2,087 km². The Chengbihe reservoir dam, located between the east longitudes 106°21′E ~ 106°48′E and the north latitudes 23°50′N ~ 24°45′N (shown in Figure 1), is the biggest earth dam in Guangxi province. Its annual average precipitation is 1,560 mm, and the rainfall during the flood season (April to October) accounts for 87% of the annual precipitation. Its inflow is highly variable on a seasonal basis. The average annual runoff of this basin is 12.82 billion m³, and the mean annual discharge is 40.64 m³/s, with the maximum daily flow of 1,350 m³/s during the flood season and the minimum flow of 0.3 m³/s during the dry season.

In recent decades, the topographic structures of Chengbihe basin, which is a karstic area, have been revealed; the structure types mainly include depression, underground stream, sinkhole, karstic cave, karstic fissure, karstic funnel, and so on. The development scale of depression increases as the elevation decreases, and the sinkhole as well as the karstic funnel mainly occur in the bottom of the depression and on both sides of the platform of Chengbihe. The development density and scale are weak in the mountainous area, but are strong in the river valley area where they connect with the horizontal karst caves or underground streams. There are four stripe-structure depressions adjacent to the right valley, while two large underground streams lie to the left. As a result, the water-flow condition is complex, and rivers flow across the surface and underground. The giant cavities can guide underground water, the fissures can...
restore water, and the surface depressions can accumulate water. Finally, the formation conditions and the cumulative process of runoff in the study area is variable and complex. However, the Chengbihe river basin is located in the mountainous area and is still at the lower level of development. The overall changing trend of karstic topography is too insignificant to influence the evolution characteristics of rainfall and runoff. Thus, the analysis of this paper is based on the original major karstic topography.

DATASETS AND METHODS

Datasets

Based on the above karstic topography and the elevation of the Chengbihe river basin, runoff is collected from the high elevation to the low elevation (Figure 1), and eight monitoring posts are set up in the areas of confluence. In this study, eight monitoring stations were used: Bai Lian station (BLS), Lin He station (LHS), Xia Tang station (XTS), Nong Tang station (NTS), Zhao Li station (ZLS), Jie Fu station (JFS), Dong He station (DHS) and Ling Yun station (LYS) and one runoff station named Ba Shou station (BSS) with 52 years’ rainfall and runoff data from 1964 to 2015. Figure 1 depicts the distribution of the rainfall and runoff recording stations.

In this paper, we adopted the following methods to interpolate and extend for monitoring stations with missing rainfall data: (1) the mean value of the adjacent data was used to interpolate the monitoring stations with few precipitation data missing; (2) for the monitoring stations with more data missing, first station XTS was used as a reference station for a simple linear regression model used to interpolate and correct the data. Finally, the mean areal precipitation was calculated according to the data from the stations. Meanwhile, by using the ‘Pre-Whitening’ methods (Zhang et al. 2001), the autocorrelation of the original data sequence is removed.

It can be seen from Figure 2(a), the autocorrelation coefficient of the original precipitation sequence, whose lag is 1, reached 0.14194, so the original precipitation
sequence is not independent and can not be directly used for the analysis. By using the ‘Pre-Whitening’ methods, the autocorrelation of the original precipitation sequence is removed. Figure 2(b) shows the results, and that after ‘Pre-Whitening’ the autocorrelation coefficient is just 0.012293. The effect of ‘Pre-Whitening’ methods is quite obvious, and the autocorrelation of the precipitation sequence is eliminated.

**Methods**

**Round analysis**

Round analysis by Ding & Liu (1997) was used to identify the $t$th year rainfall $X_t$ in the time series $X_1, X_2, ..., X_n$ ($N$ is the statistical years) to easily and effectively differentiate wet years and dry years; the analysis is based on the cutting value $y$ (usually depends on the average annual rainfall for years), and defines it as positive round ($X_t > y$) or negative round ($X_t < y$). Round analysis is particularly useful to judge the drought or flood duration and the total amount of water shortage or water surplus. It is characterized by the length of a round ($l$) and the total amount of a round ($d$)

$$l_n = \frac{1}{M} \sum_{j=1}^{M} l(j)$$

(1)

where $l_n$ is the mean value of the length of a round, which consists of $M$ sub-rounds, and

$$s_n(d) = \left[ \frac{1}{M - 1} \sum_{j=1}^{M} (d(j) - d_n)^2 \right]^{1/2}$$

(2)

where $s_n(d)$ represents the standard deviation of the total amount of $M$ sub-rounds, and $d_n$ is the average total amount of a round.

**Displacement theory**

High or low flow is mainly differentiated by the total volume of runoff and the displacement of the relative magnitude between the annual runoff ($Q_t$) and the average annual runoff ($Q_0$), and can be used for quick and effective judgements. When $Q_t - Q_0 > 0$, it is defined as a high flow year, as opposed to a low flow year ($Q_t - Q_0 < 0$). The basic displacement theory by Yevjevich (1972) consists of the sum $s$ in a high or low flow displacement for $m$ items, the intensity (the ratio of the sum $s$ and the length of a displacement $m$) and the probability of high or low flow occurrence, which can be described as:

$$P = \rho^{(K-1)} \times (1 - \rho)$$

(3)
where \( K \) is the year for high or low flow occurrence, and \( \rho \) is the model distribution parameter, which assists in the calculation and can be obtained from:

\[
\rho = \frac{(S - S_1)}{S}
\]  

where \( S \) is the accumulated frequencies of the high or low flow in the runoff series, and \( S_1 \) is the same accumulated frequencies, but specific to a high or low flow in different scales, such as for one year, two years continuously, and so on.

**Trend analysis – moving average method**

The moving average method (Sheng et al. 2001) involves starting from the first value of a rainfall or runoff series, and then sliding it item by item at a three-year interval, a five-year interval, or a natural cycle interval; the method can be used to qualitatively and visually reflect the trends in a rainfall and runoff series. Generally, the average of the continuous value of number \( 2k \) or \( 2k + 1 \) in the sequence \( x_i \) is used to get the new sequence \( y_i \) and to make the original sequence smoother. The new sequence can be expressed as:

\[
y_i = \frac{1}{2k + 1} \sum_{i=-k}^{k} x_{i+j}
\]

where \( y_i \) is the new sequence, \( k \) is the scale of the moving average method, and \( x_{i+j} \) is the original sequence. When the value of \( k \) is 2, it is called the Five-Point Moving Average method. Because it is simple and easy to understand, the Five-Point Moving Average method is widely used in the field of hydrology.

**Trend analysis – Mann-Kendall test method**

The moving average method provides no quantitative information regarding trends. For this, the statistical value of \( \tau \) in a Mann-Kendall test method is used (Mann 1945; Kendall 1957). For each value of \( x_i \) in a rainfall or runoff series \( x_1, x_2, \ldots, x_N \) (\( N \) is the length of a dataset), the number of all the subsequent terms whose values exceed \( x_i \) is tallied and denoted as \( f \). Then, the statistical value of \( \tau \) is calculated as:

\[
\tau = \frac{4f}{N(N - 1)} - 1
\]

Trends can be described quantitatively via the standard normal value \( (Z(1 - \alpha/2)) \) with a confidence level \((\alpha = 10\%, \alpha = 5\% \text{ and } \alpha = 2\%)\), and the calculated value \( (Z_c) \), which can be described as:

\[
Z_c = \frac{\tau}{\text{var}(\tau)^{1/2}}
\]

where the statistical value of \( \text{var}(\tau) = (2(2N + 5)/9N(N - 1)) \). Finally, when the value of \( |Z_c| < Z(1 - \alpha/2) \), it indicates no significant trend; a positive value of \( Z_c \) \((Z_c > Z(1 - \alpha/2))\) indicates an increasing trend, and a negative value of \( Z_c \) \((Z_c < -Z(1 - \alpha/2))\) indicates a decreasing trend. In this study, the 95% confidence level was used for the Mann-Kendall test method.

**RESULTS AND ANALYSIS**

**Inner-annual distribution analysis**

**Rainfall**

Tables 1 and 2 show the distribution of the monthly and seasonal rainfall, respectively, along with the corresponding ratio of annual rainfall in the Chengbihe river basin for the period from 1964 to 2015. For this study, spring is from March to May, summer is from June to August, autumn is from September to November and winter is from December to February. As the results show, the rainfall is concentrated with approximately 87% of the annual precipitation occurring during the flood season (from April to October), resulting in the uneven distribution and the significant differences between months. As seen from Table 1, the average annual rainfall was approximately 1,348.41 mm, with a maximum precipitation (314.62 mm) in June, which accounted for 23.33% of the annual rainfall. For May, July and August, the corresponding percentages were 14.28%, 15.57% and 14.94%,
respectively. The annual rainfall was more or less normally distributed (Gaussian distribution), which meant precipitation was greater in the middle months (April to October), but less in both ends. From Table 2, rainfall decreased in a seasonal pattern of summer-spring-autumn-winter. Studying the differences among the seasonal precipitation in detail, summer (725.65 mm) was the most rainfall season, taking up approximately 53.82% of the annual rainfall, and then for spring, autumn and winter, for which the percentages were 21.75%, 18.38% and 6.05%, respectively.

### Runoff

Depicted by four indices (the non-uniformity coefficient, the complete-adjustment coefficient, the concentration ratio and the concentration period of annual runoff (Zheng & Liu 2003), the mean monthly runoff differed significantly from month to month and mainly occurred from May to September, which accounted for 87% of the annual runoff (can be seen from Figure 6 and Table 3 later). However, the concentration ratio decreased progressively, and it is demonstrated that the inner-annual distribution of streamflow will gradually transform from non-uniformity to homogeneity (Figures 3–5). At the same time, the local climate had a wet period with a maximum in June (Table 1), while the maximum flows were observed in July (see Figure 6). It is well known that the fissures in karstic topography can cause runoff to be slow moving.

As seen from the results, Figures 3 and 4 show that the maximum non-uniformity coefficient of annual runoff...
reached up to 1.70 (in 1993). Moreover, the minimum and the mean values were 0.73 and 1.14, respectively. On the other hand, the average complete-adjustment coefficient of annual runoff was 0.47. Moreover, Figure 5 indicates that the concentration ratio of annual runoff mainly ranged from 0.5 to 0.8, with a peak value of 0.81 (occurring in 1993), but approximately presented a synchronous trend such as those in Figures 3 and 4: decreasing (1964–1983) – increasing (1984–1993) – decreasing (1994–2015).

**Inter-annual variability analysis**

**Rainfall**

Figure 7 and Table 4 illustrate that on the whole, rainfall varied to different degrees between years, and there were many more wet years than dry years in the Chengbihe river basin. On one hand, the length of the positive round and the negative round ranged from 1 to 8 and from 1 to 5, respectively, which meant that the maximal duration for wet (eight years) was longer than dry (five years), and it corresponded with the plentiful precipitation and the abundant water resources in southern China. On the other hand, the maximal duration for the dry years was five years, during 2009–2013, and the alteration of precipitation was mainly one-year dry, followed by two-year dry and three-year dry consecutively. In contrast, the maximal duration for the wet years was eight years, during 1976–1983, and for an isolated year to be wet was rare, i.e., it was generally wet for multiple years at a time.

**Runoff**

Displacement theory was applied to analyze the probability of continuous high flow and low flow in the Chengbihe river basin (Table 5) and a comparative plot was constructed (Figure 8). As seen from Table 5 and Figure 8, apart from the probability of two-year low flow continuously being greater than two-year high flow (0.11 > 0.04), the other probabilities of high or low flow did not change distinctly. On the other hand, the values of the displacement were the same, statistically, such as the model distribution parameters. Thus, their frequencies were nearly equal to each other, which meant that the continuous high flow and low flow were proportional. Hence, a deviation from the inter-annual mean rainfall and runoff, namely, the duration of the wet year, was longer than the dry year while the probabilities of the high flow and the low flow were roughly equal. Runoff did not change greatly with changes in precipitation, and the scheme can be seen in Figure 9. The double-mass curve of the depth of rainfall and runoff (Figure 10) shows that they were in good agreement before 1987, when rainfall was the main driving factor of runoff. However, the relationship between rainfall and runoff changed after 1987, which is worthy of further discussion.
Trend analysis

Annual

The annual rainfall and runoff (Figure 11) were generally decreasing at the same pace (judging from the ten-point sliding curve), and the amplitude of the change was 790.9 mm for rainfall and $0.26 \times 10^8$ m³ for runoff, respectively. On the other hand, several fluctuations occurred (five-point sliding curve indicated) between 1964 and 2015, such as an increasing trend during 1963–1967, 1972–1976 and 1985–1991, among which the trend of runoff during 1985–1991 was relatively significant, and there was a decreasing tendency in other periods. As can be seen from Table 6, both the trend of rainfall and runoff by the moving average...
method and the Mann-Kendall test method were negative, and rainfall was more significant than runoff, judging from the value of Mann-Kendall test result, in which rainfall was $-2.36$, while runoff was $-2.05$.

**Seasonal**

Rainfall had a more significant decreasing trend than runoff in spring and summer, while it showed an opposite tendency in autumn and winter (Figure 12 and Table 7). As seen from Figure 11, the trend of rainfall and runoff was more significant in summer than in spring. Rainfall decreased by $88.9$ mm in summer, which was more than in spring ($36.5$ mm), while runoff decreased by $0.79 \times 10^8$ m$^3$ in summer, also more than in spring ($0.16 \times 10^8$ m$^3$). The statistic value of rainfall in summer ($|Z_c| = 3.15$) was bigger than in spring ($|Z_c| = 2.17$), as it was with the runoff ($|Z_c| = 2.20$) in summer compared to $|Z_c| = 2.13$ in spring. On the other hand, rainfall decreased before 1992 in autumn and the period between 1971–1979 in winter, while runoff increased. During this period, rainfall decreased by $20.3$ mm in autumn and $16.4$ mm in winter, and runoff increased by $0.29 \times 10^8$ m$^3$ in autumn, and $0.05 \times 10^8$ m$^3$ in winter. However, on the whole, the seasonal trend of precipitation was more remarkable than runoff.

**DISCUSSION**

Discussion of time-course characteristics of rainfall and runoff

Through the analysis above, the inner-annual distribution and the inter-annual variations of runoff in the Chengbihe river basin kept pace with the rainfall in general, yet they were different in detail.

First, the period of concentrated rainfall is earlier, and the runoff is delayed by approximately one month. What accounts for this? As we know, precipitation in the karstic area serves both to supply the water shortage of the unsaturated zone through the huge soil water infiltration and to meet the water demand of the bedrock fissure. Thus, rainfall forms the fissure flow earlier in the month and after a month-long delay, which satisfies the water demand of river networks and can be used as runoff compensation in the dry season, induces this phenomenon.

Second, the duration of the wet years is longer than that of the dry years while the probabilities of the high flow and the low flow are roughly equal to each other. Hence, rainfall has a positive effect on runoff, but runoff does not change as much as the precipitation because rainwater can be stored in sinkholes and in the slow fissure flow. That is, precipitation directly enters underground via the sinkhole, the karstic fissure, the karstic groove and so on, where evaporation is low, and the velocity of runoff hidden in the fissure is slow.

**Figure 11** | Time series plot of annual rainfall and runoff.

**Table 6** | The trend of rainfall and runoff (annual scale)

<table>
<thead>
<tr>
<th>Item</th>
<th>Mann-Kendall test method</th>
<th>Moving average method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The calculated value $Z_c$</td>
<td>Trend</td>
</tr>
<tr>
<td>Rainfall</td>
<td>$-2.36$</td>
<td>decrease</td>
</tr>
<tr>
<td>Runoff</td>
<td>$-2.05$</td>
<td>decrease</td>
</tr>
</tbody>
</table>
Therefore, compared to rainfall, the inter-annual runoff changed steadily.

**Discussion of trend-course characteristics of rainfall and runoff**

Before 1990, rainfall and runoff in autumn and winter showed opposite overall trends. Based on the geological data, on one hand, the karstic surface is characterized by a great infiltration because of the development of the bedrock fissure, the sinkhole, the karstic funnel and so on. On the other hand, the majority of infiltration water flows out quickly through the underground streams, but the rest, which is stored in the scattered flow area combined with the small fissure or deep fissure, flows slowly and steadily. Consequently, after the abundant rainfall in spring and
summer, the rainwater stored in fissures will be a compensation for runoff in the dry season, autumn and winter, and contributes to the behavior of decreasing rainfall when runoff increases.

After 1990, rainfall and runoff exhibit the same trends. According to the Ling-yun County annals (Editorial Board of Ling-yun County 2007), the forest coverage of Ling-yun County increased from 20% in the 1970s to 41.47% in the early 1990s, which improved the underlying surface conditions of the Chengbihe river basin greatly and strengthened the capacity of water storage and water conservation of karstic pores. Hence, the pores of the river network are filled with rainwater, and the water level of the karstic fissure in the scattered flow area is relatively stable. As a result of this, rainfall does not need to add too much for the underground river network and most of the precipitation flows through the underground river directly and produces streamflow in a short period of time, except for a small portion of the precipitation which supplies the water demand of the fissure and the surface depressions. Consequently, the trend of rainfall and runoff is synchronized after 1990.

**Practical suggestions about the research work**

For the uneven distribution of rainfall and runoff and given that the majority, approximately 87% of the annual rainfall or runoff, occurs in a rather brief period, it is suggested that the reservoir manager can operate at different flood limiting water levels (FLWLs). With regard to the period of concentrated rainfall (namely, flood season), the reservoir governor should open the water gate to discharge the surplus flow and operate it at a lower FLWL for the early and main flood season, this can protect the safety of the dam and downstream areas. The FLWL should then be properly raised in the late flood season, this can restore the abundant rainwater for daily drinking, irrigation, manufacturing and so on in dry months. Because the runoff does not change greatly with the pace of precipitation and the trend of rainfall was more significant than runoff, it is suggested that the reservoir manager has to maintain the current good surface condition in the karstic basin, such as the measure of forest vegetation greening, by which the karstic topography can absorb and restore the redundant rainwater. This can compensate for runoff in the dry months and contribute to the balanced water demand for the entire year.

**CONCLUSIONS**

Rainfall was concentrated from April to October, while streamflow was concentrated from May to September, but both the concentration volumes accounted for approximately 87% of annual rainfall and runoff. Meanwhile, the maximal duration was longer for the wet years (eight years) than the dry years (five years), but the continuous high and low flow years were nearly equal to each other. The rainfall contributed to runoff, but runoff was more stable because of the water storage and the conservation of fissures in the scattered flow area.

Judging from the Mann-Kendall test results, rainfall and runoff had the same decreasing trend at the annual scale, but it was more significant for rainfall (−2.36) than for

<table>
<thead>
<tr>
<th>Table 7</th>
<th>The trend of rainfall and runoff (seasonal scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>Mann-Kendall test method</td>
</tr>
<tr>
<td></td>
<td>The calculated value $Z_c$</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Spring</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
</tr>
<tr>
<td></td>
<td>Autumn</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
</tr>
<tr>
<td>Runoff</td>
<td>Spring</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
</tr>
<tr>
<td></td>
<td>Autumn</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
</tr>
</tbody>
</table>
runoff (~2.05). There was an opposite trend before 1990 and an identical trend after 1990 for rainfall and runoff in autumn and winter, which can be attributed to the water storage of the deep fissure and the improvement of the forest coverage, respectively.

Based on the uneven distribution of rainfall and streamflow, it is suggested that the watershed management department has to consider dividing the flood season into several sub-seasons, and then operate at a lower FLWL during the early and main flood season, with a higher FLWL for the late flood season, which can use the rainwater effectively and prevent the possible flooding or droughts.

This paper studied the characteristics and trends of rainfall and runoff in a karstic area with limited indicators, and aims to offer a basis for water resources development and ecological environment protection in the karstic basin. For further study, it is worth examining the equation of balance to specify the mechanistic functioning of the karst: coefficient of infiltration, importance of the aquifer, memory effect, which can guide a better analysis. On the other hand, the possible climate changes and the future trend of climate in the karstic area will also need further study, which can give more specific guidance for reservoir operation and water management.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (Grants No. 51569003, 51579059, 51609041), the Natural Science Foundation of Guangxi Province (Grants No. 2017GXNSFAA198361) and the Innovation project of Guangxi Graduate Education (Grant No. YCSW2017052).

REFERENCES

Editorial Board of Ling-yun County 2007 *The County Annuals of Ling-yun County*. Guangxi Arts Publishing House Co. Ltd, Nanning, China.

Qin, D. H. & Stocker, T. 259 Authors & TSU (Bem and Beijing) 2014 Highlights of the IPCC working group I fifth assessment report. Advances in Climate Change Research 10, 1–6.


First received 21 January 2017; accepted in revised form 22 May 2018. Available online 29 June 2018