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The frequency of precipitation days in the Yangtze River basin

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Abstract This paper explores the frequency of precipitation days to better understand flood potential by using different percentiles in the Yangtze River basins from 1950 to 2000. The positive (increasing) trends of the precipitation days at the 75th and the 95th percentile are analysed on both yearly and decadal scales. Some interesting facts have been revealed through this study. It is observed that the precipitation days at the 75th percentile increase more than that of the 95th percentile in the basin. This explains that the yearly increasing precipitation is due to excessive rains and not heavy rains. Also, through the trends (positive and negative), the variation of yearly precipitation days can be classified.

Key words frequency; precipitation days; trends; Yangtze River basin

INTRODUCTION

Global warming in the 20th century has become a current issue in climatology. In recent years droughts and floods in many countries have stimulated further studies in global warming and its possible effects on precipitation, since it is common knowledge that climate (temperature and precipitation) change have been closely related to, and linked with, the hydrological cycle. Also, the World Meteorological Organization (WMO) warns that global warming could induce an increasing frequency and intensification of extreme climatic events. For example, the Intergovernmental Panel of Climate Change (IPCC, 1996) stated that an increasing concentration of greenhouse gases in the atmosphere is likely to lead to an increase in global average temperature of between 0.15 and 0.3°C per decade, with regionally variable effects on precipitation and evaporation rates. Hofmann *et al.* (1998) expressed that, at the planetary scale, climate change would result in variations in oceanic and atmospheric circulation which in turn would affect temperature and precipitation,

So far it is evident that the global mean surface air temperature (SAT), or the Northern Hemisphere mean SAT has increased since the late 19th century, but some scientists still argue that the mean precipitation around the world has not formed a definite tendency of increasing trend. This is due to the fact that the temporal and spatial distribution of precipitation for special regions is more unstable than that of temperature. However, analyses of trends in mean precipitation during the past century reveal compelling evidence of the presence of trends over much regions of the world (IPCC, 1996, 1998). This conclusion was based on much evidence from different regions. For example, Karl *et al.* (1995) and Karl & Knight (1998) provide evidence for a statistically significant increase in extreme precipitation (> 50 mm day^{-1}) in the United States. Similarly for Australia, Suppiah & Hennessy (1996) show significant increases for the higher percentiles, e.g. the 90th and 95th percentiles. This was augmented by an increase in heavy-rain days in eastern Australia associated with East Coast cyclones reported by Hopkins & Holland (1997). Iwashima & Yamamoto (1993) analysed daily precipitation data for the period from 1890 to 1980 at Japanese stations and found that more stations recorded their highest, second highest or third highest precipitation event in more recent decades. Thus, the frequency of years with extremely heavy daily precipitation was increasing at Japanese stations throughout the 20th century. Tosnis (1996) also shows that the total monthly precipitation variability over the United States, Europe, and Australia has increased during the past 100 years. Beniston *et al*. (1994) concluded that "in a warmer global climate, precipitation events could be expected to increase significantly". This empirical conclusion is supported by the modelling assessment of Schaer *et al*. (1996). Generally, climate model simulations consistently project an increase in global precipitation, particularly for the mid and high latitudes (IPCC, 1990, 1996) due to global warming stemming from increases in greenhouse gases.

The observational data from several regions of the Yangtze River basin also show that the daily precipitation seems to increase because some of the precipitation data recorded in the observational stations far exceed the historical heaviest record of daily precipitation, such as Zhangjiajie in Hunan province, Nanjing in Jiangsu province and Xuxian in Anhui province in 2003 (http://www.jschina.com.cn/gb/jschina/news/zhuanti/guonei/node3891/node3893/node4084/userobject1ai290579.html). A significant trend of precipitation increase along the Yangtze River can also be proved by frequent severe floods since the mid 1980s, such as in 1991 along the lower reaches of the Yangtze River, 1998 and 1999 along the middle and lower reaches of the Yangtze River.

As the third largest river in the world, the Yangtze River originates in the Tibetan Plateau with a total length of 6300 km and a drainage area of 1 800 000 km^2. The river flows eastward through central China on its way to the East China Sea in Shanghai. Running through the mountain areas in the upper reaches west of Yichang, hills and Jian Han plain between Yichang and Jiu Jiang in the middle reaches, and plains and delta east of Jiu Jiang to Shanghai in the lower reaches (Fig. 1). The upper basin is in the province of Sichuan, the middle reaches are in the provinces of Hunan, Hubei, Jiangxi and Anhui, while the delta is in the provinces of Jiangsu and Zhejiang and the city of Shanghai. The Yangtze River basin is the grain region of China, contributing about 40% of the crops (including about 70% of the rice); it also produces two thirds of the freshwater fish and is responsible for about 40% of the gross national product of China. About 40% of the Chinese population lives here; major cities such as Chengdu, Chongqing, Wuhan, Changsa, Nanchang, Nanjing, Hangzhou and Shanghai with populations greater than one million are located along the river. In addition, many heavy industries are located in the basin.

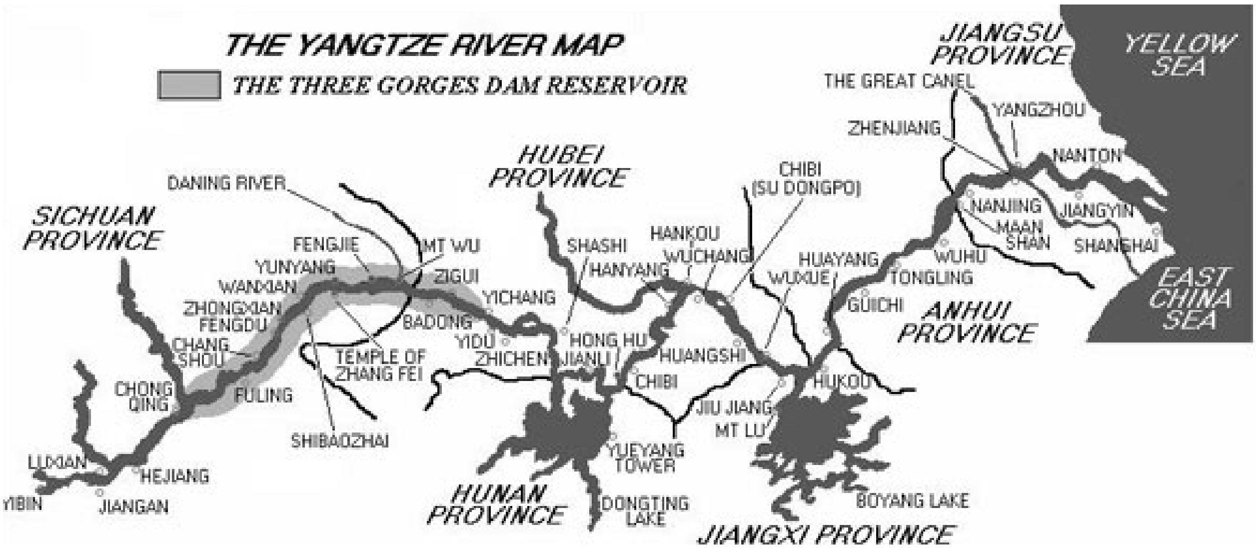

Fig. 1 Map of the Yangtze River basin. Source: http://www.water-technology.net/-projects/chongqing/images/chongqing04.jpg.

DATA AND METHODS

Because of the large scope and the limited meteorological data, data sets are selected following the regulation of the even spatial distribution so that they adequately cover the Yangtze River basin. Data sets used in the present study are the daily precipitation data of 24 stations. The data were collected from 1950 to 2000.

The Chinese national meteorology centre defines a rainstorm as a day on which precipitation exceeds 50 mm. This definition sometime causes problems for the forecast of floods because rain less than 50 mm could also produce large flow in some tributaries of the Yangtze River. To solve this problem, this paper uses daily precipitation percentiles as the level of precipitation. Two percentiles are used: 75th and 95th percentiles. It can be seen from Fig. 2 that the 75th percentile can well explain the variation of excessive rains with the daily precipitation from 0.1 mm to 2.3 mm. The geographical and spatial distribution of precipitation in mm at the 75th percentile in the Yangtze Rive basin can be found in Fig. 3.

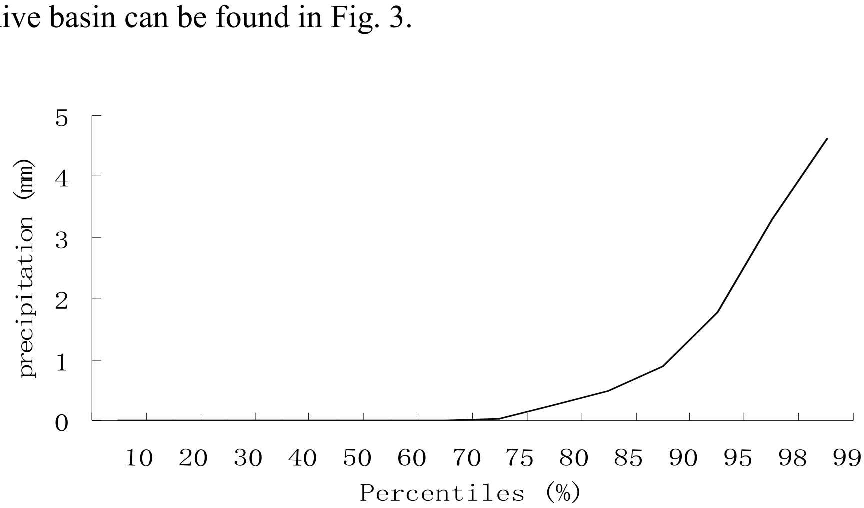

Fig. 2 The different percentiles precipitation in the Yangtze River basin.

For the 95th percentile as shown in Fig. 2, it is at the sharpest curve section among different percentiles. The daily precipitation exceeds 2.3 mm in this (95%) range. The geographical and spatial distribution of precipitation in mm at the 95th percentile can be found in Fig. 4.

From Fig. 3, it can be seen that precipitation at the 75th percentile generally increases from the northwest with the smallest precipitation (0.1 mm) in Tianshui to the southeast, with several precipitation centres such as: Exi, Hanzhou, Lingling and Ganzhou. All of those heavier precipitation centres are located in the southern regions of the Yangtze River. It has a similar pattern to the heavy precipitation as shown in Fig. 4. The geographical distribution of precipitation at the 95th percentile has an increase pattern from the northwest (8.8 mm in Tianshui, the smallest precipitation at this percentile) to the southeast (25.1 mm in Nanchang, the largest precipitation at this percentile).

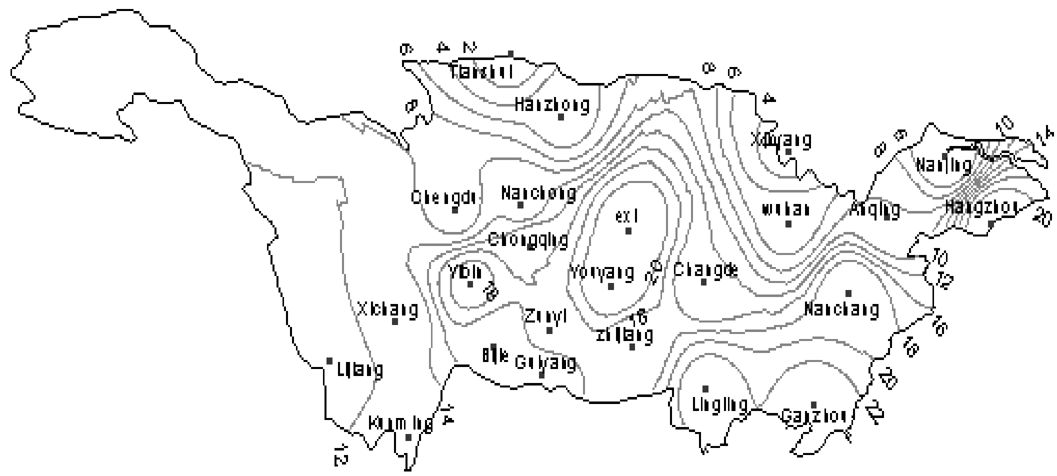

Fig. 3 The precipitation (0.1mm) at the 75th percentile in the Yangtze River basin for 1951–2000.

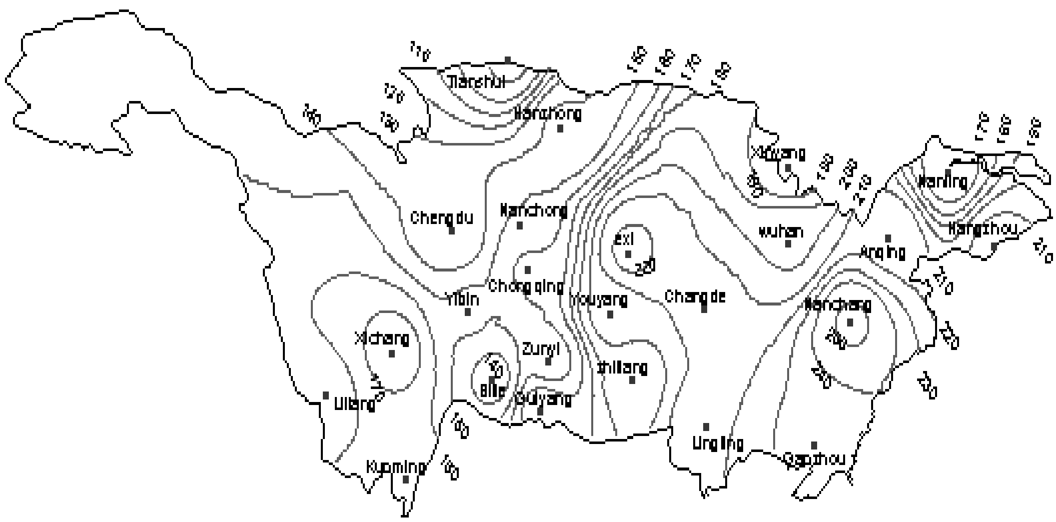

Fig. 4 The precipitation (0.1 mm) at the 95th percentile in the Yangtze River basin for 1951–2000.

The total number of precipitation days for each year at the two percentiles was analysed and the Mann-Kendall method was used to examine the trends of yearly precipitation days for the period 1951–2000.

TRENDS OF YEARLY PRECIPITATION DAYS AT THE 75TH AND 95TH PERCENTILES FROM 1951 TO 2000

The trends of yearly precipitation days at the 75th and 95th percentiles in the Yangtze River basin are shown in Figs 5 and 7, respectively. It can be seen from Fig. 5 that the yearly precipitation days at the 75th percentile show positive (increasing) trends in most of the Yangtze River basin. The northern regions of the upper (above Yichang in

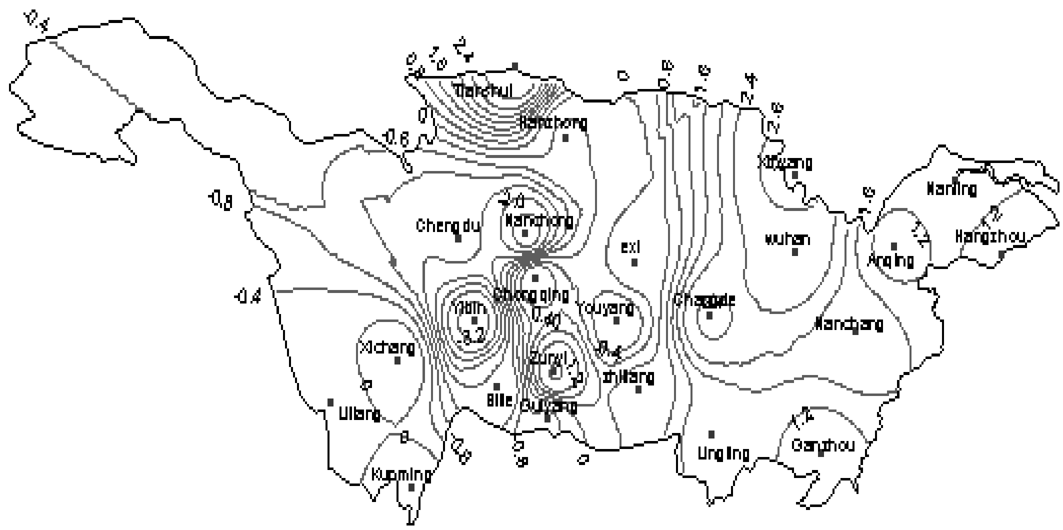

Fig. 5 The M-K distribution of yearly precipitation days at the 75th percentile in the Yangtze River basin.

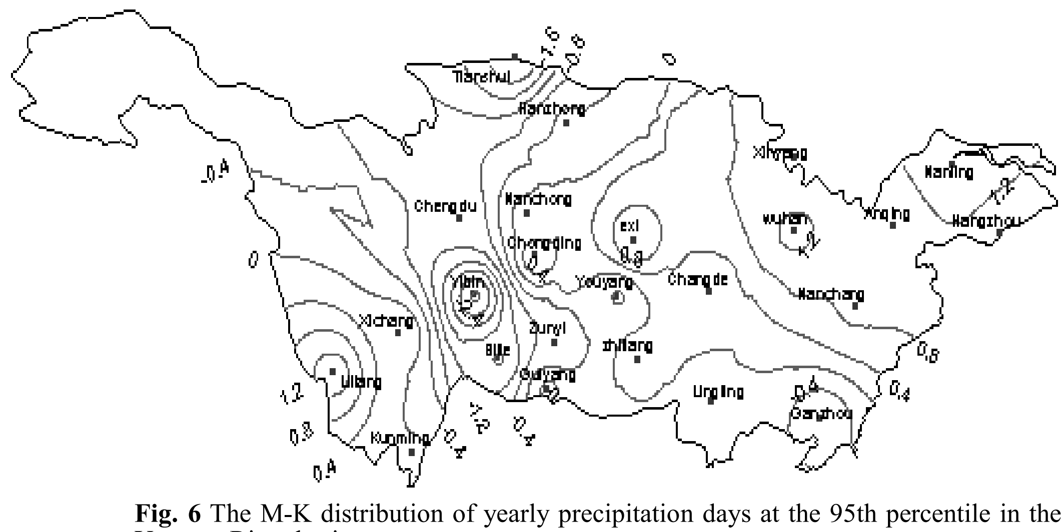

Fig. 6 The M-K distribution of yearly precipitation days at the 95th percentile in the Yangtze River basin.

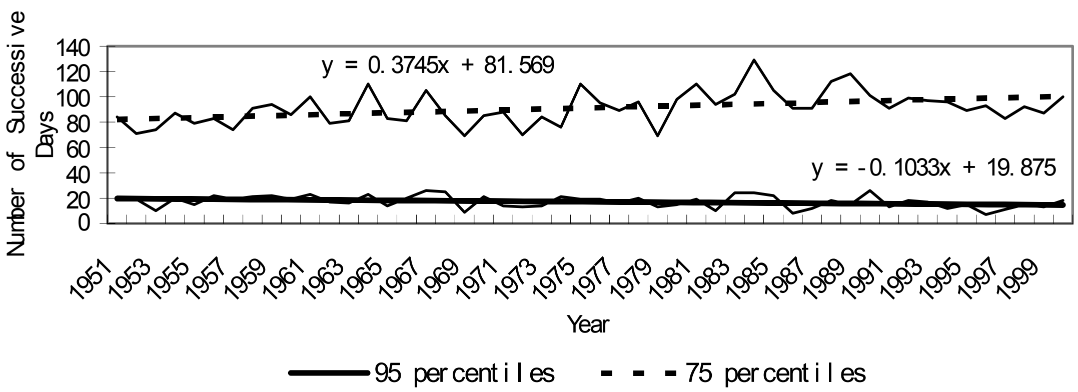

Fig. 7 The trend of yearly precipitation days at the 75th and 95th percentiles in Tianshui.

Three Gorges) and the middle reaches (from Yichang to Jiu Jiang) of the basin show the most significant positive trends, especially in Tianshui and Xinyang with the largest M-K value 3.1 and 2.92, respectively. The Sichuan basin (Chengdu, Nanchong, Yibing) is the only region that shows negative trends, with the largest negative M-K value –0.35 in Yibing. The transitional area from negative to positive trend is found east of the Sichuan basin, say the Three Gorges. The spatial distribution of yearly precipitation days at the 95th percentile (Fig. 6) shows that negative trend regions are mainly in the Sichuan basin and extend to northern regions, especially Tianshui. There are also increasing trend hubs in the middle and lower reaches (below Jiu Jiang) of the Yangtze River.

THE CLASSIFICATION OF YEARLY PRECIPITATION DAYS

Comparative analysis of Fig. 5 and Fig. 6, shows that even though the yearly precipitation days show generally positive trends in the Yangtze River basin, except the region of Sichuan basin, the intensity of positive or negative trends between 75th and 95th percentiles differs greatly.

Also, some regions show opposite trends at different percentiles. For those cases, several yearly precipitation days variation at the 75th and 95th percentiles can be identified as follows:

Type 1: an increasing trend at the 75th percentile but a decreasing trend at the 95th percentile. This type occurs mainly in the northern and the southern regions of the upper reaches of the Yangtze River basin, such as Tianshui, Gangzhou, Lingling and Zunyi. Even though the yearly excessive rain days in those regions are increasing, the yearly heavy precipitation shows a decrease. For example at Tianshui (Fig. 7), the trend of yearly precipitation days at the 75th percentile has an extremely positive M-K (3.1) but a negative trend is found at the 95th percentile (M-K: –2.32).

Type 2: decreasing trends of yearly precipitation days for both percentiles. This type occurs mainly in Sichuan Basin, such as Bijie, Chengdu and Yibing. Take Yibing as an example (Fig. 8), the M-K value of yearly precipitation days at the 75th and the 95th percentiles are –3.35 and –2.84, respectively.

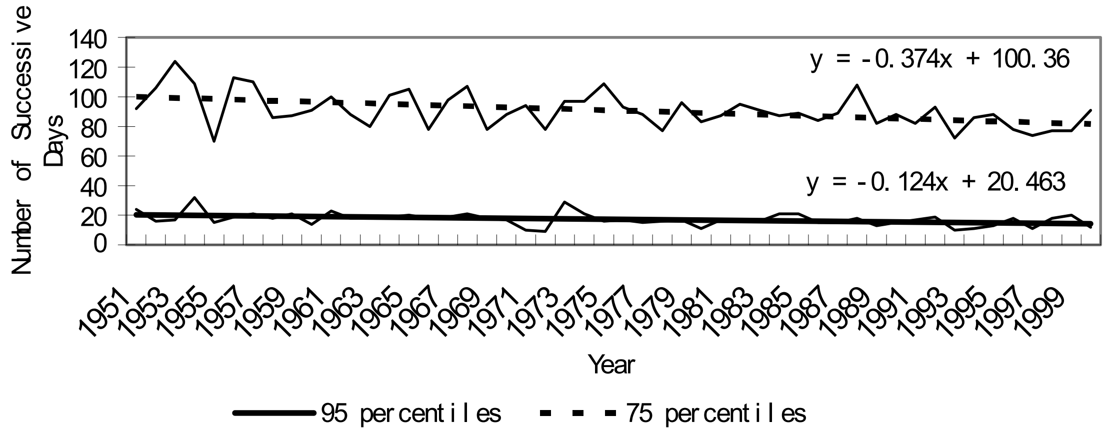

Fig. 8 The trend of yearly precipitation days at the 75th and 95th percentiles in Yibing.

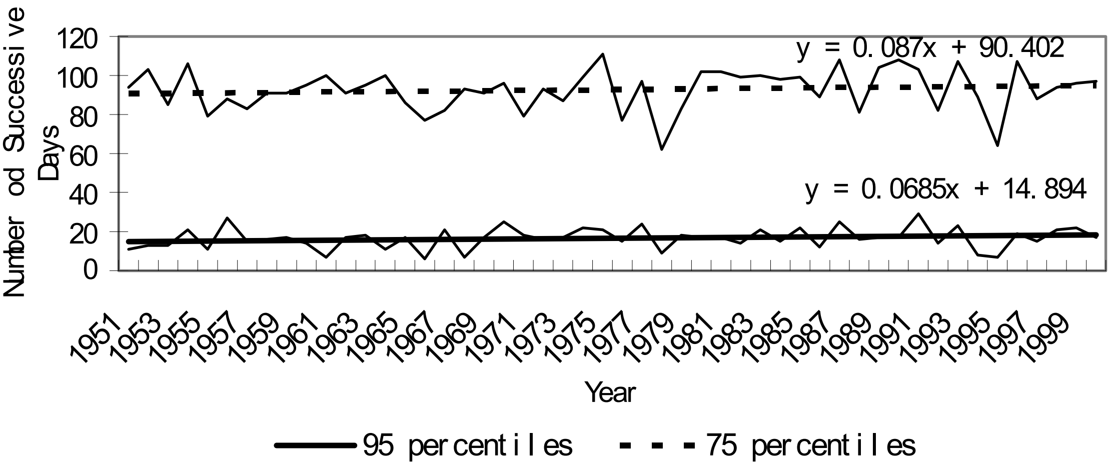

Fig. 9 The trend of yearly precipitation days at the 75th and 95th percentiles in Nanjing.

Type 3: increasing trends of yearly precipitation days for both percentiles. This type covers mainly in the middle and lower reaches of the Yangtze River basin, such as Anqing, Hanzhou, Nanchang, Nanjing, Xinyang and Wuhan. Take Nanjing as an example (Fig. 9), the M-K value of yearly precipitation days at the 75th and 95th percentiles are 1.36 and 1.54, respectively.

THE TEMPORAL FLUCTUATION OF YEARLY PRECIPITATION ON THE DECADAL SCALE

The previous section (Section 4) analyses the average yearly precipitation days for the period 1951–2000. However, some interesting facts are revealed in more detail for the temporal fluctuation of the yearly precipitation days at the 75th and the 95th percentiles over space and time. The anomalies of yearly precipitation days at the 75th and 95th percentiles on the decadal scale for the period 1951 to 2000 is shown in Table 1 and Table 2, respectively.

Table 1 The anomaly of 10-year precipitation days at the 75th percentile from 1951 to 2000.

Time period	1950s	1960s	1970s	1980s
Upper reaches	–4.8	3.2	–12.6	9.7
Middle reaches	–32.7	–40.3	–30.1	49.5
Lower reaches	11.3	–36.9	–9.2	51.8
Entire basin	–7.9	–12.5	–15.7	25.0

Table 2 The anomaly of 10-year precipitation days at the 95th percentile from 1951 to 2000.

Time period	1950s	1960s	1970s	1980s
Upper reaches	2.5	5.8	2.2	–6.7
Middle reaches	3.5	–14.1	–9.1	2.5
Lower reaches	1.8	–24.0	–1.8	10.0
Entire basin	2.6	–3.3	–0.8	–2.0

Also, the phase variations for the middle and lower reaches of the Yangtze River are consistent with each other, which may be due to the consistent shift of seasonal wind directions (monsoon). The primary reason for the precipitation changes trend may be linked with the evolution of the East Asian monsoon system in the last century.

Table 1 shows the anomalies of each 10-year precipitation days at the 75th percentile from 1951 to 2000. Generally, the temporal fluctuation in the upper reaches is not as large as that of the middle and lower reaches. The most significant positive trends are in the middle reaches in the 1980s and 1990s, while the lower reaches also show significant positive trends in the 1980s. Precipitation in the whole basin has been increasing continuously. Meanwhile, the most significant negative phase occurs in the middle reaches during the earlier three decades. In this case, it seems that the precipitation days in the middle reaches are more subject to changes and variations than other regions within the Yangtze Rive basin. For the entire Yangtze River basin, the positive trend is very obvious.

Table 2 shows the anomalies of 10-year precipitation days at the 95th percentile from 1951 to 2000. The middle and lower reaches of the river shows a drastic change of precipitation days. From 1960 to 1970s, negative phases occur in the middle and lower reaches then a drastic increasing trend occur in the last two decades of 1980 to 1990s. On the other hand, over the 50 years the fluctuation of the precipitation days in the upper reaches is relatively smoother than other regions in the basin. For the entire Yangtze Rive basin, the precipitation days have a positive phase in the 1950s and 1990s; this indicates a high precipitation frequency during the period.

Comparative analysis of Tables 1 and 2, shows that the fluctuation of the precipitation days at the 75th percentile increases more noticeably than at the 95th percentile in the entire basin due to many geographic and climatic factors of the middle and lower reaches of the river basin. This result indicates that the increasing precipitation in the recent two decades is mainly because of excessive precipitation. The heavier precipitation events occur mainly in the upper reaches in the 1960s, in the middle and lower reaches in the 1950s, in the 1980s and in the 1990s. Frequent floods along the Yangtze River have caused enormous losses during those decades. Despite the fact that there are different trends in different reaches and regions of the Yangtze

River basin, the change between the middle and lower reaches of the Yangtze River is similar. Less precipitation occurs in the 1960s and 1970s, while high precipitation appears in the 1980s. Considering the changes and trends of frequency of precipitation days, the precipitation in the upper reaches of the Yangtze River is moderate, except in the Sichuan basin. This phenomenon needs to be further analysed.

CONCLUSIONS

The positive (increasing) trends of the yearly precipitation days at the 75th percentile appears in most of the Yangtze River basin, especially in the northern regions of the upper and the middle reaches of the basin. The Sichuan basin is the only region with negative trends. The transitional area from negative to positive trends is found east of the Sichuan basin in the Three Gorges area. For the 95th percentile, the negative trend regions are mainly in the Sichuan basin, but extend to northern regions. Increasing trend also centres in the middle and lower reaches of Yangtze River basin.

On the decadal time scale, the most significant positive trends at the 75th percentiles are in the middle reaches in the 1980s and 1990s. The lower reaches show significant positive trends in the 1980s. Those positive phases contribute greatly to the positive trends of the entire basin during the last two decades. The most significant negative phase also occurs in the middle reaches during the earlier three decades. It seems that the precipitation days in the middle reaches are more likely to be subject to changes and variations than other regions in the Yangtze River. For the Yangtze River basin taken as a whole, a positive trend is very obvious for this percentile.

For the 95th percentile, the trends between the middle and lower reaches of the Yangtze River basin are coherent. After two decades (1960s and 1970s) of negative phases, the most significant increasing trend is shown in the last two decades. On the other hand, there is less fluctuation of the precipitation days in the upper reaches of the river basin over the 50 years as compare to other regions. The precipitation days in the Yangtze River basin in the 1950s and 1990s have a positive phase (increase), which indicates the frequency of heavier precipitation events occurring in those periods.

The precipitation days at the 75th percentile increase more apparently than the 95th percentile in the basin. This result indicates that an increasing precipitation in the recent two decades is mainly caused by excessive precipitation. The heavier precipitation events occur mainly in the upper reaches in the 1960s; and in the middle and lower reaches in the 1950s, 1980s and 1990s.

According to the trends that occurred at different percentiles, the yearly precipitation days can be classified into Type 1—the increasing trend at 75th percentile but decreasing trend at 95th percentile; Type 2—decreasing trends of yearly precipitation days for both percentiles; and Type 3—increasing trends of yearly precipitation days for both percentiles.

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