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Trends of precipitation in Beijiang River Basin, Guangdong Province, China

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Abstract:

An analysis of spatial and temporal trends of precipitation in Beijiang River basin, Guangdong Province, China during 1959–2003 was performed using 17 time series (including monthly, annual, wet season, dry season, early flood period and late flood period totals) both on station based and sub-basin based data sets. Two nonparametric methods (Mann–Kendall and Sen's T) were used for data analysis. The results showed that (1) downward trends of temporal distribution were mostly detected during the early flood period, especially in May, while upward trends were observed in July and the dry season; (2) downward trends of spatial distribution were mostly detected in the southern Beijiang River basin, while upward trends were observed north of this area. Our results indicated a delayed rainy season and a northward trend of the precipitation belt compared to recent years. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS precipitation trends; Mann-Kendall test; Sen's method; Beijiang River basin

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INTRODUCTION

Since global climate changes may influence long-term precipitation patterns and result in increasing occurrences of droughts and floods, changing patterns of precipitation around the world deserve urgent attention (Gemmer *et al.*, 2004; Dore, 2005).

Related studies have demonstrated that global land precipitation has increased significantly by about 2% since the beginning of the 20th century. However, this increase has not been either spatially or temporally uniform (IPCC, 2001). For example, precipitation in Canada has increased by an average of more than 10% over the 20th century (Mekis and Hogg, 1999). There have been marked increases in precipitation in the latter part of the 20th century over northern Europe, with a general decrease southwards to the Mediterranean (Schönwiese and Rapp, 1997). Over the former USSR, precipitation has increased since 1891 by about 5% west of 90 °E for both warm and cold seasons (Bogdanova and Mestcherskaya, 1998; Groisman and Rankova, 2001). A large decrease in total precipitation and related rain days has been reported in southwestern Australia (Haylock and Nicholls, 2000). In northeast Brazil and northern Amazonia, regional positive but non-significant trends have occurred in the rainy season rainfall (Marengo *et al.*, 1998). An increasingly erratic monsoonal rainfall has appeared for much of the period since the early 1940s in western Mexico (Douglas and Englehart, 1998).

In China, trends of precipitation are uneven both in space and time. For annual precipitation, an upward trend was observed in the west, southeast and northeast of China, while a downward trend has been observed in other regions since the 1950s. Seasonal variation also exist in other regions (Zhai *et al.*, 1999; Ren *et al.*, 2000; Wang *et al.*, 2004; Ye *et al.*, 2004; Qin *et al.*, 2006). The IPCC (2001) reported a 30–50% increase of precipitation in southern China during the winter months (December–February) from 1900–1999. During summer months (June–August), precipitation in the middle and lower reaches of the Yangtze River demonstrated a significant upward trend, while that in the north and northeast of China showed a downward trend (Zhai *et al.*, 1999; Ren *et al.*, 2000; Wang *et al.*, 2004; Ye *et al.*, 2004; Qin *et al.*, 2006).

Beijiang River is one of the four largest rivers in Guangdong Province, and the region around its basin is one of the most developed areas of China. It is also an important water source and river channel for Guangdong Province. Disasters such as floods and droughts occur annually in this region due to temporally and spatially heterogeneous distributions of precipitation. With a background of global climate variation, the detailed analysis of precipitation trends and temporal and spatial distributions are important for the assessment of climate induced risks and the pursuit of countermeasures. Although several studies have been carried out to detect the trend of precipitation in this region (e.g. Xie, 1997; Liu *et al.*, 1998; Wang, 2006), most of them were concerned only with the temporal trend, neglecting the spatial factor. Moreover, parametric methods as opposed to

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nonparametric methods were generally employed in these studies to detect trends. In the rare cases where a nonparametric method such as the Mann–Kendall test was used, no studies applied a serial correlation test beforehand. The existence of a positive serial correlation in a time series will increase the probability of detecting a significant trend with the Mann–Kendall test (von Storch, 1995). Another shortcoming of these studies in this particular region is that small data sets were used for trend analysis.

Through performing nonparametric methods for more data sets to analyze the precipitation trend both in station based analysis and sub-basin based analysis, we try to provide more accurate results of regional changing precipitation patterns in China.

STUDY AREA AND DATABASE

The Beijiang River flows about 468 km from its major headwaters in Damaoshan Mountain of Jiangxi Province, converges to Pearl River Delta and finally discharges into the South China Sea. Its basin covers about 22% of the land area in Guangdong Province, one of the most developed provinces in China. A series of dams have been built along the river to provide water for agricultural, industrial, municipal and hydroelectric power uses and flood control. Its annual average flow is $48{\cdot}2 \times 10^9$ m^3 (Editorial Committee of Biography of Beijiang Levee, 1995).

Precipitation in Beijiang River basin occurs mostly during the wet season (from April to September), which accounts for about 70% of the total precipitation. Wet season is divided into early flood period (EFP, April–June) and late flood period (LFP, July–September). The precipitation of EFP is usually greater than that of LFP in Beijiang River basin, by a factor of ca. 1·8. The precipitation during the EFP is mostly attributed to frontal precipitation, while that during the LFP is mainly the result of tropical cyclones. The period from October to March is the dry season.

The monthly precipitation data in Beijiang River basin are from the precipitation stations of Guangdong Provincial Hydrologic Bureau which has long-term monthly precipitation records. There are 312 precipitation stations in this area, from which 63 precipitation stations were selected for this study (Figure 1).

All 63 stations have 45 years (1959–2003) of precipitation records, with 90% complete data. At no time did a period of missing data total 12 months or more. All missing data were estimated by linear regression based on precipitation at neighbouring stations when the correlation coefficient was larger than 0·85. During the 45 years, the annual precipitation ranged from 1390–2475 mm with a mean of 1778 mm.

METHODOLOGY

Both spatial and temporal trends of precipitation were analyzed for 17 time series from the 63 stations and

Figure 1. Study area showing the precipitation stations

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7 sub-basins in Beijiang River basin. The time series include monthly, annual, wet season, dry season, EFP and LFP totals. Two different nonparametric methods (Mann–Kendall and Sen's T) were utilized after applying a serial correlation test. It has been reported that aligned rank methods such as Sen's T are asymptotically more powerful than intra-block methods such as the Mann–Kendall test; however, intra–block methods are more adaptable (van Belle and Hughes, 1984). The purpose of employing both methods is to obtain a more confident analysis of our data. We also detected the change per unit time with Sen's estimator, and the starting point of trends with the Sequential Mann–Kendall test. The method of analysis is described below.

Database standardization

The database includes monthly, wet season, dry season, EFP, LFP and annual totals for each station. Seven sub-basins (Wujiang, Zhenjiang, Lianjiang, Wengjiang, Suijiang, upper and middle/lower reaches, referred to as Wu, Zhen, Lian, Weng, Sui, Up and Low respectively) were partitioned according to five branches and the position of the main stream for the Beijiang River basin. The regional index for the 17 time series was calculated from the arithmetical average of the stations included in each sub-basin. The arithmetical average is a simple method of obtaining the sub-basin index, useful for detecting trends when the same method is applied in all the sub-basins (Figure 2).

Testing serial correlation effect

If the calculated lag 1 serial correlation coefficient r_1 was not significant at the 5% level, then the Mann–Kendall test was applied to original values of the time series. If the calculated r_1 was significant prior to application of the Mann–Kendall test, then the 'pre-whitened' time series may be obtained as $(x_2 - r_1x_1, x_3 - r_1x_2, \ldots x_n - r_1x_{n-1})$ (Partal and Kahya, 2006)

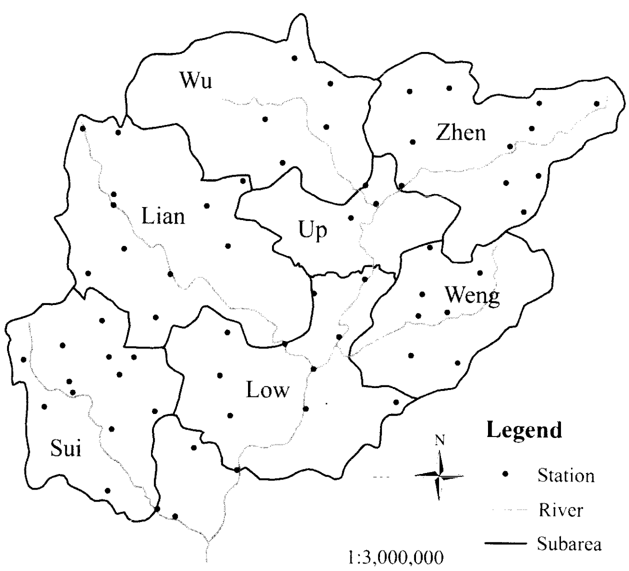

Figure 2. Distribution of the seven regions according to sub-basin

For station based analysis, no significant lag 1 serial correlation coefficient was detected in most of the time series and the same results appeared in analyses of sub-basins. However, the series in dry season showed significant serial correlation values both in individual stations (33·3%) and sub-basins (85·7%). The locations of the stations with a significant serial correlation were mostly in southern Beijiang River basin (Sui and Low).

Mann–Kendall test

The Mann–Kendall test is applicable to the detection of a monotonic trend in a time series with no seasonal or other cycle (Salmi *et al.*, 2002).

The null hypothesis H_0 is that the observations x_i ($i = 1, 2, \ldots n$) are independent and identically distributed. The alternative hypothesis H_1 is that a monotonic trend exists in x_i. The Mann–Kendall test statistic S is calculated using the formula

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k) \quad (1)$$

$$\text{sgn}\,(x_j - x_k) = \begin{cases} +1 & \text{if} \quad x_j - x_k > 0 \\ 0 & \text{if} \quad x_j - x_k = 0 \\ -1 & \text{if} \quad x_j - x_k < 0 \end{cases} \quad (2)$$

where n is the number of observed data series, x_j and x_k are the values in periods j and k respectively, $j > k$.

For $n < 10$, $|S|$ is compared directly to the theoretical distribution of S derived by Mann and Kendall (Gilbert, 1987). At a certain probability level, H_0 is rejected in favour of H_1 if $|S| \geq S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S which has a probability less than $\alpha/2$ to appear in the case of no trend. A positive value of S indicates an upward trend; a negative value of S indicates a downward trend.

For $n \geq 10$, the statistic S is approximately normally distributed with the mean and variance as follows:

$$\text{E}(S) = 0 \quad (3)$$

$$\text{VAR}(S) = \frac{1}{18}\left[\begin{array}{c} n(n-1)(2n+5) \\ -\sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \end{array}\right] \quad (4)$$

where q is the number of tied groups and t_p is the number of data values in the pth group.

The standard test statistic Z is computed as follows

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\text{VAR}(S)}} & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0 \\ \dfrac{S+1}{\sqrt{\text{VAR}(S)}} & \text{if} \quad S < 0 \end{cases} \quad (5)$$

The statistic Z follows the standard normal distribution. If $|Z| > Z_{1-\alpha/2}$, H_0 is rejected and a significant trend exists in the observed time series. A positive value of Z indicates an upward trend; a negative value of Z indicates a downward trend.

Sen's method

Sen's T and Sen's estimator was used for trend detection and for estimation of the change per unit time of significant trends, respectively.

Sen's T test. This method is an aligned rank method. It is distribution-free and not affected by seasonal fluctuations (Sen, 1968a,b; van Belle and Hughes, 1984). The raw monthly data have the seasonal signal removed first of all, and are then substituted by their ranks to calculate the test statistic T as follows:

$$T = \left[\frac{12m^2}{n(n+1)\sum_{i,j}(R_{ij} - R_j)^2} \right]^{1/2} \times \left[\sum_{i=1}^{n} \left(i - \frac{n+1}{2} \right) \left(R_i - \frac{nm+1}{2} \right) \right] \quad (6)$$

where n is the total number of years, m is the number of observations in a year and R_{ij} refers to the rank of $(X_{ij} - X_j)$ where X_j is the averages of j^{th} months and X_i is the averages of i^{th} years, $(1 < i < n,\ 1 < j < m)$. R_i and R_j are computed as follows:

$$R_i = \frac{\sum_j R_{ij}}{m} \quad (7)$$

$$R_j = \frac{\sum_i R_{ij}}{n} \quad (8)$$

The test statistic T follows an $N(0,1)$ under the null hypothesis of no trend. If $|T| > Z$, a significant trend exists in the observed time series. A positive value of T indicates an upward trend; a negative value of T indicates a downward trend.

Sen's estimator. Sen's estimator can be used in cases where the trend is assumed to be linear (Salmi *et al.* 2002). This means that

$$f(t) = Qt + \mathrm{B} \quad (9)$$

where Q is the slope and B is a constant.

To derive an estimate of the slope Q in Equation (9), the slopes of all data pairs are calculated:

$$Q_i = \frac{x_j - x_k}{j - k}; \quad i = 1, \ldots N \quad (10)$$

where $j > k$.

If there are n values x_j in the time series, we get as many as $N = n(n-1)/2$ slope estimates Q_i. Sen's estimator of slope is the median of these N values. The N values of Q_i are ranked from the smallest to the largest, and the Sen's estimator is

$$Q = \begin{cases} Q_{\frac{N+1}{2}} & \text{if } N \text{ is odd} \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}} \right) & \text{if } N \text{ is even} \end{cases} \quad (11)$$

A two-sided confidence interval about the slope estimate is obtained by the nonparametric technique based on the normal distribution. The method is valid for n as small as 10 unless there are many ties.

Sequential Mann–Kendall test

The sequential Mann–Kendall test is used to determine the starting point of a trend (Partal and Kahya, 2006). This test considers the relative values of all terms in the time series $(x_1, x_2, \ldots x_n)$. The following steps are applied in sequence.

It is assumed that the null hypothesis of no trend H_0, i.e. the observations x_i randomly ordered by time, is against the alternative hypothesis H_1, where there is an increasing or decreasing monotonic trend. The magnitudes of x_j $(j = 1, \ldots n)$ are compared with x_k, $(k = 1, \ldots j-1)$. In each comparison, the number of cases $x_j > x_k$ is counted and denoted by n_j.

The test statistic t is then given by the following equation:

$$t_j = \sum_{1}^{j} n_j \quad (12)$$

The mean and variance of the test statistic are:

$$\mathrm{E}(t) = \frac{n(n-1)}{4} \quad (13)$$

and

$$\mathrm{VAR}(t_j) = \frac{j(j-1)(2j+5)}{72} \quad (14)$$

The sequential values of the statistic $u(t)$ are then calculated as:

$$u(t) = \frac{t_j - E(t)}{\sqrt{\mathrm{VAR}(t_j)}} \quad (15)$$

where $u(t)$ is a standardization variable with zero mean and unit standard deviation.

The inverse sequential values of the statistic $u'(t)$ are computed as

$$u'(t) = -u(t) \quad (16)$$

and

$$j' = n + 1 - j \quad (17)$$

where $u(t)$ and $u'(t)$ are depicted in Figure 3. The point of intersection refers to the starting point of the trend if any of the curves is beyond the reliability lines.

The sequential version of the Mann–Kendall test could be considered as an effective way of locating the starting year(s) of a trend.

RESULTS AND DISCUSSION

Mann-Kendall test

Seventeen time series were analyzed with the Mann–Kendall test at each station and every sub-basin. The results at the 5% significance level are shown in Figure 4. Details are presented in the following sections.

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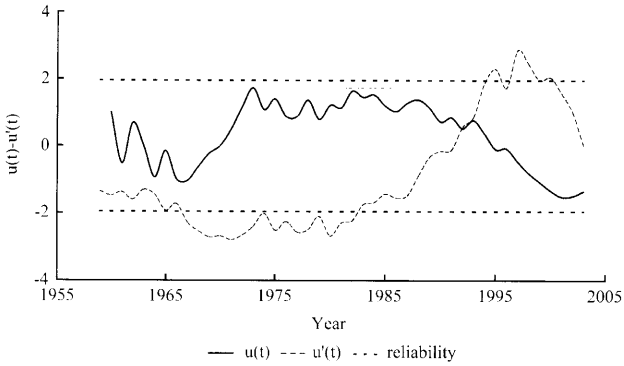

Figure 3. Sequential values of the statistics $u(t)$ and $u'(t)$ from the Mann–Kendall test for Baishui station in May

Station based analysis. For temporal distribution, the results demonstrated that upward trends were observed mostly in the dry season and July, while downward trends were detected mainly in EFP, especially in May (Figure 4). It is indicated that there might be a postponement of the wet season and a precipitation reduction in EFP in the future. Annual precipitation trend was generally downwards, but not for the entire basin. The upward trend in dry season and the downward trend in EFP may indicate a shift in the annual cycle of the hydrologic regime and a more even annual distribution of precipitation in the future.

For spatial distribution, trends of different parts in Beijiang River basin in 17 time series varied as shown

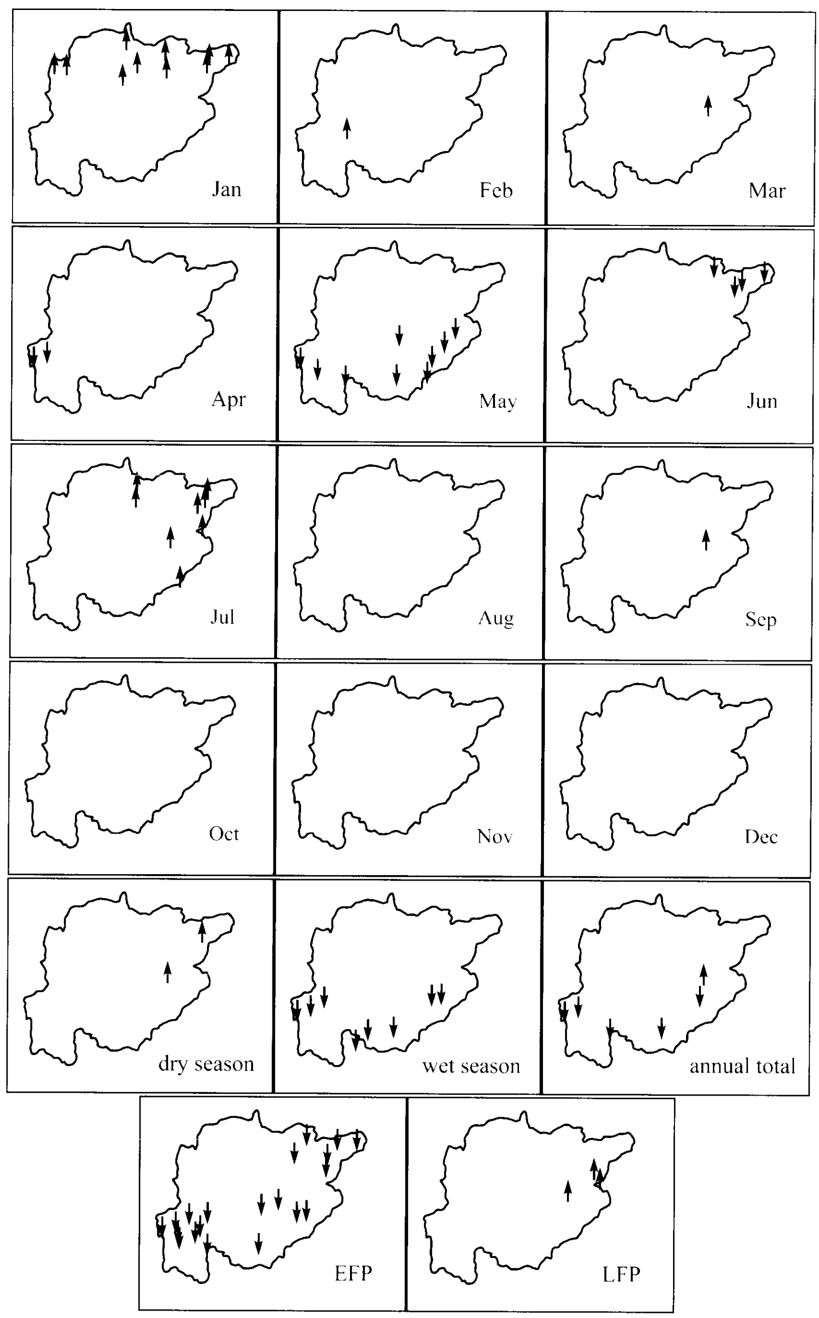

Figure 4. Spatial distribution of significant precipitation trends of all relative time series at the 5% level. Downward trend is represented by ↓ and upward trend by ↑

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Table I. The contribution of each month to the annual trend at six stations with a trend in annual total precipitation

Station	Annual total precipitation (mm)	Months with trend	Total precipitation in months with trend (mm)	Ratio of column 4: column 2 (%)	Mann-Kendall test statistic	Mann-Kendall test statistic of N_{annual}
Beishi	1698·5	May	271·0	16·0	−2·06	−1·57
Hengshi	2325·8	May	469·5	20·2	−2·67	−0·83
Hongqiao	1787·9	May	308·1	17·2	−2·06	−1·31
Maningshui	1883·0	April, May	595·3	31·6	−2·06	−1·26
Taipingwengyuan	1816·6	Mar, Jul, Sep	471·8	26·0	1·97	0·17
Zhongzhou	1829·8	Apr	275·1	15·0	−2·71	−2·24

in Figure 4. Upward trends were detected mostly in Wu and Zhen and downward trends appeared mainly in Low, Sui and Weng. Few trends were detected in Lian and Up. In general, downward trends were detected mostly in southern parts while upward trends were observed mainly in the north. Our results suggest that the trend of spatial precipitation distribution in Beijiang River basin was northward.

In order to distinguish the contributions of monthly precipitation to the annual total, six stations with significant annual trends were examined. Firstly, the total precipitation of the months with a significant trend and the ratio to the total annual amount were computed. Secondly, a new time series (N_{annual}) was established by subtracting the sum of precipitation total from the total annual precipitation for the months with a significant trend. Thirdly, the Mann–Kendall test was performed on N_{annual}.

Results showed that four stations demonstrated significant trends in one month while two other stations demonstrated significant trends over two and three months (Table I). For Maningshui and Taipingwengyuan, the ratios of average precipitation totals for months with a significant trend to the average annual total were greater than 25%. It is therefore understandable that similar monthly and annual trends were observed. However, this could not be applied to the other four stations, in which only one month showed a significant trend. Comparing the Mann–Kendall test statistic of annual total with that of N_{annual}, we found that there was an obvious decrease in the test statistic at every station. It suggested that particular months had strong effects on the annual trend. This may be the reason why the remaining four stations only demonstrated a significant trend during one month.

Sub-basin based analysis. For the seven sub-basins, significant trends were only detected during January, May and July (during the EFP and wet season) for the 17 time series, which was similar to the results of station-based analysis.

Sequential Mann–Kendall test

The sequential Mann–Kendall test was performed to detect the starting point of the trend in 28 stations, and the results showed significant trends at 5% level in different time series. Results revealed that different starting points of the trend existed in different time series (Table II). For most monthly series, the starting points of trends fell within 1965–1980. During the May series, the starting points of trends were after 1990. For annual total precipitation, a significant trend began during 1970–1980 at three stations located in Sui and Low. Starting points for the other three stations with a significant trend were the years 1969, 1987 and 1993. The starting points of trends during the wet season and the dry season were mostly during 1970–1990, while in the EFP and the LFP the starting point was during 1980–2000. In general, a significant trend of different time series started mainly before the year 1990.

Sen's method

Sen's method was employed to detect the trend and the change per unit time of the significant trends in the 17 time series. Details are presented below.

Station-based analysis. Results of the trend test with Sen's T appeared to be consistent with that of the Mann–Kendall test. However, more stations with significant trends were detected with Sen's T in most time series (Figure 5).

Change per unit time of the significant trends in the 17 time series was shown in Figure 6. For the annual total precipitation, slope value varied from $-13{\cdot}0$ mm yr^{-1} (at Hengshi station) to 9·4 mm yr^{-1}(at Taipingwengyuan

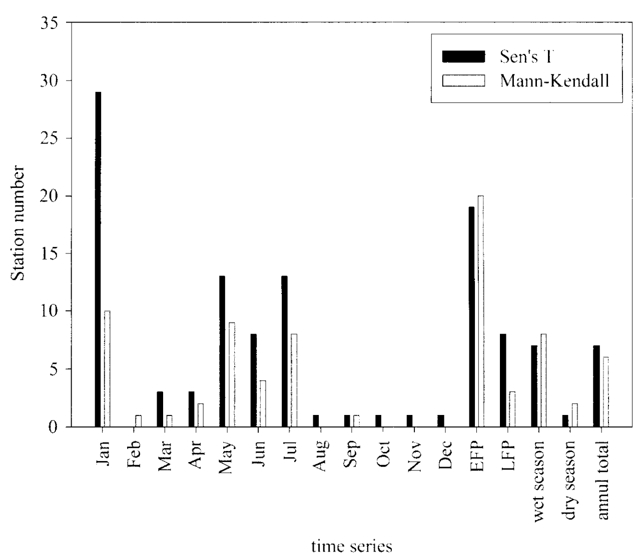

Figure 5. Comparison of Sen's T and the Mann–Kendall test

Table II. Starting point of the detected trend in different time series

Station	Time series	Direction of trend	Starting point of trend	Station	Time series	Direction of trend	Starting point of trend
Chengkou	Jan	Upward	1967	Beishi	wet season	Downward	1974
Daqiao	Jan	Upward	1988	Hengshi	wet season	Downward	1977
Lechang	Jan	Upward	1967	Hongqiao	wet season	Downward	1982
Nanxiong	Jan	Upward	1967	Maningshui	wet season	Downward	1985
Renhua	Jan	Upward	2000	Weizheng	wet season	Downward	1981
Tianxin	Jan	Upward	1969	Wengjiang	wet season	Downward	1964
Yunwu	Jan	Upward	1988	Zhongzhou	wet season	Downward	1980
Wujing	Jan	Upward	1967	Zhukeng	wet season	Downward	1983
Hengjiang	Jan	Upward	1967	Baishui	EFP	Downward	1994
Qixialing	Jan	Upward	1967	Beishi	EFP	Downward	1994
Taipingyangshan	Feb	Upward	1967	Changjiang	EFP	Downward	1978
Taipingwengyuan	Mar	Upward	1978	Daxiang	EFP	Downward	1992
Maningshui	Apr	Downward	1986	Hengshi	EFP	Downward	1993
Zhongzhou	Apr	Downward	1985	Hongqiao	EFP	Downward	1982
Beishi	May	Downward	1994	Huaiji	EFP	Downward	1997
Hengshi	May	Downward	1994	Jielongwan	EFP	Downward	1992
Huaiji[a]	May	Downward	1998	Machi	EFP	Downward	1985
Maningshui	May	Downward	1995	Maningshui	EFP	Downward	1994
Taipingyingde	May	Downward	1990	Renhua	EFP	Downward	1980
Wengjiang	May	Downward	1993	Shakou	EFP	Downward	1977
Yingdeliukuangshan	May	Downward	1994	Shangliang	EFP	Downward	1991
Guntiancun	May	Downward	1993	Taiping(Yangshan)	EFP	Downward	1990
Songtang	May	Downward	1990	Wengjiang	EFP	Downward	1981
Changjiang	Jun	Downward	1975	Xiaogulu	EFP	Downward	1994
Nanxiong	Jun	Downward	1967	Yingdeliukuangshan	EFP	Downward	1988
Xiaogulu	Jun	Downward	1969	Zhongzhou	EFP	Downward	1984
Wujing	Jun	Downward	1967	Wujing	EFP	Downward	1994
Duheng	Jul	Upward	1976	Hengjiang	EFP	Downward	1972
Jiufeng	Jul	Upward	1967	Duheng	LFP	Upward	1987
Lechang	Jul	Upward	1968	Jielongwan	LFP	Upward	1991
Nanxiong	Jul	Upward	1973	Taipingwengyuan	LFP	Upward	1970
Taipingwengyuan	Jul	Upward	1968	Beishi	annual total	Downward	1974
Xiaogulu	Jul	Upward	1973	Hengshi	annual total	Downward	1976
Hengjiang	Jul	Upward	1989	Hongqiao	annual total	Downward	1993
Xiahedong	Jul	Upward	1972	Maningshui	annual total	Downward	1987
Taipingwengyuan	Sep	Upward	1969	Taipingwengyuan	annual total	Upward	1969
Nanxiong	dry season	Upward	1977	Zhongzhou	annual total	Downward	1979
Taipingwengyuan	dry season	Upward	1974				

[a] Since there are no significant trends at the Huaiji station in May, the 'pre-whitened' time series is utilized in a sequential Mann–Kendall test.

station). For the monthly total precipitation, slope value ranged from $-5\cdot5$ mm yr^{-1} in May at Hengshi station to $3\cdot3$ mm yr^{-1} in July at Taipingwengyuan station.

Sub-basin based analysis. Similar trends were obtained by adapting Sen's T and the Mann–Kendall test. Like the station based analysis, more significant trends were detected by Sen's T.

Changes per unit time of the significant trends is shown in Figure 7. For the monthly total precipitation, slope value ranged from $-3\cdot4$ mm yr^{-1} in May at Up to $1\cdot5$ mm yr^{-1} in July at Zhen. For the EFP, the lowest slope values were $-6\cdot6$ mm yr^{-1} (at Weng) while the lowest slope value in wet season was $-6\cdot5$ mm yr^{-1} (at Low).

Causes of precipitation changes

Precipitation occurring in the EFP is mostly due to frontal precipitation while that occurring in the LFP can be attributed to tropical cyclones.

Frontal precipitation results from the meeting of the leading edge (front) of a warm air mass and a cool air mass. Any weakening or strengthening of the air masses would therefore result in a reduction of precipitation. A lower precipitation during the EFP has been reported in Guangdong, due to a weakening of cool air mass resulting from a weaker middle latitude circulation (East Asian Trough and south of the westerly jet), caused by a positive anomaly in Western Pacific Warm Pool (Liang and Wu, 2001). From 1951–1997, a climatic jump of the Western Pacific Warm Pool was observed in the 1980s. The Western Pacific Warm Pool turned from a weakening stage to a strengthening stage and a positive anomaly was in the ascendant (Zhao *et al.*, 2002).

Similarly, the upward trend of precipitation during the LFP could also be due to the positive anomaly of sea surface temperature (SST). The positive anomaly of SST in the northern Pacific Ocean would result in stronger summer monsoons, which may contribute more

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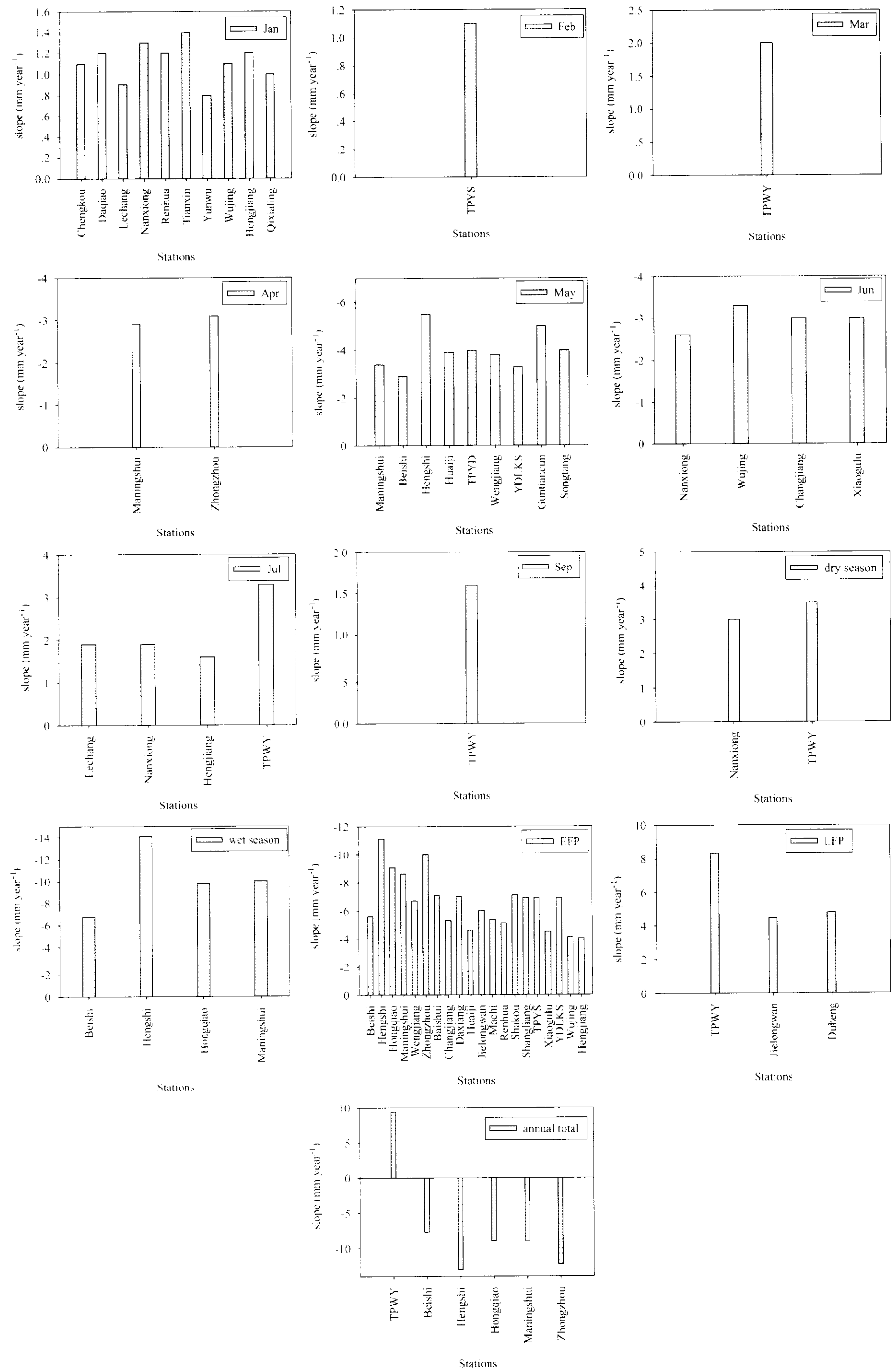

Figure 6. Sen's estimator of the slope of significant trend in station based analysis (TPWY, TPYD, TPYS and YDLKS refer to Taipingwengyuan, Taipingyingde, Taipingyangshan and Yingdeliukuangshan respectively)

precipitation than usual during the LFP in Guangdong (Liang and Wu, 2001; Wu *et al.*, 2003). Tropical cyclones (such as tropical depressions, storms and typhoons) were another factor that influenced the precipitation during the LFP in Beijiang River basin. It was reported that the positive anomaly of SST in tropical western Pacific Ocean would cause the region from the south China Mainland to the north of the South China Sea and to the east of Philippines to become a strong convergence zone. It would also cause a strong convergence centre to appear within the China Sea and to the east of Luzon. Such phenomena would facilitate the occurrences of tropical cyclones and the increments of precipitation in Southern China during the LFP (He *et al.*, 1998).

The upward trend from January to March was also related to the changes in SST. A positive correlation was detected between precipitation and SST in terms of Niño 1 + 2 index (Extreme Eastern Tropical Pacific SST, 0–10 °S, 80–90 °W), Niño 3 index (Eastern Tropical Pacific SST, 5 °N–5 °S, 90–150 °W), Niño 3 + 4 index (East Central Tropical Pacific SST, 5 °N–5 °S,

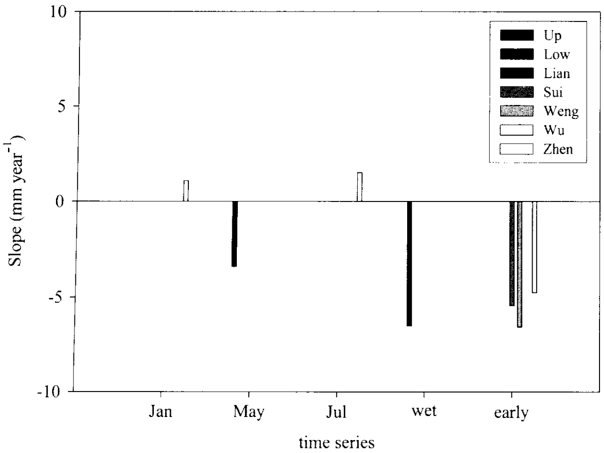

Figure 7. Sen's estimator of the slope of significant downward trend in sub-basin based analysis

120–170 °W) and Niño 4 index (Central Tropical Pacific SST, 5 °N–5 °S, 160 °E–150 °W)(http://www.cdc.noaa.gov/).

The spatial variation of precipitation trend could be accredited to SST variations, which may change the atmospheric circulation and result in the movement of the precipitation belt. In general, spatial and temporal changes of precipitation in Beijiang River basin were probably attributed to a positive anomaly of SST. Further research is, however, necessary in this field.

CONCLUSION

Using time series of monthly, annual, wet season, dry season, EFP and LFP totals, trend analyses of precipitation records at 63 stations and 7 sub-basins of Beijiang River basin were conducted. For station based time series, results demonstrated that there were changes in the spatial and temporal distribution of precipitation in Beijiang River basin. With the postponement of the wet season and increase of precipitation during the dry season, precipitation may become more evenly distributed throughout the year in the future. Spatially, the precipitation centre was previously south of Beijiang River, in which a downward trend in annual total precipitation was detected. Upward trends were mostly detected in the north. It indicated that the precipitation centre had been shifting northwards in recent years. Similar trends were detected in sub-basin based analysis. All changes may be the result of a positive anomaly in SST.

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