Indonesian Journal of Electrical Engineering and Computer Science
Vol. 5, No. 1, January 2017, pp. 41 ~ 47
DOI: 10.11591/ijeecs.v5.i1.pp 41-47

Monthly Precipitation Trend Analysis by Applying Nonparametric Mann-Kendall (MK) and Spearman's rho (SR) Tests In Dongting Lake, China: 1961-2012

Muhammad Tayyab[1, 2*], Jianzhong Zhou[1, 2], Rana Adnan[1, 2], Aqeela Zahra[3]
[1]School of Hydropower and Information Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
[2]Hubei Key Laboratory of Digital Valley Science and Technology, Wuhan 430074, China
[3]School of Psychology, South China normal university, Guangzhou 510600, China
*Corresponding author, email: mtayyab@hust.edu.cn

Abstract

This research highlights the precipitation trends and presents the results of the study in temporal and spatial scales. Precise predictions of precipitation trends can play imperative part in economic growth of a state. This study examined precipitation inconsistency for 23 stations at the Dongting Lake, China, over a 52-years study phase (1961–2012). Statistical, nonparametric Mann-Kendall (MK) and Spearman's rho (SR) tests were applied to identify trends within monthly, seasonal, and annual precipitation. The trend-free prewhitening method used to exclude sequential correlation in the precipitation time series. The performance of the Mann-Kendall (MK) and Spearman's rho (SR) tests was steady at the tested significance level. The results showed fusion of increasing (positive) and decreasing (negative) trends at different stations within monthly and seasonal time scale. In case of whole Dongting basin on monthly time scale, significant positive trend is found, while at Yuanjiang River and Xianjiag River both positive and negative significant trends are identified.

Keywords: *Mann-Kendall (MK), Spearman's Rho (SR), Dongting Lake, increasing trend and decreasing trend*

1. Introduction

The discovery of variations in precipitation is a vital and hard issue that is of growing interest because of its central role in the development of future water resources and flood safety. Numerous statistical tests and dynamic approaches have been established to trace trends in hydro-meteorological and hydrological time series, categorized as parametric and nonparametric tests [1, 2]. Parametric tests stand dominant but need data should be normally distributed and independent or autonomous, which is hardly real in case of hydrological time series data. On behalf of nonparametric tests, data should be independent, but other condition can be better tolerated. Scientists have found that the most common nonparametric tests are the Mann-Kendall [3, 4], Spearman's rho [5, 6] and Theil Sen's [7, 8] tests for research with time series trends. The Mann-Kendall test is the most common one used by researchers in studying hydrologic time series trends [9-12]; less common, Theil Sen's and Spearman's rho are used to detect magnitude and monotonic trends in hydrometeorological data respectively [13]. In several researches, Spearman's rho is used as the combination with the Mann-Kendall test for evaluation purposes [14-17].

Numerous investigators have led a large number of investigations around the world to notice the climate change and carrying out trend analysis. He and Zhang calculated the climate variables trend in China beside Lancer River using the data from 19 stations for the duration of 1960–2000, [18]. Gu et al. applied Mann Kendall method for finding runoff trend in main rivers of China [19]. Fan and Wang calculated temperature trend in Shanxi province in China, and found an increase in the temperature trend [20]. Zhong and Li (2009) have applied empirical orthogonal function and continuous power spectrum method to detect the precipitation trend in Mianyang of Sichuan in China and found declined tendency [21]. Xu et al. (2010) identified increasing precipitation trend by using Mann Kendall method for the Tarim River in the phase of

Received August 12, 2016; Revised November 28, 2016; Accepted December 11, 2016

1960–2007 [22]. Jiang et al. examined wind speed trend during 1956–2004 in China. They used two datasets and found that the trend is decreasing in the area [23]. Mostly earlier studies concentrated on regional precipitation fluctuations at Yangtze River basin [24-27]. Singh et al. used Mann Kendall approach in order to determine the trend of precipitation and relative humidity in India. Results showed that there is an increasing trend in relative humidity in most parts of the river basin [28]. Sequential Mann Kendall technique is becoming popular for the determination of start of trend and abrupt change in trends [29-31].

In present research, we examined monthly, seasonal and annual precipitation from 23 main meteorological stations during the period of 1961–2012 in the Dongting Lake. The short term trends of monthly and long term trends of precipitation on seasonal and annual time scale are studied, which develops our thoughts on the climate variation in the Dongting Lake. At the same time, individual each sub-basin as well as whole basin's characteristics of precipitation trends are studied for the first time in this paper. The outcomes of this research can possibly deliver significant evidence for the preparation of upcoming water resources and flood safety in the Dongting Lake.

2. Research Area and Data

This study investigates the variability inprecipitation time series for a 52-year period (1961–2012) in the Dongting Lake Figure 1. The Dongting Lake is situated in the south shoreline of the middle ranges of the Yangtze River. The Dongting Lake observed a frequent progression procedure beginning from small to big and big to small, which is thoroughly connected to the evolution of the Jingjiang network. Since freedom, numerous structural developments have been upsetting the state of the water flowing to the Lake, primarily the assembly of Tiaoxian Dam, the project of Jingjiang and Wanjiangfengxi Reservoir, the Zishuituoxi Reservoir, the Gezhouba dam and the Three Gorges Reservoir. The inflow of Dongting Lake largely comes from the Yangtze Riverangtze River (YR).

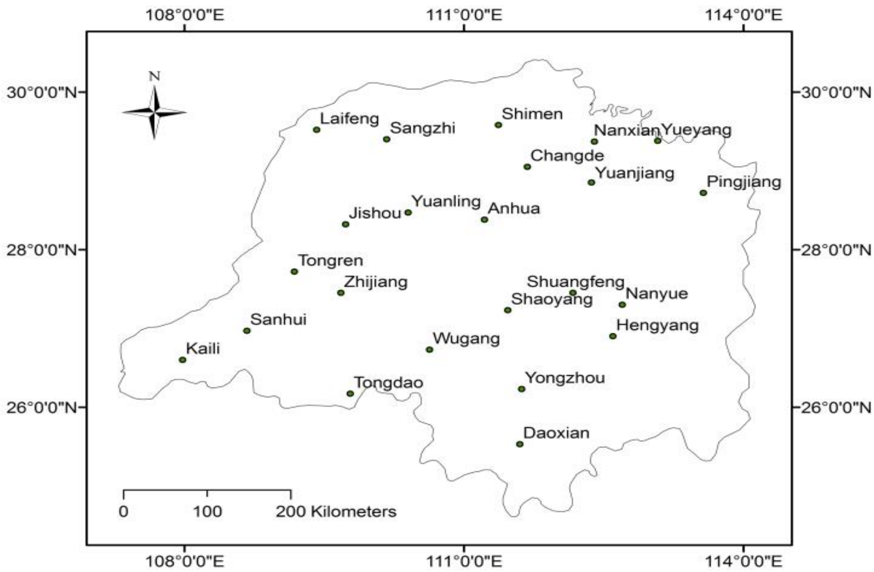

Figure 1. Location of study Area

3. Methodology

3.1. Statistical Tests

Prior to applying MK and SR tests to identify precipitation trends over the time series from selected stations, data were tested according to the tests' requirements. The trend-free prewhitening (TFPW) method was used to remove serial or sequential correlations in the time series data. The scale of the slope in time series data was attained by using Sen's slope method. The statistical methods used are briefly discussed below. In the case of the nonparametric tests the data set should be serially autonomous or independent. On the basis of achieved researches, the presence of serial correlation will raise the prospect for important trend finding. That clues to a inconsistent refusal of the null hypothesis of no trend, while the null hypothesis is really true. Thus, the impact of serial correlation should be removed. For this purpose, few methods such as variance correction, pre-whitening [1] and TFPW [2] have been recommended. The TFPW method offered here delivers a well valuation of the significance of the trends for serially correlated data than the further methods and numerous investigators also have used this technique [3]. In this research, to eliminate the consequence of serial correlation on both tests (MK and SR) the TFPW technique was used for time series with significant autocorrelation (at 5% significant level).

3.1.1. The MK Test

This is an overgrown statistical nonparametric test, established by Mann (1945) and Kendall (1975). For this test, the null (H0) and another hypotheses (H1) are equivalent to the absence and being of a trend in the time series of the present observational data, correspondingly. The null hypothesis (H0) is rejected When $Z > Z1\text{-}\alpha/2$, and a significant trend exists in the time series. $Z1\text{-}\alpha/2$ is the acute value of Z from the standard normal table, for 5% significant level the value of $Z1\text{-}\alpha/2$ is 1.96.

3.1.2. Spearman's rho Test.

This test is also rank-based statistical nonparametric technique applied for trend analysis and used for comparison purpose with Mann-Kendall test [4, 5]. In Spearman's rho test, which undertakes that time series data are autonomous or independent and distributed identically, the null hypothesis (H0) yet again specifies no trend over time; the alternative hypothesis (H1) is that a trend should be present and that data rise or fall with [6].

4. Results and Discussion

4.1. Monthly Analysis Trend Analysis on Each Station

The Mann-Kendall (MK) and Spearman's rho (Tt) tests were used in a monthly scale to identify trends in precipitation series at different stations. Table 1 shows the results and illustrates that the results of both tests were similar to one another. The magnitude of statistically significant trends on a monthly scale was detected by using Sen's slope estimator. At different stations monthly trend tests showed a mix of positive and negative trends. At Sangzhi, Kaili, Shuangfeng and Hengyang stations statistically significant positive trends were found in January, no significant trends were found for other months. Singnificant positive trends were detected at Nanxian, Yueyang and Changde stations in January and July. At Jishou, Tongdao, Shaoyang and Wuganag stations statistically significant positive and negative trends were found in January and April, respectively. In April Zhijiang station had showed significant negative trend. The Tongren staion exhibited significant positive trend in January but had significant negative trends in April and October like this station Nanyue station is the only one which had showed significant negative trend in month of October. Stations which had showed statistically significant only negative trends in August include Sanhui and Yongzhou stations. Singnificant negative trends were detected at Daoxian station in April and November. All remaining stations had not shown any statistically significant trends in any case in any month.

Figure 2 shows the spatial variation in the monthly precipitation time series in the Dongting region from 1961 to 2012. The magnitude of statistically significant trends on a monthly scale was determined using Sen's slope estimator. The results show that trends at Nanxian and Daoxian stations were rapid as compared to other stations. The Nanxian station had the maximum positive increase in monthly precipitation (1.86 mm/month) and maximum negative decline (0.032 mm/month) during the months July and September; respectively. Jishou, Tongdao, Shaoyang and Wugang stations had shown sharp change from significant positive to negative trends in January and April respectively.

4.2. Monthly Analysis Trend Analysis Over Entire Basin and Sub-Basins

The effect of climate change on precipitation was also analyzed for the entire Dongting region basin by applying the Mann-Kendall (MK) and Spearman's rho (Tt) tests on monthly, seasonal, and annual scale. As Figure 1 showed, the entire Dongting River catchment (A) is divided into five subbasins: Lake Region (A1), Lishui River (A2), Yuanjiang River (A3), Zishui River (A4) and Xianjiang River (A5). Table 2 presents trends in monthly precipitation across the sub-basins and for the entire basin. The significant positive trends in the months of January and July for the Lake Region (A1). In the Lishui River (A2), statistically No significant trends were identified. In the Yuanjiang River (A3), statistically significant positive and negative trends were recognized in January and April. The Zishui River (A4) showed statistically significant positive trends in January. The maximum numbers of significant cases (three) were observed in results from the Xianjiang River (A5). The Xianjiang River (A5), showed significant positive trend during January and significant negative trends were identified in April and October. At whole Dongting Basin (A), statistically significant positive trends were detected in January and July. As a simpler summary, significant positive trends in precipitation over time were seen in January and July; negative trends over time were seen in April and October in different Dongting sub-basins. To detect precipitation trends in each sub-basin and entire Dongting basin, the Mann-Kendall and Spearman's rho tests were again applied to seasonal and annual precipitation data for the 52-year study period (1961–2012) at 23 meteorological stations. As Table 2 shows, both test methods showed similar results. Except Yuanjiang River (A3), other entire Dongting River catchment (A), Lake Region (A1), Lishui River (A2), Zishui River (A4) and Xianjiang River (A5) showed no statistically significant positive or negative trends. The Yuanjiang River (A3) showed only significant negative trend in spring. This study investigated variability in monthly precipitation at 23 stations in the Dongting basin over a 52-year study period (1961–2012). Precipitation trends were also analyzed for each subbasin and entire Dongting Lake basin. The mean annual precipitation at different stations showed considerable variation. The Nanxian, Yueyang, Changde, Kaili, Shuangfeng and Hengyang stations showed significant positive trends (increased precipitation over time) at 5% significance level in the annual precipitation series. Shaoyang station showed the maximum decreasing slope (indicating sharpest change over time) of -0.06 mm/year among the selected stations in the Dongting lake Basin. These variations in precipitation trends may lead Pakistan towards more water related disasters such as droughts and floods in the near future. [7] Proposed possible causes of the changing precipitation trends, such as global climate shifts [8], dwindling global monsoon circulation [9], decline in forest cover, [10, 11] land use changes and practices (e.g., irrigated agriculture) [11], and increasing aerosols from anthropogenic activities [12].

5. Conclusions

In this study we examined trends in monthly, seasonal, and annual precipitation at Dongting Lake over the 52-year study period (1961–2012). Both positive and negative trends were detected at various stations and subbasins. The months of January, April, July, August, September and October presented the extreme number of significant cases at various stations in monthly precipitation. The trends were positive in January and July and were negative in April, August, September and October. This indicates a shift in precipitation series on monthly scale. Significant positive trends were detected in winter; negative trends were seen in spring. Nanxian, Yueyang, Changde, Kaili, Shuangfeng and Hengyang exhibited significant positive trends; Tongren, Zhijiang, Tongdao, Nanyue, Yongzhou and Daoxian exhibited negative trends in monthly precipitation at a 95% confidence level; the remaining stations did not experience a statistically significant trend. None of the stations experienced any trend in annual precipitation. For the entire Dongting Lake basin and Lake Region (A1) months of January and July has shown significant positive trend. Seasonally, only spring has experienced significant positive trends for Yuanjiang River (A3) while other subbasins have no significant trends. Most statistically significant trend cases under different scenarios were equal (50%) of positive and 50% of negative. The results obtained with the Mann-Kendall and Spearman's rho tests showed agreement in their assessments of monthly, seasonal, and annual precipitation trends. The variability of negative and positive trends at various stations points to the essential for more detailed studies on the climate change of this region.

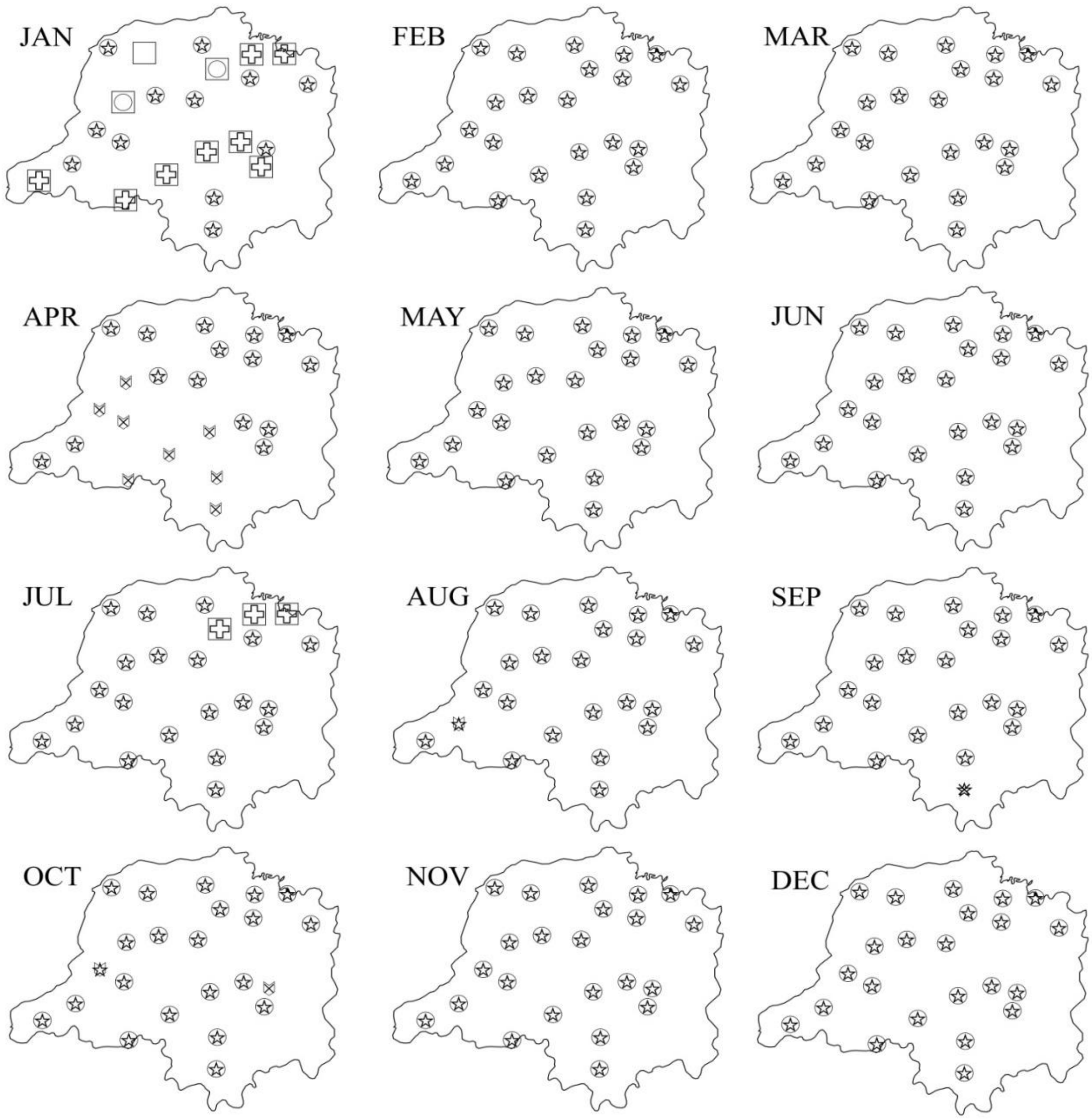

Figure 2. Locality of stations with positive, negative and no trends at 5% significance level for the monthly precipitation time series.Mann-Kendall (MK) No Significant Trends [○], Mann-Kendall (MK) Significant Positive Trends [✚], Mann-Kendall (MK) Significant Negative Trends [▽], Spearman's rho Tests (Tt) No Significant Trends [☆], Spearman's rho Tests (Tt) Significant Positive Trends [□], Spearman's rho Tests (Tt) Significant Negative Trends [×]

Table 1. MK and SR Tests Results for Precipitation in Monthly Time Series

Stations	TEST	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Sangzhi	MK	1.98	1.00	-0.21	-1.03	-0.67	0.40	1.02	-0.80	-0.70	-0.29	0.40	-1.29
	Tt	2.08*	1.02	-0.17	-1.05	-0.70	0.27	0.93	-0.81	-0.65	-0.39	0.39	-1.27
Nanxian	MK	2.37*	0.44	-0.39	0.23	-0.62	-0.73	2.31*	0.20	-0.66	0.17	0.17	-0.99
	Tt	2.53*	0.48	-0.48	0.27	-0.51	-0.64	2.55*	0.21	-0.69	0.03	0.26	-1.17
Yueyang	MK	2.15*	1.05	-0.96	-0.15	-0.02	-0.81	2.63*	0.84	0.48	-0.29	0.71	-0.66
	Tt	2.49*	1.17	-1.10	-0.14	0.09	-0.71	2.89*	0.93	0.47	-0.35	0.65	-0.70
Yuanjiang	MK	1.91	-0.01	-0.88	-0.89	-0.58	-0.81	1.70	-0.12	-0.59	-0.12	0.84	-0.67
	Tt	1.93	0.00	-0.90	-0.83	-0.57	-0.70	1.75	-0.24	-0.46	-0.29	0.83	-0.83
Pingjiang	MK	1.91	-0.31	-1.03	-1.40	-1.16	0.81	1.08	1.41	0.17	-0.79	0.54	-0.13
	Tt	1.88	-0.25	-0.96	-1.48	-1.15	0.82	0.88	1.54	-0.08	-0.70	0.53	-0.11
Laifeng	MK	1.02	1.07	-0.92	-0.97	-1.05	-0.31	0.29	-0.42	-1.74	-0.81	-0.66	-1.37
	Tt	1.08	1.09	-0.84	-0.84	-1.02	-0.40	0.29	-0.45	-1.78	-0.70	-0.66	-1.44
Shimen	MK	1.94	0.62	-0.47	-0.86	-0.53	0.13	1.44	-0.83	-1.25	0.00	0.01	-0.92
	Tt	1.87	0.43	-0.09	-1.39	-0.67	0.00	1.55	-1.05	-1.30	-0.02	-0.02	-0.88
Jishou	MK	1.91	-0.29	-1.14	-2.14*	-1.14	1.35	1.21	-0.73	-1.76	-0.99	-0.19	-1.08
	Tt	2.23*	-0.71	-1.01	-2.23*	-0.87	1.07	1.23	-0.91	-1.80	-1.15	-0.36	-1.01
Yuanling	MK	1.16	-0.13	-0.64	-1.65	-0.80	0.07	0.83	-0.23	-0.42	0.25	0.45	-0.97
	Tt	1.22	-0.20	-0.75	-1.70	-0.67	0.12	0.74	-0.30	-0.46	0.27	0.42	-0.84
Changde	MK	1.94	0.66	-0.77	-0.28	-0.20	0.24	2.47*	-0.84	-0.61	-0.35	0.70	-1.03
	Tt	2.30*	0.73	-0.92	-0.35	-0.11	0.36	2.63*	-0.81	-0.63	-0.60	0.68	-1.26
Tongren	MK	1.21	0.90	0.07	-2.94*	-0.75	0.96	1.10	-0.47	-0.37	-2.34*	-1.26	-1.19
	Tt	2.00*	0.42	0.83	-2.52*	-1.72	1.32	0.97	-0.38	-0.31	-1.82	-1.17	-1.08
Zhijiang	MK	1.85	0.54	1.11	-2.42*	-1.60	1.11	1.03	-0.47	-0.40	-1.71	-1.35	-1.02
	Tt	1.80	0.25	0.17	-2.16*	-1.72	0.56	1.00	-0.74	-1.92	-1.21	-0.61	-0.79
Kaili	MK	2.29*	0.50	1.21	-1.31	-1.03	0.23	0.56	-1.38	-0.61	-1.03	-1.80	-0.51
	Tt	2.27*	0.48	1.30	-1.50	-1.09	0.29	0.43	-1.39	-0.69	-0.99	-1.90	-0.72
Sanhui	MK	0.97	0.31	1.85	-1.59	-1.78	0.01	0.39	-2.11*	0.43	-1.94	-1.14	-1.10
	Tt	1.03	0.30	1.83	-1.67	-1.76	-0.02	0.47	-1.98	0.43	-1.87	-1.21	-1.06
Tongdao	MK	2.56*	1.05	1.79	-2.63*	0.44	1.41	0.34	-1.32	-0.34	-0.84	-1.31	-0.83
	Tt	2.61*	1.18	1.74	-2.50*	0.43	1.41	0.28	-1.18	-0.17	-0.84	-1.21	-0.81
Anhua	MK	1.77	-0.39	-0.28	-0.84	-0.43	1.10	1.78	-1.30	-0.70	-0.84	-0.02	-0.84
	Tt	1.83	-0.31	-0.43	-0.76	-0.28	1.08	1.86	-1.29	-0.76	-0.94	-0.12	-0.53
Shaoyang	MK	2.18*	-0.10	0.18	-3.24*	-0.51	0.06	0.47	-0.02	0.04	-1.13	-1.03	-0.28
	Tt	2.17*	-0.09	0.13	-3.30*	-0.64	0.08	0.36	-0.09	0.21	-1.09	-0.89	-0.25
Wugang	MK	2.03*	0.62	1.19	-2.55*	-0.62	-0.37	0.26	-0.54	-0.17	-1.60	-0.96	-0.61
	Tt	2.01*	0.49	1.13	-2.50*	-0.68	-0.21	0.30	-0.62	-0.16	-1.51	-0.92	-0.64
	MK	2.38*	-0.07	0.32	-1.92	0.21	0.75	1.11	-0.18	0.79	-1.05	-0.61	0.02
	Tt	2.47*	-0.14	0.12	-1.93	0.05	0.83	1.08	-0.24	0.88	-1.18	-0.68	0.03
Nanyue	MK	0.75	-0.88	0.62	-1.93	-0.39	1.18	0.66	0.88	1.13	-2.47*	-1.56	-0.77
	Tt	0.91	-0.83	0.65	-1.77	-0.59	1.22	0.50	0.83	1.17	-2.59*	-1.59	-0.77
Yongzhou	MK	1.80	0.36	1.08	-2.83*	-0.04	0.92	0.84	-0.29	0.06	-1.68	-0.70	-0.72
	Tt	1.90	0.43	1.08	-2.76*	0.04	0.91	0.77	-0.33	-0.02	-1.76	-0.65	-0.65
Hengyang	MK	2.23*	0.02	0.99	-1.77	0.18	0.00	0.91	-0.01	1.08	-1.68	-0.16	-0.89
	Tt	2.38*	0.16	1.09	-1.66	0.14	0.12	0.80	0.00	1.10	-1.88	-0.15	-0.70
Daoxian	MK	1.60	0.28	0.12	-2.17*	0.48	0.53	1.08	-0.88	-2.00*	-1.13	-0.55	-0.85
	Tt	1.80	0.25	0.17	-2.16*	0.65	0.56	1.00	-0.74	-1.92	-1.21	-0.61	-0.80

Table 2. MK and SR Tests Results for Monthly Precipitation Time Series in Entire Dongting Basin and Sub-Basin

River Name	T	J	F	M	A	M	J	J	A	S	O	N	D
A1	MK	2.22*	0.54	-0.73	-0.92	-0.80	-0.28	1.96	0.53	-0.40	-0.26	0.58	-0.77
	Tt	2.29*	0.57	-0.89	-0.92	-0.81	-0.25	2.12*	0.53	-0.42	-0.29	0.53	-0.89
A2	MK	1.63	0.83	-0.37	-0.67	-0.34	0.29	1.07	-0.92	-1.52	-0.20	-0.59	-1.29
	Tt	1.64	0.85	-0.41	-0.73	-0.58	0.28	1.09	-1.00	-1.57	-0.25	-0.47	-1.23
A3	MK	2.09*	0.58	0.36	-2.17*	-1.21	0.59	1.48	-1.54	-0.95	-1.82	-1.11	-1.33
	Tt	2.13*	0.57	0.28	-2.36*	-1.19	0.65	1.48	-1.44	-0.96	-1.93	-1.09	-1.19
A4	MK	2.08*	0.02	0.26	0.86	-0.15	0.37	1.10	-0.70	-0.54	-1.43	-0.70	-0.70
	Tt	2.15*	0.04	0.18	0.97	-0.59	0.49	1.10	-0.80	-0.47	-1.43	-0.65	-0.58
A5	MK	1.92	-0.17	0.53	-2.35*	0.23	1.18	1.21	-0.18	0.43	-1.92	-0.59	-1.33
	Tt	2.06*	-0.05	0.52	-2.30*	0.20	1.11	1.07	-0.25	0.48	-2.01*	-0.66	-1.25
A	MK	2.11*	0.50	-0.04	-1.44	-0.61	0.39	2.09*	-0.67	-1.07	-1.40	-0.28	-1.00
	Tt	2.46*	0.48	-0.10	-1.42	-0.66	0.39	2.13*	-0.68	-1.09	-1.55	-0.35	-1.03

Acknowledgments

This study was supported by the State Key Program of National Natural Science of China (No. 51239004) and the National Natural Science Foundation of China (No. 51309105).

References

[1] Hamed KH and AR Rao. A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology*. 1998. 204(1): p. 182-196.
[2] Yue S, P Pilon, and G Cavadias. Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of hydrology*. 2002; 259(1): 254-271.
[3] Kumar S et al. Streamflow trends in Indiana: effects of long term persistence, precipitation and subsurface drains. *Journal of Hydrology*. 2009; 374(1): 171-183.
[4] Zhang Q, et al. Observed trends of annual maximum water level and streamflow during past 130 years in the Yangtze River basin, China. *Journal of Hydrology*. 2006; 324(1): 255-265.
[5] Mann HB. Nonparametric tests against trend. *Econometrica: Journal of the Econometric Society*. 1945: 245-259.
[6] Longobardi A and P Villani. Trend analysis of annual and seasonal rainfall time series in the Mediterranean area. *International journal of Climatology*. 2010; 30(10): 1538-1546.
[7] Basistha A, D Arya and N Goel. Analysis of historical changes in rainfall in the Indian Himalayas. *International Journal of Climatology*. 2009; 29(4): 555-572.
[8] Baines PG. *The late 1960s Global Climate Shift and its influence on the Southern Hemisphere.* Transport. 2006; 10: 10E.
[9] Duan K and T Yao. *Monsoon variability in the Himalayas under the condition of global warming (SCI).* 2003.
[10] Nair U et al. Impact of land use on Costa Rican tropical montane cloud forests: Sensitivity of cumulus cloud field characteristics to lowland deforestation. *Journal of Geophysical Research: Atmospheres*. 2003; 108(D7).
[11] Avissar R and D Werth, Global hydroclimatological teleconnections resulting from tropical deforestation. *Journal of Hydrometeorology*. 2005; 6(2): 134-145.
[12] Pielke R, et al. *An overview of regional land‐use and land-cover impacts on rainfall*. Tellus B. 2007; 59(3): 587-601.