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Spatial and temporal variations of precipitation: case study of Zhanghe River Basin, P. R. China

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Abstract

From the day first droughts and over wettings remains important in the economic development of humankind. In this study, monthly and annual trends of precipitation were analyzed for eight different weather stations in the Zhanghe River Basin, China over 30 years period (1980–2010). Prior to applying MK (Mann-Kendall test), trend-free Pre-whitening (TFPW) approach was applied to eliminate serial correlations in the time series data. The Mann-Kendall and Sen's slope methods were used to ascertain the trends in the precipitation data. The results demonstrated both positive (increasing) as well as negative (decreasing) trends at the 90, 95 and 99% significance levels. The present study further revealed that the variability in the spatial distribution of precipitation trends were highly significant. In the month of February, most of the stations had upward precipitation trends (99% significance level) whereas that of March showed a downward trend in the Anyang station (99% significance level). This study mainly points out that there is a high probability of water scarcity occurrence in this region. The information provided in this study is therefore useful in drought assessment in this particular region. It is also concluded that the Mann-Kendall and Sen's tests are suitable for the precipitation trend analysis in the study area.

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Introduction

The occurrence of floods and drought is a major problem across the globe. This particular problem is more pronounced in China. Due to China's large landmass and different climatic change, weather and climate extremes frequently cause havoc to the country. The Yellow River, the second largest river in China, has frequently dried up which has interrupted discharge since 1985. Notably, a devastating drought over north China in 1997 resulted in a 226-day dry up period for this particular river. It must be pointed out that these severe conditions are all related to the variation of total and extreme precipitation. Ding (1994) reported that the major rain belt stagnates over different parts of China at different periods within the year. It must be noted that it occurs within south China in May–early June, over central China from 20 June to 10 July, and over north China from 5 to 25 August. The summer monsoon rainfall is a major source of water supply for agricultural purposes in the country. As such, variability in precipitation amounts and extreme precipitation are critical for both the Chinese government and the general public. Previous study on 361 stations in China observed a trend in normalized annual precipitation anomalies and in some annual extremes for the period 1951–95 (Zhai *et al.,* 1999). According to (Zhang *et al.,* 2004) changes in precipitation have led to very contrasting occurrences. Specifically, more frequent droughts have been observed in northern China whereas the south experiences severe floods, especially in the mid–lower reaches of the Yangtze river. These authors also pointed out that changes in the number of extreme precipitation events are the result of changes in both the number of rain days and the intensity. Limited rainfall and unreasonably high temperatures have led million hectares of land unproductive for agricultural purposes. These occurrences have also cause some rivers in the region to dry up. Several indices have been used in describing drought, its trends in frequency as well as its duration due to changes in precipitation (Moreira *et al.*, 2008; Paulo *et al.*, 2008; Shahid, 2008; Khalili *et al.*, 2011; Mishra *et al.*, 2010; Tabari *et al.*, 2012; Hisdal *et al.*, 2001). (Hisdal *et al.*, 2001; Khalili *et al.*, 2011; Mishra *et al.*, 2010; Moreira *et al.*, 2008; Paulo *et al.*, 2008; Shahid, 2008; Tabari *et al.*, 2012;). It is important to note that precipitation plays more critical role in the occurrence of drought and flood. Previous studies that analyzed the trends in intensity of precipitation during the period 1951–1996 found significant positive trend in northern Italy and longest wet periods were also observed in Western Greece (Gemmer *et al.*, 2004; Tabari *et al.*, 2012; Brunnetti *et al.*, 2001; Tolika *et al.*, 2005). Koleva *et al* 2008 and Ruiz Sinoga *et al*, 2011 analyzed the patterns of monthly and annual precipitation variability and variation in the precipitation in east and central Europe over the period1851-2007. These authors observed dry period in the 1980s and the first half of the 1990s.

Precipitation is an important influencing factor of the drought disaster and also has a significant influence on the spatial and temporal changes of risk of drought disaster. Zhanghe river region is a semiarid and needs comprehensive analysis of trends and variability in precipitation.

The purpose of this study is to analyze the variability of trends in precipitation from 1980 to 2010 in the region Zhanghe river basin. Specifically, this study seeks to compare the results of the Mann-Kendall test and the Sen's slope estimator using the precipitation data. In addition, the present study seeks to identify drought prone areas within the region.

Materials and methods

Study area and data collection

This study covers the upstream of Zhanghe River (Fig. 1). The Zhanghe River commences in Shanxi province and flows toward east. Then it flows towards the border of Hebei and Henan province to west of Handan and Anyang. On the Zhang River a Dam diverts water into the Red Flag Canal. The River has a catchment area of 18200km². The watershed falls approximately between113°-116° East and 36°-38° North. This study covers the daily precipitation data sets comprising of 30 years of data (1980–2010) and covering 8 weather stations.

Data Processing

Prior to applying MK test, trend-free pre-whitening (TFPW) approach was applied to eliminate serial correlations in the time series data. The magnitude of the slope in time series data was calculated using Sen's slope method.

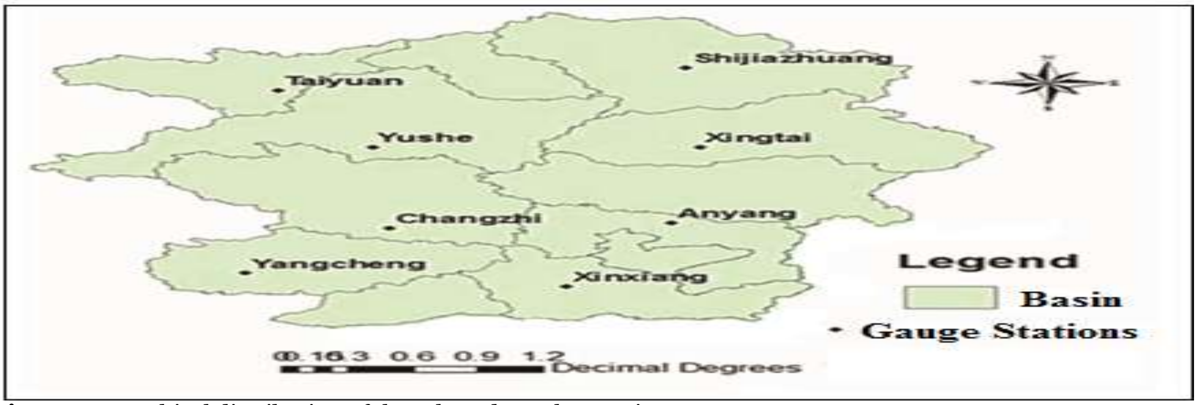


Fig. 1. Geographical distribution of the selected weather stations.

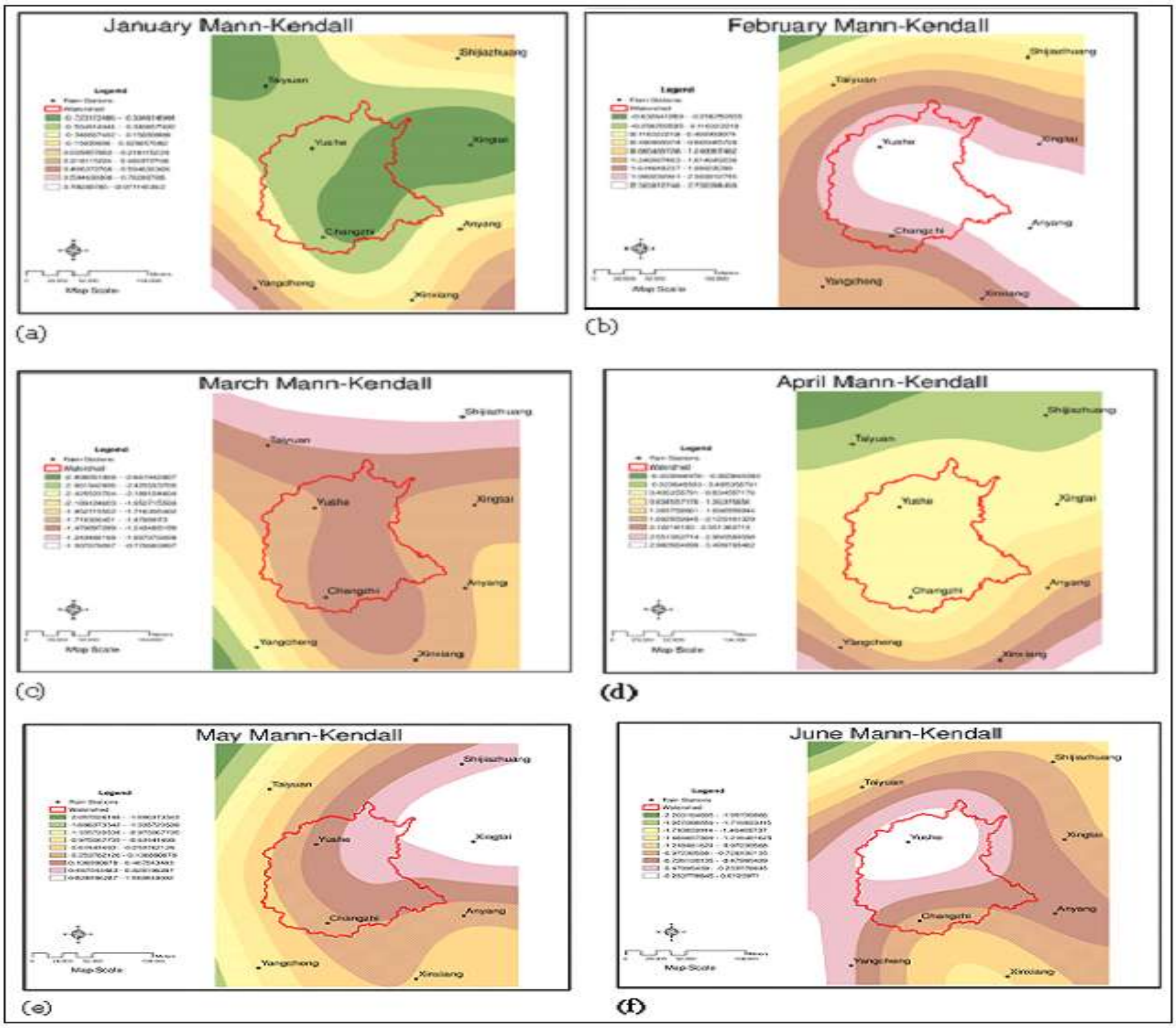
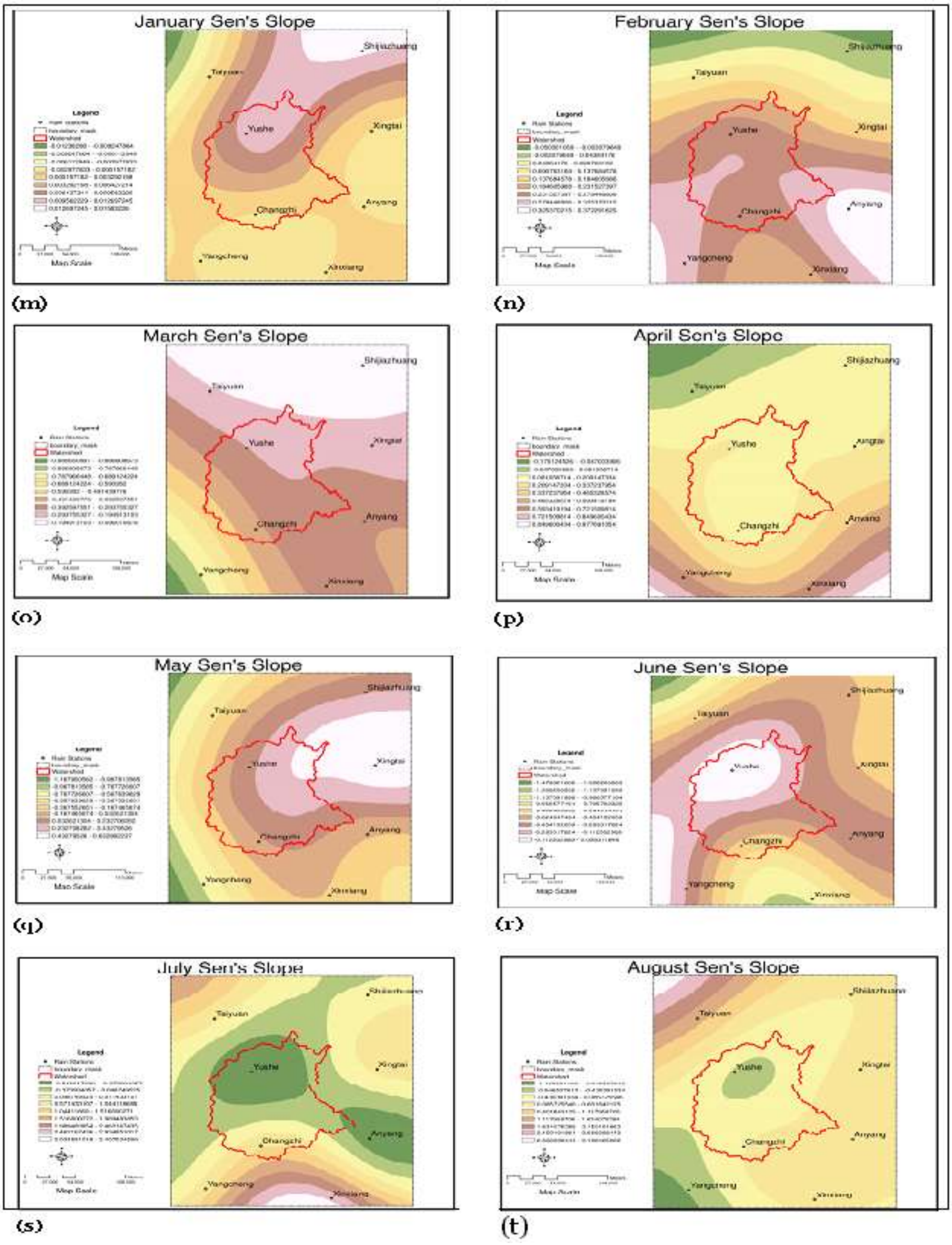


Fig. 2. (a-l). Monthly precipitation trends (January to December) Mann-Kendall Z Statistic.

Trend analysis methods

Mann-Kendall test

Non-parametric methods Mann (1945) and Kendall (1975) test was used to analyze all the trends of precipitation at 90%, 95% and 99% level (Onoz *et al.*, 2003). This method is usually adopted to estimate the significance of monotonic trends in hydrological and meteorological time series. The test is based on the statistic S, which is calculated by using the following formula.



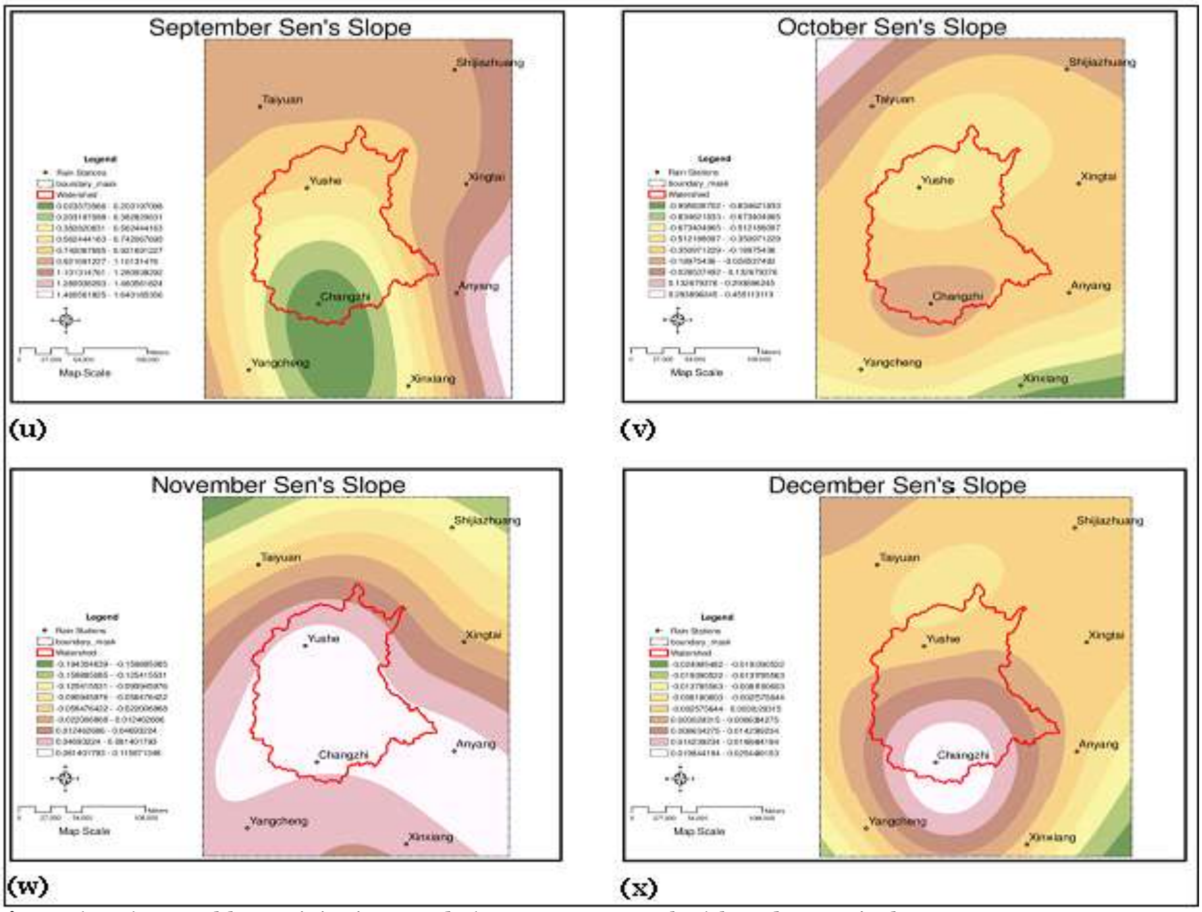


Fig. 3. (m-x). Monthly precipitation trends (January to December) based on Sen's slope.

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

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

Where n shows the number of observed data series, x_j and x_k are the values in periods j and k, respectively, $j > k$. For ≥ 10, the sampling distribution of S and Z computed as Follows:

$$Z=\begin{cases}\frac{S-1}{\sqrt{VAR(S)}} & \text{if } s>0\\ 0 & \text{if } s=0\\ \frac{S+1}{\sqrt{VAR(S)}} & \text{if } s<0\end{cases} \quad (3)$$

Where $VAR(S)$ is calculated with following formula

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

Where q the number of is tied groups and t_p is the number of data values in the p^{th} group. If $|z| > Z_{1-\propto/2}$, null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\propto/2}$ is the critical value of Z from the Standard Normal table. For 95% confidence, the value of $Z_{1-\propto/2}$ is 1.96. A positive value of Z indicates an upward trend and a negative value of Z indicates a downward trend. In this study, 90%, 95% and 99% significance levels were used.

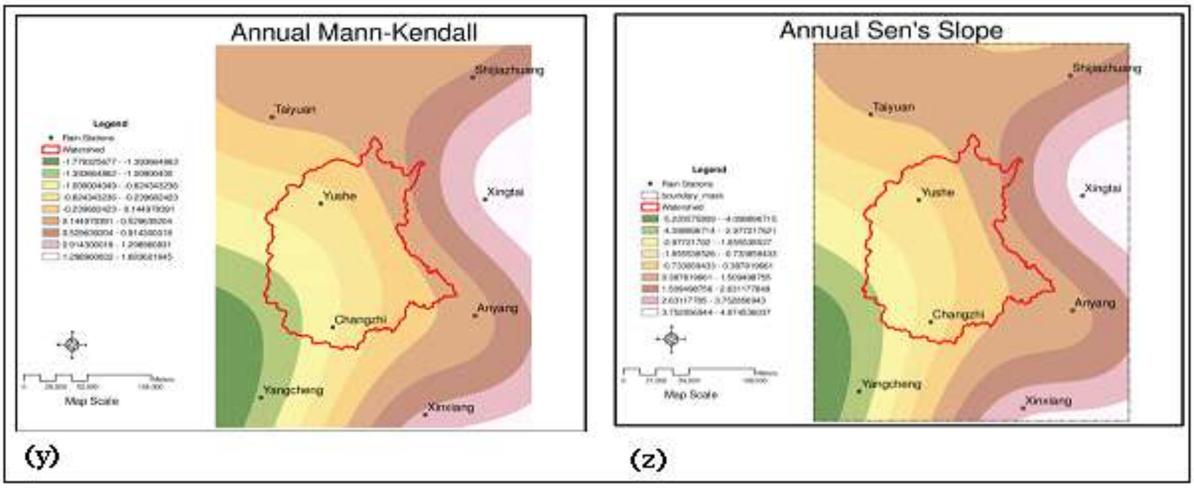


Fig. 4. Annual precipitation trends on Mann-Kendall (y) and Sen's Slope (z).

Sen's slope estimator

Sen (1968) developed the non-parametric procedure for estimating the slope of trend in the sample of pairs of data as given in Eq. 5.

$$Q_i = \frac{x_j - x_k}{j-k} \quad for\ i = 1, \ldots, N, \tag{5}$$

Where x_j and x_k are the data values at times j and k $(j > k)$, respectively. Sen's slope estimator is computed as shown in Eq. 6.

$$Q_{med} = \begin{cases} Q[(N+1)/2] & if\ N\ is\ odd \\ \frac{Q[N/2] + Q[(N+2)/2]}{2} & if\ N\ is\ even \end{cases} \tag{6}$$

The Q_{med} sign reflects data trend reflection, while its value indicates the steepness of the trend. A positive Q_{med} values represents an increasing trend, a negative Q_{med} value represent a decreasing trend over time series.

Results

Monthly precipitation trends on Mann-Kendall Basis

Fig. 2a shows that in the month of January, there are no significant trends in precipitation. Moreover, according to Mann-Kendall, during this month precipitation was less. As a result of the less precipitation, negative trends appeared in the Taiyuan, Yushe, Xingtai and changzhi stations. In this month, negative trend of (-0.723 to -0.158) and positive trend ranging from (0.029 to 0.971) were observed. In February, significant changes were observed in the trends as shown in Fig. 2b. The observations from the Mann- Kendal approach revealed that the Anyang, Yushe, Xingtai, Changzhi and Xinxiang stations had significant trends at 90%, 95%and 99%, respectively. During this month, few dry days appeared (-0.632 to -0.258) and positive trend (0.116 to 2.738) was observed.

Yangcheng and Anyang stations had negative significant trends in the precipitation at 95% and 99%, respectively in March. This month was observed to have dry days throughout the whole month (-2.898 to –0.77). Two stations (Xinxiang and Yangcheng) recorded positive significant trends in the precipitation at 95% significant level. In this month, precipitation increased more relative to the other months. According to the results from the Mann-Kendall test, Taiyuan and Shijiazhuang was affected by the dry days at the rate of (-0.453 to -0.02). Mann-Kendall test showed that there was no significant trend in the month of May and June. However, in the month of July, Xinxiang station had significant trend at 95% significant level. During May, Taiyuan and Yangcheng experienced dry days due to negative trends in the precipitation. Whilst in June, all eight stations were under stress due to dry days (-2.203to -0.233). In the month of July and August, Yushe, Anyang and Yangcheng were more affected due to negative trend in precipitation. Anyang station had positive significant trends in the month of September at 99% significant level. It must be noted that there were no dry days during this period at the Anyang station.

Table 1. Results of the statistical test on the Mann-Kendall Z statistics basis over the period (1980-2010).

Station	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Anyang	-0.132	2.696**	-1.686+	1.572	-0.113	-0.648	-0.454	0.081	1.687+	-0.973	0.633	0.829	0.372
Changzhi	-0.119	1.954+	-1.393	0.543	-0.016	-0.815	0.798	0.033	0.237	-0.339	0.544	0.823	0.405
Shijiazhuang	0.512	0.719	-0.968	0.288	0.645	-0.985	0.271	0.033	1.189	-0.543	-0.664	1.14	0.611
Taiyuan	-0.017	0.986	-1.292	0.237	-0.849	-1.053	0.509	0.951	1.087	-0.22	-0.615	0.298	0.203
Xingtai	-0.554	2.109*	-1.599	0.645	1.087	-0.781	0.662	0.067	1.325	-0.951	-0.187	1.035	1.359
Xinxiang	-0.719	1.684+	-1.53	2.209*	-0.271	-1.206	2.43*	0.271	0.543	-1.495	0.323	0.398	0.985
Yangcheng	-0.017	1.495	-2.311*	2.022*	-0.917	-0.441	0.764	-1.206	0.611	-0.662	0.663	0.499	-1.325
Yushe	0.443	2.532*	-1.496	0.714	0.237	0	-0.526	-0.373	1.036	-0.9	0.697	1.14	-0.373

+Statistically significant trends at 99%, *statistically significant trends at 95%, ** statistically significant trends at 90%.

In winter season, due to shortage of rain, more areas experienced dry days. For instance, in October, all 8 stations experienced shortage of water. It must be pointed out that negative trends (-2.142 to -0.197) were observed in Taiyuan, Shijiazhuang and Xingtai during November. However, all stations recorded positive trends in December. Table 1 presents the results of the statistical analysis on the basis of Mann-Kendall test. This table shows both positive and negative trends of precipitation during the study period at different significant levels. All the stations had negative trends in January except Yushe. However, it must be pointed out that there was no significant trend in the precipitation. On the other hand, there were significant trends in most of the stations in February. It is important to note that Anyang station recorded positive trend at 90% significant level. Also, Changzhi and Xinxiang both had positive tends at 99% significant level. In addition, Xingtai and Yushe had positive tends at 95% significant level.

Table 1 and 2 shows that in March and October, both months recorded negative trends. Anyang and Yangcheng had negative trends during March at 99% and 95% significant levels respectively. Whereas, in July Xinxiang had positive trend at 95% significant level. The remaining months recorded positive and negative trends but the trends were not statistically significant. Table 2 presents the statistical analysis on Sen's slope basis. This table shows that all the stations had positive and negative trends during the analysis period but the trends were not statistically significant.

Monthly precipitation trends on Sen's slope Basis

Monthly precipitation trends on the basis of Sen's slope had both negative and positive trends throughout the whole study period Fig.3 (m-x). On the basis of this analysis, it was observed that in the month of January, only Taiyuan station was affected (-0.012 to -0.002) due to negative trend in the precipitation. Whilst the remaining stations had positive trends. In February, only Shijiazhuang station had dry days and due to shortage of precipitation, there was negative trend in this station.

It must be noted that all the remaining stations recorded positive trends in the precipitation (0.043 to 0.372). Furthermore, all the stations had negative trends in precipitation during the month of March and most affected station was Yangcheng (-0.98 to -0.096). During April, only Taiyuan had negative trend whereas all the remaining stations had positive trends in the precipitation. Shijiazhuang and Xingtai stations were showed negative trends of precipitation in May. It must be pointed out that same conditions were observed for this month on the basis of Sen's and Mann-Kendall test.

July had positive trends at most of the stations including Taiyuan, Shijiazhuang, Xingtai, Yangcheng, Xinxiang and Changzhi. However, Yushe and Anyang had negative trends. The same observation was made when the Mann-Kendall approach was used. During August Yushe, Yangcheng and Changzhi had negative trends of precipitation. Contrary, Taiyuan, Shijiazhuang, Xingtai, Xinxiang and Anyang recorded positive trends of percipitation in these satations. Mann-Kendall and Sen's analysis demonstrated that all stations had positive trends of percipitation in September. October and December had negative trends of precipitation at all stations except Changzhi.

Table 2. Results of the statistical test on the Sen's slope Q statistics basis over the period (1980-2010).

Station	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Anyang	0	0.35	-0.376	0.444	-0.136	-0.385	-0.597	0.298	1.204	-0.278	0.098	0	1.144
Changzhi	0	0.25	-0.418	0.158	-0.009	-0.683	0.923	0.06	0.063	-0.111	0.088	0.025	-1.287
Shijiazhuang	0.013	0.02	-0.15	0.128	0.22	-0.587	0.24	0.113	1.063	-0.191	-0.1	0	1.419
Taiyuan	0	0.1	-0.209	0.048	-0.42	-0.69	0.665	1.322	0.942	-0.111	-0.05	0	0.4
Xingtai	0	0.169	-0.235	0.2	0.6	-0.616	0.675	0.3	1.086	-0.3	-0.009	0	4.077
Xinxiang	0	0.221	-0.362	0.63	-0.185	-1.093	2.79	0.207	0.488	-0.756	0.057	0	3.4
Yangcheng	0	0.3	-0.781	0.64	-0.745	-0.282	0.862	-0.9	0.633	-0.427	0.075	0	-3.62
Yushe	0.0105	0.263	-0.295	0.211	0.181	0.05	-0.833	-0.466	0.736	-0.482	0.1	0	-0.9

Annual Precipitation trends based on Mann-kendall and Sen's slope

Fig. 4 (y, z) shows precipitation trends on annual basis. Results shows that Taiyuan, Yushe, Changzhi and Yangcheng were affected by negative trends of precipitation. On an annual basis, Mann-Kendall test exhibited variation in precipitation ranging from (-1.778 to -0.239) whilst the Sen's slope graph showed the variation in precipitation to be between (-5.220 to -0.733). Fig. 4 shows that in both annual graphs, Yangcheng station was more affected due to negative trends in the precipitation. The precipitation variation at Anyang, Xingtai, Shijiazhuang and Xinxiang was quite high. Annual Mann- Kendall showed that precipitation in these stations varies from (0.1449 to 0.1.683) whilst that of the Sen's slope is (0.387 to 4. 874).

Discussion

On the basis of monthly analysis

The variability in precipitation trends on monthly basis demonstrated that, maximum number of significant changes were found in the precipitation during February, March and April months. While maximum no of stations were faced negative trend of precipitation during January, March, May, June and in October. During these months, precipitation is rare but due to high evaporation, the land surface warms rapidly, which leads to negative trends in the precipitation. Same trends results reported by Koleva and Alexandrov (2008). These variations in precipitation may cause by global warming and variation in humidity (Gocic and Trajkovic, 2013).

On the basis of annual analysis

Results did not depicted statistically significant trends for the annual precipitation time series. This result is in line with the results showed by (Ijaz *et al.*, 2015). Results from Mann-Kendall and Sen's statistical test were shows both negative and positive trends in precipitation time series. Same findings reported by (Song *et al.*, 2011) for the eastern China. Such kind of variability in precipitation trends may cause China towards water related issues like flood and drought in future.

Conclusion

This paper analyzed the trends in monthly and annual precipitation in the Zhanghe river basin over 1980-2010 period. Results exhibited both positive and negative trends during the study period. Both the Mann-Kendall and Sen's slope methods showed similar trends.

1. For instance, in September, both Mann-Kendall and Sen's slope recorded positive trends throughout the whole month.

2. March and June recorded negative trends during the study period, While In July month negative trend was observed in Yushe and Anyang stations.

3. April had more precipitation during the study period (2.9mm to 3.4mm).
4. The statistical analysis on the basis of the Mann-Kendall test and Sen's slope approaches demonstrated that March and October had negative trends.

It is concluded that in these eight stations, dry days occur more frequently and these dry days create water scarcity in this region which in turn leads to drought in this area. This study provides vital information on drought assessment in China. It adds to the already existing measures to help define and assess agricultural planning and other related developments associated with the mitigation and adaptation strategies for climate change.

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