Study on Change Trend of Monthly Grid Precipitation in China

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Abstract: In this paper, a set of monthly grid precipitation data CN05.1 with spatial resolution of 0.5 degrees and time scale from 1982 to 2015 is used, and three improved Mann-Kendal test methods (M-MK, PW-MK and TFPW-MK) are used to test the trend change of the whole country and six regions in north China, northeast China, east China, south central, southwest China and northwest China. The results show that the monthly grid precipitation does not show a significant and consistent change trend in most areas, especially in most densely populated areas such as North China, Central South China and East China, showing a relatively stable trend during this period, except for a few areas which have a significant upward or downward trend in individual months.

1 INTRODUCTION

The China has a vast territory, high terrain in the west and low terrain in the east, complicated topography, crisscrossing water systems and remarkable monsoon climate, which leads to great changes in monthly precipitation between years and years, and extremely uneven distribution of time and space. At the same time, under the climate change background dominated by the gradual increase of global average temperature, it is likely to gradually change the water cycle process of atmosphere-land-ocean, which will lead to the further increase of seasonal and regional differences in precipitation frequency, intensity, area, total amount and duration (Liang et al., 2018; Li et al., 2020; Xie et al., 2021; Bennett et al., 2016).

Moreover, for the temporal and spatial variation and precipitation distribution, the previous studies have mainly focused on the analysis of the frequency of extreme precipitation (Wang & Zhou, 2005), the variation characteristics in a single period (Li et al., 2016), and the evolution trend of local areas (Qian et al., 2005). Above research may have some shortcomings such as lack of attention to less precipitation seasons and relatively limited coverage areas. Therefore, it is necessary to use a set of precipitation data with suitable time series and high resolution to make further in-depth analysis of the total precipitation in China during the whole period and in the whole region. Based on the above considerations, this paper uses a set of monthly precipitation grid data with spatial resolution of 0.5 degrees and time scale of 1982-2015, and carries out trend analysis and test on the whole of China and six regions of North China, Northeast China, East China, Central South, Southwest China and Northwest China according to three improved Mann-Kendal test methods (M-MK, PW-MK and TFPW-MK), in order to find out the monthly grid of China.

2 DATA

The measured grid data set CN05.1 was used in this study (Wu et al., 2012). The time scale of this dataset is from 1982 to 2015, and the spatial resolution is 0.5×0.5 degree, with a total of 3781 grid points. CN05.1 based on the daily data of more than 2,400 meteorological observation stations (including national reference climate stations, national basic weather stations and national general weather stations) distributed all over the country, interpolation calculation is carried out by anomaly approximation method, and its production method and performance evaluation can be referred to reference (Wu et al., 2012), which will not be carried out here. At the same time, in order to study the distribution characteristics of monthly

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precipitation in China in detail, China is divided into six geographical regions, namely North China, Northeast China, East China, Central South, Southwest China and Northwest China, which correspond to 661, 355, 293, 360, 860 and 1252 grid points respectively.

3 METHODOLOGY

3.1 Mann-Kendall Test

Mann-Kendall test (MK) is a method recommended by WMO to test the trend and significance of meteorological and hydrological time series (Mann, 1945; Kendall, 1948). As a nonparametric test method, MK is widely used in meteorological-hydrological and other element tests which are skewed and often do not obey the same distribution because it does not require the sample sequence to obey a specific distribution and is less interfered by outliers. A set of observations for a given meteorological-hydrological variable $X_t = (x_1, x_2, \dots, x_n)$; the definition of statistic S of MK test method is as follows:

$$S=\sum_{i}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}\left(x_j-x_i\right)$$
$$\operatorname{sgn}\left(x_j-x_i\right)=\begin{cases}1 & x_j>x_i\\ 0 & x_j=x_i\\ -1 & x_j<x_i\end{cases} \tag{1}$$

When $n \geq 10$, statistics S can be considered as approximately obeying normal distribution, namely:

$$E(S)=0$$
$$D(S)=\frac{n(n-1)(2n+5)+\sum_{i=1}^{k}m_i(m_i-1)(2m_i+5)}{18} \tag{2}$$

where k is the number of groups with the same numerical value in the sample sequence, and m_i is the number of the same numerical value in the i group, so that the standard normal distribution statistics U_{MK} can be obtained:

$$U_{MK}=\begin{cases}\dfrac{(S-1)}{\sqrt{D(S)}} & S>0\\ 0 & S=0\\ \dfrac{(S+1)}{\sqrt{D(S)}} & S<0\end{cases} \tag{3}$$

The original hypothesis is that the sample sequence has no change trend. At the significance level α, the two-sided test is adopted. When $|U_{MK}| < U_{1-\alpha/2}$, the original hypothesis is accepted, the sample sequence has no significant trend; When $|U_{MK}| > U_{1-\alpha/2}$, the original hypothesis is rejected and the sample sequence has a significant trend. when $S > 0$, the sample sequence has an upward trend; When $S < 0$, the sample sequence has a downward trend. $U_{1-\alpha/2}$ is the quantile of $\alpha/2$ in the standard normal distribution.

The original hypothesis of MK test method is based on the mutual independence of sample sequences, but in meteorological-hydrological element sample sequences, there is a certain degree of autocorrelation. In order to reduce the influence of autocorrelation on trend analysis, variance correction method and pre-removal method are generally used. Variance correction method mainly focuses on the mechanism of autocorrelation's influence on MK test, and proposes corresponding correction. Pre-removal rule is to remove the inherent autocorrelation of a sample sequence before MK test. In order to compare the differences between the two methods, the paper adopts the Modified Mann-Kendall Test (M-MK) (Hamed & Rao, 1998), the Pre-Whitening (PW-MK) (Yue & Wang, 2002) and the Trend-Free Pre-Whitening (TFPW-MK) (Yue et al., 2002).

3.2 Modified Mann-Kendall Test

M-MK reconstructs the sample sequence by subtracting nonparametric trend estimators from the original sample sequence. Specifically, when calculating $D(S)$, the coefficient Cor is introduced to correct the original sample sequence, and Cor is defined as[11]:

$$Cor = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-1)(n-1-i)(n-2-i) r(i) \quad (4)$$

In this formula, $r(i)$ is the autocorrelation coefficient of order i, and $i = 1$ is defined in this study, and the calculation formula is:

$$r(1) = \frac{\sum_{i=1}^{n-1} (x_i - \bar{x})(x_{i+1} - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \quad (5)$$

$$D(S)^* = D(S) \times Cor$$

3.3 Pre-Whitening Mann-Kendall Test

PW-MK trend test method performs preset whitening treatment on the original sequence samples to remove the influence of autocorrelation on the test results. The specific steps are as follow (Yue & Wang, 2002):

Step 1: Firstly, the first-order autocorrelation coefficient $r(1)$ of sample sequence $X_t = (x_1, x_2, \ldots, x_n)$ is calculated, and under the confidence level α, the bilateral significance test of $r(1)$ is carried out:

$$\frac{-1 - U_{1-\alpha/2}\sqrt{n-2}}{n-1} \le r(1) \le \frac{-1 + U_{1-\alpha/2}\sqrt{n-2}}{n-1} \quad (6)$$

Step 2: Assuming that the sample sequence satisfies the first-order autocorrelation process $AR(1)$, the preset white method is adopted to eliminate the autocorrelation of the sample sequence:

$$X_t' = X_t - r(1) X_{t-1} \quad (7)$$

Step 3: The new sample sequence X' has no first-order autocorrelation, and then MK is used to test the trend and significance of the sample sequence.

3.4 Trend-Free Pre-Whitening Mann-Kendall Test

TFPW-MK includes two processes: trend removal and preset whitening, which can effectively reduce the influence of autocorrelation in sequence on inspection results and avoid inspection errors caused by distortion. The specific steps are as follows (Yue et al., 2002):

Step 1: If sample sequence $X_t = (x_1, x_2, \ldots, x_n)$ consists of linear trend and $AR(1)$, TSA method is used to calculate linear trend (inclination) β of sample sequence:

$$\beta = median\left(\frac{x_j - x_i}{j - i}\right) \quad \forall i < j \quad (8)$$

Step 2: Removing the trend item T_t to obtain a new sample sequence Y_t without the trend item:

$$Y_t = X_t - T_t = X_t - \beta t \quad (9)$$

Step 3: Calculate the first-order autocorrelation coefficient r_1 of the new sample sequence Y_t, and eliminate the autocorrelation term in Y_t:

$$Y_t' = Y_t - r(1) Y_{t-1} \quad (10)$$

Step 4: Adding the trend item T_t again to obtain a new sample sequence Y'' without autocorrelation effect:

$$Y_t'' = Y_t' + T_t = Y_t' + \beta t \quad (11)$$

Step 5: Substituting MK method to test the trend and significance of new sample sequence Y''.

4 RESULTS

Using the three improved M-K trend test methods mentioned above, the annual trend analysis of monthly precipitation in 3781 grid points in China from 1982 to 2015 is carried out. The results are shown in Figure 1 (the upper left corner is marked with "Jan_M" to indicate the test of M-MK method in January, the same below), and each grid point represents the value of the unified measurement S in the three trend test methods. Light blue (1.64≤S<2.32) and dark blue (S≥2.32) are defined as showing a significant upward trend at 95% and 99% confidence levels respectively (95% is a significant upward trend, 99% is a very significant upward trend), light red (-2.32<S≤-1.64) and deep red.

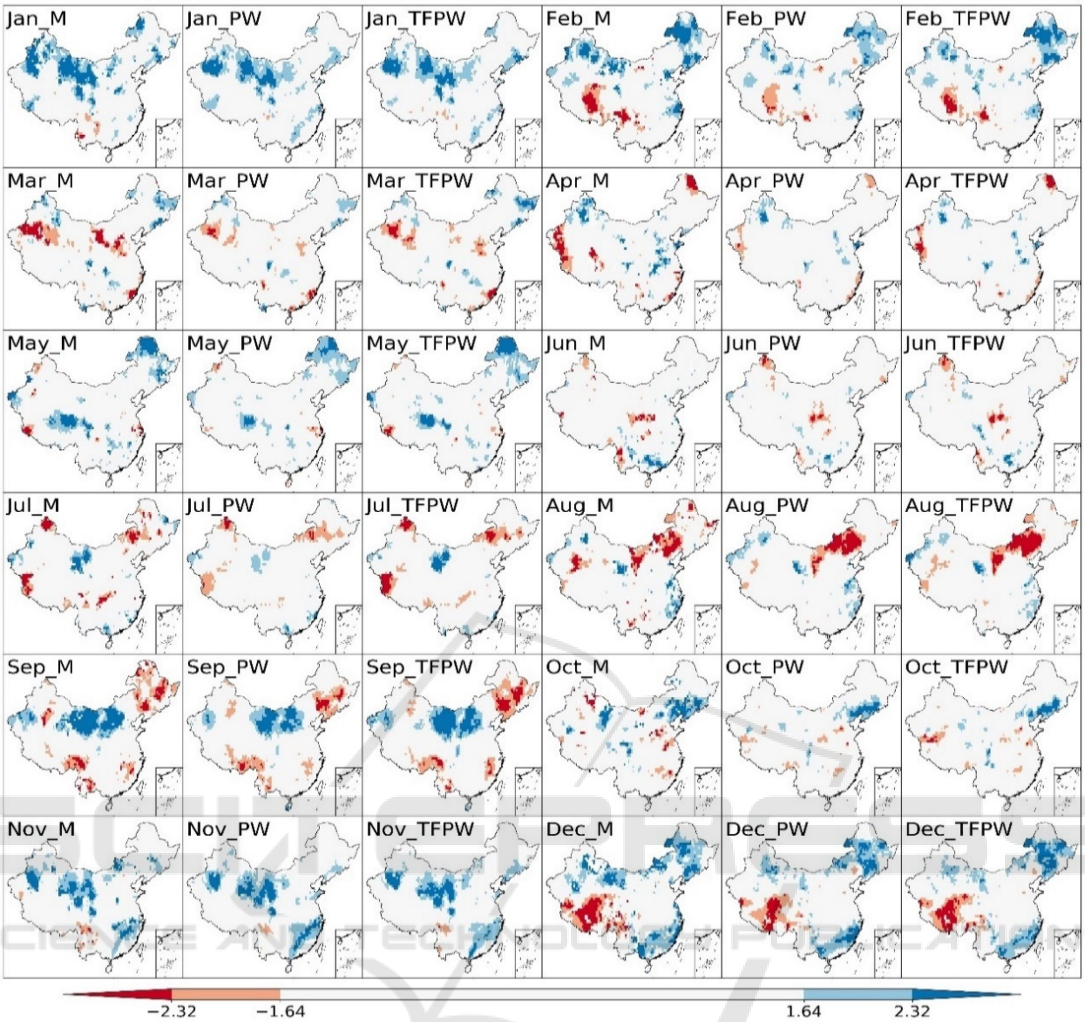

Figure 1: Spatial distribution of test results of three trend analysis methods (M-MK, PW-MK and TFPW-MK).

It can be seen from figure 1 that the three trend test methods show similar results, and the points where the trend does not change significantly in all months are dominant. For example, in January, only the northwestern and northeastern regions of Xinjiang showed a significant upward trend; In April, the areas with significant changes further decreased, and only the northern part of Xinjiang showed an increase, while the western part of Tibet and the northern part of Northeast China showed a decrease; In July, only the central part of Northeast China, the northern part of Xinjiang and the western part of Tibet showed a significant decline, while the small part of Northeast China in Northwest China showed a significant increase; In October, only a small area in the middle of Northeast China showed a significant increase; In December, most of Tibet experienced a significant decline in a large area, while the central part of Northeast China, some parts of East China and Central South China experienced a significant increase. In December, most of Tibet experienced a significant decline in a large area, while the central part of Northeast China, some parts of East China and Central South China experienced a significant increase.

Figure 2 further counts the percentage of M-MK(a), PW-MK(b) and TFPW-MK(c) in the area with trend mutation in each month, and (d) shows the monthly percentage change after the arithmetic average of the three methods. As far as the national average is concerned, the minimum, maximum and average proportions of monthly precipitation showing an upward trend (including significant and very significant) are 10.4%, 24.3% and 14.2% respectively; The minimum, maximum and average proportions of monthly precipitation show a

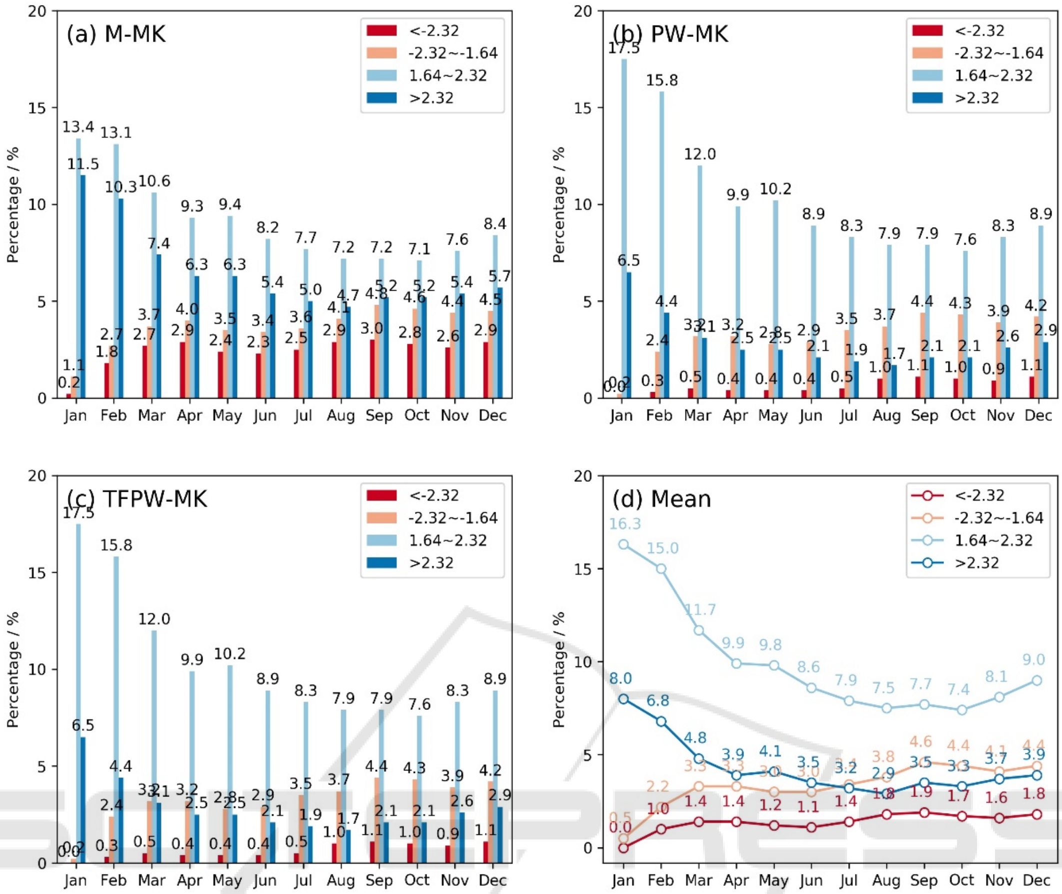

Figure 2: Percentage of three trend analysis methods and their average results in the trend mutation area of each month.

downward trend (including significant and very significant), which are 0.5%, 6.5% and 4.7%, respectively, indicating that monthly precipitation changes are complex and do not show obvious similar laws, but on the whole, the upward trend is more significant than the downward trend.

The monthly grid precipitation is accumulated to get the annual grid precipitation, and the areal precipitation of each sub region is obtained by arithmetic average according to the number of grid points included in six geographical sub regions. The trend test of each sub region is further carried out by using linear regression, and the results are shown in Figure 3, where (a)~(f) are northwest, southwest, north China, northeast, central south and east China, and S1~S3 are M-MK, PW-MK and TFPW-respectively It is not difficult to find that except the northwest, the other regions have not shown a significant change trend; However, there are few meteorological stations in Northwest China, and the uncertainty of precipitation assessment is large. During the period of 1982-2015, the monthly grid precipitation in China did not show a significant and consistent change trend, especially in most densely populated areas such as North China, Central South China and East China, showing a relatively stable trend.

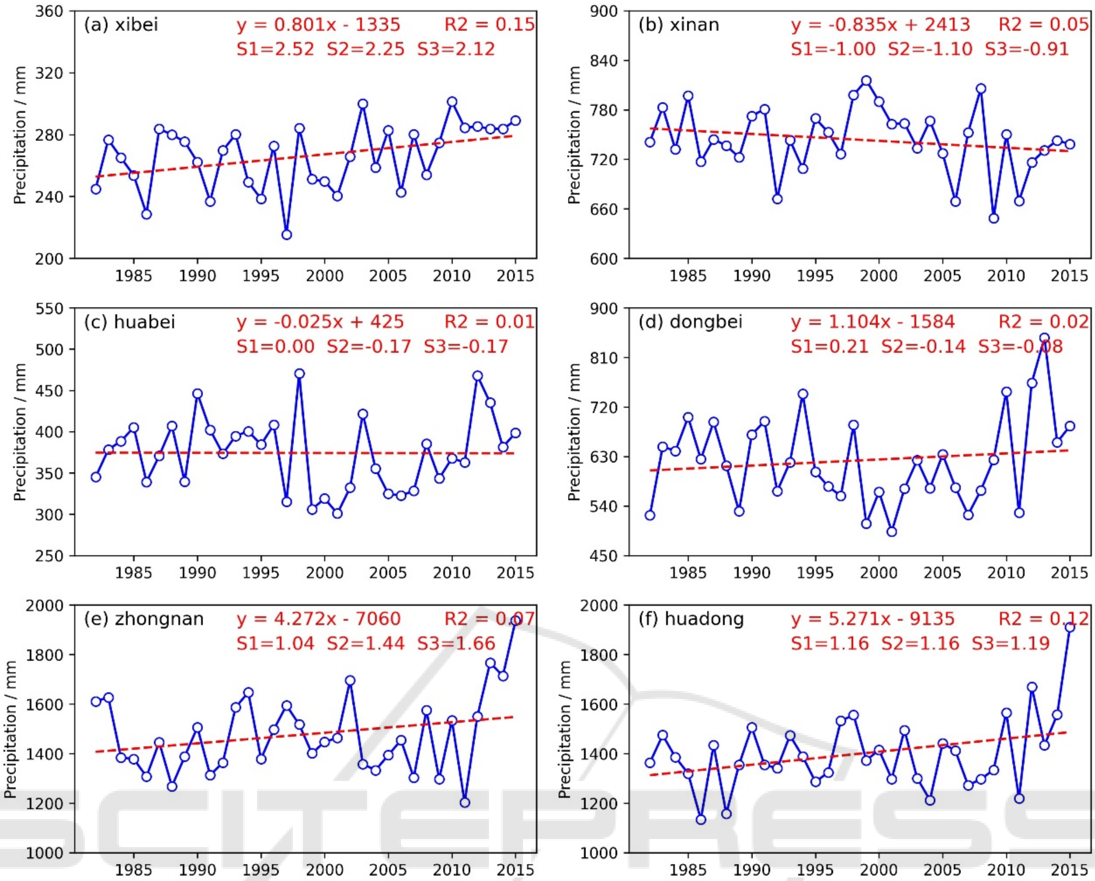

Figure 3: Annual precipitation variation trend in six geographical regions.

5 CONCLUSIONS

In this study, a set of monthly grid precipitation data CN05.1 with spatial resolution of 0.5 degrees and time scale of 1982-2015 was used, and three improved Mann-Kendal test methods (M-MK, PW-MK, TFPW-MK) were used to test the trend change of 3781 grid points covering China and six regions of north China, northeast China, east China, south central China, southwest China and northwest China The results show that the spatial-temporal distribution and inter-annual distribution of precipitation in China are extremely uneven, which brings great challenges to accurate and stable medium-and long-term precipitation forecast. Under the climate change background of global warming and frequent extreme events, the monthly grid precipitation in China did not show a significant and consistent change trend, especially in most densely populated areas such as North China, Central South China and East China, showing a relatively stable trend, except for a few areas which showed a significant upward or downward trend in individual months. In the future research, we will further study what mutations will occur in local areas and the reasons for the changes

REFERENCES

Bennett, J. C., Wang, Q. J., Li, M., Robertson, D. E., & Schepen, A. (2016). Reliable long‐range ensemble streamflow forecasts: Combining calibrated climate forecasts with a conceptual runoff model and a staged error model. *Water Resources Research*, *52*(10), 8238-8259.

Hamed, K. H., & Rao, A. R. (1998). A modified Mann-Kendall trend test for autocorrelated data. *Journal of hydrology*, *204*(1-4), 182-196.

Kendall, M. G. (1948). *Rank correlation methods*. Oxford: Oxford University Press.

Li, B., Chen, Y., Chen, Z., Xiong, H., & Lian, L. (2016). Why does precipitation in northwest China show a significant increasing trend from 1960 to 2010? *Atmospheric Research*, *167*, 275-284.

Li, Y., Liang, Z., Hu, Y., Li, B., Xu, B., & Wang, D. (2020). A multi-model integration method for monthly streamflow prediction: modified stacking ensemble strategy. *Journal of Hydroinformatics*, *22*(2), 310-326.

Liang, Z., Li, Y., Hu, Y., Li, B., & Wang, J. (2018). A data-driven SVR model for long-term runoff prediction and uncertainty analysis based on the Bayesian framework. *Theoretical and Applied Climatology*, *133*(1), 137-149.

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the Econometric Society*, *13*(3), 245-259.

Qian, W. H., & Lin, X. (2005). Regional trends in recent precipitation indices in China. *Meteorology and Atmospheric Physics*, *90*(3), 193-207.

Wang, Y., & Zhou, L. (2005). Observed trends in extreme precipitation events in China during 1961‐2001 and the associated changes in large‐scale circulation. *Geophysical Research Letters*, *32*(9), L09707.

Wu, J., Gao, X., Giorgi, F., Chen, Z., & Yu, D. (2012). Climate effects of the Three Gorges Reservoir as simulated by a high resolution double nested regional climate model. *Quaternary International*, *282*, 27-36.

Xie, S., Wu, W., Mooser, S., Wang, Q. J., Nathan, R., & Huang, Y. (2021). Artificial neural network based hybrid modeling approach for flood inundation modeling. *Journal of Hydrology*, *592*, 125605.

Yue, S., & Wang, C. Y. (2002). Applicability of prewhitening to eliminate the influence of serial correlation on the Mann‐Kendall test. *Water resources research*, *38*(6), 4-1.

Yue, S., Pilon, P., Phinney, B., & Cavadias, G. (2002). The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological processes*, *16*(9), 1807-1829.