ACADEMY JOURNAL OF SCIENCE AND ENGINEERING
Available online @
www.academyjsekad.edu.ng
AJSE 17 (1) 2023
Original Research

A NON-PARAMETRIC MANN-KENDALL AND SEN'S SLOPE ESTIMATE AS A METHOD FOR DETECTING TREND WITHIN HYDRO-METEOROLOGICAL TIME SERIES: A REVIEW

Abdullahi, N.I.,* Mohammad, S.J., Oweseni,Y., Ijimdiya, S.J. and Sulaiman, K.

Department of Water Resources and Environmental Engineering;
Ahmadu Bello University Zaria, Nigeria

Abstract

Climate and water resources are interconnected in a complex way such that a change in any one induces a change in another. Trend analysis is usually employed to assess and understand the long term pattern of climatic and hydrologic (hydro-meteorological) time series data in order to assess its impact on the environment, particularly water resources. Parametric and non-parametric statistical methods were employed at various times for trend tests depending on the nature of the data at hand. Even though the parametric method was observed to be more robust in making a decisive conclusion, there are certain conditions that need to be met by the data and it was observed that Hydro-meteorological data does not meet most of the conditions. As such, non-parametric procedures for detecting trends were found to be suitable for hydro-meteorological time series. This paper found the rank based Mann-Kendall as one of the most commonly method employed in detecting the trend of hydro-meteorological and Seasonal Kendall Slope (Sen's slope) for detecting the magnitude of the trend. It was observed that hydro-meteorological data are sometimes serially dependent therefore the problem of serial correlation and seasonality will make the application of Mann-Kendall test to have limited applicability, hence, application of pre-whitening procedure is recommended before subjecting the data to the test. But Monte Carlo Simulation Investigation reveals that effect of serial correlation is dependent upon sample size and trend magnitude, when the sample size and trend magnitude are large, the serial correlation will no longer affect Mann-Kendall test. It is concluded that Mann-Kendall and Sen's Slope Estimate method to be a suitable method of assessing trends within hydro-meteorological time series and authors were advised to make the sample size hydro-meteorological time series to be analyzed to be large enough to take care of the effect of serial correlation.

Keywords: Hydro-meteorology, Mann-Kendall, Non-parametric, Time series, Trend

Corresponding author's e-mail: nurafbg@gmail.com

1.0 INTRODUCTION

Trend analysis of hydro-meteorological timeseries data involves studying the patterns and changes in meteorological and hydrological variables over a given period. It helps in identifying the long-term trends, seasonality, variability, which can be vital for understanding climate change impacts on water resources. It also helps in decision-making processes related to water management and risk assessment analysis of hydrological system. The effect of global climate change (among others) that has important implications for water resources include an increase in evaporation, a change in precipitation pattern, and a change in water quality (Adam & Peck, 2008). Intergovernmental Panel on Climate Change (IPCC) observed that a temperature rise would rapidly increase the number of people at risk of water, with impacts in arid and semi-arid regions expected to be much (Ozor & Urama, 2010). There is a high vulnerability of streamflow to changes in temperature and rainfall; a decrease in streamflow occurs as a consequence of the increase in temperature and decrease in rainfall (Arias *et al.*, 2014). Climate, water resources, biophysical, and socioeconomic systems are interconnected in a complex way, so a change in any one of these induces a change in another (Ozor & Urama, 2010). To assess the long-term impact of climate variability on the environment, particularly water resources, an assessment of the long-term trends of hydro-meteorological parameters are necessary. Different methods were applied in assessing the long-term trends of hydro-meteorological parameters. Among the methods are Mann-Kendall and Sen's Slope Estimate. The Method is World Meteorological Organization recommended method (Chen et al 2019). This paper is therefore set out to review of methods of trend analysis of hydro-meteorological time series and their application. Methods that can be applied in the analysis of hydro-meteorological time series data and will enable the identification and quantification of trends in variables such as stream flow, rainfall, temperature, evaporation, wind, relative humidity, evapotranspiration etc.

2.0 METHODOLOGICAL REVIEW

Parametric and non-parametric statistical methods were employed at various times for trend tests (UNESCO/WMO, 2000; Lozano, 2006; Worms & Touati, 2016; Sharma *et al.*, 2016). Remote sensing was also applied to test the trend pattern of climatic data (Awange *et al.*, 2016). Parametric methods were observed to be more robust in making more decisive conclusions and require less data (Neideen & Brasel, 2007). However, to arrive at a more robust conclusion, there are certain conditions or assumptions that the population parameter (data) needs to fulfil. It needs to be normally distributed (all data points must follow a bell-shaped curve without any skewed above or below the mean), has an equal variance and the same standard deviation, and must be continuous (Neideen & Brasel, 2007). Examples of the parametric test include t-test, z-test, least square linear regression, ANOVA (Hess *et al.*, 2001; Lozano, 2006) and Pearson's correlation coefficient method (Tao *et al.*, 2011). If data analysis does not meet the criteria for the parametric test (customarily distributed, equal variance, and continuous), it must be analyzed with a non-parametric test (Neideen & Brasel, 2007). Non-parametric tests do not rely on an assumption about the shape or parameter of the underlying population distribution (Neideen & Brasel, 2007). The method is a rank-based procedure that is robust against the influence of extremes and is less sensitive to outliers than other parametric procedures; therefore is suitable for biased data (Tao *et al.*, 2011).

Hydro-climatic time series data are often characterized by data that is not normally distributed, and therefore non-parametric tests are considered more robust compared with the parametric test (Omar, 2014).

2.1 Non-parametric trend analysis of hydro-meteorological data

The long-term trends of all climatic parameters are necessary to assess the long-term impact on the environment of an area (Kundu *et al.*, 2015). The non-parametric techniques performed the test on each of the several seasons; summing the test statistics and their expectation and variance as such can remove the effect of seasonality on hydro-meteorological time series without attempting to explicitly model it as in the case of the parametric method, (Hirsh & Slack, 1984). The rank-based non-parametric Mann-Kendall test suggested by Mann (1945) and advanced by Kendall (1975) is the most common method employed in most hydro-meteorological time series analyses (Yue *et al.,* 2002; Yue & Pilon, 2004; Ismail & Oke, 2012; Gao *et al.*, 2012; Safari, 2012; Rahaman& Begum, 2013; Salami *et al.*, 2014a; Ahmad *et al.*, 2015; Onyutha, 2016a; Pohlert, 2016). Theil (1950) and Sen (1968) proposed a non-parametric estimator that determines trend magnitude in addition to the original Mann-Kendall trend significance test. The method referred to as "Theil-Sen" provide a more robust slope estimate of the trend magnitude and is sensitive to outliers and extreme values. Hirsh *et al.* (1982) developed another estimator that is an extension to Theil-Sen referred to as the seasonal Kendall slope estimator, which is robust against seasonality and departures from normality and may be used in a situation where there are missing values. The method is, however, not robust against serial dependence, which was corrected by Hirsh and Slack (1984) in a modified version of the earlier method. Mann-Kendall test has extensively been employed in testing trends in various hydro-meteorological variables in Nigeria and around the globe. Mann-Kendall test was extensively utilized in analyzing the trend within the hydro-meteorological time series across the globe. Obot *et al.* (2010) evaluated rainfall trends of selected locations in the six geopolitical zones of Nigeria for 30 years (1978-2007). They established an increasing trend at Maiduguri at a rate of 9.88 mm/year. Karmeshu (2012) employed it in trend detection in annual temperature & precipitation in Select States in the northeastern United States. The study found a statistically significant increasing trend of temperature in the range of 0.00006 to 0.02 °F/yr and that of precipitation in the range of 0.03 to 0.13 mm/yr. Noorunnahar and Rahaman (2013) employed the Mann-Kendall method and estimated regional temperature trends in Bangladesh and found monthly variability of trends within the time series temperatures, with some months showing increasing trends while some were showing decreasing trends. Mustapha (2013) detected surface water quality trends. It revealed significant parameter variations due to trend in trend in the level of 5-day biochemical oxygen demand (BOD5), chemical oxygen demand (COD), nitrogen in the form of ammonia (NH3-N), nitrates (NO3), total solids (TS), dissolved solids (DS). They also found a decreasing trend in precipitation, dissolved oxygen (DO), and suspended solids (SS). Mishra *et al.* (2014) analysed the air temperature time series trend of Upper Ganga Canal Command, India. They found an increasing trend in annual mean, maximum, and minimum temperature by 0.60ºC, 0.60ºC and 0.62ºC, respectively, over the past 101 years and observed the increase to be more during the more urbanised period. Trends and variations of monthly temperatures (1950-2012) of 20 meteorological stations were assessed by

Amadi *et al.* (2014), where they found increasing trends of minimum and maximum temperature in 85% and 80% of the stations, respectively. Ismail and Oke (2014) also found a downward rainfall trend in the North Wet Zone of Nigeria. In the Niger River and Benue Sub-basin, Salami *et al.* (2014b) found a statistically significant increasing trend of minimum and maximum temperatures and evaporation while runoff and water levels of five out of six locations exhibit a significantly decreasing trend. The analysis of rainfall trends in the Niger River and the Benue Sub-basin returns insignificant increasing and decreasing trends in five and six locations, respectively. Ibrahim and Mohammed (2015) also assessed temperature records from 1970-2012 for 11 northern states and found a positive increasing trend of temperatures in the region. Chen *et al*. (2019) established an insignificant rising trends in the intensity and frequency of extreme precipitation and statistically significant increasing trends in temperature in the Jinsha River Basin, China. Agoh *et al.* (2021) found a significant upward trend of average temperature, minimum temperature, maximum temperature, and insolation evaporation series. Kumar &Varija (2023) established an upward shift in the maximum temperature time series and a downward shift in the rainfall and streamflow time series in Aghanashini River watershed, India. Analysis conducted by Toma *et. al.*, (2023) established a significant increasing trend of minimum, maximum, and mean annual temperatures showed of 0.01 °C, 0.04 °C, and 0.025 °C, respectively and insignificant trend in rainfall and discharge over time at Omo-Gibe River basin, Ethiopia.

The Spearman's rho (SR) test is another rank-based non-parametric statistical test that can also be used to detect a monotonic trend in a time series. Examples of where SR was employed can be found in Ogolo and Adeyemi (2009) and Hess *et al.* (2001). However, since the appearance of the paper by Hirsch et al. (1982), the Mann-Kendall test has been popularly used to assess the significance of trends in hydro-meteorological time series; for whatever reason, the SR test is seldom used in hydro-meteorological trend analysis, (Yue *et al.*, 2002). Cumulative Rank Difference is also employed in detecting trends (Onyutha, 2016b). Time variable regression was also employed by Kelly *et al.*, (2022) and GIS techniques by Pokhrel *et. al.,* (2019).

2.2 Controversies surrounding non-parametric test on hydro-meteorological data

The problems of serial correlation and seasonality within hydrological and climatic time series data make non-parametric tests have limited applicability to such data (Wolski, 2012). The assumption that most hydro-meteorological data are serially independent may only sometimes be valid. Yue and Wang (2004a) observed a serial correlation between water quality and stream flow time series. Conducting a Mann-Kendall trend detection test on time series that is serially correlated returns an incorrect rejection rate that is too large, mainly when applied to an auto-correlated series with no trend (Bayazit & Onoz, 2007). In the time series where a trend does not exist, Von Storch (1995) observed that the presence of serial correlation would increase the possibility of rejecting the null hypothesis of no trend while it is accurate and therefore proposed the application of a pre-whitening procedure to the time series before subjecting it to Mann-Kendall test. Pre-whitening reduces serial correlation within a given time series by adding white noise (serially independent) series to the original series (Sen, 2012). Many authors applied pre-whitening to hydro-meteorological time series in preparation for the Mann-Kendall test. Douglas *et al.* (2000) applied it in the analysis of floods and low flow; Admassu and Seid (2006) in the analysis of rainfall trend; Shadmani *et al.* (2012) in the analysis of reference evapotranspiration, Mishra *et al.* (2013) in a study of temperature variation, Akhtar *et al.* (2015) in climate change analysis; and Verma *et al.* (2016) in precipitation analysis.

Despite the argument put forward on the need to apply pre-whitening before the Mann-Kendall test, some authors still find it unnecessary and observed that pre-whitening is not suitable for eliminating the effect of serial correlation on the Mann-Kendall test when a trend exists. Yue and Wang (2002) investigated the issue by Monte Carlo simulation. The findings from the study indicate the presence of a linear trend and a lag one autoregressive (AR(1)) process with noise as such for any time series that trend exists, the effect of negative/positive serial correlation on Mann-Kendall test is not only defended on the presence of the serial correlation, it is defendant upon sample size as well as on the magnitude of the serial correlation and trend. For a time series in which the sample size and magnitude of the trend are large enough, the serial correlation will no longer affect Mann-Kendall test statistics significantly. Yue and Wang (2002) concluded that pre-whitening removes positive auto-regression, AR(1), from the time series, which in turn removes a portion of the trend; hence it reduces the possibility of rejecting the null hypothesis when it is false; similarly, removal of negative AR(1) by pre-whitening inflates the trend and leads to an increase in the possibility of rejecting the null hypothesis when it is true.

Notwithstanding the findings of Yue and Wang (2002), Zhang and Zwiers (2004) countered their findings that serial correlation does not significantly influence the Mann-Kendall test when the sample size and magnitude of trend is significant, as such their recommendation on using Mann-Kendall on the original of such data without pre-whitening to be poor advice. Zhang and Zwiers (2004) observed that it is wrong for Yue and Wang (2002) to, without any analysis, know whether a trend exists and cannot, with a degree of certainty, distinguish between trends and persistent from serial correlation by subjective visual means. On Yue and Wang (2002) conclusion that the actual trend might be estimated from serially correlated data without considering autocorrelation, Zhang and Zwiers (2004) result demonstrated that the estimated trend is positively biased where there is positive autocorrelation in the series. On Yue and Wang (2002) objection to the use of the pre-whitening procedure, because the computed trend from pre-whitening tends to be smaller than a true trend, Zhang and Zwiers (2004) observed that there is a distinction between a deterministic trend that has a physical basis and an apparent trend that only reflects low-frequency variability such as red noise; the former is likely to continue while the latter may change sign any time in the future.

Yue and Wang (2002) replied to all the observations raised by Zhang and Zwiers (2004) regarding their findings through (Yue & Wang, 2004b) and pointed out that none of the misconceptions raised by Zhang and Zwiers (2004) existed in their study. Yue and Wang, (2004b) observed that their work was intended to show the result of trend analysis for the case where real trends exist in a time series by applying pre-whitening without considering its limitation in removing serial correlation from a time series. Their work suggested that it is not wise to blindly pre-whiten the series based on empirical simulation results of time series that are big enough to have a clear trend. Yue and Wang (2004b) found a comment by Zhang and Zwiers (2004) that "require the user to first judge visually whether a trend is present in data to be analysed" as a misrepresentation of their study because nowhere they imposed such a condition in their suggestion. Yue and Wang (2004b) concluded by contracting all the observations raised by Zhang and Zwiers (2004) regarding their Yue and Wang (2002) findings.

In addition to the Mann-Kendall trend detection test, Sen (2012) developed a new methodology for calculating trends in time series data, such as hydro-meteorological data. The methodology has avoided all restrictive assumptions in estimating true slope in time series data, such as; independent structure of the time series, normality of the distribution, length of data, and the impossibility of calculating slope magnitude (slope) by other methods than regression approach found in other methods of trend detection. The validity of the methodology was documented through a set of Monte Carlo simulations by considering independent and dependent processes. It was presented based on subsection time series plots derived from a given time series on a Cartesian coordinate system. In such a plot, trend-free time series subsections appear along the 45° straight line. Increasing (decreasing) trends occupy upper (lower) triangular areas of the square area defined by the variation domain of the variable concerned. An extensive computer simulation for a robust trend identification procedure was proposed by Sen (2012) and presented by Sen (2014). This new method, described by Kisi (2015) as an "Innovative Method", has widely been utilised by many authors in analysing the trend of various hydro-meteorological parameters in the past. Examples can be found by Gotic and Serbia (2013); Mishra *et al.* (2013); Rahman and Begum (2013); Kisi and AY (2014); Kundu *et al.* (2015); Sayemuzzaman *et al.* (2015); Bari *et al.,* (2016); Onyutha *et al.,* (2016b); Sharma *et al.,* (2016); and Peng *et al.,* (2017); Phuong *et al.,* (2020); Banda *et al.,* (2021).Wang *et. al.,* (2020)also re-evaluated Mann-Kendall by carrying out Monte-Carlo simulation and recommends that researchers should slightly increase the significance level and lengthen the time series sample to improve the power of the Mann-Kendall test in future studies.

It can be seen that some authors are of the view that conducting Mann-Kendall test on serially correlated time series returns incorrect rejection rate and increases the possibility of rejecting the null hypothesis of no trend when trend exist as such proposed pre-whitening procedure to the time series before Mann-Kendall test. But when the issue was investigated by Monte-Carlo simulation, it was found that the pre-whitening is not always necessary as Mann-Kendall test was found to be defended on the sample size of the data and the magnitude of the trend. Where the sample size and the madnitude of trend are large, seriuel correlation will no longer affect Mann-Kendall test. The controversies of applying Mann-Kendall test on time series may linger, it can be seen that the test remain one the most utilized and suitable in testing the trend within hydro-meteorological time series. Authors should ensure that time series data are large enough to take care of the effect of serial correlation.

3.0 CONCLUSION

This paper reviewed different methods for conducting trend test on hydro-meteorological time series. It was observed that parametric and non-parametric statistical methods were employed at various times for trend tests depending on the nature of the data at hand. Even though the parametric method was observed to be more robust in making a decisive conclusion, there are certain conditions that need to be met by the data. For Parametric test the data needs to be to be normally distributed (all data points must follow a bell-shaped curve without any skewed above or below the mean), has an equal variance and the same standard deviation, and must be continuous. It was found that hydro-meteorological data does not meet most of the conditions. As such, non-parametric procedures for detecting trends were found to be suitable for hydro-meteorological time series. This paper found the rank based Mann-Kendall as one of the most commonly method employed in detecting the trend of hydro-meteorological and Seasonal Kendall Slope (Sen's slope) for detecting the magnitude of the trend. It was observed that hydro-meteorological data are sometimes serially dependent therefore the problem of serial correlation and seasonality will make the application of Mann-Kendall test to have limited applicability. Conducting Mann-Kendall test on serially correlated data may returns incorrect rejection rate that is too large. In time series that trend does not exist, the presence of serial correlation would increase the possibility of rejecting null hypothesis of no trend while it is accurate. Application of pre-whitening procedure is therefore recommended before subjecting the data to Mann-Kendall test. But Monte Carlo Simulation Investigation reveals that effect of serial correlation is dependent upon sample size and trend magnitude, when the sample size and trend magnitude are large, the serial correlation will no longer affect Mann-Kendall test significantly. It was found that pre-whitening removes positive AR(1) which in turn removes part of the trend, hence it reduces the possibility of rejecting the null-hypothesis when it is false. Similarly, when pre-whitening removes negative AR(1) it will inflate the trend and increase the possibility of rejecting the null-hypothesis when it is true. Authors are advised to make the sample size hydro-meteorological time series to be analyzed to be large enough and have a large trend magnitude in order to take care of the effect of serial correlation. Though this paper is not expected to end controversies regarding the direct application of the non-parametric method, it may still provide support and shed some light on those using it.

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