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Rainfall and Streamflow Trends in the Upper *Maduru Oya* Sub-watershed in Sri Lanka: A Comparative Study Using Different Statistical Methods

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ABSTRACT

Analysis of historical data on rainfall and streamflow provides useful information for water resources management in a river basin. The objective of this study was to assess the variations and trend analysis of rainfall and streamflow data in the upper Maduru Oya sub watershed in Sri Lanka during a 30 year period (1989 October to 2019 September) using daily rainfall data from two gauging locations (Padiyathalawa and Bibile) and daily average streamflow data from one gauging location (Padiyathalawa). Descriptive statistics were used to assess the variations. The Mann Kendal Trend Test (MK test) and Innovative Trend Analysis method (ITA) were used to analyze the trend, and Sen's Slope Estimator was used to assess the magnitude of the trend. Based on the MK test, most of the rainfall trends obtained are in an increasing direction, and streamflow trends are in a decreasing direction. Rainfall trends found in Padiyathalawa are not statistically significant. Annual, First Inter Monsoon, March, and May time scales of rainfall showed significant upward trends at Bibile ($p<0.1$) while streamflow in January, April, and September showed significant negative trends ($p<0.1$) at Padiyathalawa. The results displayed by all three tests were in very good agreement for rainfall. ITA results showed similar trend types of 77%, 95% and 41% at Padiyathalawa and Bibile rainfall and streamflow, respectively. A significant positive ($\rho<0.01$) strong and lower correlation between the trend value of the ITA and the Z value of the MK test were found for rainfall and streamflow, respectively. Changes in rainfall are not sufficient to explain the observed trends in streamflow. Therefore, future research should be directed at the causal aspects of streamflow change in this watershed.

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INTRODUCTION

Climate change causes slow long-term climatic changes, short-term climatic fluctuation, and unpredictable extreme weather events (Costa, 2010). Climate change would have a significant impact on agriculture, forestry, water supplies, and a variety of other sectors(IPCC, 2007; Lanka, 2009; Gajbhiye et al., 2016). At the watershed level, it is crucial for water supply planning and land use management due to the significant impact on the variability of hydro-meteorological parameters (Wang et al., 2020). Rainfall is the most essential of these parameters since it is the most important component of the hydrological cycle. As a result, its variability is closely linked to floods and droughts (Wang et al., 2017). Another important aspect of the hydrological cycle is streamflow, which is directly related to water resource utilization and management. Changes in long-term streamflow discharge can be caused by decadal or inter-decadal climate variability and anthropogenic activities (Nilsson et al., 2005). Therefore, one of the most important and widely discussed aspects of climate variability is how to cope with its effects on the hydrological cycle, specifically on the statistical properties and seasonal changes of precipitation and runoff on river discharge (Arora & Boer, 2001; Halwatura & Najim, 2013; Hasson et al., 2013). As a result, assessment of long-term hydro-climatic variability and trend have become an important study area worldwide in order to reduce streamflow and rainfall-induced problems (Chiew & McMahon, 2002; Chiew et al., 2006; Barua et al., 2013; Wang et al., 2020).

Numerous studies have been conducted on the trend analysis of hydro-meteorological time series in different parts of the world (Dabanlı et al., 2016; Agarwal et al., 2019; Almazroui & Şen, 2020; Banda et al., 2021). Many parametric and non-parametric methods have been developed for estimating long-term rainfall (Gajbhiye et al., 2016; Silva Junior et al., 2018; Wang et al., 2020) and streamflow (Yue et al., 2003; Kahya & Kalayci, 2004) trends and variabilities. In addition, studies of streamflow have found either increased river discharge or increased water stress due to climate variability (Charles and Mark, 2010).

Some studies have identified the changes in streamflow in different seasons (Panda et al., 2013). Gudmundsson et al. (2019) discovered a significantly decreasing regional trend of streamflow in South Asia from 1971 to 2010, but a growing trend in the streamflow in East Asia from 1961 to 2000. In Sri Lanka, the country's eastern, southeastern, northern, and north central areas exhibited an increase in rainfall trends over the past 31 years (1987–2017), whereas the western, northern, and central regions of the country showed a decrease in rainfall trends in a study conducted using an innovative trend analysis method over the same time period (Nisansala et al., 2020). A negative trend in annual precipitation was found in a study conducted using the Mann-Kendall test in the Kalu Ganga watershed in Sri Lanka (Ampitiyawatta and Guo, 2010). In a study conducted in the Uma Oya basin, Sri Lanka, the non-parametric Mann-Kendall test was used to analyze the data spanning 26 years. The authors discovered that there are no water scarcity issues in the basin (Khaniya et al., 2019). Commonly used methods for trend detection include both parametric and non-parametric tests. The advantage of parametric trend tests over non-parametric ones depends on the independence and normality of the data. However, non-parametric trend tests can accept outliers in the data, and the only requirement is that the data be independent (Hamed & Ramachandra Rao, 1998). The most common trend detection technique is the Mann Kendall (MK) test (Mann, 1945, Kendall, 1957) and the linear slope of the trend can be determined by the method suggested by Sen (1968). It is unaffected by outliers and does not require normally distributed data. It is affected by the presence of serial correlation in time series data and has a higher dependence on the degree, distribution, and size of the samples (Yue & Wang, 2004). To address the aforementioned issues, Sen (2012) developed a brand-new method known as the creative trend analysis. The ITA has become a popular statistical tool since it is not affected by sample size or distribution, and also displays trends in a graphical way (Şen, 2012; Gedefaw et al., 2018; Mallick et al., 2021)

One of the most important economic sectors in Sri Lanka is agriculture, which makes up a considerable component of the country's GDP and employs a sizable section of the population directly or indirectly. Agriculture is particularly sensitive to climate change both in the short- and long-term (Costa, 2010). First inter-monsoon (FIM) (March-April), Southwest monsoon (SWM) (May-September), Second inter-monsoon (SIM) (October-November), and Northeast monsoon (NEM) (December-February) are the four main rainfall seasons in Sri Lanka. *Maha* the major cultivation season, falls from September to February, and it overlaps with SIM and NEM. *Yala* is the minor cultivation season that falls from March to August and overlaps with the FIM and SWM periods (Chithranayana and Punyawardena, 2014). Several research studies have highlighted the climatic variability that Sri Lanka has undergone in the recent past (Wickramagamage, 2016; Hemachandra *et al*., 2020). Only a few studies have looked into seasonal streamflow characteristics, the variation of streamflow extremes, and their relationships with major climatic variables in Sri Lanka. Historical data can be used to make accurate predictions about future climatic variability. Therefore, identifying possible variations and trends in historical hydro-climatic data is one of the elements in water resource management and in making policy decisions (Shelton & Lin, 2019). The objective of this study was to assess the variations and trends in long-term rainfall and streamflow data from 1989/1990 to the 2018/2019 hydrological year period in the Upper Maduru Oya sub watershed in Sri Lanka using Mann Kendall, Sen's slope estimator method and an Innovative Trend Analysis Method.

MATERIALS AND METHODS

Study area

Maduru Oya is one of the major river systems in Sri Lanka, with a length of approximately 135 km. The drainage area is about 1487 km^2. The Maduru Oya watershed begins on the western slopes of the Badulla district and stretches towards the eastern coast of the Batticaloa district. Maduru Oya reservoir, river, and Maduru Oya national park are the major components of the watershed. There are six sub watersheds (i.e; Middle Maduru Oya, Kuda Oya, Upper Maduru Oya, Upper Middle Maduru Oya, Perillaveli Aru, Lower Maduru Oya). The selected area for the study is the upper Maduru Oya sub watershed, with a catchment area of 159 km^2. A major part of this sub-watershed lies within Badulla district, and the whole sub-basin area is located in the intermediate zone. Two rain gauging stations from upstream (Bibile) and downstream (Padiyathalawa) areas and one streamflow gauging station from downstream (Padiyathalawa) were selected to obtain rainfall and streamflow data as presented in Figure 1.

Maduru Oya Reservoir was constructed under the Accelerated Mahaweli Development Program in 1983. The Maduru Oya project was implemented with the purpose of providing irrigation water to the Mahaweli System B area; one of the major irrigation systems. Maduru Oya reservoir receives water from Mahaweli diversion and Maduru Oya itself. Therefore, it is important to study hydro climatic variation in the Upper Maduru Oya watershed due to its impact on reservoir water storage and the downstream irrigation system. Studies have been conducted to assess the hydro climatic variability in order to comprehend the impact of climate variation in Sri Lankan river basins (Zubair, 2003; Abeysingha et al., 2017; Shelton & Lin, 2019). However, no trend analysis of rainfall and streamflow has been carried out in the upper Maduru Oya sub watershed.

Description of data

Daily rainfall data for a thirty year period (Hydrological year; 1989/1990 – 2018/2019) were collected from two rain gauging locations namely, Padiyathalawa (longitude - 81.1953368, latitude -7.3822097) and Bibile (longitude - 81.22083333, latitude - 7.152777778) from the Department of Irrigation and the Department of Meteorology Sri Lanka, respectively. The combination of the closely located Bible Agriculture Training

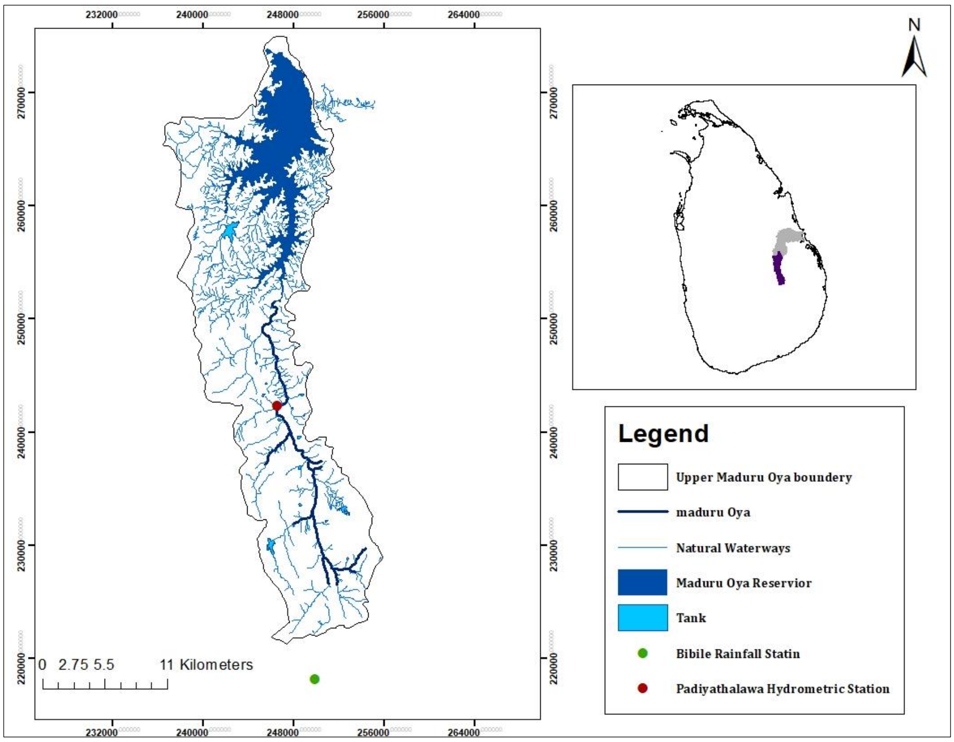

Figure 1: Map of the upper Maduru Oya sub watershed with locations of rain and streamflow gauging stations considered in the study

Centre and Bibile Dispensary was selected as the upstream rainfall station (Bibile) due to the availability of data for the recent thirty year period, having only a few missing rainfall data values, and to represent rainfall data from the upstream area. Daily average streamflow data for a thirty year period (Hydrological year; 1989/1990-2018/2019) were collected from one downstream streamflow gauging station namely, the Padiyathalawa hydrometric station.

Filling of missing data and data processing

There were no missing values at Padiyathalawa station in both streamflow and rainfall data series. Missing rainfall data (4%) were filled using the linear regression method at Bibile station using the adjacent Monaragala rainfall station. Total monthly, seasonal, and annual rainfall were calculated using daily rainfall data. Mean monthly, seasonal, and annual streamflow were calculated using daily average streamflow data for the thirty year period.

Descriptive statistics

The statistical parameters like mean, maximum, minimum, standard deviation, and coefficient of variation for monthly, seasonal and annual rainfall and streamflow data were computed for studying the variation in rainfall and streamflow. The decadal variability of climate data was obtained by using the deviation from the decadal mean (ten-year mean) as presented in Equation 1.

$$Da = \frac{\mu 10 - \mu 30}{\mu 30} \times \quad \text{Equation 1}$$

Where Da is the decadal anomaly, μ10 is the decadal mean, and μ30 is the 30 year mean.

Statistical methods for trend analysis

Trend analysis of rainfall at upstream and downstream rain gauging stations were carried out for annual, monthly, and seasonal (i.e., FIM, NEM, SIM, SWM) rainfall. Trend analysis of mean annual, monthly and seasonal streamflow was also carried out.

Autocorrelation test and Trend-free pre-whitening (TFPW)

The most important problem in non-parametric methods is serial correlation. Therefore, the serial correlation effect should be removed before calculating the monotonic trends. TFPW is based on a hypothesis by Salas (1980) that was used to remove serial dependence from the dataset. This method first checks for serial correlation, and TFPW is applied only if a serial correlation exists. This was done by computing the lag-1 serial correlation coefficient r_1 (Equation 2) for a two-tailed test at a 5% significance level. In the PW, the lag-1 correlation coefficient (r_1) is checked to see if it falls in the range of equation 3 or not. If the lag-1 correlation coefficient, r_1, is out of range, the data set is considered to be under the serial correlation effect (Mohsin and Gough, 2010; Gocic and Trajkovic, 2012). The original dataset is used for trend analysis if there is no serial correlation.

$$r1 = \frac{\sum_{i=1}^{n-1}(\mathrm{Xi} - \bar{\mathrm{x}})(\mathrm{X\ i{+}1} - \bar{\mathrm{x}})}{\sum_{i=1}^{n}(\mathrm{Xi}-\bar{\mathrm{x}})^{\wedge}2} \qquad \text{Equation 2}$$

$$\frac{-1-1.96\sqrt{(n-2)}}{n-1} \leq r1 \leq \frac{-1+1.96\sqrt{(n-2)}}{n-1} \qquad \text{Equation 3}$$

Where r1 is the lag-1 autocorrelation coefficient, $\bar{x}$ is the mean of the sample data, and n is the number of observations in the data.

Trend analysis

In this study, three different types of trend analysis methods were applied. First, the nonparametric Mann-Kendall trend test was used in order to examine the presence of monotonic increasing or decreasing trends (Mann, 1945; Kendall, 1957). Second, Şen's method was applied to estimate the true slope of a linear trend (Sen, 1968). In order to examine for potential patterns in the low, medium, and high streamflow data, the Innovative Trend Analysis approach was taken into consideration (Şen, 2012). The values of the tests were calculated using Microsoft Excel. MK and Sen's estimator tests were done using the "MAKESENS" application in Microsoft Excel (Määttä et al., 2002; Rahman et al., 2016).

Mann-Kendall test

The MK statistics, S is given as

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(Y\,j - Y\,k) \qquad \text{Equation 4}$$

$$sgn\,(Yj - Yk) = \begin{pmatrix} if\ (Yj - Yk) < 0; then - 1 \\ if\ (Yj - Yk) = 0; then - 1 \\ if\ (Yj - Yk) > 0; then\ 1 \end{pmatrix} \qquad \text{Equation 5}$$

Where Y_k and Y_j are the consecutive data values of a time series over time k and j, n designates the number of data points, and *sgn* symbolizes the function that takes the values of −1, 0 and 1; if Yj < Yk, Yj = Yk and Yj>Yk, respectively. Positive values of S designate an increasing trend, and negative values of S represent a decreasing trend in the hydro-meteorological time series. A sample size of which n > 10, the test is accompanied by a normal distribution (Mondal et al., 2012) with probability (E) and variance (Var) as shown in Equations 6 and 7.

$$E[S] = 0 \qquad \text{Equation 6}$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{Q} tp(tp-1)(2tp+5)}{18} \qquad \text{Equation 7}$$

Here, tp is the number of data values in the p^{th} group, and q is the number of tied groups. However, this summary sequence may be ignored if there are no tied groups in the data. After manipulating the variance Var(S), the standardized test statistics (Z_{MK}) value is calculated by using equation 8.

$$\mathrm{ZMK} = \begin{pmatrix} \frac{S-1}{\sqrt{Var(S)}},\ if\ S > 0 \\ 0,\ if\ S = 0 \\ \frac{S-1}{\sqrt{Var(S)}},\ if\ S < 0 \end{pmatrix} \qquad \text{Equation 8}$$

The null hypothesis (H_0) was identified as there being no trend in the data points in the record, and the alternative hypothesis (H_1) that there is an increasing or decreasing monotonic trend. In a two-tailed test, the null hypothesis (H_0) is agreed upon for no trend if the computed value of Z_{MK} falls between – $Z_{1-\alpha/2}$ and $Z_{1-\alpha/2}$, and so, H1 is rejected. The Z value of each station was calculated and compared with the critical Z values for two-tailed confidence level. In this study, the trends in the streamflow time series data were estimated at significance levels of 1%, 5%, and 10% (Yenigün et al., 2008).

Sen's slope estimator method

Sen's method (1968) is used to estimate the true slope of an existing trend (as change per unit time) (Equation 9).

$$f(t) = Qt + B \qquad \text{Equation 9}$$

Where Q is the slope and B is a constant. The linear slope value (Qi) is calculated by,

$$Qi = \frac{xj - xk}{j - k}\ (1, \dots\dots\dots . N) \qquad \text{Equation 10}$$

The data number is indicated with N, data at times j and k are indicated by xj and xk, respectively. The obtained Qi values are in ascending order, and the median value (Q median) is evaluated as a change of the relevant observations per unit time. An increasing trend is shown with a positive Q median value, whereas a decreasing trend is shown with a negative Q median value (Gan, 1998).

Innovative Trend Analysis

The first step in this strategy is to divide the data set into two equal parts and arrange each half in ascending order. A Cartesian coordinate system places the first half of the data set on the X-axis and the second half on the Y-axis. The deviation of each half would be categorized by a series of clusters. If the data points in a scatter plot are located on a 1:1 line, it indicates no-trend in the hydro meteorological time series; however, if the data points accumulated in the lower and upper triangular areas of the 1:1 line, it demonstrates downward or upward trends, respectively (Şen, 2012). The classification of given hydro-meteorological data into "low", "medium", and "high" groups can be achieved by dividing the data into three intervals in the graph based on the percentiles. It allows trend detection of rainfall for different clusters (Öztopal & Şen, 2017). In this study, total rainfall values were divided into three categories based on the percentiles, (i.e., low (<10^{th}), medium (10^{th}-90^{th}), and high (>90^{th}) rainfall (Brunetti et al., 2004).

The ITA trend indicator can be calculated according to the following expression (Şen, 2012).

$$D = \frac{1}{n}\sum_{i=1}^{n}\frac{10((\mathrm{Xj} - \mathrm{Xi})}{\mu} \qquad \text{Equation 11}$$

Where D represents the trend indicator, n indicates the length of each subseries, Xi and Xj are the observed data values in the first and second subseries, respectively, μ signifies the mean of the first subseries, and 10 represents a similar scale as that of the MK test.

Comparison of trend analysis methods

To compare the two trend analysis methods, all-time series tested were plotted, and the correlation between the two methods was tested using Spearman's rank correlation test.

RESULTS & DISCUSSION

Variability of Rainfall and streamflow

Annual rainfall in the upstream (Bibile) varied from 805 mm to 3137 mm, whereas the downstream (Padiyathalawa) varied from 1487 mm to 3183 mm. The coefficient of variation indicates the variability of rainfall. The degree of variability of climate events can be classified as less when CV < 20%, moderate when 20% < CV < 30%, high when CV > 30%, very high when > 40% and extremely high when>70% (Hare, 2003). Based on this categorization, upstream seasonal rainfall has very high variability in FIM, NEM, and SIM, while downstream rainfall demonstrated very high variability in FIM and NEM and high variability in SWM and SIM. Extremely high variability was found in the mean annual and seasonal streamflow at Padiyathalawa. NEM and SIM had higher mean rainfall at both Padiyathalawa and Bibile and higher streamflow at Padiyathalawa locations. NEM and SIM had substantially greater ranges of rainfall than other seasons at Padiyathalawa and Bibile. NEM had a greater range and SWM had a lower range of streamflow at Padiyathalawa (Table 1).

Table 1: Summary of descriptive statistics of rainfall and streamflow distributions on a seasonal and annual scale

Station		SIM	NEM	FIM	SWM	Annual
Rainfall at Padiyathalawa	Max (mm)	1214.4	1762.85	484	690.1	3183.75
	Min(mm)	324.35	357.8	13.5	174.3	1487.8
	Mean(mm)	602.34	869.02	191.61	419.05	2082.01
	SD(mm)	202.85	358.51	112.29	147.03	484.09
	CV (%)	33.68	41.25	58.6	35.09	23.25
Rainfall at Bibile	Max (mm)	1282.5	1377.8	767.8	543.2	3137.8
	Min(mm)	221.4	54.5	35.7	142.2	805.3
	Mean(mm)	635.87	685.56	260.25	312.61	1894.29
	SD(mm)	259.62	293.14	159.17	108.57	508.27
	CV (%)	40.83	42.76	61.16	34.73	26.83
Mean streamflow at Padiyathalawa	Max (mm)	16.04	50.91	9.85	2.23	14.65
	Min(mm)	0.28	1.4	0.11	0.05	0.92
	Mean(mm)	4.78	17.11	2.4	0.57	5.71
	SD(mm)	4.51	13.5	2.15	0.53	3.72
	CV (%)	94.52	78.86	89.79	92.57	65.2

Average monthly rainfall and streamflow variation during the study period are shown in Figure 3. According to Figure 3, during the months of March to September (during FIM and SWM), relatively low rainfall is present in both stations. The peak rainfall period can be observed from October to January which is during the *Maha* season. Considering the streamflow pattern, peak flow occurs after the rainfall peak during December to February. There is a time lag between the rainfall peak, and flow peak indicating a slow response of the watershed to the rainfall after a relatively long dry period from June to September. The absence of a flow peak during the *Yala* season indicates that there was no or very low runoff generation during this time due to low rainfall.

Figure 4 shows the patterns of average monthly total rainfall and mean monthly streamflow in three decades. Table 4 presents the decadal variability of the rainfall and streamflow. The decadal CV of four seasons represented a higher range, which means that all seasons have heterogeneous characteristics in terms of rainfall and

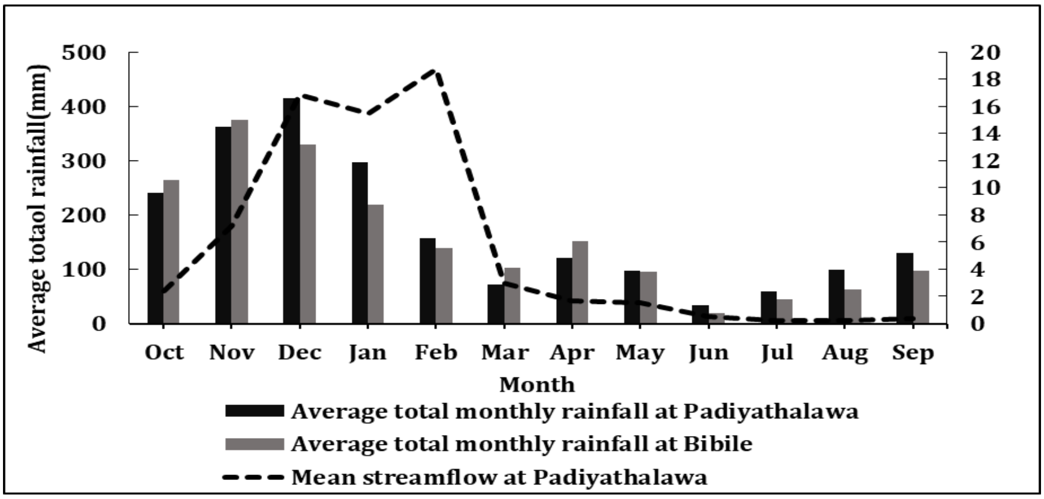

Figure 3: Average monthly rainfall and streamflow variation for the period of 1989/1990 to the 2018/2019 hydrological year

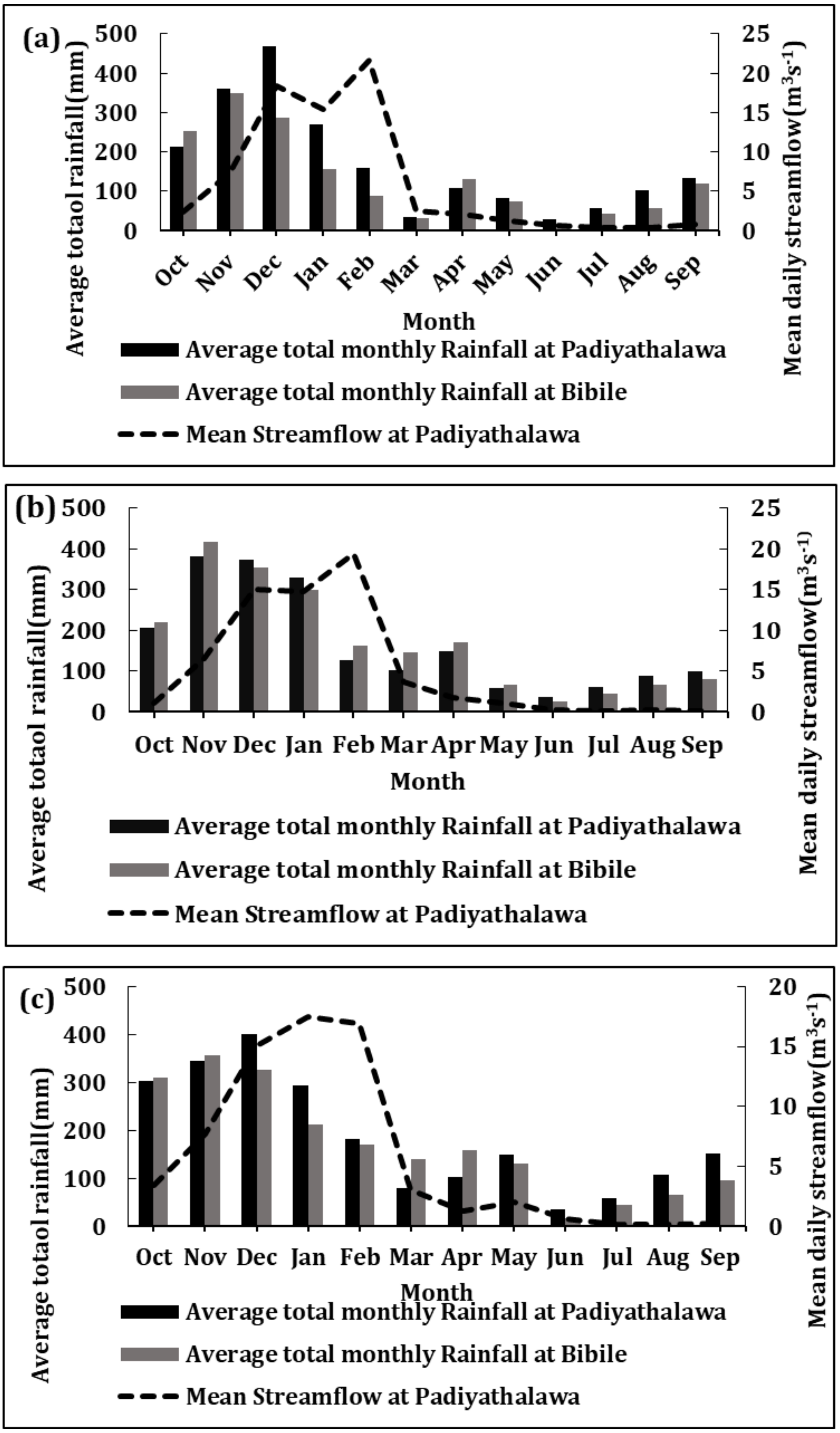

Figure 4: Rainfall and streamflow variation (a) for the period of 1989/1990 to 1998/1999 hydrological year (b) for the period of 1999/2000 to 2008/2009 hydrological year (c) for the period of 2009/2010 to 2018/2019 hydrological year.

Table 4: Decadal variability of rainfall and streamflow

Location and variable	Season	CV and Percentage change from the mean of the period (%)					
		1989/1999 to 1998/1999		1999/2000 to 2008/2009		2009/2010 to 2018/2019	
		CV	Change	CV	Change	CV	Change
Seasonal Rainfall at Padiyathalawa	SIM	48.65	-4.76	16.17	-2.8	31.75	7.49
	NEM	40.03	3.43	31.56	-4.44	52.62	1.01
	FIM	52.06	-25.21	53.89	30.92	55.78	-5.71
	SWM	34.49	-2.51	34.1	-17.76	29.23	20.27
Seasonal Rainfall at Bibile	SIM	61.75	-5.13	26.98	0.8	32.28	4.83
	NEM	42.5	-22.31	31.91	19.02	47.35	3.3
	FIM	42.5	-37.21	58.97	22.23	54.7	14.98
	SWM	33.91	-3.3	29.08	-9.8	37.66	13.1
Seasonal daily streamflow at Padiyathalawa	SIM	98.78	2.95	93.23	-23.8	95.63	17.36
	NEM	75.73	-3.64	75.29	13.86	93.22	-10.22
	FIM	42.38	8.04	112.7	-4.22	96.54	-3.82
	SWM	60.8	-31.54	110.5	-63.1	106.66	-34.42

streamflow variations. However, variability can be described by the difference between the decadal mean and the mean of a thirty year period. The positive sign signifies more rainfall (wet); while the negative sign signifies less rainfall (dry) for the particular decade under consideration. Ranasingha et al. (2014) demonstrated that rainfall variability increases in current decades (1981–1990; 2001–2010) compared to earlier decades (1951– 1960; 1961– 1970) based on an interdecadal analysis of seasonal rainfall over 1951–2010 in Sri Lanka. In this study, the recent decade (2009/2010 to 2018/2019) shows much rainfall. However, streamflow values show negative values, indicating low streamflow values in the recent decade compared to the thirty year period except for SIM. SIM shows a positive trend in streamflow at Padiyathalawa, according to Mann Kendal test results in Table 8.

Autocorrelation test and Trend-free pre-whitening procedure

The pre-whitening procedure is applied to streamflow and rainfall data before the Mann Kendal test. The majority (65%) of the calculated lag-1 correlation coefficients in streamflow time series are negative. Calculated lag-1 correlation coefficients for rainfall in the Bibile (53%) and Padiyathalawa (65%) time series are negative. According to the results of the autocorrelation test, either the total monthly, seasonal and annual rainfall data in individual locations or mean monthly, seasonal, and annual streamflow were not lag-one auto-correlated at the 5% significance level. Therefore, the MK trend test and Sen's slope estimator were directly applied to assess the trend.

Temporal trends in rainfall and streamflow

Table 5 presents the results of the MK test, Sen's slope estimate and ITA results for rainfall data at Padiyathalawa. Results indicate most of the trends obtained are in an increasing direction, and none of the time scales showed significant trends at any significant level. During the NEM seasons, especially in December and January, downward trends could be observed. Table 6 presents the results of the MK test and Sen's slope estimate for rainfall data at Bibile. According to the results, only the monthly rainfall of September shows a non-significant decreasing trend, and all other scales show increasing trends. Results indicate a significant increasing trend of monthly rainfall of March at $\alpha = 0.01$ level of significance and a significant increasing trend of seasonal rainfall in FIM at $\alpha = 0.05$ level of significance. Monthly rainfall of May and annual rainfall shows significant increasing trend at $\alpha = 0.1$ level of significance. Table 7 presents the results in MK test and Sen's slope estimate for streamflow data at Padiyathalawa. Most of the trends obtained are in a decreasing direction except for the mean monthly streamflow of October and November and SIM seasonal streamflow. Significant decreasing trends of mean monthly streamflow in January, April, and September were identified at $\alpha = 0.1$ level.

The overall results of the ITA method for seasonal rainfall indicated increasing trends during the FIM, SIM, and SWM seasons and decreasing trends during the NEM at Padiyathalawa. Bibile station data shows an increasing rainfall trend in all four seasons. These results are almost identical to the results obtained using the Mann-Kendal test. However, there are differences in rainfall at the monthly scale and streamflow at all-time scales. ITA results for rainfall showed similar trend types (i.e. increasing or decreasing) for 77% and 95% of time scales at Padiyathalawa and Bibile, respectively. Monthly rainfall in November, February, June, and July at Padiyathalawa and July at Bibile did not show similar trend types for both tests. Only 41% of trend types are the same in Mann-Kendal and the ITA method in streamflow analysis at all-time scales. It includes trends in monthly rainfall in October, November, February, July, August and September as well as the seasonal trend in SIM.

None of the seasons shows a decreasing trend in the ITA method. According to the Mann Kendal test, only SIM seasonal streamflow shows an increasing trend.

The visual representation provides key insights into identifying trends, such as increasing, decreasing, or no trend, for various clusters. Studies have observed that some trends not detected by the Mann–Kendall test can be identified by the ITA method. Hidden sub-trends can be observed from graphical representations (Kisi, 2015). Figures 5, 6, and 7 show the graphical representations of the ITA results, depicting high, medium, and low trend values. The increasing rainfall trend in the ITA method is mainly due to the increasing rainfall trend for medium rainfall values at Padiyathalawa and the increasing rainfall trend for medium and high rainfall values at Bibile. The results of the present study indicated, that changes in moderate and high values are more significant than change in low values. Table 8 shows the summary of seasonal trend types in the ITA method.

Comparison of trend analysis methods

It observed agreement as well as disagreement between different methods, and it suggests the application of more than one trend detection technique for identifying trends in hydro-meteorological variables. To compare the two trend analysis methods, D values of ITA (trend indicator of ITA method) and Z values of Mann Kendal (standardized test statistics of Mann Kendal test) of all time series tested were plotted in a scatter plot (Figure 8), and the correlation between the two methods was tested using Spearman's rank correlation test. It assesses how well the relationship between two variables can be described using a monotonic function.

Table 5: Results of statistical analysis of total monthly, seasonal, and annual rainfall data at Padiyathalawa

Time Scale	MK Test			ITA
	Test Z	Significance	Q	D
October	1.57		5.00	3.72
November	0.39		1.44	-1.737
December	-1.39		-4.87	-0.77
January	-0.36		-2.06	-0.87
February	0.21		0.69	-1.79
March	1.62		2.05	11.28
April	0.09		0.17	2.33
May	1.32		1.68	4.53
June	0.48		0.09	-0.03
July	0.41		0.40	-0.42
August	0.64		0.76	0.65
September	-0.14		-0.41	-0.98
SIM	1.32		6.05	0.65
NEM	-1.21		-6.1	-0.64
FIM	0.89		2.11	5.00
SWM	1.14		5.13	0.65
Annual	1.11		9.86	0.47

***, ** and * indicates trends that are significant at α = 0.01, 0.05 and 0.1 levels, respectively

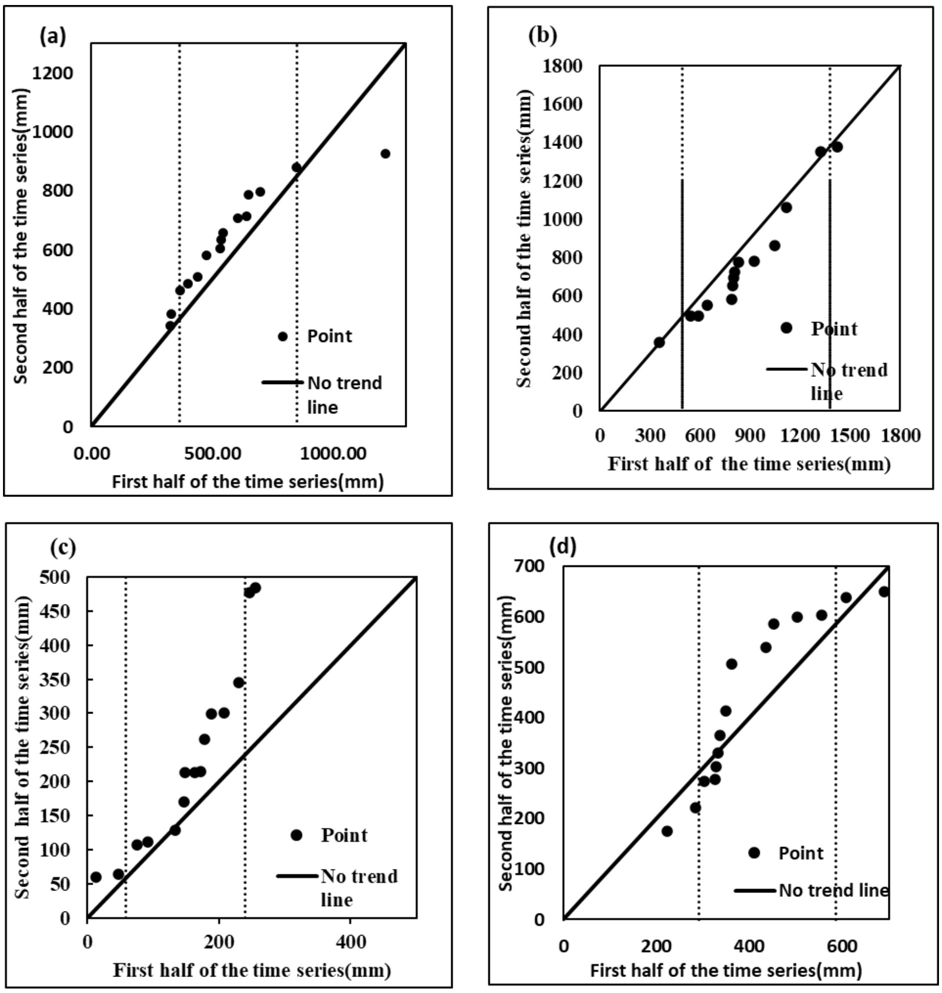

Figure 5: Results of the ITA for seasonal rainfall at Padiyathalawa (a) SIM (b) NEM (c) FIM (d) SWM. Lines indicate 10th and 90th percentile values.

Table 6: Results of statistical analysis of total monthly, seasonal, and annual rainfall data at Bibile

Time Scale	MK Test		Sen's slope estimate	ITA
	Test Z	Significance	Q	D
October	1.39		4.25	2.45
November	0.61		1.70	0.18
December	0.36		0.97	1.28
January	0.43		1.64	2.48
February	1.03		2.75	2.77
March	2.62	***	4.90	19.9
April	0.61		1.35	2.85
May	1.77	*	2.08	5.34
June	0.07		0.00	4.1
July	0.79		0.54	-1.18
August	0.87		0.61	4.6
September	-1.18		-1.45	-3.64
SIM	1.39		1.39	1.14
NEM	0.89		4.93	3.28
FIM	2.14	**	6.75	7.66
SWM	0.89		0.89	0.6
Annual	1.82	*	1.82	2.33

***, ** and * indicates trends that are significant at α = 0.01, 0.05 and 0.1 levels, respectively

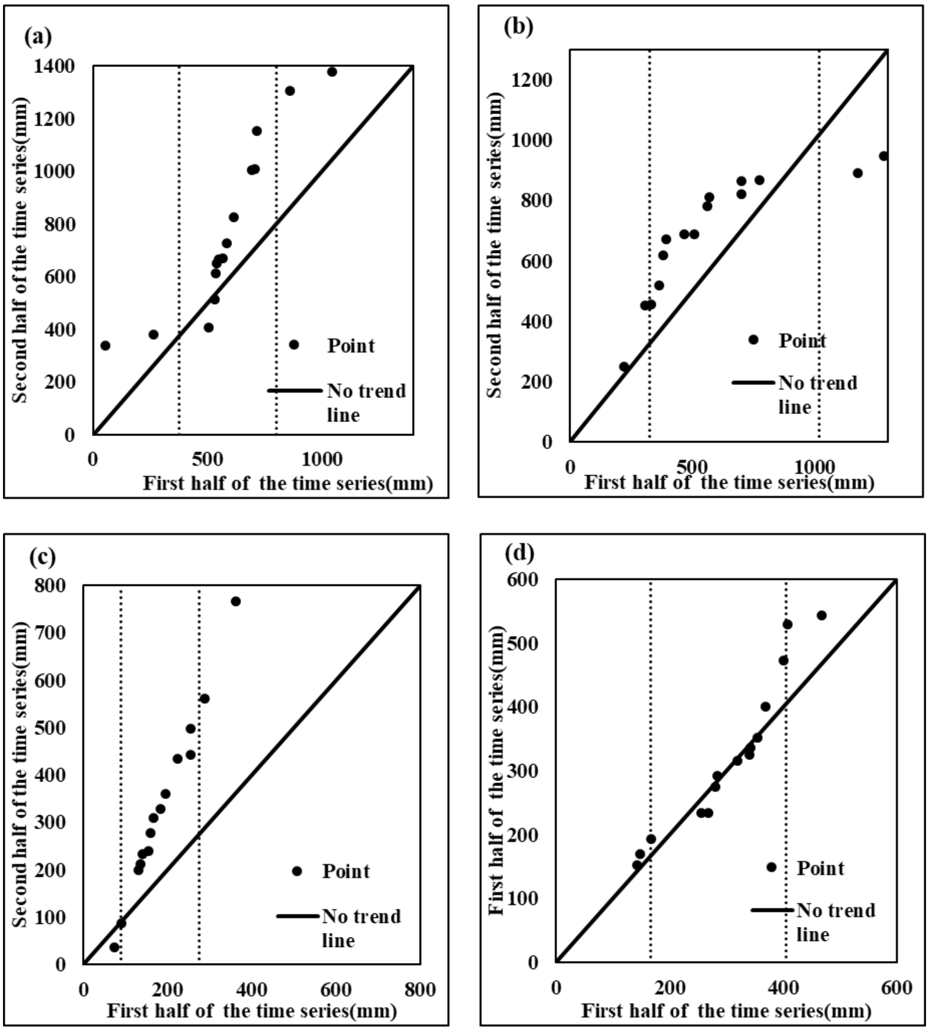

Figure 6: The results of ITA for seasonal rainfall at Bibile (a) SIM (b) NEM (c) FIM (d) SWM. Lines indicate 10th and 90th percentile values

Table 7: Results of statistical analysis of mean monthly, seasonal, and annual streamflow data at Padiyathalawa

Time Scale	Mann Kendal Test		Sen's slope estimate	ITA
	Test Z	Significance	Q	D
October	0.21		0.01	6.52
November	0.25		0.02	3.30
December	-0.64		-0.16	2.65
January	-1.71	*	-0.29	1.59
February	-0.93		-0.12	-1.75
March	-0.64		-0.03	7.61
April	-1.89	*	-0.04	0.71
May	-0.21		-0.01	9.03
June	-1.43		-0.01	2.48
July	-0.86		0.00	-2.77
August	-0.50		0.00	-2.07
September	-1.91	*	-0.01	-5.9
SIM	0.25		0.02	4.01
NEM	-0.82		-0.04	0.48
FIM	-1.43		-0.23	4.65
SWM	-0.86		-0.01	2.35
Annual	-0.32		-0.02	1.22

*** , ** and * indicates trends that are significant at α = 0.01, 0.05 and 0.1 levels, respectively

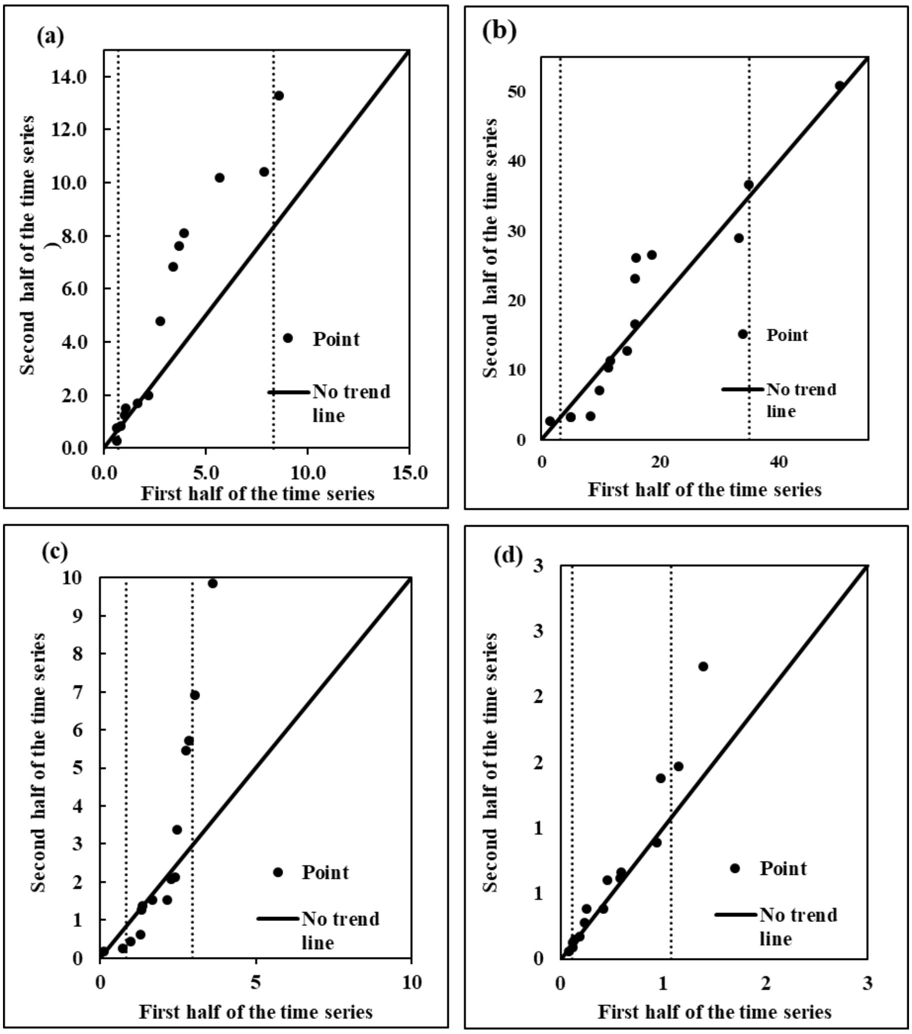

Figure 7: The results of ITA for seasonal mean streamflow (a) FIM (b) NEM (c) SWM (d) SIM. Lines indicate 10th and 90th percentile values.

Table 8: Summary of results of the ITA method in seasonal trend analysis

Station and variable	Seasonal Trend				
	SIM	NEM	FIM	SWM	Remarks
Padiyathalawa Rainfall	Increasing Non monotonic	Decreasing Non monotonic	Increasing Monotonic	Increasing Non monotonic	Increasing trend of medium values
Bibile Rainfall	Increasing Non monotonic	Increasing Non monotonic	Increasing Monotonic	Increasing Non monotonic	Increasing trend of medium and higher values
Padiyathalawa Streamflow	Increasing Monotonic	Increasing Non monotonic	Increasing Monotonic	Increasing Non monotonic	Increasing trend of medium and higher values

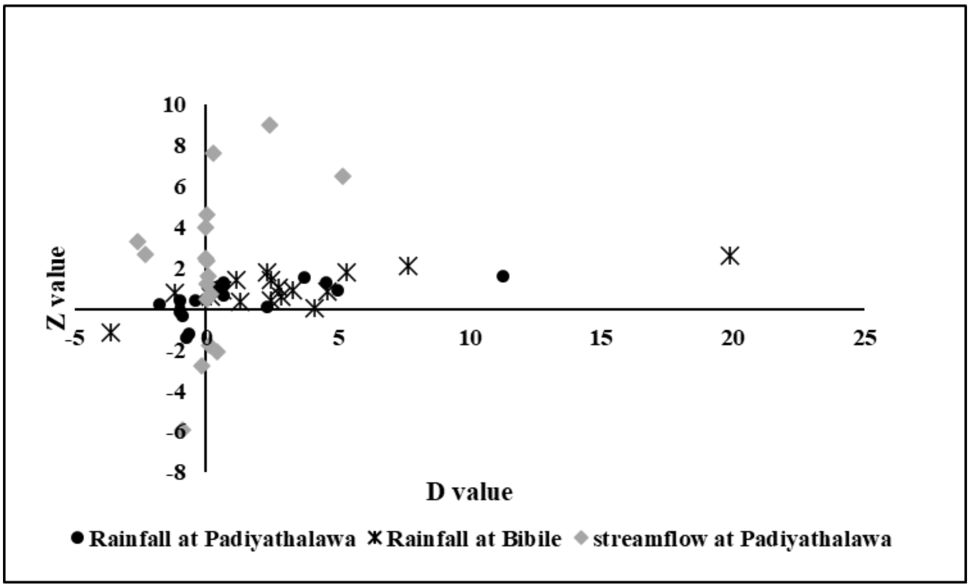

Figure 8: Scatter plots showing Z of the Mann–Kendall test versus D of the ITA

The D displays a stronger to moderate correlation with Mann–Kendall Z for both rainfall at Padiyathalawa (ρ=0.75) and Bibile (ρ = 0.47). The correlation at Padiyathalawa is significant at the 0.01 significant level. It indicates that the ITA method can be used as a simple method to visually detect the trend, and particularly to find the trend of high, medium, and low values. However, D displays a lower correlation with Mann-Kendall Z in streamflow (ρ=0.23). The applicability of the ITA method was investigated by comparing its results with those of the Mann Kendal test at monthly, seasonal, and annual scales. It is evident that statistic D of the ITA method has an agreement with statistic Z of the Mann Kendal test in rainfall trend analysis.

These trends might also be influenced by cyclical climatic teleconnections like the El Nio-Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the Quasi-Biennial Oscillation (QBO). According to De Silva and Hornberger (2019), SWM rainfall decreases during El Nio episodes. When an El Nio event occurs, rainfall increases during the first three months of the Maha season (October to December) and drops over the following three months (January to March), and rainfall during the SWM is increased by La Nia occurrences. As a result, these rainfall parameters affect how the pattern of rainfall varies around Sri Lanka.

Using data from 1981 to 2010, Wickramagamage (2015) also noted an increasing trend in inter-monsoon rainfall across Sri Lanka. Using rainfall data gathered at 32 rain gauge stations and the non-parametric Mann-Kendall trend test and Sen's slope estimator methods, Karunathilaka et al. (2017) analyzed the annual and seasonal rainfall patterns in Sri Lanka over a 50 year period (1966–2015). They noted a trend toward rising rainfall in the country's eastern region. Gudmundsson et al. (2019) discovered a significantly decreasing regional trend of streamflow in South Asia from 1971 to 2010. The results of this study clearly indicated an increasing rainfall trend and a decreasing streamflow trend considering the annual, seasonal, and monthly patterns.

Results of the present study clearly indicate the temporal variability of rainfall and streamflow over the upper Maduru Oya subwatershed, demonstrating the necessity of site-specific adaptation strategies to deal with the problems of water availability. Seasonal analysis showed an increase in rainfall during FIM, SIM, and SWM, but a decrease in rainfall during NEM. NEM rains contribute more rainfall to the upper Maduru Oya subwatershed area due to the higher mean value. It is the source of water for the Maduru Oya River, and it contributes to supplying water for the Maduru Oya Reservoir. The most important aspects of the hydrological cycle are rainfall and streamflow, which are directly related to water resource management. Considering increasing rainfall trends and decreasing streamflow trends, further studies are required to find the reasons for the opposite trends.

Identifying these sub-trends will be beneficial for managing and planning water resources as well as creating adaptation strategies. As the rainfall trend is increasing during FIM at Bibile Station, farmers can find adequate time to prepare for the cultivation. In order to plan crop cultivation, design water storage facilities, design drainage channels for flood control, etc., it is necessary to understand the fluctuations in climate both spatially and temporally. Planning water management strategies for the future will benefit from the analysis of rainfall and streamflow trends.

CONCLUSIONS

In the present study, rainfall and streamflow trends in monthly, seasonal, and annual time series were studied in the upper Maduru Oya sub-watershed, utilizing Mann Kendall (MK), Sen's slope estimator method, and Şen's innovative Trend Analysis Method (ITA). The results displayed by all three tests were in very good agreement, except for streamflow. According to the analysis, the variability of rainfall and streamflow is evident in this area. From these results, it could be concluded that non-significant trends were observed for rainfall at Padiyathalawa. However, most of the rainfall trends were in an increasing direction at Padiyathalawa and Bibile. Only annual, FIM, March, and May rainfall showed significant increasing trends at Bibile station. Most of the trends obtained are in a non-significantly decreasing direction for streamflow. Only January, April, and September showed significant decreasing trends in streamflow at Padiyathalawa station. The ITA approach has certain benefits since it provides information about patterns in terms of evaluating the low, medium, and peak values. The causes of streamflow change in this watershed should be the focus of future investigation.

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