J.Natn.Sci.Foundation Sri Lanka 2020 48 (4): 449 - 462
DOI: http://dx.doi.org/10.4038/jnsfsr.v48i4.9440

RESEARCH ARTICLE

Streamflow trends of Kelani River basin in Sri Lanka (1983-2013)

SM Jayasekara[1], NS Abeysingha[1*] and TJ Meegastenna [2]
[1] *Department of Agricultural Engineering and Soil Science, Faculty of Agriculture, Rajarata University of Sri Lanka, Puliyankulama.*
[2] *Irrigation Department of Sri Lanka*

Submitted: 11 September 2019; Revised: 20 July 2020; Accepted: 23 September 2020

Abstract: The assessment of hydro-climatic trends is useful in water resource planning, especially in river basin scale. This study investigated the trends of streamflow in the Kelani river and its association with rainfall over a 31-year period. Streamflow and rainfall were assessed using Innovative Trend Analysis (ITA) method and Mann Kendall test (MK) with Sen's slope estimator. The association between streamflow and average catchment rainfall was studied using Spearman's rho correlation coefficient (ρ). Both ITA and MK tests confirmed the decreasing annual and seasonal streamflow trend from mid-stream to downstream of the Kelani river basin. A decreasing trend of rainfall was recorded at 75 % and 63 % stations during the southwest monsoon (SWM) and second inter-monsoon (SIM), respectively. However, annual, northeast monsoon (NEM) and first inter-monsoon (FIM) rainfall showed an increasing trend at 63 %, 88 % and 100 % stations, respectively. There was a significant association between streamflow and catchment rainfall ($p < 0.05$) for 70 % of stations suggesting that the variation of streamflow is mainly attributed to the variation of catchment rainfall. The decreasing trend of streamflow and rainfall during SWM and SIM towards the downstream area with the increasing temperature trend indicate a drying tendency of the Kelani river basin over the study period.

Keywords: Innovative trend analysis, Mann-Kendall test, rainfall, streamflow.

INTRODUCTION

Climate change analyses are required both on climatic parameters such as rainfall and temperature, and hydrological parameters such as streamflow and sea levels (Ref). Therefore, to study the status of climate change, climate and hydrological parameters need to be tested for their trends. In addition, hydro-climatic trend analysis is a statistical tool used to investigate the fluctuation of parameters in agricultural industry (Kibria *et al*., 2016). Throughout the world streamflow plays an essential role in assessing the water yield of a river basin. Thus, streamflow data is one of the primary sources of data that can be used in identifying possible trends of water resources in a river basin. Furthermore, the trend of streamflow in a basin is useful to assess the impact of climate variability and changes on water resources.

There are many methods used in analysis of trends of hydro-meteorological time series in the world such as Mann-Kendall (MK), modified Mann-Kendall and regression analysis. Recently, Innovative Trend Approach (ITA) method has been introduced by Şen (2015) and successfully applied in trend analysis especially on hydrological time series.

Öztopal and Şen (2016) analysed precipitation records of 35 meteorological stations in Turkey over 60 years by using the ITA methodology. They observed that the ITA method provides an opportunity to separate out the low, high and medium flow trends and their relative intensities, durations as well as magnitudes. Wu and Qian (2016) studied annual and seasonal rainfall and extreme values in Shaanxi, China from 1950–2014 using the ITA method and highlighted the importance of graphical representation of results and sub trends in ITA method. It has been shown that the graphical technique is required for exploratory data analysis to avoid errors in

* Corresponding author (nabeysingha@gmail.com; https://orcid.org/0000-0003-4635-3285)

detecting significant hidden (short-durational) sub-trends (Kundzewicz & Robson, 2000).

In Sri Lanka, there has been a few studies conducted to find out the trends of streamflow of river basins. Abeysingha *et al*. (2017) analysed the status of streamflow trends in up and midstream of Kirindi Oya river basin in Sri Lanka, using MK test and Sen's slope estimator. Ampitiyawatta and Guo (2010) used the MK test to analyse the precipitation trend in the Kalu Ganga basin during 1965–2004. However, the use of ITA method to test river flow trends in Sri Lanka was not available in literature. This method is not affected due to serial correlation, non-normality, sample number, etc., and also helps to identify significant hidden sub-trends.

A large fraction of water resources management structures in Sri Lanka is associated with Mahaweli and Kelani river basins (De Silva *et al*., 2019). Kelani river ranks as the fourth longest river in Sri Lanka. The water is used for hydropower generation, transport, irrigation and fisheries (Zubair *et al.*, 2003). The National Water Supply and Drainage Board (NWSDB) in Sri Lanka uses Kelani river water to meet the water demand in metropolitan areas of Colombo and Gampaha districts. The NWSDB is facing difficulties during February, March, August and September in withdrawing water from the Kelani river. Therefore, it is worth to examine the streamflow trends in Kelani river basin and to find out the possible linkages for the observed changes in streamflow with rainfall.

Study area

The Kelani river basin is located in between Northern latitudes 6° 47' to 7° 05' and Eastern longitudes 79° 52' to 80° 13'. This river is 145 km long and has a catchment area of 2,292km^2 (De Silva *et al*., 2012). It originates in the central hills of the country and reaches the Indian Ocean by the capital city of Colombo (Fayas *et al*., 2018). It flows through the districts of Nuwara Eliya, Rathnapura, Kegalle, Gampaha and Colombo. Two reservoirs and five hydropower plants have been built to utilise the flow for hydropower generation. Kelani river consists of two main tributaries in its upper reaches. These are Kehelgamu Oya and Maskeli Oya. Mainly tea, rubber, other crops, grass and forest are the land uses in the upper catchment of the river, and the lower catchment is highly urbanised (Kottagoda & Abeysingha, 2017).

METHODOLOGY

Data and data preprocessing

Quality tested daily streamflow data were collected from six streamflow gauging stations for 31 years (1983–2013) from the Irrigation Department of Sri Lanka. Daily rainfall data of eight meteorological stations for the same duration (1983–2013) were collected from the records maintained by the Irrigation Department of Sri Lanka, Meteorological Department of Sri Lanka and the Natural Resources Management Centre (NRMC), Sri Lanka (Figure 1). Monthly temperature data of two meteorological stations (Colombo and Nuwara Eliya) for 31 years (1983–2013) were also collected from the Meteorological Department of Sri Lanka and the Department of Census and Statistics of Sri Lanka. This study was limited to the period 1983 to 2013 as quality tested flow data were not available for 2013 onwards at the time of carrying out the analysis.

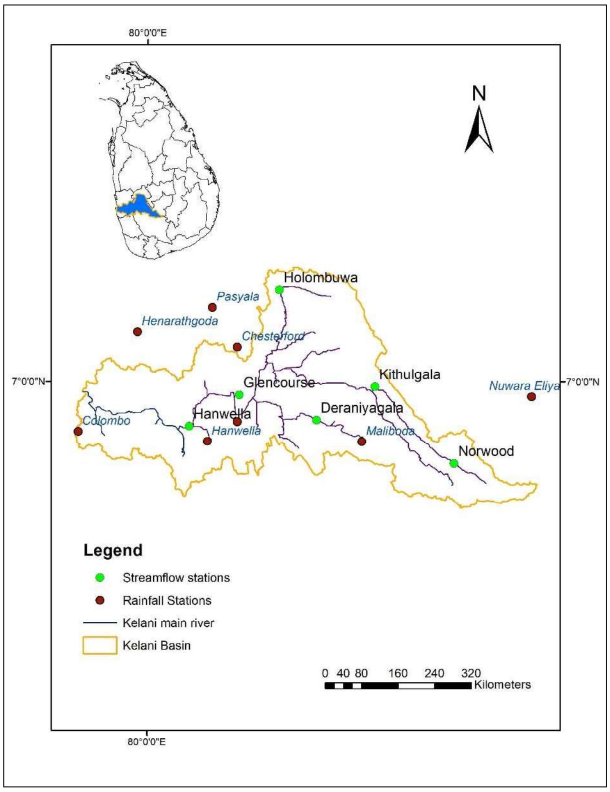

Figure 1: Kelani river basin, streamflow and rainfall stations

A digital elevation model (DEM) generated from 30 m × 30 m resolution ASTER Dataset (*https://asterweb.jpl.nasa.gov*) was used to delineate the *Kelani* river basin using ArcGIS 10.1 (Figure 1). The six streamflow stations and eight rainfall stations used for the analysis are also shown in Figure 1. Six sub-basins, Norwood, Deraniyagala, Holombuwa, Kithulgala, Glencourse and Hanwella were delineated using the streamflow stations as an outlet of each sub-basin. Norwood sub-basin can be considered as the most upstream sub-basin. Kithulgala, Deraniyagala, and Holombuwa were considered as midstream and Hanwella and Gelncourse as downstream catchments in the present study.

Preprocessing of data

There were 2.23 % missing values in streamflow dataset and 3.92 % missing values in rainfall dataset. These missing values were filled using the correlation method. Then the following indicators were calculated and subjected to trend analysis. Monthly values for both rainfall and streamflow were calculated from the respective daily values.

(a) Annual streamflow/rainfall
Twelve monthly values from October to September (hydrological year) for a station.

(b) Seasonal streamflow/rainfall
Monthly values for first intermonsoon (FIM), i.e. March to April, southwest monsoon (SWM), i.e. May to September, second intermonsoon (SIM), i.e. October to November and northeast monsoon (NEM), i.e. December to January, separately. FIM, SWM, SIM and NEM are the four main rainfall seasons in Sri Lanka.

(c) Cropping seasons streamflow/rainfall
There are two cropping seasons, *Maha* (October to March) and *Yala* (April to September) which are coincided with northeast monsoon and southwest monsoon, respectively (Chandimala & Zubair, 2007). Monthly values for *Yala* and *Maha* (October to March) seasons were separately analysed.

(d) Annual maximum and minimum streamflow/ rainfall
Maximum and minimum streamflow/ rainfall values recorded in a year at a gauging station.

(e) Annual mean temperature for two weather stations (Colombo and Nuwara Eliya)

Average rainfall for the different catchments of the river basin was calculated using the Thiessen polygons method, which is one of the generally used methods in calculating the average rainfall for catchment in ArcGIS environment.

Methods of analysis

The trend of hydroclimatic data series in this study was tested using the trend detection technique of ITA method and MK test along with the Sen's slope estimator method.

Innovative trend analysis (ITA) method

ITA is a novel technique suggested by Sen (2012, 2014) for the identification of monotonic and holistic trends, and also the partial trend components in low, medium and high data values. This method can be employed without any restrictive assumption and has a non-parametric basis. Sub-series comparisons extracted from the main time series is the concept of this method (Sen, 2015). MATLAB (R2014) software was used to test the dataset for ITA trend test. The available quality tested data from 1983 to 2013 and respective time series were used and subdivided into two halves. Plots were derived on a Cartesian coordinate system. The first part of the time series was placed on the horizontal (X-axis) and other part of the time series was placed on the vertical (Y-axis). In those plots, trend-free time series subsections appear along the 45^0 straight-line (Sen, 2015). When streamflow points are fallen between the ± 10 % lines, it indicates insignificant variations. Points generally fallen below the -10 % line indicate a downward trend while points fallen above the +10 % indicate an upward trend. The scattered streamflow data can also be divided into low, medium and high groups as three consecutive equal length and non-overlapping pieces (Öztopal & Şen, 2016).

The trend indicator is given by:

$$D = \frac{1}{n}\sum_{i=1}^{n} 10\,\frac{(y_i - x_i)}{\bar{x}} \quad ...(1)$$

where n is the number of each sub-series; and x is the mean of the first sub-series; D is the trend indicator (a positive D value indicates an upward trend and a negative D value denotes a downward trend); the indicator is multiplied by 10 for comparison with the MK test (Wu & Qian, 2016).

Mann-Kendall (MK) test

MK trend test is widely used to detect the monotonic trends of time series of hydrology and climatology. MATLAB software was used to analyse the data for the MK test. One error of the MK test is that it does not account for the serial correlation, which is very often observed in hydro-climate time series (Hamed & Rao, 1998). However, the modified MK test was used whenever there is a lag one autocorrelation of a time series tested. For autocorrelated data, we used the Modified Mann-Kendall test proposed by Hamed and Rao (1998). To get the magnitude of the trend, Sen's slope method proposed by Theil (1950) and Sen (1968) was used.

Spearman's rho correlation coefficient

Spearman's rho correlation coefficient test was used to find the correlation between MK and ITA. Spearman's rho is a rank-based non-parametric statistical test, which is used to determine whether a correlation exists between two groupings of the same series of observations (Rahmat *et al*., 2012).

RESULTS AND DISCUSSION

Before analysing the trends in streamflow and rainfall, lag-one autocorrelation was tested in all the time series datasets (annual, climate seasons, and cropping seasons). The results of autocorrelation analysis for the period 1983–2013 indicated that 83.33 % of annual streamflow series was autocorrelated at 5 % significant level at least at lag one. Furthermore, approximately 50 % of SWM and SIM seasonal streamflow and also Yala and Maha cropping seasonal streamflow time series were also auto correlated at 5 % significant level at lag one. In order to remove the autocorrelations, this study used modified MK test by Hamed and Rao (1998) as the test method for those time series having lag one autocorrelations.

Annual streamflow and rainfall trend in *Kelani* river basin

Annual streamflow and rainfall trend based on MK test and Sen's slope estimator

According to the MK test results, five streamflow stations out of six stations exhibited significant downward trend. Streamflow decreased at Glencourse was significant at 1 % confidence level while the other four stations have the significance at 5 % confidence level (Table 1). Norwood streamflow station has a downward trend but not significant. A decreased quantity of flow is expressed by Sen's slope and the highest decrease was recorded in Glencourse (-1204.48 $m^3 s^{-1} year^{-1}$) while the lowest was recorded in Norwood (-20.45 $m^3 s^{-1} year^{-1}$) during the period 1983 to 2013.

Table 1: The trend tested based on ITA, and MK on annual streamflow and rainfall at different streamflow stations in Kelani river basin

Station	ITA	MK	Sen's slope
	D	Calculated Z value	Slope ($m^3 s^{-1} year^{-1}$)
Streamflow			
Deraniyagala	- 3.13	- 2.43**	- 139.91
Glencourse	- 3.96	- 3.93***	- 1204.48
Hanwella	- 2.64	- 2.39**	- 766.07
Holombuwa	- 4.37	- 2.31**	- 94.50
Kithulgala	- 2.83	- 2.17**	- 176.07
Norwood	- 0.44	- 1.49	- 20.45
Rainfall			
Avissawella	- 0.41	- 0.82	- 10.65
Chesterford	1.32	2.53**	30.59
Colombo	0.39	1.32	9.73
Hanwella	- 0.94	- 0.89	- 15.03
Henarathgoda	0.31	0.21	3.38
Maliboda	0.14	0.93	25.39
Nuwara Eliya	- 1.02	- 1.46	-11.43
Pasyala	0.82	0.86	11.62

***trend at 0.01 significant level, **trend at 0.05 significant level

The MK test results for annual rainfall showed that only Chesterford rainfall station has a significantly increasing trend with respect to 5 % confidence level (Table 1). Avissawella, Hanwella and Nuwara Eliya stations exhibited a downward trend while Colombo, Henarathgoda, Maliboda and Pasyala stations showed an upward trend. According to Sen's slope results for the period of 1983–2013, the trend magnitude varies between -10.65 $mmyear^{-1}$ (Avissawella) to 30.59 $mmyear^{-1}$ (Chesterford).

Annual streamflow and rainfall trends based on ITA method

The visual display provides observed changes as increasing, decreasing or no trend (Figure 2). The results showed decreasing annual streamflow trends at all the stations and the *D* values were always negative. Thus, these results are comparable with the MK test results.

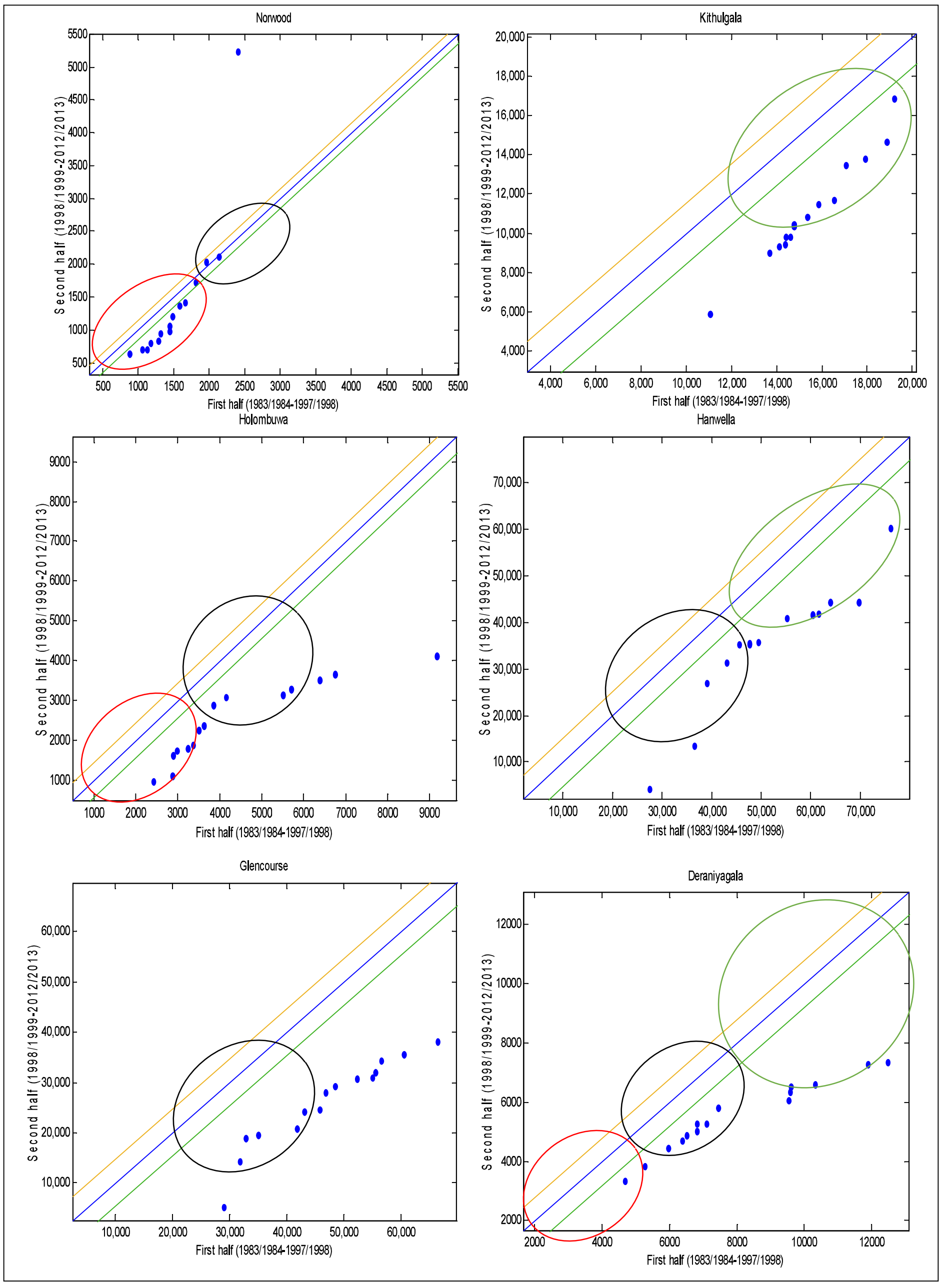

Figure 2: The results of ITA for annual streamflow of Kelani river

Holombuwa station showed low and medium streamflow values in decreasing trend. At Norwood streamflow station, no significant trend was observed for the medium streamflow (between 1500–2500 m^3 s^{-1}year^{-1}). Glencourse station showed a higher decreasing trend of medium streamflow values. Furthermore, Hanwella and Deraniyagala exhibited medium and high streamflow values in decreasing trend and Kithulgala showed a decreasing trend of higher streamflow values. Considering the magnitude of the innovative trend of annual streamflow and spatial distribution of the gauging stations, the declining trend of streamflow exhibits an upward trend from the midstream to the downstream of the Kelani river. There may be different causes for the streamflow declining trend such as lowering rainfall, land use change, water withdrawal, dam constructions, water infiltration, surface evapotranspiration, etc. (Abeysingha *et al*., 2015).

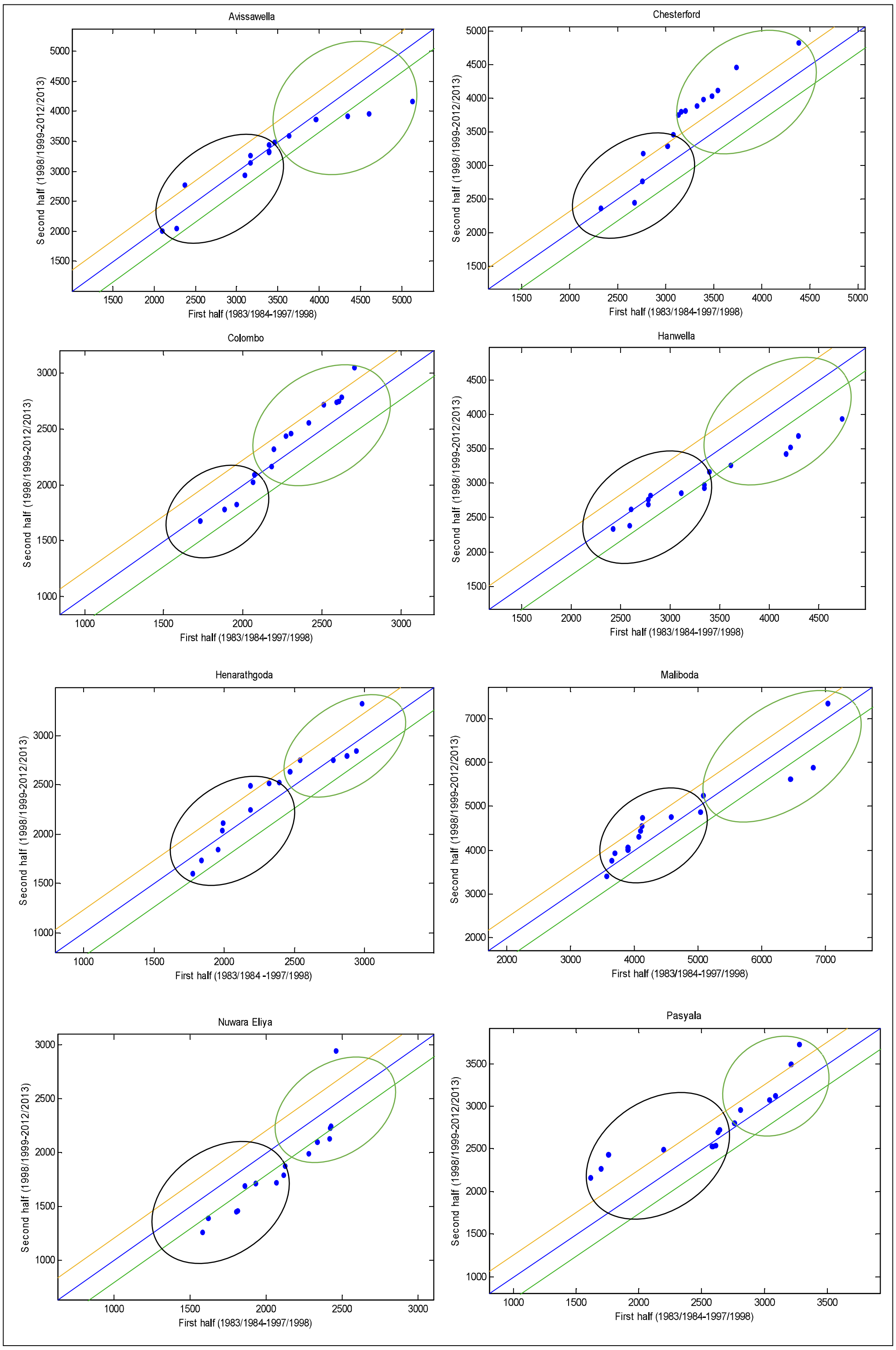

Figure 3: The results of ITA for annual rainfall of Kelani river

An increasing trend in annual rainfall was observed in 62 % of the stations, and there is a decrease in annual rainfall in 37 % of the stations (Table 1). In Chesterford and Pasyala stations, medium and high rainfall values showed a considerable increasing trend than Colombo, Henarathgoda and Maliboda. Therefore, the increase in higher rainfall may affect the erosion of the soil and may also lead to flood conditions in these downstream areas. Therefore, proper land and soil management practices are needed for these locations. Moreover, a decreasing trend in annual rainfall is observed in three stations. At Avissawella and Hanwella stations high rainfall values were slightly decreasing and in Nuwara Eliya, the medium and high rainfall values showed a decreasing trend (Figure 3). As a whole, the results infer that the trend of annual rainfall tested using ITA and MK tests gave similar results for all of the stations. Similarly, comparing the results of the MK test and ITA method, Gedefaw *et al.* (2018) reported similar results for annual rainfall variability in Amhara Regional State, Ethiopia.

Overall, 67 % and 83 % of streamflow stations in Kelani basin showed a decreasing trend in medium and high values, respectively, in annual streamflow time series. However, 50 % of rainfall stations showed an increasing trend in both high and medium rainfall values when the trend was analysed using ITA method.

Seasonal streamflow and rainfall trend analysis in *Kelani* river basin

Seasonal streamflow and rainfall trends based on MK test and Sen's slope estimator

Sri Lanka experiences two monsoon seasons, namely, SWM and NEM and the same seasonal pattern is observed for the selected Kelani basin. Seasonal streamflow trend according to the MK tests showed that all stations during SWM and SIM were in decreasing trend with all stations showing a significant decreasing trend ($\alpha = 0.05$) during SWM (Table 2). According to the MK trend test, streamflow during the FIM showed a decreasing trend at four stations out of six stations. Streamflow during the NEM showed a decreasing trend at five stations out of six stations. However, out of those, Hanwella (-130.50 $m^3 s^{-1} season^{-1}$) and Holombuwa (-9.64 $m^3 s^{-1} season^{-1}$) stations showed a statistically significant decreasing trend ($\alpha = 0.01$ and 0.05) during NEM. This study could observe a statistically significant decreasing trend of streamflow ($\alpha = 0.01$ and 0.1) at Deraniyagala (-36.92 $m^3 s^{-1} season^{-1}$) and Holombuwa (-22.256 $m^3 s^{-1} season^{-1}$) during SIM. Overall, almost all seasonal streamflow values at all stations were decreasing except the most upstream Norwood station.

Rainfall during the FIM showed an increasing trend at seven stations out of eight stations (Table 2) for MK trend test. However, only Chesterford, Colombo and Maliboda stations exhibited statistically significant increasing trends at 7.18, 6.18 and 10.72 mm $season^{-1}$, respectively ($\alpha = 0.01$ and 0.1).

This study observed a decreasing trend only at *Hanwella* station (-0.100 mm $season^{-1}$) during FIM for the MK test. Similarly, the trend of rainfall in four stations showed an increasing trend during SIM (Table 2). The MK test results of this study generally showed that the rainfall trend during SWM (at six stations) is decreasing during 1983–2013.

However, during SWM season, Chesterford and Pasyala stations exhibited significant increasing trends at rates of 11.96 and 15.18 mm $season^{-1}$, respectively, and Nuwara Eliya station showed a statistically significant decreasing trend at a rate of -16.24 mm $season^{-1}$ ($\alpha = 0.05$). Rainfall during NEM did not show any significant trend, but seven stations showed increasing trends, and only Hanwella station exhibited a decreasing trend. However, these results confirm that the climate seasonal rainfall during NEM is increasing while it is decreasing during the SWM season. Similar results have been reported by Karunathilaka *et al*. (2017) using the MK test and Sen's slope estimator for rainfall during 1966 to 2015 for entire Sri Lanka. Raj and Azeez (2012) also reported significantly decreasing trend of SWM season rainfall over the Bharathapuzha river basin in Kerala during 1968 to 2002.

Seasonal streamflow and rainfall trends based on (ITA) method

The ITA results of FIM indicated that 50 % of the stations recorded an increasing streamflow trend in low values at Norwood, Glencourse and Deraniyagala and 50 % of the stations had decreasing streamflow trend in both low and medium streamflow values at Kithulgala, Hanwella and Holombuwa (Figure not shown).

The ITA and MK tests demonstrated similar trend results for 83 % of the stations for seasonal trend analysis (Table 3). Although Deraniyagala station showed a decreasing trend according to the MK test, it showed an increasing trend based on ITA test results (Table 2). During SIM season, all of the stations showed a decreasing trend while Deraniyagala, Kitulgala, Glencourse, Hanwella and Holombuwa stations showed a highly decreasing trend for both medium and high streamflow values. Norwood station showed both increasing and decreasing trends in medium streamflow

Table 2: Climate seasonal streamflow and rainfall in *Kelani* river basin

Station	FIM			SWM			SIM			NEM		
	ITA	MK	Sen's slope	ITA	MK	Sen's slope	ITA	MK	Sen's slope	ITA	MK	Sen's slope
	D	Calculated Z value	Slope ($m^3 s^{-1} season^{-1}$)	D	Calculated Z value	Slope ($m^3 s^{-1} season^{-1}$)	D	Calculated Z value	Slope ($m^3 s^{-1} season^{-1}$)	D	Calculated Z value	Slope ($m^3 s^{-1} season^{-1}$)
Streamflow												
Deraniyagala	0.09	- 0.11	- 0.50	- 3.86	- 2.20**	- 76.54	- 3.46	- 2.71***	- 36.92	- 1.44	- 0.16	- 1.15
Glencourse	0.12	0.14	2.64	- 4.55	- 2.22**	- 557.92	- 4.68	- 1.63	- 231.47	- 1.71	- 1.14	- 50.43
Hanwella	- 0.39	- 1.71*	- 66.96	- 2.99	- 2.14**	- 389.69	- 2.55	- 1.13	- 157.08	- 2.85	- 2.99***	- 130.50
Holombuwa	- 2.67	- 1.29	- 5.08	- 4.95	- 2.03**	- 40.88	- 4.06	- 1.86*	- 22.26	- 4.39	- 2.03**	- 9.64
Kithulgala	- 2.26	- 1.49	- 16.06	- 2.99	- 2.28**	- 132.63	- 2.79	- 0.96	- 29.10	- 2.21	- 1.46	- 16.56
Norwood	7.42	0.99	2.04	- 1.59	- 1.99**	- 13.23	- 2.44	- 0.99	- 3.13	2.16	0.14	0.29
Rainfall												
Avissawella	2.25	0.57	3.07	- 1.58	- 1.53	- 13.57	- 0.94	- 0.04	- 0.53	2.21	0.49	2.35
Chesterford	3.98	1.73*	7.18	0.65	1.96**	11.96	0.03	0.75	7.64	3.48	0.64	3.63
Colombo	3.99	1.71*	6.18	- 1.64	- 1.36	- 8.12	1.06	1.64	8.45	2.85	0.39	1.49
Hanwella	1.07	- 0.05	- 0.10	- 1.74	- 1.25	- 10.52	- 0.39	- 0.18	- 1.04	- 1.33	- 1.46	- 6.32
Henarathgoda	2.83	0.89	2.16	- 1.23	- 0.75	- 4.63	0.98	0.75	3.69	1.98	0.86	2.42
Maliboda	5.25	2.64***	10.72	- 1.13	- 0.39	- 5.89	- 0.83	- 0.39	- 2.01	3.80	1.49	8.19
Nuwara Eliya	2.86	1.18	3.92	- 2.89	- 2.49**	- 16.24	- 0.94	0.93	2.30	1.94	0.86	4.21
Pasyala	3.24	1.14	6.34	1.19	2.39**	15.18	- 2.00	- 1.49	- 9.90	0.39	0.75	5.00

***trend at 0.01 significant level, **trend at 0.05 significant level, *trend at 0.1 significant level values (Figure not shown). During SWM season, all the stations showed a decreasing trend while Hanwella, Glencourse, Holombuwa and Kithulgala stations showed a highly decreasing trend for both medium and high streamflow values (Figures not shown). Deraniyagala and Norwood stations showed a slightly decreasing trend according to the Figures. However, Norwood station displayed a slightly increasing trend for medium and high streamflow values. During NEM season, 83 % of the stations showed a decreasing streamflow trend while Deraniyagala, Glencourse, Holombuwa and Hanwella stations exhibited a highly decreasing trend for medium values. Kithulgala station showed a slightly decreasing trend for medium and high values while Norwood station showed an increasing trend for low values.

Table 2 presents the ITA results for seasonal rainfall. All of the tested locations showed an increasing trend of rainfall during FIM and 87 % of the stations showed an increasing trend during NEM season with their *D* values being always positive. In contrast, rainfall trend at 75 % of the stations during SWM season and at 62 % of the stations during SIM season exhibited a decreasing trend (Table 2). The overall result of the ITA method for seasonal rainfall indicated an increasing trend during the FIM and NEM seasons at majority of the stations, which is approximately similar to the results based on the MK test. The SWM and SIM seasons show downward rainfall trends similar to the findings from the MK test results. The results showed an overall increasing trend during NEM and FIM, which is also similar to the findings of Karunathilaka *et al*. (2017) for most of the stations in Sri Lanka.

Out of the stations which exhibited increasing rainfall trends during FIM, at Chesterford and Maliboda, both low and medium precipitation values were recorded to be increasing. Avissawella, Hanwella, Henarathgoda, Nuwara Eliya, Colombo and Pasyala exhibited increasing rainfall trends in all low, medium and high values during FIM for the ITA test (Figure not shown). It is clear from Table 2 that the ITA and MK trend test presented similar trend results for 87 % of the stations during 1983–2013 for FIM. However, Hanwella station showed a decreasing rainfall trend according to the MK test and an increasing trend based on ITA test result.

During the SIM season, 62 % of the stations showed a moderate decreasing trend while Pasyala station showed a highly decreasing trend for low and medium rainfall values. A highly increasing trend was observed at Henarathgoda and Colombo stations for high rainfall values (Figure not shown). The ITA and MK test gave similar trend results for 87 % of the stations during SIM (Table 2) while Nuwara Eliya station showed an increasing trend according to the MK test. However, this station showed a decreasing trend based on the ITA test result. During SWM season, 75 % of the stations showed a decreasing trend while Nuwara Eliya station showed a highly decreasing trend for medium and high precipitation values. Similarly, Avissawella, Henarathgoda and Hanwella stations exhibited a decreasing trend for medium and high rainfall values. However, Chesterford and Pasyala stations showed a slightly increasing trend for low, medium and high values during SWM (Figures not shown). Decrease in rainfall during the SWM, which is the main rainfall season for the basin may be partly attributed to the decrease in streamflow during the same period at most of the stations and annual decreased streamflow at most of the stations.

During NEM season, 87 % of the stations exhibited an increasing rainfall trend while Avissawella, Chesterford, Colombo and Maliboda stations showed a highly increasing trend for medium and high values. Henarathgoda, Nuwara Eliya and Pasyala stations exhibited a slightly increasing trend for low, medium and high values. Only Hanwella station showed a decreasing trend for medium and high value (Figure not shown). Moreover, the FIM and NEM seasonal rainfall is increasing for the entire basin. Although rainfall has increased, the decreased trends in streamflow indicate that the rate of water withdrawal from the basin is much higher than the runoff generated from increased rainfall. The months of FIM and NEM are comparatively drier seasons for the basin. During this time the river may act as an influent stream which causes the decreased streamflow. In addition, during this time, there is a saltwater intrusion issue in the river towards the downstream. Thus, the decreased streamflow may aggravate the problems along with seawater intrusion.

Streamflow and rainfall trends during cropping seasons in Kelani river basin

Cropping season streamflow and rainfall trends based on MK test and Sen's slope estimator

The MK test results of this study exhibited that the streamflow trend during *Maha* and *Yala* are in a decreasing trend in all stations. According to MK trend test, streamflow during *Maha* showed a 100 % decreasing trend at all stations. Deraniyagala, Glencourse, Hanwella and Holombuwa stations showed statistically significant decreasing trends (α = 0.05) at rates -44.31, -327.49, -353.06 and -39.21 $m^3 s^{-1} season^{-1}$, respectively during 1983–2013. Kithulgala and Norwood showed non-significant decreasing trends (Table 3). Similarly, during *Yala* season, Deraniyagala, Glencourse, Hanwella, Holombuwa and Kithulgala stations exhibited statistically significant decreasing trends (α = 0.05 and 0.1) at -71.27, -538.12, -422.34, -48.51 and -143.76 $m^3 s^{-1} season^{-1}$, respectively. Moreover, Norwood station showed a non-significant decreasing trend. The MK test on rainfall during *Maha* did not show any significant trend (α = 0.01, 0.05 and 0.1). However, rainfall showed a non-significant increasing trend at six stations out of eight stations and Avissawella (-1.48 mm $season^{-1}$) and Hanwella (-13.12 mm $season^{-1}$) showed a decreasing trend. During *Yala* season, Chesterford and Pasyala stations showed a statistically significant increasing trend (α = 0.05) at a rate of 24.89, 16.31 mm $season^{-1}$, respectively and Nuwara Eliya station exhibited a statistically significant decreasing trend (α = 0.05) at a rate of -16.59 mm $season^{-1}$ during *Yala* season for the MK test (Table 3).

Table 3: Trends on cropping season streamflow and rainfall in Kelani river basin

Station	*Maha*			*Yala*		
	ITA	MK	Sen's slope	ITA	MK	Sen's slope
	D	Calculated Z value	Slope ($m^3 s^{-1} season^{-1}$)	D	Calculated Z value	Slope ($m^3 s^{-1} season^{-1}$)
Streamflow						
Deraniyagala	- 2.78	- 2.43**	- 44.31	- 3.31	- 1.86*	- 71.27
Glencourse	- 3.66	- 2.17**	- 327.49	- 4.16	- 2.27**	- 538.12
Hanwella	- 2.60	- 2.03**	- 353.06	- 2.64	- 1.96**	- 422.34
Holombuwa	- 4.18	- 2.32**	- 39.21	- 4.55	- 1.91*	- 48.51
Kithulgala	- 2.65	- 1.21	- 55.13	- 2.96	- 2.43**	- 143.76
Norwood	- 0.18	- 0.96	- 5.97	- 0.67	- 1.11	- 9.89
Rainfall						
Avissawella	0.26	- 0.21	- 1.48	- 0.92	- 1.07	- 15.34
Chesterford	1.29	1.11	11.82	1.35	2.46**	24.89
Colombo	1.73	1.29	9.68	- 0.66	- 0.64	- 3.09
Hanwella	- 0.73	- 1.39	- 13.12	- 1.12	- 0.93	- 8.90
Henarathgoda	1.54	0.68	3.83	- 0.61	- 0.71	- 3.92
Maliboda	1.88	1.57	16.62	- 0.71	- 0.36	- 4.87
Nuwara Eliya	0.72	0.96	6.25	- 2.94	- 2.53**	- 16.59
Pasyala	0.56	0.11	1.48	1.05	2.14**	16.31

***trend at 0.01 significant level, **trend at 0.05 significant level, *trend at 0.1 significant level

Cropping season streamflow and rainfall trends based on ITA method

All stations showed a negative *D* value for the ITA test, indicating a decreasing trend of streamflow during both *Maha* and *Yala* seasons. This study could observe 100 % similar results from both trend tests during *Yala* and *Maha* cropping season streamflow. In *Maha* season, Kithulgala station showed a highly decreasing trend for medium and high values. Low and medium streamflow at Gelncourse, Deraniyagala, Holombuwa and Norwood stations exhibited slightly decreasing trends for low and medium streamflow (Figure not shown). At Hanwella station, the low, medium and high streamflow values were in a slightly decreasing trend in *Maha* season. Glencourse station showed a highly decreasing trend for medium values in *Yala* season (Figures not shown). In Kithulgala station, the low and medium flow values expressed a decreasing trend and high streamflow value showed a highly decreasing trend. Holombuwa, Deraniyagala and Hanwella stations exhibited a decreasing trend for low and medium flow values according to the graphs. In Norwood station, low streamflow values showed a slightly decreasing trend and medium flow values showed a slightly increasing trend.

The ITA results for cropping seasonal rainfall indicated that 87 % of the stations recorded an increasing trend during *Maha,* while 75 % of the stations showed a decreasing trend during *Yala* season (Table 3). The ITA and MK test produced similar trend results for 87 % of the stations during Maha season. Only Avissawella station showed a decreasing trend according to the MK test and this station showed an increasing trend based on ITA test result during Maha season. During Maha season, Chesterford and Colombo showed a highly increasing rainfall for medium values. Holombuwa, Kithulgala and Hanwella stations exhibited highly decreasing trends for high values. During *Yala* season, Hanwella, Maliboda, Avissawella and Henarathgoda stations showed a decreasing trend for high values (Figures not shown). In between these stations, Nuwara Eliya exhibited a highly decreasing trend for both medium and high values. Chesterford and Pasyala showed slightly increasing trends for medium values. Medium and high rainfall values in Colombo station showed a slightly decreasing trend.

Overall, 87 % and 75 % of rainfall stations showed increasing trends in medium and high values, respectively in *Maha* season, and 62 % of the rainfall stations showed a decreasing trend in both medium and high values in *Yala* season. This increase of high and medium rainfall values may create flood conditions and the retainable and utilisable water may be less. When streamflow stations are concerned, 83 % showed a decreasing trend in medium values during *Maha* season and 83 % and 50 % of streamflow stations showed a decreasing trend in medium and high values, respectively, in *Yala* season.

To compare the two trend analysis methods, *D* values of ITA and *Z* values of MK test of all time series tested were taken into a scatter plot (Figure not shown) and the correlation between the two methods using Spearman's rho correlation test was determined. *D* displays very strong correlation with mostly accepted MK *Z* values both in annual streamflow and rainfall (ρ = 0.71), cropping season streamflow and rainfall time series (ρ = 0.71) and climate seasonal streamflow and rainfall (ρ = 0.67). It indicates that the ITA method can be used as a simple method to test the trend and also visually detect the trend, and mainly to find the trend of high, medium and low values.

Spearman's rho correlation coefficient (ρ) between streamflow and rainfall

Average rainfall was computed using the Thiessen polygon method for the delineated sub-basins of the Kelani river basin (Deraniyagala, Glencourse, Hanwella, Holombuwa, Kithulgala and Norwood). Then the catchment rainfall and streamflow (at the outlet of each catchment) were compared using Spearman's rho correlation coefficient (ρ). There was a positive correlation between streamflow and catchment rainfall at all time scales tested for all catchments. The maximum ρ was observed for annual streamflow at Kithulgala gauging station (ρ = 0.61) with its catchment annual rainfall and the minimum ρ was at Holombuwa station (ρ = 0.17) with its catchment rainfall. Association between streamflow and catchment rainfall for the tested average annual, climate and cropping seasons were significant (α = 0.05) for 50 %, 75 % and 41 % of stations, respectively. These significant correlations suggest that the variation of streamflow is partly attributed to the variation of catchment rainfall. Particularly, the variation of climate seasonal streamflow is strongly attributed to the variation of rainfall.

Table 4: Trend of mean annual temperature of two stations in Kelani river basin

Temperature gauging stations	Mean annual temperature (°C)		
	D	Z	Sen's slope (°C year^{-1})
Colombo	0.007	1.003	0.005
Nuwara Eliya	0.071	0.935	0.004

Moreover, this study tested the temperature trend of the basin taking the available data during 1983–2013. According to the MK test and Sen's slope values, Colombo and Nuwara Eliya showed an increasing trend in mean annual temperature (Table 4). Moreover, ITA results for mean annual temperature exhibited an increasing trend for both stations. Therefore, the decreasing trend of streamflow and rainfall during SWM and SIM towards the downstream area with the increasing temperature trend indicate a drying tendency of Kelani river basin over the study period.

The trend results from both ITA and MK test have been were summarised in Table 5. The table shows that more than 50 % of the stations recorded similar trend results when tested with MK test and ITA. It is alarming that the streamflow is in a decreasing trend during annual, seasonal, and *Yala* and *Maha* seasons in more than 50 % of the streamflow stations. However, annual, NEM and FIM and *Maha* rainfall stations showed an increasing trend. The SWM, SIM and *Yala* rainfall which cover the main months that brings rainfall to the basin have a decreasing trend and this study also showed the strong relationship between the streamflow and rainfall. Therefore, one of the main drivers of the decreasing trend of streamflow is the decreasing trend of rainfall in the basin. The decreasing trend of streamflow in the downstream areas of the river may be partly caused by the variations in rainfall and partly by other anthropogenic factors such as increased water withdrawal.

Table 5: Summary of the trend results of MK test and ITA method

Time scale		ITA (≥ 50)	MK (≥ 50)
Annual streamflow		↓	↓
Annual rainfall		↑	↑
Climate seasonal streamflow	FIM	↓	↓
	SWM	↓	↓
	SIM	↓	↓
	NEM	↓	↓
Climate seasonal rainfall	FIM	↑	↑
	SWM	↓	↓
	SIM	↓	↓
	NEM	↑	↑
Cropping seasonal streamflow	*Yala*	↓	↓
	Maha	↓	↓
Cropping seasonal rainfall	*Yala*	↓	↓
	Maha	↑	↑

Streamflow reduction mainly affects municipal water use of the metropolitan cities of Colombo and Gampha area as NWSDB tap water mostly from the Kelani river basin. In addition, these trend results in both streamflow and rainfall are useful in planning especially for the agriculture sector because a large number of minor irrigation projects in the Colombo and Gampaha districts are based on the Kelani River and its tributaries (Goonatilake *et al*., 2016).

In most of the stations rainfall has increased during the *Maha* seasons. The decreased trends in streamflow in *Maha* season indicate that the rate of water withdrawal from the basin is much higher than the runoff generated from increased rainfall.

Kelani river and its tributaries support about 150 km^2 of paddy lands and a range of other crops (Goonatilake *et al*., 2016). In addition, the NWSDB obtains water from the Kelani river. Two large industrial zones located at Seethawaka and Biyagama are in the river basin and a large number of industries are located outside the industrial zones along the river (Abeykoon & Nawarathna, 2011). These industries use Kelani river water for their industrial purposes. There are five hydropower dams in the most upstream reach of the basin and in a tributary of the middle reach of the basin, while there are two dams to supply municipal water to the Colombo metropolitan area (Abeykoon & Nawarathna, 2011). The retention of water in these reservoirs and water withdrawn influence the deceased trend of water in the river during *Maha* season although the rainfall has an increased trend. Moreover, agro-based small-scale businesses use Kelani river basin water. Since streamflow in most of the stations (annual, climate seasons, *Yala* and *Maha* seasons) are in a decreasing trend, increased water withdrawal in the future would have an effect on the environmental flow of the river and its tributaries. Moreover, declining streamflow may have detrimental impacts on the aquatic biodiversity of the river and its ecosystem, recharging capacity of groundwater and natural decontamination ability of the river water.

The present study showed a downward trend of streamflow at all selected flow stations. However, it is reported that the Kelani river spills over in a considerable frequency (Nanseer & Rajkumar, 2006). Two-thirds of the entire catchment is in the upper reaches in the hilly region with steep slopes and the lower reaches are in the coastal area which is very flat (Abeykoon & Nawarathna, 2011). Consequently, heavy precipitation and the quick runoff in the upper catchment cause the river to overflow its banks in the lower flat region. Another reason would be the sea level rise and salt water intrusion in the lower basin. It is visible during the low flow periods with salt water travelling up to Ambathale water treatment plant area (Abeykoon & Nawarathna, 2011).

These hydroclimatic trends demand to modify the prevailing cropping and water withdrawal patterns and to develop suitable strategies to improve agricultural production with less agricultural water and industrial water usage with proper care and planning.

CONCLUSION

Streamflow of Kelani river basin at an annual scale showed a decreasing trend at all flow stations tested during 1983–2013. This result has been confirmed by both ITA and MK tests. Moreover, the MK test confirms the significant decrease at five stations out of the tested six stations. However, the annual rainfall at 62 % of the stations in the basin showed an increasing trend based on the MK test and 62 % of the stations showed an increasing trend based on the ITA test. Streamflow during FIM and SWM showed to be decreasing in more than 50 % and 83 % of the stations, respectively, and this result is confirmed by both test methods. However, rainfall during both FIM and NEM recorded an increasing trend at more than 87 % of the stations. The ITA and MK analysis methods confirmed that streamflow and also rainfall during SWM and SIM were in a decreasing trend for more than 50 % of the stations. Both analysis methods showed that streamflow during *Maha* and *Yala* seasons were in a decreasing trend at all the stations. However, rainfall during *Maha* was in an increasing trend at more than 75 % of the stations and rainfall during *Yala* was in a decreasing trend at 75 % of the stations. Increased *Maha* rainfall also includes high rainfall values, which may not contribute to the effective utilisable water in the river. There was a positive correlation between the streamflow and catchment rainfall at all time scales tested. A significant association between streamflow and catchment rainfall ($p < 0.05$) for the tested time period for 70 % of the stations suggesting that the variation of streamflow is mainly attributed to the variation of catchment rainfall. The decreasing trend of streamflow and rainfall during SWM and SIM towards the downstream area with the increasing temperature trend indicate a drying tendency of the Kelani river basin over the study period. The results of this study are useful in formulating a sustainable plan for water usage in the Kelani river basin.

REFERENCES

Abeykoon A.M.H.K. & Nawarathna N.M.A.L.B. (2011). Enhancing water quality by salinity barriers and its impact on environment, *XIVth IWRA World Water Congress*, 25–29 September, Pernambuco, Brazil, pp. 1–8.

Abeysingha N.S., Jayasekara J.M.N.S. & Meegastenna T.J. (2017). Stream flow trends in up and midstream of Kirindi Oya river basin in Sri Lanka and its linkages to rainfall. *Mausam* **68**: 99–110.

Abeysingha N.S., Singh M., Sehgal V., Khanna M. & Pathak H. (2015). Analysis of trends in streamflow and its linkages with rainfall and anthropogenic factors in Gomti River basin of North India. *Theoretical and Applied Climatology* **123**(3–4): 785–799. DOI: https://doi.org/10.1007/s00704-015-1390-5

Ampitiyawatta A. & Guo S. (2010). Precipitation trends in the Kalu Ganga basin in Sri Lanka. *Journal of Agricultural Sciences* **4**(1): 1–10. DOI: https://doi.org/10.4038/jas.v4i1.1641

Chandimala J. & Zubair L. (2007). Predictability of stream flow and rainfall based on ENSO for water resources management in Sri Lanka. *Journal of Hydrology* **335**(3–4): 303–312 DOI: https://doi.org/10.1016/j.jhydrol.2006.11.024

De Silva M.M.G.T., Weerakoon S.B., Herath S. & Ratnayake U.R. (2012). Flood inundation mapping along the lower reach of Kelani river basin under the impact of climatic change. *Engineer: Journal of the Institution of Engineers, Sri Lanka* **45**(2): 23–29. DOI: https://doi.org/10.4038/engineer.v45i2.6938

De Silva M.T., Hornberger G.M. & Baroud H. (2019). Decision analysis to support the choice of a future power generation pathway for Sri Lanka. *Applied Energy* **240**: 680–697. DOI: https://doi.org/10.1016/j.apenergy.2019.02.074

Fayas C. M., Abeysingha N.S. & Nirmanee K.G.S. (2018). Soil loss estimation using RUSLE model to prioritize erosion control in Kelani river basin in Sri Lanka. *International Soil and Water Conservation Research* **7**(2): 130–137. DOI: https://doi.org/10.1016/j.iswcr.2019.01.003

Gedefaw M., Yan D.,Wang H., Qin T., Girma A., Abiyu A. & Batsuren D. (2018). Innovative trend analysis of annual and seasonal rainfall variability in Amhara regional state, Ethiopia. *Atmosphere (Basel)* **9**(9): 1–10. DOI: https://doi.org/10.3390/atmos9090326

Goonatilake S. de A., Perera N., Silva G.D., Weerakoon D. & Mallawatantri A. (2016). *Natural Resource Profile of the Kelani River Basin*, pp. 1–38. International Union for Conservation of Nature Sri Lanka Country Office and Central Environmental Authority, Colombo.

Hamed K. & Rao A.R. (1998). A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology* **204**(1–4): 182–196. DOI: https://doi.org/10.1016/S0022-1694(97)00125-X

Karunathilaka K.L.A.A., Dabare H.K.V. & Nandalal K.D.W. (2017). Changes in rainfall in Sri Lanka during 1966–2015. *Engineer: Journal of the Institution of Engineers, Sri Lanka* **50**(2): 39–48. DOI: https://doi.org/10.4038/engineer.v50i2.7251

Kibria K.N., Ahiablame L., Hay C. & Djira G. (2016). Streamflow trends and responses to climate variability and land cover change in South Dakota. *Journal of Hydrology* **3**(1): 1–20. DOI: https://doi.org/10.3390/hydrology3010002

Kottagoda S. & Abeysingha N. (2017). Morphometric analysis of watersheds in Kelani river basin for soil and water conservation. *Journal of the National Science Foundation of Sri Lanka* **45**(3): 273. DOI: http://dx.doi.org/10.4038/jnsfsr.v45i3.8192

Kundzewicz Z.W. & Robson A. (ed.) (2000). *Detecting Trend and Other Changes in Hydrological Data.* World

Climate Programme-Water, World Climate Programme Data and Monitoring, WCDMP-45, WMO/TD-No. 1013, World Meteorological Organization, Geneva, Switzerland. Available at *https://library.wmo.int/doc_num.php?explnum_id=4183*

Nanseer N. & Rajkumar S. (2006). Kelani Ganga conservation barrage and results of model studies. *Engineer: Journal of the Institution of Engineers, Sri Lanka* **39**(2): 42. DOI: https://doi.org/10.4038/engineer.v39i2.7185

Öztopal A. & Şen Z. (2016). Innovative trend methodology applications to precipitation records in Turkey. *Water Resources Management* **31**(3): 727–737. DOI: https://doi.org/10.1007/s11269-016-1343-5

Rahmat S.N., Jayasuriya N. & Bhuiyan M. (2012). Trend analysis of drought using Standardised Precipitation Index (SPI) in Victoria, Australia. *34th Hydrology and Water Resources Symposium*, 19–22 November, Sydney, Australia, pp. 441–448.

Raj P.P.N. & Azeez P.A. (2012). Trend analysis of rainfall in Bharathapuzha River basin, Kerala. *International Journal of Climatology* **32**(4): 533–539. DOI: https://doi.org/10.1002/joc.2283

Sen P.K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association* **63**: 1379–1389.

Şen Z. (2012). Innovative trend analysis methodology. *Journal of Hydrologic Engineering* **17**: 1042–1046. DOI: https://doi.org/10.1061/(ASCE)HE.1943-5584.0000556

Şen Z. (2014). Trend identification simulation and application. *Journal of Hydrologic Engineering* **19**: 635–642. DOI: https://doi.org/10.1061/(ASCE)HE.1943-5584.0000811

Şen Z. (2015). Innovative trend significance test and applications. *Theoretical and Applied Climatology* **127**(3–4): 939–947. DOI: https://doi.org/10.1007/s00704-015-1681-x

Theil H. (1950). A rank-invariant method of linear and polynomial regression analysis, *International Proceedings, Koninklijke Nederlandse Akademie van Wetenschappen* A53: 386–3

Wu H. & Qian H. (2016). Innovative trend analysis of annual and seasonal rainfall and extreme values in Shaanxi, China, since the 1950s. *International Journal of Climatology* **37**(5): 2582–2592. DOI: https://doi.org/10.1002/joc.4866

Zubair L., Rao S.A. & Yamagata T. (2003). Modulation of Sri Lankan Maha rainfall by the Indian Ocean Dipole. *Geophysical Research Letters* **30**(2): 106. DOI: https://doi.org/10.1029/2002GL01563