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Stream flow trends in up and midstream of Kirindi Oya river basin in Sri Lanka and its linkages to rainfall

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सार – जल संसाधनों तथा कृषि उत्पादन के लिए प्रभावकारी योजना बनाने एवं प्रबंधन के लिए जल जलवायविक भिन्नताओं के ट्रेण्ड विश्लेषण से उपयोगी जानकारी प्राप्त होती है। मान केन्डल संशोधित मान-केन्डल तथा सेन के ढाल (स्लोप) का उपयोग करके वेलावाया, थनामालवीला में उर्ध्वप्रवाह तथा मध्यप्रवाह मापक स्टेशनों पर नदी के प्रवाह के ट्रेण्ड को प्रेक्षित किया गया है तथा किरीन्दी ओया नदी बेसिन में वर्षा और तापमान का निर्धारण किया गया है। 'थिसेन पोलीगन' विधि का उपयोग करके दो जल ग्रहण क्षेत्रों की तथा समूचे बेसिन की औसत वर्षा की गणना की गई है। नदी प्रवाह के ट्रेण्ड्स और जलग्रहण क्षेत्र की वर्षा के संबंधों का अध्ययन स्पीयरमैन्स रो सहसंबंध गुणांक (ρ) द्वारा किया गया है।

इसमें वेलावाया और थनामालवीला के जल ग्रहण क्षेत्रों में वार्षिक नदी प्रवाह तथा वर्षा का पाँच-पाँच वर्षों की मानक विसंगतियों का औसत (FMSA) लिया गया है जो गैर-महत्व ($p < 0.05$) की है और वर्ष 1994 से 2010 तक इसके ट्रेण्ड में गिरावट देखी गई है। यद्यपि इन दोनों जल ग्रहण क्षेत्रों में हुई वार्षिक वर्षा और नदी प्रवाह में सकारात्मक सहसंबंध रहा है, यह सहसंबंध केवल थनामालवीला (0.69) में महत्वपूर्ण ($p < 0.05$) रहा है। इससे पता चला है कि थनामालवीला जी एस (GS) के वार्षिक नदी प्रवाह में भिन्नता मुख्य रूप से जलग्रहण क्षेत्र में हुई वर्षा के कारण है। यद्यपि इन दोनों जल ग्रहण क्षेत्रों की वर्षा में भिन्नता महत्वपूर्ण रही है जिसका उच्चतम मान 'ρ' वेलावाया में 0.61 तथा थनामालवीला में 0.69 रहा है। इस अध्ययन में यह भी पाया गया है कि समूचे बेसिन, थनामालवीला तथा वेलावाया के उप-जलग्रहण क्षेत्रों में दक्षिण पश्चिमी मॉनसून (SWM) वर्षा के FMSA के ट्रेण्ड में महत्वपूर्ण रूप से गिरावट आई है। दक्षिण पश्चिमी मॉनसून के दौरान वेलावाया जी एस के जल प्रवाह में भी अधिक गिरावट पाई गई है जबकि थनामालवीला के जल प्रवाह में मामूली गिरावट पाई गई है। अप्रैल माह में मॉनसून कैसा रहेगा इसके आरंभिक पूर्वानुमान (FIM) के दौरान वर्षा एवं नदी जल प्रवाह दोनों में वृद्धि की प्रवृत्ति रही है। दक्षिण पश्चिमी मॉनसून (SWM) और मॉनसून कैसा रहेगा इसके आरंभिक पूर्वानुमान (FIM) की प्रेक्षित प्रवृतियाँ यह दर्शाती हैं कि बेसिन में दक्षिण पश्चिमी मॉनसून (SWM) का आभासी रूप से पूर्व आगमन होगा, या किरीन्दी ओया रिवर बेसिन में SWM के दौरान होने वाली वर्षा में भारी विचलन होगा।

ABSTRACT. Trend analysis of hydro-climatic variables provide useful information for effective planning, designing and management of water resources and agricultural production. Trends in observed stream flow at upstream and midstream gauging stations (GS), Wellawaya, Thanamalwila & rainfall and temperature in the Kirindi Oya river basin were assessed using the Mann-Kendall, Modified Mann-Kendall and Sen's slope. Average rainfalls for the two catchments and for the entire basin were computed using '*Thessen* polygon' method. The relationships between trends in stream flow and catchment rainfall were studied by Spearman's Rho correlation coefficient (ρ).

Five year Moving averaged Standardize Anomalies (FMSA) of both annual stream flow and rainfall at Wellawaya and Thanamalwila catchments were in a non-significant ($p < 0.05$) decreasing trend for 1994 to 2010.Though there was a positive correlation between annual catchment rainfall and stream flow of these two catchments, correlation was significant ($p < 0.05$) only at Thanamalwila (0.69) suggesting that the variation of annual stream flow at Thanamalwila GS was mainly attributed to the variation of catchment rainfall. However, variation of stream flow during North East Monsoon (NEM) season was mainly attributed to the variation of respective catchment rainfall of both the catchments as evident by significant higher 'ρ' at Wellawaya (0.61) and Thanamalwila (0.69). This study also found that trend of FMSA of South West Monsoon (SWM) rain was significantly ($p < 0.05$) decreasing for the entire basin, Thanamalwila and

Wellawaya sub-catchments. Stream flow at Wellawaya GS during SWM was also found to be significantly decreasing while Thanamalwila stream flow was non-significantly decreasing. Both rainfall and stream flow during First Inter Monsoon (FIM) was in a significant increasing trend particularly in the month of April. These observed trends during SWM and FIM suggest an apparent early onset of SWM in the basin, or drastic deviation in receiving rain during SWM in the Kirindi Oya river basin.

Key words – Kirindi Oya river basin, Mann-Kendall, Rainfall, Stream flow, Trend analysis.

1. Introduction

Trend detection of stream flow and rainfall is an active area of interest for both hydrology and climatology particularly in the context of climate change. Stream flow is known to reflect an integrated response of the entire river basin, while rainfall serves as one of the major inputs into the stream flow generation processes. Stream flow trend assessment can identify needs and directions for future research and it also helps decision makers for better planning (Gautam and Acharya, 2012).The detection of changes and finding the attribution to the detected changes in the long-term time series of hydrological data is of scientific and practical importance in the water resource management and is regarded as a permanent exercise with continuously updated data. Rai *et al*. (2010) reported that the analysis of hydro - climatic condition at larger scale may lead to loss of spatial information of the variable. Therefore, it seems to be logical to analyze hydro-climatic variables at a small scale such as river basin or sub river basin scales.

A wide range of literature is available on hydro climatic trend assessment at different scales for different parts of the world, but there are a few published stream flow studies in Sri Lanka. This may probably be due to non-availability of long-term data. However, we found that Zubair (2003) analyzed the El Niño-southern Oscillation (ENSO) influences on the Mahaweli stream flow using data from 1869 to 1998. He identified a clear relationship between various ENSO indices and rainfall and stream flow in the Upper Mahaweli catchment. El Niño conditions were associated with lower average rainfall and stream flow and La Niña with the converse in upper Mahaweli catchment. Ampitiyawaththa and Guo (2009) analyzed precipitation trend in Kalu Ganga basin by using data of eight rain gauging stations for the period from 965 to 2004 and they showed decreasing trend in annual precipitation across all the gauging locations in Kalu Ganga basin. Further they found decreasing trend is more severe in downstream areas rather than the upstream areas. However, they have not analyzed the stream flow trend of Kalu Ganga river basin.

Jayawardene *et al*. (2005) analyzed trends in rainfall in Sri Lanka over the last century, utilizing over 100 years of rainfall records of 15 meteorology stations, and they found that Colombo was showing a significant increase in rainfall trend and while, in contrast Nuwara-Eliya and Kandy was showing decreasing trends. According to the results, there were no significant monotonic trends in most of the stations in Sri Lanka in the long-term rainfall records. In contrast, very heavy rainfall data analysed by Punyawardana and Premalal (2013) for the period from 1961 to 2010 in central highland in Sri Lanka showed to be increasing. It is very rare to find published literature on the trend of stream flow and their association with rainfall and other influencing factors at river basin scale in Sri Lanka. Therefore this study was carried out to investigate the stream flow trends in Kirindi Oya river basin and possible linkages for the observed changes in stream flow with rainfall. The importance of water resources planning and management in Kirindi Oya basin is increasing with the population rise, climate change and industrialization etc. According to the published literature, there were no trend analyses performed for the observed climatic variables or stream flow of the Kirindi Oya river basin. Detailed knowledge in hydro-climatic trends is essential in proper water management practices and thereby the agricultural planning in Kirindi Oya river basin.

Study area

The Kirindi Oya river basin in the South-Eastern part of the dry zone of Sri Lanka (Fig. 1.) flows from the medium range hills of Sri Lanka to the Indian Ocean (Molden *et al*., 2001). This river is 118 km long and is fed by a catchment area of 1,203 km² (Sirisena, 2008). The basin is considered closing because during parts of the year there are only very limited outflows to the Indian Ocean. During the wet seasons, there is utilizable outflow to the Indian Ocean through drains and the river is in excess of environmental requirements (Molden *et al*., 2001). The area is characterized by its arid conditions, especially the low rainfall and high ambient temperatures and lower relative humidity. This results in high evaporation, which exceeds the rainfall during most months of the year. Hence, water deficit has become a critical problem and a major deterrent on the farming systems practiced in this region. Water resources in the basin have supported agriculture since ancient time (Molden *et al*., 2001). Downstream tanks of the basin such as Yoda Wewa, Debara Wewa, Badagiriya Tank and Lunugamwehera reservoir utilize the upstream stream flow of the basin for irrigation and other users.

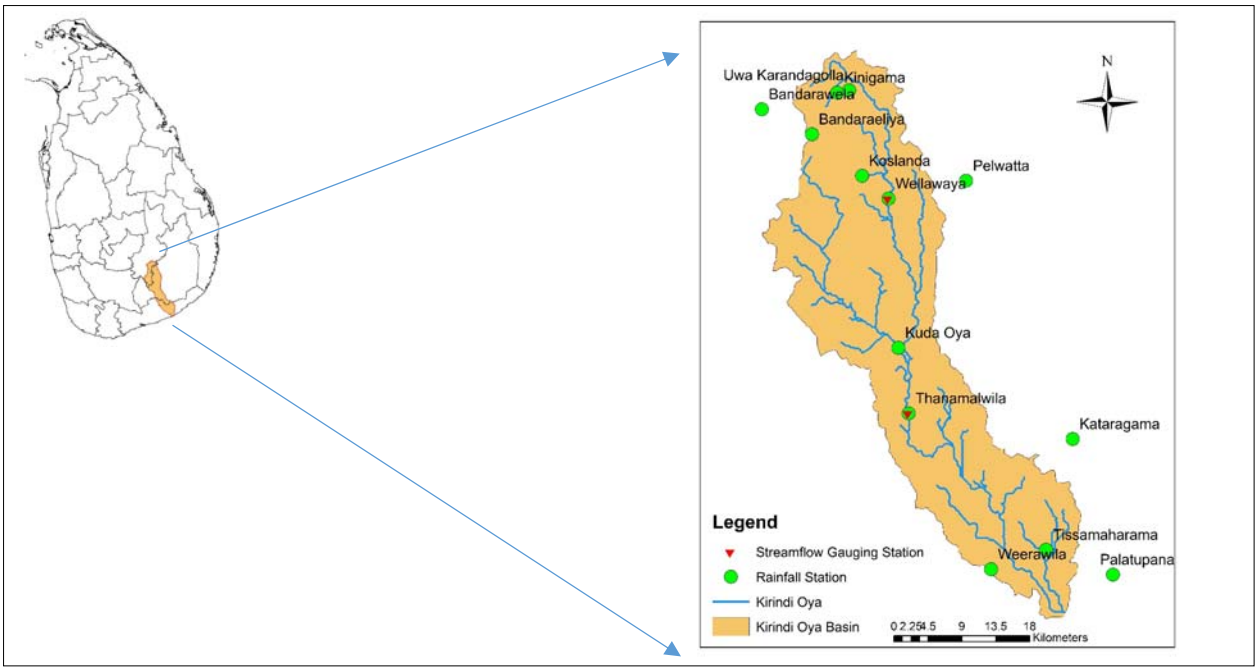


Fig. 1. Geographical distribution of major stream network, stream flow gauging stations and the rainfall stations of the Kirindi Oya river basin in Sri Lanka

TABLE 1

Characteristics of Stream flow, rainfall and temperature data used for the analysis

Name of the station	Latitude	Longitude	Data type	Period of records
		Stream flow		
Wellawaya	6.703308 °N	81.1137 °E	Daily	1980-2010
Thanamalwila	6.444935 °N	81.1375 °E	Daily	1987-2013
		Rainfall		
Bandaraeliya	6.780833 °N	81.02201 °E	Monthly	1970-1999
Bandarawela	6.810831 °N	80.962 °E	Monthly	1976-2014
Kataragama	6.41406 °N	81.3339 °E	Monthly	1989-1999
Kinigama	6.830832 °N	81.0520 °E	Monthly	1960-1992
Koslanda	6.730825 °N	81.0820 °E	Monthly	1985-2001
KudaOya	6.523832 °N	81.13761 °E	Daily	1989-2014
Palatupana	6.250777 °N	81.38206 °E	Monthly	1969-1999
Pelwatta	6.724818 °N	81.20656 °E	Monthly	1982-2011
Thanamalwila	6.444935 °N	81.13759 °E	Daily	1989-2014
Tissamaharama	6.280783 °N	81.30205 °E	Monthly	1975-2014
Weerawila	6.257376 °N	81.2363 °E	Monthly	1976-2014
Wellawaya	6.703308 °N	81.1137 °E	Daily	1989-2014
UwaKaradhagolla	6.833807 °N	81.0666 °E	Daily	1989-2014
		Temperature		
Bandarawela	6.810831 °N	80.962 °E	Monthly min and max	1979-2014
Weerawia	6.257376 °N	81.2363 °E	Monthly min and max	1990-2014

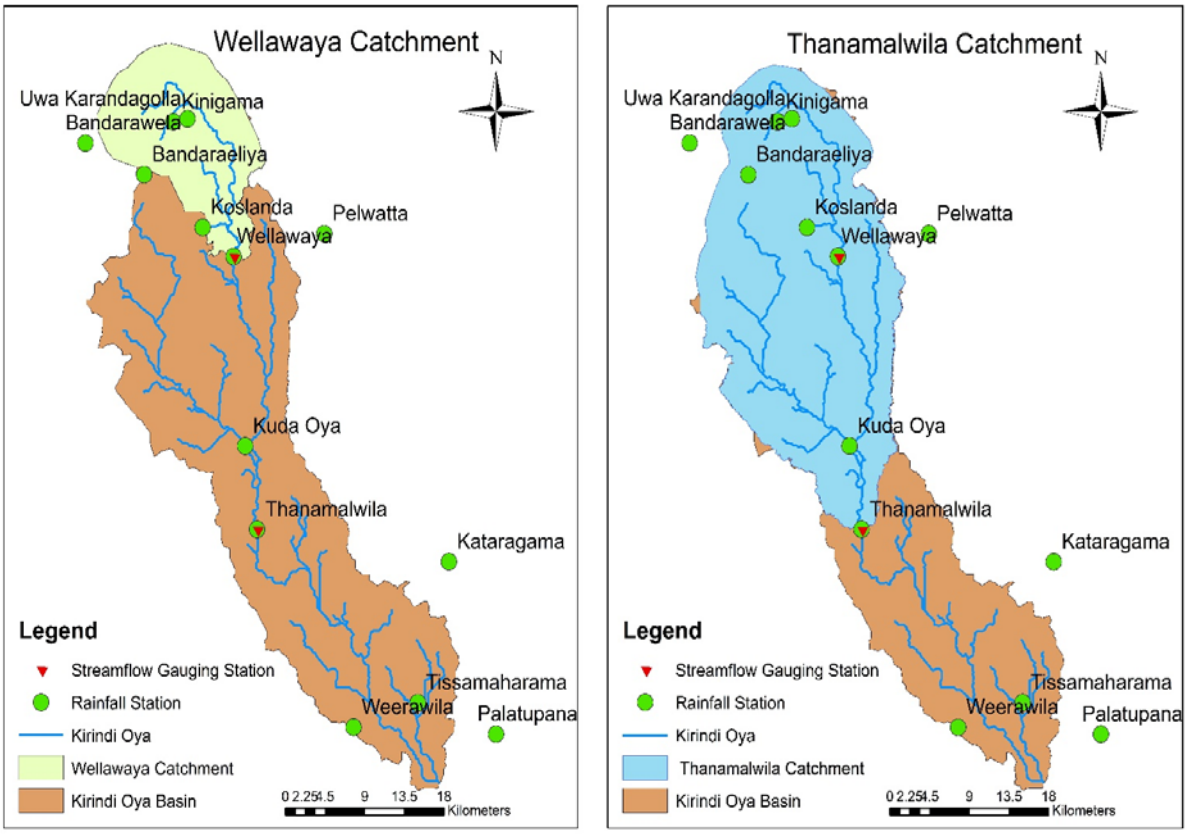


Fig. 2. Delineated catchments, Wellawaya and Thanamalwila in Kirindi Oya river basin in Sri Lanka

2. Materials and method

2.1. *Data set*

Stream flow data were collected for two gauging station from the Department of Irrigation, Sri Lanka (Table 1). The Irrigation Department is the nodal agency in Sri Lanka to record, compute, and quality check and archive all the river hydrologic data. Rainfall and temperature data were collected from the Department of Meteorology, Irrigation, and Natural Resources Management Centre (NRMC) Sri Lanka (Table 1). Length of the records varied with the stations; however, common period of records (1989-2008) were also used to assess and compare the spatial distribution of the trend of stream flow and rainfall.

In this study river basin was delineated using 30 m resolution ASTER data (www.asterweb.jpl.nasa.gov) set in ArcGIS (Ver 10.1) and the total drainage area of the river was estimated to be 1 265 km^2 (Fig. 1). Elevation of the basin ranged from 3 to 255 m amsl. Catchments with respect to two gauging stations, Wellawaya and Thanamalwila were also delineated using ArcGIS (Fig. 2).

Catchment area of Thanamalwila and Wellawaya was estimated to be 772 and 243 km^2 respectively. We considered Wellawaya sub catchment as upstream as its elevation range from 144 to 255 m amsl while Thanamalwila catchment was considered as mid-stream catchment as its elevation varies from 54 to 255 m amsl.

2.2. *Analysis of data*

Following indicators were calculated and subjected to trend analysis.

(*i*) *Monthly mean stream flow* : Mean of 30 day values of the month for a gauging station.

(*ii*) *Inter annual monthly mean stream flow* : Monthly mean stream flow of the same month over the years (Jan_{1982}, Jan_{1983}, Jan_{1984} ,…) for a gauging station.

(*iii*) *Annual mean stream flow* : Mean of twelve monthly mean stream flow values from October to September (Hydrological year) for a gauging station.

(*iv*) *Seasonal mean stream flow* : Mean of monthly mean stream flow values for first inter monsoon, northeast monsoon, second inter monsoon and southwest monsoon seasons separately.

(*v*) *Monthly maximum and minimum stream flows* : Maximum and minimum stream flow values recorded in a month for a gauging station.

(*vi*) Monthly and annual rainfall for each weather station.

(*vii*) Annual, seasonal and monthly weighted average rainfall for each of the two catchments and for the entire river basin.

(*viii*) Annual and seasonal maximum and minimum mean temperature for two whether stations.

The climate of Sri Lanka is dominated by two monsoon seasons namely the Southwest and Northeast monsoons. In between monsoon, there are two inter monsoon periods which dominate convective type rainfall. Hence, the study used four seasons, *i.e*., first inter monsoon (March to April), southwest monsoon (May to September), second inter monsoon (October to November) and northeast monsoon (December to January) in seasonal trend analysis. These durations for seasons were taken as per the guidelines of Meteorological Department of Sri Lanka (Meteorological Department of Sri Lanka, 2015). Duration of the northeast monsoon was based on December of the previous year and January and February of the following year.

Average rainfall for the two different catchments and for the entire river basin were calculated using *Thiessen* polygons method in Arc GIS environment. *Thiessen* polygon method is one of the most commonly used approach in computing average rainfall for catchments.

2.3. *Statistical analysis*

First, all these time series data used in the study (section 2.2) were tested for normal distribution using Shapiro-wilk statistical test by using XLSTAT program. The analysis revealed that more than 60% of the time series were not following a normal distribution. Therefore, monotonic trend of hydro-climatic data series in this study was tested using widely used non parametric trend detection method of Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975; Sharif *et al*., 2013) and Sen's slope estimator (Zhang and Lu, 2009; Abeysingha, 2015). However, the MK test for detecting trends may not always be ideal. That is because the original MK test does not account for the serial correlation that very often exists in a hydro-climatic time series (Hamed and Rao, 1998; Yue *et al.*, 2002; Abeysingha *et al*., 2014). Hence, each time series was first checked for a significant lag one auto-correlation. If a time series did not show a significant autocorrelation, the original MK test was used to analyze the data. When there was a significant lag-one autocorrelation in a time series, the modified MK test proposed by Hamed and Rao (1998) was adopted. The calculation algorithm of these method have been described in many authors (Rao *et al*., 2003; Rao and Azli, 2010).

The standardized anomaly was calculated for time series data of each parameter and the anomaly was smoothened by moving-window-average with a span of 5 years and then it was subjected to trend analysis. This indicator minimizes the spatial bias and reduces the random fluctuation and thus helps in comparing spatio-temporal variability in the parameters over the basin. Prospective association of stream flow with rainfall was tested using non-parametric Spearman's Rho correlation coefficient (ρ).

3. Results and discussion

3.1. *Rainfall and Stream flow Behaviour of the Kirindi Oya Basin*

In order to understand the overall behaviour of stream flow and rainfall of the basin, mean monthly stream flow and rainfall of the entire basin and two sub catchments were calculated over the period of 1980-2010. In most of the years and for all the gauging stations, the maximum mean monthly stream flow was in November; similarly, the maximum mean monthly catchment rainfall occurred in November. This implies that most of the rainfall occurring in November may be contributing to stream flow. Of the two gauging stations, the maximum stream flow was recorded at Thanamalwila gauging station (G.S.) which is the most lowest station located in the stream, and the lowest stream flow was recorded at Wellawaya G.S. which is located in the most upstream of the basin. Bimodal rainfall pattern was observed both the catchments and in the entire basin while the same pattern was recorded in stream flow of the two sub catchments.

3.2. *Trends in annual stream flow and catchment rainfall*

Trends in annual rainfall and corresponding annual mean stream flow of two catchments, Wellawaya and Thanamalwila in Kirindi Oya river basin showed no

TABLE 2

Summarized results of Mann-Kendall test with Sen's slope estimator for annual mean stream flow and annual rainfall

Station	Annual mean stream flow (Periods)	Annual mean stream flow (1990-2010)	Catchment Rainfall (1990-2010)
Wellawaya	-0.035 (1980-2009)	-0.018	-11.448
Tanamalwila	0.044 (1988-2013)	-0.024	1.693
Entire basin	-	-	15.532**

(**: 0.05 level of significance)

TABLE 3

Summarized results of Mann-Kendall test with Sen's slope estimator for seasonal mean stream flow ($m^3s^{-1}year^{-1}$) and catchment rainfall (mm $year^{-1}$) of Kirindi Oya river basin

	FIM	SWM	SIM	NEM
Stream flow at Gauging Stations				
Wellawaya (1980-2009)	0.004	-0.018	-0.123**	-0.017
Thanamalwila (1988-2013)	0.16	-0.044	-0.088	0.112
Catchment Rainfall (1989-2014)				
Entire basin	2.285	-6.595**	2.986	1.284
Wellawaya	4.867	-11.879**	-8.569	-9.72
Thanamalwila	5.353	-7.573**	-0.641	-1.589

(**: 0.05 level of significance)
Note : FIM : First inter monsoon, SWM : Southwest monsoon, SIM : Second inter Monsoon, NEM : Northeast monsoon.

statistically significant trends at significant level 0.05 (Table 2). As shown in the Table 2, trend of annual mean stream flow for the common period also showed no statistically significant differences. However, *Thiessen* polygon average catchment rainfall for the entire basin showed an increasing trend.

Both the rainfall and stream flow at Wellawaya sub catchment showed decreasing trends while stream flow at Thanamalwila GS (1980-2009) also exhibited a decreasing trend. Thanamalwila catchment rainfall showed non-significant increasing trend in annual scale. In order to compare the trends in different stations, 5-year moving averaged standardized anomalies (FMSA) of annual stream flow and rainfall were calculated and analyzed for trends and their temporal distribution is shown in Fig. 3. Sen's slope for rainfall and stream flow and also the correlation coefficient between stream flow and rainfall are also shown in Fig. 3.

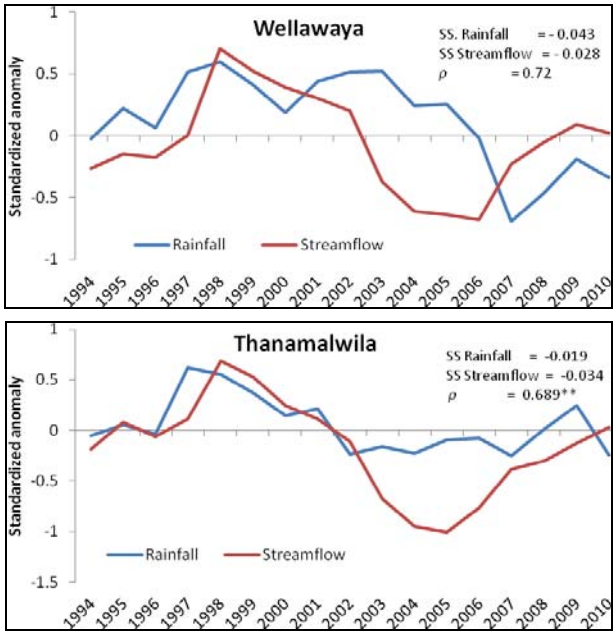


Fig. 3. The temporal distribution of the 5-year moving average of standardized anomalies of annual stream flow and rainfall for Thanamalwila, Wellawaya catchment in Kirindi Oya river basin. S.S. : Sen's slope, ρ : correlation coefficient

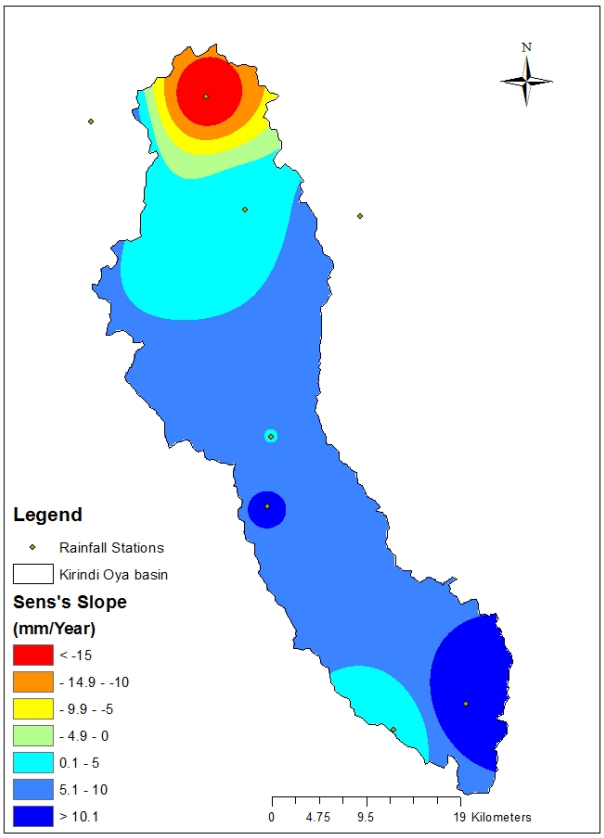


Fig. 4. Spatial distribution of annual rainfall trends (1990-2013) of *Kirindi Oya* river basin by interpolating the point data using IDW technique in ArcGIS 10.1

FMSA of both stream flow and rainfall at Thanamalwila and Wellawaya showed decreasing trends. As shown by Spearman's Rho correlation coefficient *(ρ),* there was a statistically significant positive correlation between catchment rainfall and stream flow of Thanamalwila GS. Therefore, it can be considered that the annual variation of stream flow at Thanamalwila is mainly attributed to the variation of rainfall. Meanwhile, Wellawaya GS showed a non-significant positive correlation between rainfall and stream flow. This implies that the rainfall and some other factors attribute to the variation of annual stream flow of *Wellawaya* catchment.

Fig. 5 shows the trends in annual rainfall of the entire KirindiOya river basin. This figure was obtained by interpolating the Sen's slope of eight stations with a common period of rainfall records (1990 - 2013). Interpolation method used was Inverse Distance Weighted (IDW) in Arc GIS 10.2 interface. IDW method is used to estimates the values at unknown points using the distance and values to nearby known points (Childs, 2004). This figure generally shows that the upstream area of the basin is in drying tendency when compared to the downstream area.

3.3. *Trends in mean seasonal stream flow and seasonal rainfall*

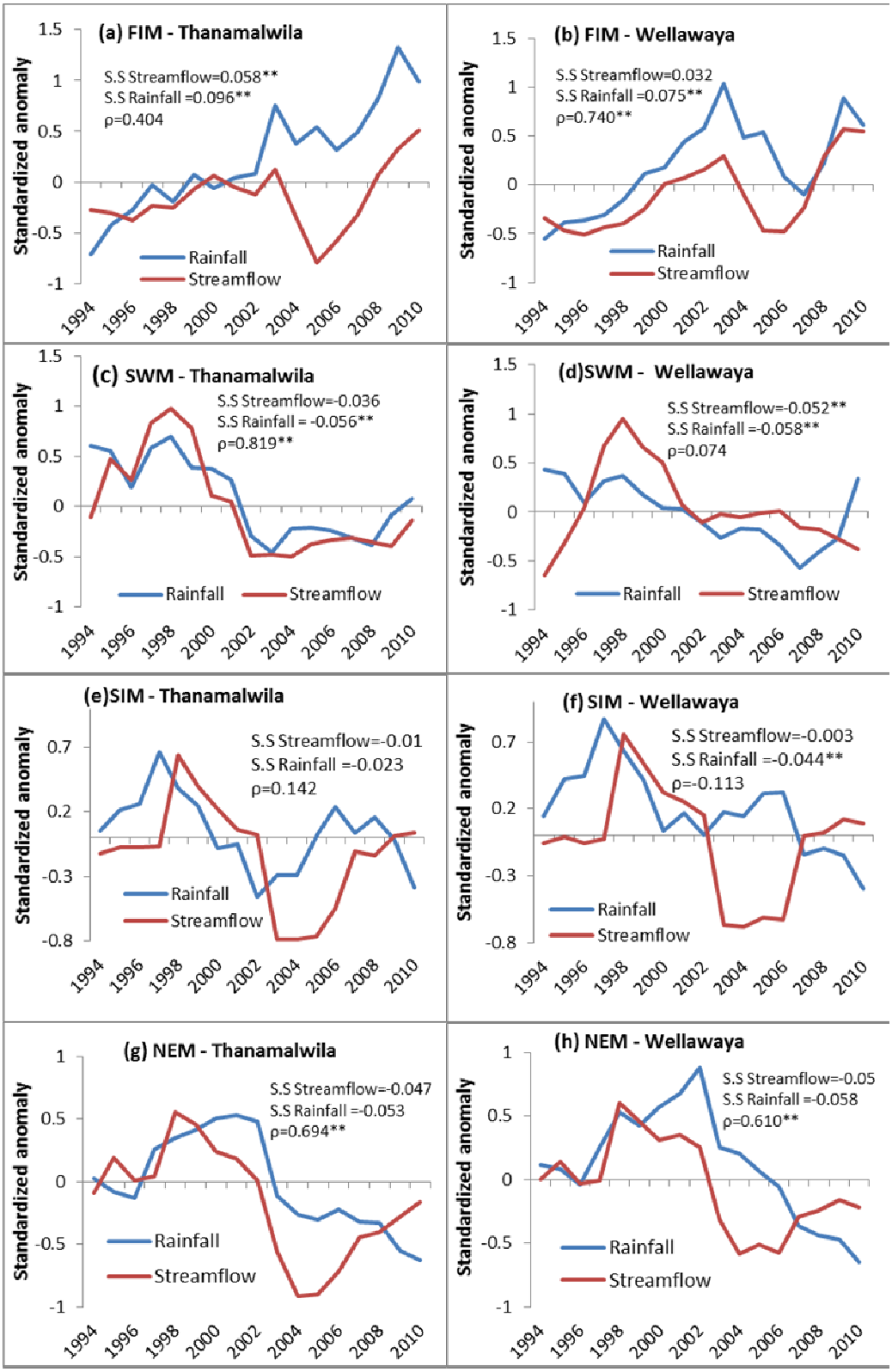
Monotonic trends in stream flow and rainfall for four seasons were analyzed separately for two catchments, and the results are shown in Table 3. Considering the overall behaviour of seasonal rainfall of the entire basin, Wellawaya and Thanamalwila catchment rainfall during South West Monsoon (SWM) season showed to be significantly decreasing. Corresponding trends in stream flow at Wellawaya and Thanamalwila GSs found to be non- significant decreasing.

In contrast, both stream flow and rainfall during First Inter Monsoon (FIM) were in increasing trend though the trends are not statistically significant. These observations occurring during SWM and FIM suggest a shifting or early onset of SWM in the basin or drastic reduction of receiving rainfall in the basin during SWM. This behaviour is further corroborated by the five year moving averaged standardized anomaly of stream flow and rainfall during FIM and SWM [Figs. 5(a-h)]. However, further analysis is required for the concrete confirmation of these behaviour.

Moreover, the trends of catchments rainfall of both Wellawaya and Thanamalwila during both Second Inter Monsoon (SIM) and North East Monsoon (NEM) were in decreasing trend from 1989 to 2014. However, rainfall trend in the entire basin during the same periods was increasing. These results infer that increasing rainfall of the downstream areas may considerably contribute to increasing trend of rainfall of the entire basin during the considered periods. Stream flow at Wellawaya and Thanamalwila during the SIM showed as decreasing trend. The significant decreasing was observed at Wellawaya GS. Stream flow during NEM were also lowering at Wellawaya. However, stream flowincrease at Thanamlwila was not significant during NEM season.

Figs. 5(a-h) show FMSA for seasonal stream flow and rainfall for the Thanamalwila and Wellawaya catchments. Both rainfall and stream flow were in an increasing trend during FIM both at Thanamalwila and Wellawaya GSs [Figs. 5(a&b)]. But, significant increasing trend for both stream flow and rainfall were observed at Thanamalwila catchment for MK test. Only rainfall at Wellawaya catchment was in a significantly increasing trend. However, there was a significant positive correlation between stream flow and rainfall at Wellawaya station whereas it was not significant at Thanamalwila though there is a positive correlation. As shown in general rainfall and stream flow trend analysis (Table 3), FMSA of both rainfall and stream flow at Thanamalwila and Wellawaya catchments showed decreasing trend during SWM, SIM and NEM [Figs. 5. (c-h)]. However, trends during SWM exhibited significant decrease. There was a positive correlation between seasonal stream flow and rainfall for all the four seasons and correlation was significant during NEM in both the catchments. This relationship indicates that seasonal variation of rainfall affects the variation of stream flow. But, variation of stream flow during NEM in both the catchments is mainly attributed to the variation of rainfall as evident by significant positive correlation coefficients. Driving forces other than rainfall may be playing a role in lowering the stream flow in other three seasons. Human activities such as water consumption, land use and land cover changes caused by forest disturbance, soil and water conservation projects, new dam construction and city expansion, soil water infiltration and surface evapotranspiration results in significant stream flow alteration (Wei and Zhang, 2010).

As shown in the Figs. 5(a-h) both the rainfall and stream flow at these two stations tend to become negative anomaly after 2002 during SWM, SIM, and NEM. This behaviour is consistent with the annual FMSA of rainfall and stream flow (Fig. 3). According to literature, year 2002 has been identified as a drought year for Hambantota district where most downstream part of the river is located. It was a two year long drought and 40,000 villagers were affected (Sirisena, 2008).



Figs. 5(a-h). The temporal distribution of the 5-year moving average of standardized anomalies of seasonal stream flow and rainfall for Thanamalwila, Wellawaya catchment in Kirindi Oya river basin
S.S. : Sen's slope, ρ : correlation coefficient

TABLE 4

Summarized results of Mann-Kendall test with Sen's slope estimator for inter annual mean, monthly minimum and maximum mean stream flow in a month in ($m^3s^{-1}year^{-1}$) Min : Minimum, Max : Maximum

Month	Wellawaya (1980-2009)			Thanamalwila (1988-2013)		
	Mean	Min	Max	Mean	Min	Max
Oct	-0.033	0.0	-0.369	-0.08	-0.029**	-0.469
Nov	-0.156**	-0.038	-0.707**	0.003	-0.12	1.258
Dec	0.024	-0.006	0.007	0.332	-0.011	0.855
Jan	-0.04	0.0	-0.079	-0.032	-0.033	0.303
Feb	-0.019	0.0	-0.101	0.026	-0.004	0.517
Mar	-0.034	0.0	-0.075	0.079	-0.024	0.457
Apr	0.055	0.003	0.223	0.285	0.09	1.493**
May	-0.028	0.018	-0.117	0.008	0.003	-0.037
Jun	-0.012	-0.008	-0.035	-0.027	-0.025	-0.053
Jul	-0.027	-0.007	-0.068	-0.036	-0.015**	-0.08
Aug	-0.012	0.008	-0.027	-0.026**	-0.012**	-0.043
Sep	-0.016	0.0	-0.043	-0.047**	-0.018**	-0.138

(** : 0.05 level of significance)

TABLE 5

Summarized results of Mann-Kendall test with Sen's slope estimator for inter annual mean monthly catchment rainfall

Month	Wellawaya	Thanamalwila	Entire basin
Jan	-5.363	-2.144	0.52
Feb	0.292	0.929	0.918
Mar	1.795	2.005	1.681
Apr	6.587	3.63	3.836
May	-0.855	-1.175	-0.937
Jun	0.15	0.1	-0.091
Jul	-0.806	-0.043	-0.203
Aug	-0.777	-0.169	0.11
Sep	-2.256	-1.136	-0.748
Oct	-2.384	-0.657	0.63
Nov	-4.764	-1.501	1.006
Dec	-2.558	-0.855	1.966

TABLE 6

Summarized results of Mann-Kendall test with Sen's slope estimator for annual and seasonal maximum and minimum temperature (°C/year) of two stations in Kirindi Oya basin

Station	Annual		FIM		SWM		SIM		NEM	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Bandarawela	0.017**	0.012	0.016	0.01	0.028**	0.001	0.015	0.025**	0.006	0.021
Weerawila	0.001	0.098**	-0.011	0.069	-0.001	0.142**	-0.009	0.084**	0.013	0.132**

Weerawila (1990-2014), Bandarawela (1979-2014), (**: 0.05 level of significance)

3.4. *Trends in monthly mean stream flow*

In order to understand the monthly wise behaviour of stream flow, inter annual monthly mean and monthly maximum and minimum flows were tested for trend using MK test and the Sen's slope. Inter annual monthly mean stream flow and maximum stream flow at Wellawaya catchment showed a negative trend for all month except for December and April (Table 4). Significant decreasing trends were observed for November month. At Thanamalwila, 50% of the months showed a decreasing trend of inter annual monthly mean stream flow and maximum stream flow. Significant trends were observed for August and September months only for mean stream flow. Inter annual mean minimum flow at both the sub catchments showed a decreasing trend for most of the month while it was significantly decreasing in August, September and October month at Thanamalwila catchment.

3.5. *Trend in monthly rainfall*

Monotonic trends in inter annual mean monthly catchment rainfall were analyzed for Wellawaya and Thanamalwila catchments and for the entire basin and the results are shown in Table 5. No any significant trend was observed in both the catchments and the entire basin. Moreover, eight months in Wellawaya and Thanmalwila catchments showed drying tendency specially months July to January. However, when entire basin is considered, only four months of the year showed drying status.

3.6. *Trends in temperature*

Table 6 shows the trends in annual and seasonal maximum and minimum temperature in two stations in and around the Kirindi Oya river basin. Annual mean temperature was in an increasing trend for both the stations in terms of annual minimum and annual maximum. However, annual maximum temperature at Bandarawela and annual minimum temperature at Weerawila only showed significant trends in annual scale assessment. In seasonal analysis, minimum temperature was on the increase in all four seasons in both the stations. However, it was significantly increasing during SIM in both the stations and further significant increase in minimum temperature was observed at Weerawila station during SWM and NEM (Table 6). Overall these trends show that the basin temperature is on the increase.

Even a temporary change in climate can have profound impact on agricultural production and on the use of energy and water resources (Gates, 1988; Sharma and Chaudhary, 2014). Frequently occurring hydro-climatic changes and also trends demand to modify the existing cropping patterns and develop suitable strategies to improve the agricultural production. Since agriculture is the main land use and the occupation of the people in the area, immediate actions are needed to adopt to the existing drying trends especially in the mid and upstream of this basin. Decreasing stream flow of Kirindi Oya river is likely to have an adverse impact on the aquatic biodiversity of the river and areas in its periphery, recharging capacity of the groundwater and natural purification capacity of the river water. One constraint of the study was non availability of long term stream flow, rainfall and temperature records and sparse distribution of stream flow, rainfall and temperature monitoring stations in the basin.

4. Conclusions

This study on the annual, seasonal and inter annual monthly stream flow and rainfall showed that there is a drying tendency of the upstream catchments, Wellawaya and also the mid-stream sub catchment Thanamalwila of

Kirindi Oya river basin. This is in spite of increasing stream flow and rainfall during FIM of the two sub catchments. Though the rainfall of the entire basin showed a significant increasing trend, rainfall during SWM showed a significant decreasing trend during the last 25 years. Therefore, immediate action may require in order to avoid the detrimental effects of drying tendency of the area and ensure the agricultural production and ecosystem sustainability. Increasing trends of stream flow and rainfall during FIM and significant decreasing trends of stream flow and rainfall during SWM suggest an apparent shifting of the onset of rainfall to the basin or drastic deviation of receiving rainfall from SWM to the basin. Understanding these tendencies is useful in planning the cropping pattern and its temporal distribution of the basin. Further this study suggests that the variation of stream flow of the up and mid-stream is partly attributed to the variation in rainfall and stream flow variation during NEM is mainly attributed to the variation in rainfall. Increasing temperature at upstream (significant during SIM) may also be responsible for lowering the upstream stream flow of the basin. These finding is helpful in formulating holistic water management planning especially in up and mid-stream of Kirindi Oya basin by undertaking practices at different spatial scales, which may be helpful to reserve the drying trends by increasing the use efficiency of river water in various sectors.

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