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Application of Standard Precipitation Index (SPI) to Assess Rainfall variability in a Major Agricultural Area in Dry Zone of Sri Lanka

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ABSTRACT

Agriculture in the dry zone of Sri Lanka is highly constrained by the inadequacy of irrigation water. The small village tanks located in these areas help farmers to cultivate their lands during dry periods by storing rainwater. However, the rainfall variability has made a considerable threat to functioning of these tanks and in providing expected benefits to the farmers. The objective of this study was to assess the climatic variability using 30-year (1989 to 2018) daily rainfall data from six rain gauging locations (Anuradhapura, Mahagalkadawala, Hingurakgoda, MahaIlluppallama, Girithale and Diyabeduma) in a small tank dominated area in the Dry Zone. Standard Precipitation Index (SPI) was calculated to assess the temporal variability of dry and wet extremes. Mann Kendal Trend Test (MK test) was used to analyze the trend of SPI and Sen's Slope Estimator to assess the magnitude of the trend. The results of Anuradhapura, Diyabeduma and Mahagalkadawala show significantly increasing trend of SPI 12/ annual rainfall. According to the SPI, there were increasing trends in First Inter Monsoon in Anuradhapura and MahaIlluppallama, which have resulted an increasing rainfall trend in Yala season. Additionally, there was an increasing trend in Second Inter-Monsoon in Anuradhapura. These changes highlight that there are extreme rainfall events occurring in some seasons without making a significant impact in the annual rainfall pattern of the area.

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INTRODUCTION

Water is a main constraint for agriculture in the Dry Zone of Sri Lanka due to temporal variability of rainfall. Sri Lanka's climate is divided into four rainfall seasons: First inter-monsoon (FIM) (March-April), Southwest monsoon (SWM) (May-September), Second inter-monsoon (SIM) (October-November) and Northeast monsoon (NEM) (December-February). *Maha*, the major cultivation season falls from September to February, which overlaps with SIM and NEM. *Yala*, the minor cultivation season falls from March to August which is during FIM and SWM periods (Chithranayana and Punyawardena, 2014).

Climate variability brings adverse weather conditions such as droughts and floods (Trenberth, 2008), and high intensity rainfall. Accordingly, the rainfall variability can result in number of adverse impacts such as landslides (Melchiorre and Frattini, 2012, Rathnayake and Herath, 2005), destruction of infrastructure, agricultural lands and ecosystems (Smith, 2011, Vogel *et al.*, 2019, Eriyagama *et al.*, 2010). Several studies have revealed the climatic variability experienced during recent past in Sri Lanka (Wickramagamage, 2016, Jayawardena *et al.*, 2018, Hemachandra *et al.*, 2020).

Village tanks/ cascade systems have been constructed in Dry Zone of Sri Lanka to harvest rainwater. So that the collected water can be utilized for irrigation and other uses during dry periods (Madduma Bandara, 1985; Jayatilaka *et al.*, 2003; Panabokke *et al.*, 2001; Dharmasena, 2010). Therefore, small tanks/ cascade systems can be affected by climatic variability (Chandrasiri *et al.*, 2020). Droughts affect the small tanks by depleting soil moisture, drying up vegetation (crops, natural fauna), increasing wild animal problems, etc. (Dharmasena, 2010). Heavy rains and floods also can damage the crops and the livelihood of people. Hence it is necessary to have an understanding of the pattern of rainfall variability for planning and management of farming under small tanks in order to minimize crop failures.

Standard Precipitation Index (SPI) can be identified as a widely applied methodology which only requires the precipitation data for investigating droughts and wet spells (McKee *et al.*, 1993, Rawat and Tripathi, 2016, Abeysingha and Rajapaksha 2020, Herath *et al.*, 2015, Khan *et al.*, 2008, Li *et al.*, 2008, Sönmez *et al.*, 2005).

The objective of this study was to assess the variability of SPI and its trends from 1989 to 2018 in six rain gauging locations situated in an area dominated by small tanks and Tank Cascade Systems in North Central Dry Zone of Sri Lanka.

METHODOLOGY

Description of data

Daily rainfall data of thirty-year period (1989 – 2018) were collected from six rain gauging locations namely, Anuradhapura, Mahagalkadawala, Hingurakgoda, Maha Illuppallama, Girithale and Diyabeduma. These gauging stations are located in close proximity to numerous small village tanks and a number of important small tank cascade systems including Rathmale, Divulwewa, Athabendiwewa, Mahakanmulla, Thirappane, Ulagalla, Thoruwewa, Horivila- Palugaswewa and Ethabendiwewa in the North Central dry zone of Sri Lanka. Selection of the rain gauging stations was mostly influenced by the availability of data for the recent thirty year period and having only few missing rainfall data values. The rainfall data were collected from the Department of Meteorology, Natural Resources Management Centre of the Department of Agriculture and the Department of Irrigation, Sri Lanka. Figure 1 depicts the rain gauging locations and some important small tanks/ cascades present in the area.

Analysis of Standard Precipitation Index

The daily rainfall data were examined for missing rainfall values and other inconsistencies. The missing values of each station were filled with the values of the closest rain gauging station as it was considered as the most suitable option with the available data. The consistency of rainfall values at each station was assessed using mass curves and found to be consistent. It requires at least 30-year historical rainfall data to develop SPI (WMO, 2012). The SPI values can be interpreted as the number of standard deviations by which the observed value deviates from the long-term mean. Accordingly, the SPI is computed by dividing the difference between the normalized seasonal precipitation and its long-term seasonal mean by the standard deviation (Equation 1).

$$SPI = (Xi - Xm)/\sigma \qquad .Eq: 1$$

where, Xi is i th observation of the seasonal precipitation at a particular rain gauge station, Xm the long-term seasonal mean of that particular rain gauge station and σ is its standard deviation (Bhuiyan *et al.*, 2006). The categorization of the moisture based on SPI value is presented in

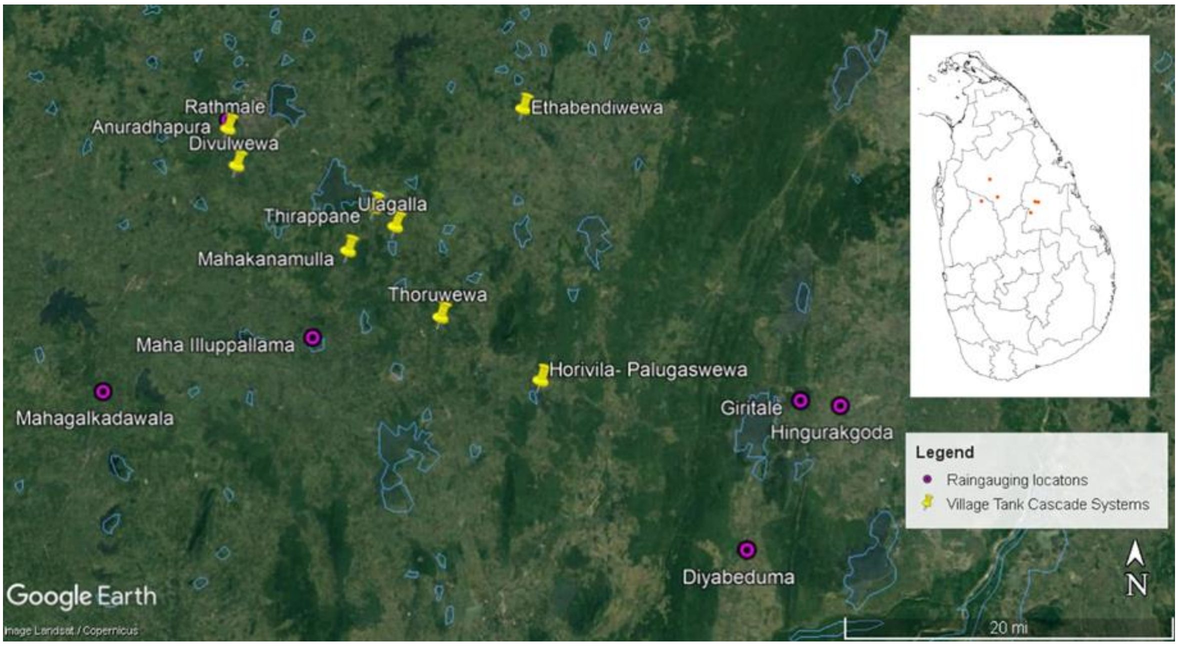

Figure 1: Locations of rain gauges considered in the study

Table 1. According to the classification of the index values, a level crossing at SPI= +2/ -2 indicates transition to extreme wetness/dryness, which corresponds to all values exceeding 5% confidence interval (Bordi *et al.*, 2004).

Table 1: SPI categorization scheme

SPI value	Moisture Category
>2.00	Extreme wet
1.50 to 2.00	Very wet
1.00 to 1.49	Moderate wet
0.00 to 0.99	Mild wet/Near normal
0.00 to -0.99	Mild dry/ Near normal
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
<-2.00	Extreme drought

Source: McKee *et al.*, 1993

In this study, SPI related to three-time scales; 3-month SPI (SPI 3), 6-month SPI (SPI 6) and 12-month SPI (SPI 12) were developed.

SPI 12 was developed to assess the long-term precipitation patterns. Accordingly, SPI 12 for month of September (SPI 12 September) was taken for the analysis representing the annual rainfall variation of the hydrological years. "Water year/ Hydrological year" is defined as the 12-month period from October 1 for any given year through September 30 of the following year (Dodge *et al.*, 1998).

SPI 12 is a cumulative result of the shorter periods. Therefore, SPI 3 and SPI 6 were developed to assess the seasonal rainfall variations (main rainfall seasons and cultivation seasons).

SPI 3 for month of February (SPI 3 February) indicating the NEM, SPI 3 for month of May (SPI 3 May) indicating the FIM, SPI 3 for month of August (SPI 3 August) indicating SWM and SPI 3 for month of November (SPI 3 November) indicating SIM were developed.

According to WMO (2012) the 6-month SPI indicates seasonal to medium-term trends in precipitation and it is very effective in showing the precipitation over distinct seasons. Therefore, SPI 6 was developed to assess the droughts and wet extremes related to major cultivation seasons of *Yala* and *Maha*. Accordingly, SPI 6 was developed for months of February and August (SPI 6 February and SPI 6 August) to indicate the influences of the rainfall for two major cultivation seasons of *Yala* and *Maha*.

Statistical methods for rainfall trend analysis

A widely used non parametric trend analysis method of Mann Kendal Trend Test (MK test) and Sen's Slope estimator (Gocic and Trajkovic, 2013, Kumar *et al.*, 2017) were used to assess the trends and magnitude of trends of developed SPI 3, 6 and 12 (Abeysingha and Rajapaksha., 2020; Li *et al.*, 2008; Rahmat *et al.*, 2012; Zhang *et al.*, 2012) using "MAKESENS" application in Microsoft Excel (Rahman *et al.*, 2016, Määttä *et al.*, 2002, Sutapa, 2014, Sarkar and Ali, 2009). "MAKESENS" application can test the trend at significance levels of 0.001, 0.01, 0.05 and 0.1.

Autocorrelation test

Since the null hypothesis in the Mann-Kendall test is that the data are independent and randomly ordered, the existence of positive autocorrelation in the data increases the probability of detecting trends when actually non-exist, and vice versa (Hamed and Rao, 1998, Mondal *et al.*, 2012, Yue and Wang 2004). Therefore, the serial autocorrelation was tested in the monthly rainfall data as well as the derived SPI 3,6 and 12 values to observe the presence of any serial dependency of rainfall data during 1989 to 2018 period prior to apply Mann Kendall test.

Mann Kendal Trend Test (MK test)

The null hypothesis (H_0) was identified as there is no trend in the data points in the record and the alternative hypothesis (H_1) was that there is an increasing or decreasing monotonic trend. Depending on the Z value, null hypothesis was accepted or rejected.

The MK test statistic S was calculated using Equation 2 and Equation 3 where x_j and x_k are the annual values in years j and k, j > k, respectively.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \qquad \text{Eq: 2}$$

$$sgn(x_j - x_k) = \begin{cases} 1 \ \ if \ x_j - x_k > 0 \\ 0 \ \ if \ x_j - x_k = 0 \\ -1 \ \ if \ x_j - x_k < 0 \end{cases} \qquad \text{Eq: 3}$$

However, when n ≥ 8, the statistic S is approximately normally distributed with the mean (Mondal *et al.*, 2012). Hence the variance statistic is given as in Equation 4.

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \qquad \text{Eq: 4}$$

Here q is the number of tied groups and tp is the number of data values in the p th group. The values of S and VAR(S) are used to compute the test statistic Z as Equation 5.

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} \ if \ S > 0 \\ 0 \ if \ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} \ if \ S < 0 \end{cases} \qquad \text{Eq: 5}$$

Accordingly, Z test was used to assess the trend of SPI as this analysis provides 29 data points (from the hydrological year of 1989/1990 to 2017/2018).

Sen's Slope Estimator

Sen's method is used to estimate the true slope of an existing trend (as change per unit time) where it is assumed to be linear (Equation 6).

$$f(t) = Qt + B \qquad \text{Eq: 6}$$

where Q is the slope and B is a constant.

For obtaining Q, slopes of all the data value pairs were calculated. The estimation of slope of N pairs of data is expressed as Equation 7.

$$Q_i = \frac{x_j - x_k}{j - k} \qquad \text{Eq: 7}$$

where, J > k and xj and xk are data values at times j and k respectively. Hence, Q was estimated by the Sen's non-parametric method where the trend was assumed as linear using MAKESENS application. Hence, Sen's estimator for a linear trend calculated with the equation 8 by MAKESENS (Salmi *et al.*, 2002).

$$f(year) = Q \times (year - first\ year) + B \qquad \text{Eq: 8}$$

RESULTS AND DISCUSSION

Autocorrelation analysis

According to the results of autocorrelation test, either the monthly rainfall data in individual locations or derived SPI 3, 6 and 12 are not autocorrelated. Therefore, the MK trend test and Sen's slope estimator was directly applied to assess the trend of SPI.

Variability of SPI 12 September

Figure 2 presents the occurrence of drought and wet events according to the derived "SPI 12 September" values during the period of 1989 to 2018. Accordingly, it indicates that 11 hydrological years of 1990 – 1991, 1991 – 1992, 1992 – 1993, 1995 - 1996, 1996 – 1997, 1998 – 1999, 2001 – 2002, 2003 – 2004, 2005 -2006, 2008 – 2009 and

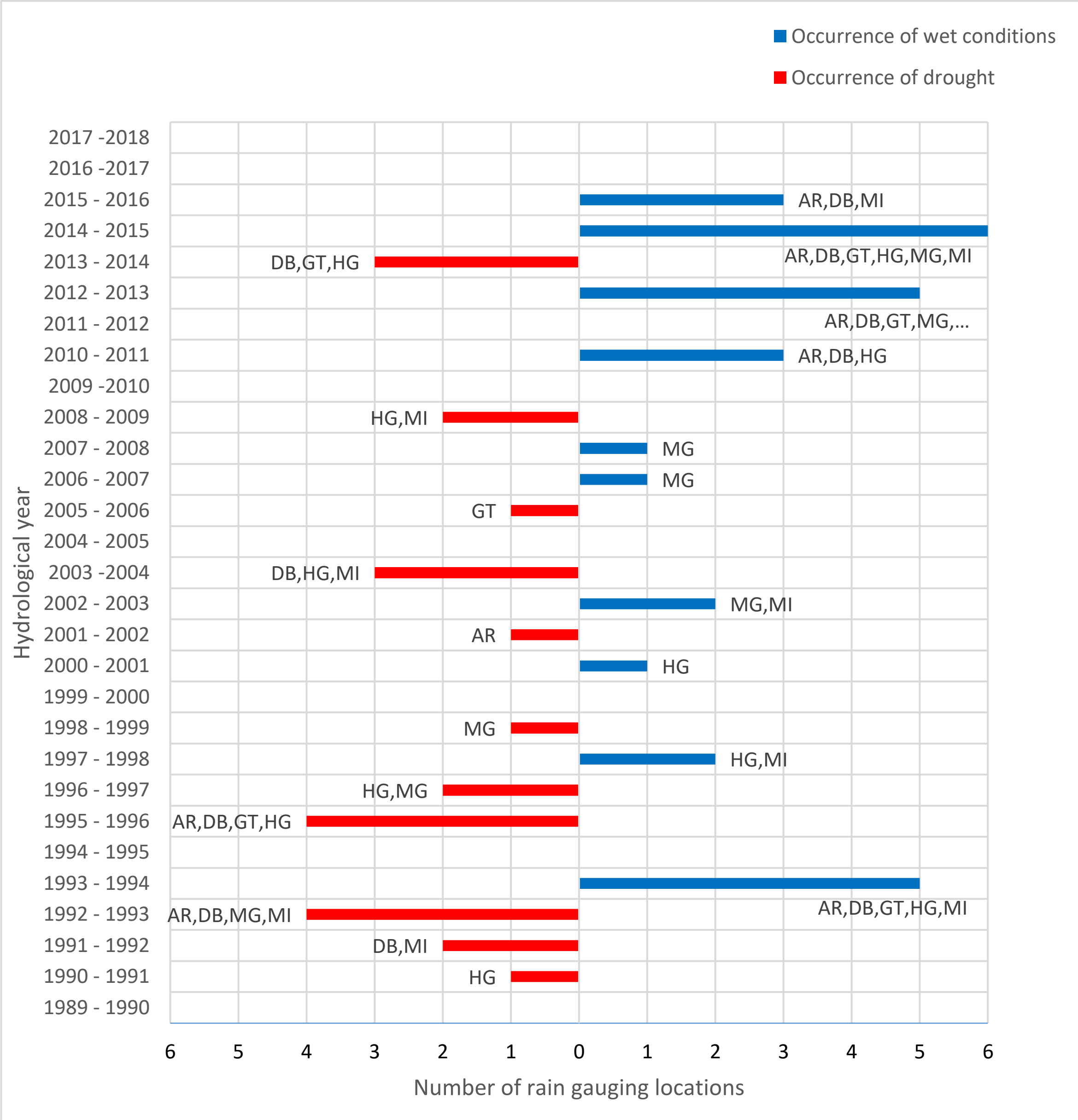

Figure 2: Number of rain gauging locations showing dry/ wet events in each hydrological year (1989 to 2018). Rain gauging locations: AR - Anuradhapura, DB - Diyabeduma, GT – Girithale, HG – Hingurakgoda, MG – Mahagalkadawala, MI – Maha Illuppallama.

2013 -2014 as drought years (SPI <=-1) while 10 hydrological years of 1993 – 1994, 1997-1998, 2000 – 2001, 2002 - 2003, 2006 – 2007, 2007-2008, 2010 – 2011, 2012-2013, 2014-2015 and 2015 - 2016 as wet years at least for one of the rain gauging location used in the study.

The SPI 12 looks at the annual rainfall variability considering the hydrological year. Table 2 presents the results of MK test and Sen's Slope Estimate for SPI 12 September.

Results indicate a significant increasing trend of annual rainfall in Anuradhapura, Mahagalkadawala and Diyabeduma. There is no trend of annual rainfall in Maha Illuppallama, Girithale and Hingurakgoda.

MK test for Anuradhapura indicates an increasing trend of SPI 12 September at α = 0.01 level of significance. SPI 12 September increases by 0.06 towards "wet" per year in Anuradhapura. Accordingly, SPI 12 September for the future in there can be predicted by Equation 9. Abeysingha and Rajapaksha (2020) also have showed an increasing trend for SPI 12 for most of the locations in Dry Zone including Anuradhapura.

Table 2: Results of Statistical analysis of SPI 12 September

Rain gauging location	Mann-Kendall trend		Sen's slope estimate	Intercept
	Test Z	Signific.	Q	B
Anuradhapura	2.72	***	0.06	-0.89
Maha Illuppallama	1.18		0.02	-0.34
Mahagalkadawala	1.74	*	0.05	-0.49
Diyabeduma	2.23	**	0.06	-0.75
Giritale	1.33		0.03	-0.56
Hingurakgoda	0.43		0.01	-0.43

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

$SPI\ 12\ sep\ in\ n\ th\ year\ in\ Anuradhapura =$
$0.06 \times (n - 1990) - 0.8$ Eq: 9

Additionally, it indicates an increasing trend of SPI 12 September at α = 0.1 level of significance in Mahagalkadawala. Hence SPI 12 September increases by 0.05 towards "wet" per year in Mahagalkadawala. Accordingly, SPI 12 September for the future in there can be predicted by Equation 10.

$SPI\ 12\ sep\ in\ n\ th\ year\ in\ Mahagalkadawala =$
$0.06 \times (n - 1990) - 0.49$ Eq:10

MK test for Diyabeduma indicates an increasing trend of SPI 12 September at α = 0.05 level of significance. Hence SPI 12 September increases by 0.06 towards wet per year in Diyabeduma. Accordingly, SPI 12 September for the future in there can be predicted by Equation 11.

$SPI\ 12\ sep\ in\ n\ th\ year\ in\ Diyabeduma =$
$0.06 \times (n - 1990) - 0.75$ Eq: 11

The short term or the seasonal variabilities of rainfall can cause more impacts on the functioning of small tanks/ tank cascade systems than the long-term variabilities such as SPI 12 and SPI 24. Therefore, SPI 3 and SPI 6 analyses present the short term and seasonal variabilities of rainfall.

Variability of SPI 3 during 1989-2018 years

SPI 3 provides a comparison of the precipitation over a specific 3-month period with the precipitation totals from the same 3-month period for all the years included in the historical record. Therefore, SPI 3 reflects short and medium-term moisture conditions and provides a seasonal estimation of precipitation. It is highly suitable for primary agricultural regions (WMO, 2012).

SPI 3 February

SPI 3 February in this analysis compares precipitation total of December, January and February in a particular year with the precipitation totals of the same period (December, January and February) in past thirty-years (1989 – 2018) in a particular location. Since the NEM rains also occur during December to February (Domroes and Ranatunge, 1992), SPI 3 February presents the changes of NEM rains.

According to MK test and Sen's Slope Estimate, none of the rain gauging locations showed significant trends in SPI 3 February. Hence it indicates that there is no significant trend in NEM rains for this area (Data are not presented).

SPI 3 May

SPI 3 May compares precipitation total of March, April and May in a particular year with the precipitation totals of the same period (March, April and May) in past thirty-years (1989 – 2018) in a particular location. Hence it includes the FIM which occurs during the months of March and April.

Table 3 shows that there is an increasing trend of rainfall at α = 0.05 level of significance in SPI 3 May at Anuradhapura and Maha Illuppinallama. Accordingly, SPI 3 May in Anuradhapura increases by 0.06 towards "wet" per year. SPI 3 May in Anuradhapura for the future can be predicted by Equation 12.

$SPI\ 3\ May\ in\ n\ th\ year\ in\ Anuradhapura =$
$0.06 \times (n - 1990) - 0.77$ Eq: 12

Additionally, SPI 3 May in Maha Illuppallama increases by 0.05 towards wet per year.

Accordingly, SPI 3 May in Maha Illuppallama for the future can be predicted by Equation 13.

$SPI\ \ 3\, May\ in\ n\ th\ \ year\ in\ Maha\ Illuppallama\ = 0.05 \times (n - 1990) - 0.72$ Eq: 13

In fact, it shows that there is an increasing trend in the FIM rains in these areas. However, there is no trend of rainfall in Mahagalkadawala, Diyabeduma, Giritale and Higurakgoda during FIM.

Since dry zone of Sri Lanka is receiving highly intensive rains during inter monsoonal periods (Abeysekera *et al.*, 2015), the increments of SPI 3 could be due to increase of high intensive rains.

SPI 3 August

SPI 3 August compares the precipitation total of June, July and August in a particular year with precipitation totals of the same period (June, July and August) in past thirty-years (1989 – 2018) in a particular location. It represents the SWM season. However, according to, MK test and Sen's Slope Estimate, there was no trend of SPI 3 August in all the rain gauging locations (Data are not presented).

SPI 3 November

SPI 3 November in this analysis compares precipitation totals of September, October and November in a particular year with the precipitation totals of the same period (September, October and November) in past thirty-years (1989 – 2018) of a particular location. Hence it represents the SIM period of October and November.

Table 4 shows that SPI 3 November in Anuradhapura increases by 0.05 towards "wet" per year. Accordingly, SPI 3 November in Anuradhapura for the future can be predicted by Equation 14.

$SPI\ \ 3\, Nov\ in\ n\ th\ \ year\ in\ Anuradhapura = 0.05 \times (n - 1990) - 0.65$ Eq:14

Table 3: Results of statistical analysis of SPI 3 May

Rain gauging location	Mann-Kendall trend		Sen's slope estimate	Interceptor
	Test Z	Signific.	Q	B
Anuradhapura	2.53	**	0.06	-0.77
Maha Illuppallama	2.01	**	0.05	-0.72
Mahagalkadawala	1.48		0.02	-0.07
Diyabeduma	1.59		0.03	-0.42
Giritale	0.28		0.01	-0.23
Hingurakgoda	-0.13		0.00	0.02

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

Table 4: Results of statistical analysis of SPI 3 November

Rain gauging location	Mann-Kendall trend		Sen's slope estimate	Interceptor
	Test Z	**Signific.**	**Q**	**B**
Anuradhapura	1.82	*	0.05	-0.65
Maha Illuppallama	-0.43		-0.01	0.26
Mahagalkadawala	0.73		0.02	-0.13
Diyabeduma	1.22		0.03	-0.49
Giritale	0.13		0.00	-0.22
Hingurakgoda	-0.51		-0.01	0.12

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

In fact, the trend of SPI 3 can be neglegible in relation to four rainfall seasons during 1989- 2018 in the study area. Perera *et al.*, 2016 also have revealed that there was no significant variability in four rainfall seasons in Maha Illupalama during 1991 to 2010.

Variability of SPI 6 February and August

SPI 6 provides a comparison of the precipitation over a specific 6-month period with the precipitation totals from the same 6-month period for all the years included in the historical record. SPI 6 February compares the precipitation total for the September to February period in a particular year with precipitations for that same period (September to February) in past thirty-years (1989 – 2018) in a particular location. Hence it indicates the variabilities of the effective rainfall for the *Maha* season (September to February). Generally, in *Maha* season this area receives high amount of rainfall and people expect the village tanks to be filled during the period. Hence, they can use the water for irrigation during *Maha* season and store the extra water for cultivation in *Yala* season. However, if a drought occurres during *Maha* season, the farmers who cultivate using village tanks have to face a risk due to lack of water for the cultivations in both seasons. However, MK test showed that none of the rain gauging locations have shown a significant trend in SPI 6 February (Data are not presented).

SPI 6 August compares the precipitation totals of March to August period of a particular year with precipitations for that same period (March to August) in past thirty-years (1989 – 2018) in a particular location. Hence it indicates the rainfall variability of *Yala* season (March to August).

According to Table 5, Anuradhapura and Maha Illuppallama show significant increasing trends of rainfall in *Yala* season. MK test for Anuradhapura indicates an increasing trend of SPI 6 August at α = 0.05 level of significance. Accordingly, SPI 6 August in Anuradhapura increases by 0.05 towards wet per year. SPI 6 August in Anuradhapura for the future can be predicted by Equation 17.

$$SPI\ 6\ Aug\ in\ n\ th\ year\ in\ Anuradhapura = 0.05 \times (n - 1990) - 0.84 \qquad \text{Eq: 15}$$

Additionally, MK test for Maha Illuppallama indicates an increasing trend of SPI 6 August at α = 0.1 level of significance. Accordingly, SPI 6 August in Maha Illuppallama increases by 0.05 towards wet per year. SPI 6 August in Maha Illuppallama for the future can be predicted by Equation 16.

$$SPI\ 6\ Aug\ in\ n\ th\ year\ in\ Maha\ Illuppallama = 0.05 \times (n - 1990) - 0.69 \qquad \text{Eq:16}$$

Even though most of the rain gauging locations show random increasing trends of seasonal or annual rainfalls (SPI3/ SPI 6/ SPI 12) a continuous increasing or decreasing trend was not observed except in Anuradhapura. Hence it is obvious that the increasing trends of SPI at different locations at different time periods were due to extreme rainfall events. Abeysekera *et al.* (2015) also revealed about an increasing trend of extreme rainfall events during 1990 – 2014 period in dry zone of Sri Lanka

Hence the untimely rainfall can adversely affect to the sustainability of village tanks/ cascade systems interrupting human activities, crop production, hydrologic relations including eco system functions. Since small village tanks play a vital role in livelihood of the people in this area, it is important to consider sustainable management of these tanks and cascade systems to cope up with the changing climatic conditions. Hence it is understood that future studies should be focused on shifting of the rainfall seasons and defining the cultivation seasons accordingly as an adaptation strategy.

Table 5 Results of Statistical analysis of SPI 6 August

	Mann-Kendall trend		**Sen's slope estimate**	**Interceptor**
Rain gauging location	Test Z	Signific.	Q	B
Anuradhapura	2.31	**	0.05	-0.84
Maha Illuppallama	1.86	*	0.05	-0.69
Mahagalkadawala	1.48		0.02	-0.21
Diyabeduma	1.63		0.03	-0.38
Giritale	0.28		0.00	0.17
Hingurakgoda	-0.62		-0.02	0.33

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

CONCLUSIONS

The variability of rainfall is evident in this area according to the SPI analysis which shows alternative dry and wet periods. Rain gauging locations of Anuradhapura, Diyabeduma and Mahagalkadawala shows an increasing trend of annual rainfall. In seasonal rainfall, there are no trends in the main two monsoons (either NEM or SWM) in any of the rain gauging location. However, increasing trends were observed in FIM in Anuradhapura and Maha Illuppalama which had resulted in an increasing rainfall trend in *Yala* season. Therefore, it can be considered as a positive impact for agriculture since water scarcity is a major obstacle for farming in *Yala* season. Additionally there was an increasing trend of SIM in Anuradhapura. There were no trends of SPI 3 and SPI 6 Hingurakgoda, Diyabeduma and Mahagalkadawala and there may be random extreme rainfall events which have made the increasing trend only for the annual rainfall. Hence it can be concluded that there can be an increment of random extreme heavy rainfalls in this area in the future.

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