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Research

Assessment of Climate Extremes Based on SPI in $WL1_a$ Agroecological Zone - A Case Study from Kuruwita, Sri Lanka

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***Abstract*—**Drought and flood are the simple most significant climatological hazards in Sri Lanka, which primarily affects agricultural productivity. Proper understanding and investigation of climatic extremes like drought and floods, plays a key role in planning and management of household, municipal, agricultural and industrial activities even with varied water availability. Therefore, the present study aimed to asses onset, severity and occurrence of drought and wet episodes (months) in Kuruwita region, which belongs to the Low Country Wet Zone Agro-ecological region using the Standardized Precipitation Index (SPI) at various time scales. SPI analyzed at 12 months' time interval revealed that out of 45 years of study period (1961-2005), there were only four (1976, 1980-1981 and 1996) and six (1985-1986, 1988-1989, 2003-2004) drought and wet hydrological years, respectively. Further, the hydrological years 1981 and 2004 were identified as more affected years by drought and wet events, respectively, with relatively higher occurrence of climate extremes depicted by SPI, than normal conditions. The South-West monsoon (SWM) was found to be more prone to extreme climatic conditions, leading the Yala cropping season to become more abnormal with occurrence of more drought and wet months in Kuruwita. Therefore, the study suggests that implementation of proper mitigative measures like installation of rainwater harvesting systems, reuse or recycling of rainwater, cultivation of stress tolerant crop varieties, adaption of different cropping systems would be beneficial to minimize such adverse effects and for sustainable development in Kuruwita area.

***Keywords*—**Drought, Kuruwita, Occurrence, SPI, Wet.

I. Introduction

Changes in climate primarily with emission of greenhouse gases become a serious challenge all over the world since industrial era. One of the main climatic components subjected to change over years is rainfall and its anomalies associated with surplus and scarce result in two extreme conditions, namely floods and droughts, respectively. Prolonged extreme climatic conditions affect crop and livestock production in agriculture-based countries influencing employment and income of the households (Omotosho et al., 2000; Sanogo et al., 2015). Beyond the agriculture, changes in climate, especially rainfall cause adverse effects on human health, environment, infrastructure and ecology (Coates, 1996) which may cause negative impacts on economies of nations throughout the world. In Sri Lanka context, extreme climates, especially extreme winds connected with heavy rainfall in 2000 affected human settlements and caused causalities too (Thevakaran et al., 2019) in Batticaloa. On the other hand, drought prevailed during September 2017 in Polonnaruwa affected 24,099 people from 6,714 families (Lokuhetti et al., 2017). Furthermore, drought spelled in part of Yala season in 2016 and part of Maha season in 2017 has resulted a loss in paddy production in Sri Lanka (Lokuhetti et al., 2017). With respect to other countries, prolonged droughts have resulted in death of livestock and crop loss (Rusinamhodzi et al., 2012; Tambo Abdoulaye, 2013), loss in family revenues of rural farmers relying primarily on rainfed agriculture in several parts of Africa (Omotosho et al., 2000; Sanogo et al., 2015) and increases risk of ecosystems rehabilitation (Halwatura et al., 2015).

Being an agricultural country, Sri Lanka is not exceptional for climate change and its consequences. Many parts of Sri Lanka from all three climatic zones have been affected by rainfall anomalies. The significance and or magnitude of effects caused by the extreme climate depends on several factors, inclusive of rainfall characteristics (amount, intensity, duration), geographical characteristics (altitude, topography) and anthropogenic activities. For example, GDP growth rate dropped by 1% due to protracted droughts occurred in Sri Lanka in 2001–2002 as it affected hydropower generation and agriculture sector (Lyon et al., 2009). Furthermore, it has been foretold that the decrease in annual surface runoff from 2799 to 2232 cubic meters by 2050 would cause severe impacts on the facets of society, economy and environment in Sri Lanka (Udayanga Najim, 2014). Therefore, to minimize adverse effects caused and to facilitate economy loss assessments, evaluation of changes in climate is vital, especially for better planning and utilization of resources and implementation of mitigation measures. Hence, it should be done at the specific localities level rather than considering the broader manner. The present study attempted to study the variation in climate at a specific locality known as "Kuruwita" to predict the extremes in climate in future with reference to past events using reputed index. Kuruwita is one of the District Secretariat Division in Ratnapura district in Sri Lanka. Plantation, agriculture, gem mining are main operational activities in study area that are influenced by the availability of water. Changes in climate may affect these sectors and in turn lead to reduced economy of the country. Therefore, the present study was aimed to assess the variations in climatic conditions in Kuruwita region in order to facilitate and manage water dependent activities sustainably in future.

II. Materials and Methods

A. Study area and rainfall data

Kuruwita District Secretariat (DSD) located in between 6° 49' 18.48" N and 80° 21' 41.4" E in Ratnapura district, was selected as the study area. Daily rainfall data over 45 years (1961-2005) from the Kuruwita rain gauging station were used in this study. The collected data were not subjected to any reconstruction of missing rainfall data, as those might cause errors in the original data. The daily rainfall values were converted to monthly rainfall values, which were further used in the calculation of SPI values.

B. Analysis of extreme climate events

The well-known index SPI was used to analyze the extremes of climatic events which are expressed as anomalies of rainfall. SPI was calculated based on monthly rainfall using the formula given below (Equation 1), which was proposed by McKee et al. (1993) as a comparison of rainfall over a specified period with the long-term precipitation records for the same period. SPI values range between +2 to -2 in which negative values show drought conditions, while positive values show wet conditions. Based on the SPI values, drought and wet events are classified into different classes (TABLE I) as mentioned by Andrade and Belo-Pereira (2015) and Das et al. (2016).

$$SPI = .X_{\text{i}} - \bar{X}/S \qquad (1)$$

Where, X_i= Seasonal precipitation $\bar{X}$ = Long term seasonal mean precipitation S= Standard deviation

C. Characterization of extreme events

Further analysis was done to characterize the extremes of climate events referring to onset, severity and occurrence. As monthly analysis of SPI is not appropriate to measure the severity and continuity of extremes of climate, cumulative SPI values at various short time scales (3 and 6 months) were calculated to investigate the onset, length and strength of drought and wet events (Maneesha et al., 2015). Drought onset was defined as the first month in which SPI values become negative and vice versa for onset of wet condition. When the SPI values are less than -1 and continued for a minimum of two consecutive months, they were recognized as drought events (Lokuhetti et al., 2017). Meanwhile, when the SPI values were greater than 1 and continued for a minimum of two consecutive months those were recognized as wet events.

TABLE I
SPI values and their interpretation for extreme climate

SPI	Interpretation (Classes of extremes of climate)
SPI $\leq$ -2	Extremely dry
-2 $<$SPI$\leq$ 1.5	Severely dry
-1.5 $<$SPI$\leq$ 1.0	Moderately dry
-1.0 $<$SPI$<$ 1.0	Near normal
1.0 $\leq$SPI$<$ 1.5	Moderately wet
1.5 $\leq$SPI$<$ 2	Severely wet
2 $\leq$SPI	Extremely wet

Hydrological year, in which development of hydrological processes takes place and precipitation totals are measured, was used in the study to demarcate the year for calculation of SPI at various time scales. In Northern hemisphere hydrological years starts from 1st October and ends on 30th September, whereas it is from 1st July to 30th June for the Southern hemisphere (American Meteorological Society, 2020). Sri Lanka is positioned above the equator, belonging to the Northern hemisphere. Therefore, according to Abeysingha and Rajapaksha (2020) the period between October to September was considered as the hydrological year. The periods of October to March and April to September were considered as 6-month time scales, while October to December, January to March, April to June, and July to September were used in calculation of 3-months cumulative SPI.

D. Occurrence analysis

Occurrence of extremes of climate was tested at various time periods, especially during cropping seasons; *Maha* and *Yala* and rainfall seasons; First Inter Monsoon (FIM), North-East Monsoon (NEM), Second Inter Monsoon (SIM) and South-West Monsoon SWM). The periods Oct-Feb and Mar-Sep were considered as cropping seasons *Maha* and *Yala*, respectively. Hence, the periods Oct-Nov, Dec-Feb, Mar-Apr, May-Sep were respectively considered as SIM, NEM, FIM and SWM. Total number of months' fall with cropping and or rainfall seasons at either each hydrological year or throughout the study period was calculated. Based on this percentage of occurrence of each class of extreme events was calculated using the Equation 2, as shown below.

$$A = B/C \times 100 \qquad (2)$$

Where,
A=Percentage occurrence for each class of extreme climate events

B=Number of months with each class of extreme climate during cropping or rainfall seasons in a hydrological year
C=Total number of months fall with cropping seasons/rainfall seasons in a hydrological year

E. Statistical and trend analysis

The significance in variation for the percentage occurrence of each classes of extreme climate events during the respected periods was statistically tested with the Paired-Chi-square test using SPSS (Version 25) software. Further, the non-parametric Mann-Kendall (MK) test was performed using XLSTAT 2020 software to detect trends in temporal variations of dryness and wetness during the study period in the study area.

III. Results and Discussion

A. Analysis of extremes of climate

1) Identification of wet and drought years: SPI calculations subjected to annual rainfall of 12-month time scale was used to identify drought and wet years in the study area. Figure 01 shows that out of 45 hydrological years of study period (1961-2005), there were four drought and six wet years. The wet conditions in the wet years (1985-1986, 1988-1989, 2003-2004) ranged from moderate (1<SPI<1.5) to extreme (SPI $\geq$ 2). The drought conditions occurred in all four drought years (1976, 1980-1981 and 1996) in the study area were moderate as the SPI values ranged between -1 to -1.5. The results of the current study are agreeing with the findings of Abeysingha and Rajapaksha (2020) who also reported the hydrological year 1976 as an extreme drought year for Hanwella and Matala located within the in Wet Zone.

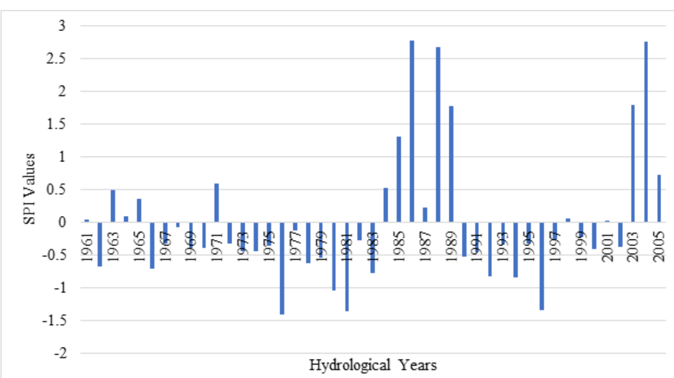

Fig. 1. Variations in 12 months' time scale SPI during hydrological years at Kuruwita rain gauging station

2) Characterization of events: Analysis done to characterize the severity of extreme climate events using cumulative SPI values during these extreme climatic hydrological years revealed that the hydrological years 1981 and 2004 were the more affected years, respectively by drought and wet events associated with greater occurrence of the extreme events and greater deviation of SPI values than normal (Almost throughout the year May-Mar) events as depicted in Figure 2. It was noticed that the rainfall seasons SIM and NEM which are not the actual rainy seasons in the study area were experienced with extreme wet events in the years 1985-1986 and 2004. Meanwhile, the climatic conditions spelled during *Yala* (wet) and *Maha* (drought) also were extreme in the hydrological years of 1988, 2003 and 1980, 1996, respectively.

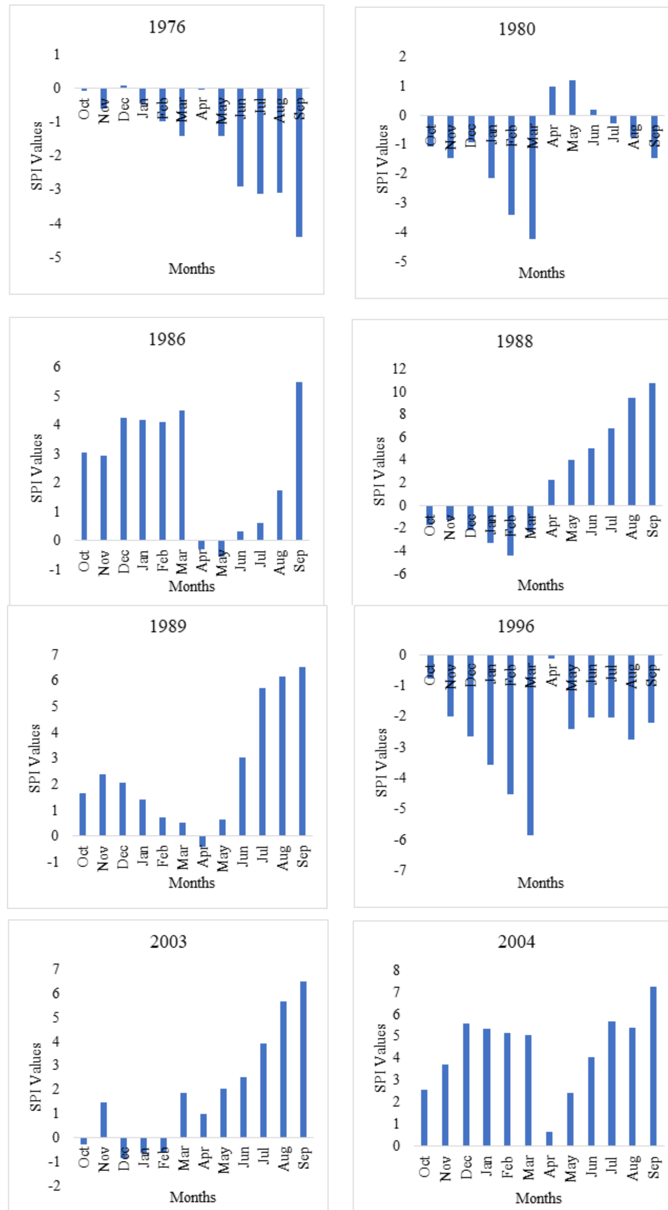

Fig. 2. Severity of extreme climate events during selected hydrological years at 6 months intervals as suggested by the SPI at Kuruwita rain gauging station

3) Occurrence of extreme climate events : Identification of extreme months than the normal condition is important in planning and management of water related agricultural and or industrial activities. Occurrence of wet and drought months during cropping seasons is shown in the Figure 3. It depicts that more wet months were spelled during *Yala* (30 years out of 45 years) than the *Maha* season (22 years), within the study period as the study area is being in Wet Zone. Occurrence of drought months also was greater in *Yala* (32 years out of 45 years) than in the *Maha* cropping season (27 years of 45 years). Meanwhile, the percentage occurrence of wet and drought months in *Maha* season was also notably high. Uncertainty and variations in the rainfall associated with extreme wind events, depression in Bay of Bengal and cyclones might be the reasons for the extremes of climatic events in the study area (Thevakaran *et al.*, 2019). Abeysingha and Rajapaksha (2020) has also reported more drought events during *Yala* season than *Maha* in 56 rainfall stations across three climatic zones in Sri Lanka. Further, Chirthranayana and Punyawardene (2008) additionally expressed that no drought occurs in wet zone exclusive of WL_{2b} and WL_3, which could have slight vulnerableness for drought.

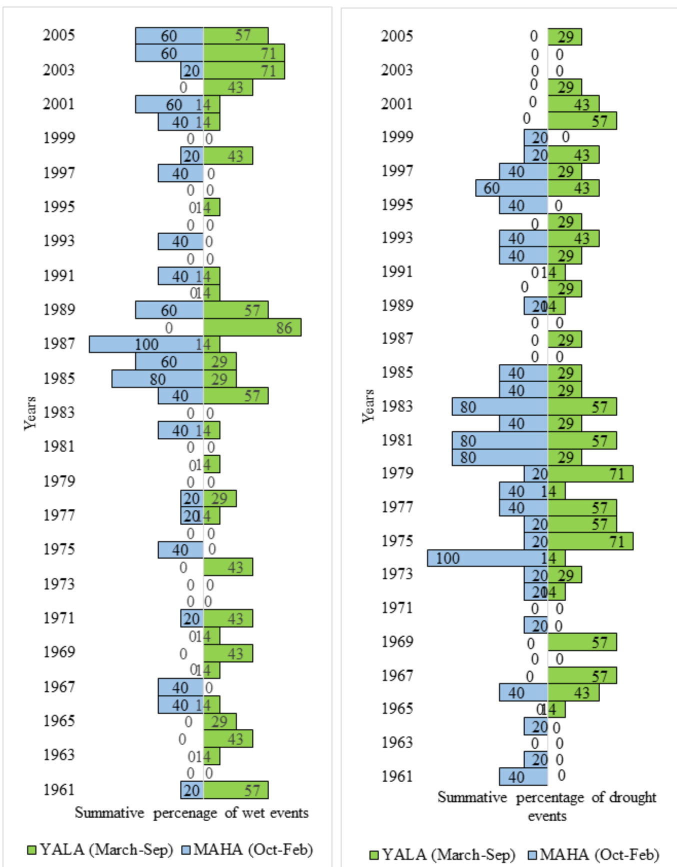

Fig. 3. Occurrence of wet and drought months during cropping seasons

Regarding rainfall seasons, TABLE II shows the changes in occurrence of extremes of wet and drought months during the study periods divided into two time periods; 1961-1983 and 1984-2005 each with 23 and 22 years, respectively. It explains that climatic conditions occurred during rainfall seasons throughout the half of the study period was mostly near normal. However, SWM rainfall seasons were more prone to climate extremes, in which comparatively a greater number of months was spelled with extremes wet and drought conditions (moderate, severe and extreme) than the other rainfall seasons. Further, it was noticed that occurrence of drought months in the second half of study period (1984-2005) decreased while wet months increased during all the rainfall seasons. The change in climatic condition from dryness to wetness in the study area after 1984 might be resulted from a strengthened relationship between ENSO and NEM after 1980s, as reported by Zubair and Ropelewski (2006). Extremes of rainfall, especially wetness (severe wet, extreme wet) in the study area may result in flooding and enhance the chance for runoff and causes soil erosion, thus degrading the soil quality and ending up productivity loss in plantation sector. Further, gem mining in the study area also might got interrupted as flooding affect mining operations because of soil erosion.

TABLE II
OCCURRENCE OF EXTREMES OF CLIMATE DURING RAINFALL SEASONS

	Occurrence (%)								Significance
	1961-1983				**1984-2005**				
	SIM	NEM	FIM	SWM	SIM	NEM	FIM	SWM	Interpretation
Extreme drought	4	10	20	9	2	8	9	8	NS (0.67)
Severe drought	9	10	2	10	7	2	7	10	S (0.04)
Moderate drought	11	14	9	10	2	14	2	7	NS (0.09)
Near normal	70	52	57	53	59	42	55	45	NS (0.92)
Moderate wet	2	6	9	10	9	8	5	6	NS (0.07)
Severe wet	2	6	2	3	7	3	5	5	NS (0.21)
Extreme wet	2	1	2	6	14	24	18	18	NS (0.17)
Total	100	100	100	100	100	100	100	100	

S-significant NS = not significant.

Hence, when considering Chi-square test results (TABLE II), it was explained that the variation noted in different classes of extreme climate was not significant during respective periods. Meanwhile, the severe drought condition only significantly decreased ($P<0.05$) in the second half of the study period than the first half. Thereby, extremes in rainfall, especially referring to dryness, may directly reduce the soil water content which becomes an abiotic stressor to plants. Hence, lack of water availability in water bodies because of drought condition might reduce the drinking water availability, electricity generation and industrial operations too in the study area. However, in contrast, trend analysis performed by Mann-Kendall's test for mean seasonal and annual rainfalls revealed that there was no increasing or decreasing trend in rainfalls (TABLE III) and rainfall over study region was almost quietly stable during 1961-2005. Similar to this result, Jayawardene *et al*. (2005) has also reported no trend for short term rainfall records (50 years) in tested stations like Colombo (WL_3) and Ratnapura (WL_{1a}) which were also located in Wet Zone. Further, Malmgren *et al*. (2003) also mentioned in their study that there were no significant tendencies in NEM in tested places in all three climatic zones.

IV. CONCLUSION

The study showed the changes in climatic conditions in Kuruwita located in Low Country Wet Zone during 1961-2005. Based on the findings, it can be concluded that the

TABLE III
TREND ANALYSIS OF RAINFALL PERIODS DURING 1961-2005 AT KURUWITA RAIN GAUGING STATION

Rainfall period	Kendall's tau	p-value at 5% significance	Existence of trend
SIM	0.123	0.245 (P>0.05)	No
NEM	0.144	0.172 (P>0.05)	No
FIM	-0.063	0.551 (P>0.05)	No
SWM	-0.027	0.8 (P>0.05)	No
Annual	0.101	0.337 (P>0.05)	No

climatological hazards are less common in Kuruwita region, as it is noticed only in 10 years intermittently out of 45 years. However, the *Yala* cropping season and SWM rainfall season in study area are more sensitive to both climate extremes (wet and drought) associated with greater occurrence of extreme climatic conditions. Since SWM is the main rainy season in the Wet Zone, variation in SWM may result either surplus or scarcity in water availability. Therefore, water dependent activities like agriculture, plantation, industrial, mining operations in Kuruwita region should be properly planned and managed either to meet the requirement with limited water or to store the excess water for sustainable usage particularly during Mar-Sep periods of a hydrological year.

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