THE INSTITUTE OF BIOLOGY SRI LANKA

Adapting to Climate Change: A Sri Lankan perspective

Adapting to Climate Change: A Sri Lankan Perspective

Published by
The Institute of Biology, Sri Lanka
25th September, 2020

CHAPTER

11

© Tilina Dissanayake

Climate Change Induced Variations in Rainfall Patterns & Potential Adaptation Options of DL1b Agro-Ecological Zone of Sri Lanka: A Case Study

N.W.B.A. Lahiru Udayanga[1] and M.M.M. Najim[2]*

[1]Department of Bio-Systems Engineering, Faculty of Agriculture & Plantation Management, Wayamba University of Sri Lanka, Makandura, Sri Lanka.
[2]Department of Zoology and Environmental Management, Faculty of Science, University of Kelaniya, Kelaniya, Sri Lanka.
*mnajim@kln.ac.lk

Climate Change Induced Variations in Rainfall Patterns and Potential Adaptation Options of DL_{1b} Agro-Ecological Zone of Sri Lanka: A Case Study

Abstract

An analysis of the shifts and trends of climate patterns with respect to wet and dry events and rainfall seasonality is vital for the effective planning and management of water resources in tropical countries such as Sri Lanka, which have agriculture-based economies. Hence, temporal and spatial variations of climate extremes and rainfall seasonality in Sri Lanka, were evaluated in the DL1b Agro-Ecological Zone through the Standardized Precipitation Index (SPI) and Seasonality Index (SI) utilizing 58 years of daily rainfall data of five selected localities. The Chi-square test of independence was used to statistically compare the percentage occurrence of each event recorded during 1961-1988 and 1989-2018. The dryness of all study areas denoted increments in terms of both severity and frequency of occurrence in accordance with SPI. However, among the studied localities of the DL_{1b} agro-ecological zone, only the increment of dryness in Vavuniya remained statistically significant ($X^2_{(df = 4)}$ <9.78; P=0.04) at 95% level of confidence. Rainfall seasonality of the localities was characterized with a markedly seasonal climatic condition with a long, dry season (0.95 – 0.97) with no significant variations and shifts. Cultivation of low water demanding crops, adjustment of cropping seasons, use of more efficient water smart irrigation methods, implementation of agro-forestry systems and employment of smart and integrated watershed management practices could be recommended as potential adaptation measures to compensate the impacts of climatic change.

Keywords: *Climate adaptations, climate change, rainfall, seasonality, Standardized Precipitation Index (SPI)*

Introduction

Any change in climate over the time whether due to natural variability or as a result of human activity has been described as climate change (IPCC, 2007). At present the whole world is experiencing adverse impacts of climate change, which is one of the most serious threats to sustainable development, including impacts on environment, health, agriculture, food security, economic activity, natural resources and physical infrastructures (IPCC, 2007). Southeast Asia is already experiencing the adverse impacts of climate change, which have affected the quantity and quality of available water resources. Extreme weather events such as droughts, floods, and other tropical cyclones are increasing in frequency and intensity and have contributed to decline in the production of crops (Zougmoré *et al*., 2016).

Climatic patterns of tropical islands are characteriozed by rainfall. Recent observations indicate significant alterations in rainfall patterns in both dry and wet zones in many tropical islands including Sri Lanka. Erratic rainfall events such as higher intensity of rains with less number of rainy days have increased significantly in Sri Lanka, along with increased possibility of climatic extremes like irregular monsoon patterns, droughts, floods and heat stroms (Naveendrakumar *et al.*, 2018). Intensity of rainfall events is predicted to increase, particularly within tropical and higher latitude areas that are expected to experience increments in mean precipitation. Even in areas where mean precipitation decreases, precipitation intensity is predicted to increase yet with longer periods between rainfall events. A possible tendency of increasing of dryness of the mid-continental areas during summer, indicating a greater risk of droughts in those regions has also been recognized. Rainfall extremes have shown more increase than the mean in most of the tropical and mid- and high-latitude areas (Meehl, 2007).

Climatic changes should be understood in terms of their hydrological, agricultural, and socio-economic impacts. As the agriculture of most of the tropical countries is often restricted by patterns of rainfall, the planning and management of water resources especially within the dry zone play vital roles in achieving self-sufficiency in agricultural productions (Eriyagama *et al.*, 2010). Thus, due consideration should be given to the climate patterns, shifts and trends in seasonality and dry and wet events since the climatic patterns of tropical countries are often characterized by both severity and frequency of occurrence of dry and wet events. The proper planning of water resources should be done in accordance with specific climatic patterns such as seasonality, severity and frequency of occurrence of dry and wet events (Udayanga and Najim, 2013).

A drought is characterized by an abnormally dry weather that lasts long enough to result an imbalance (mild to severe) in the water cycle (Liu *et* *al*., 2011). Although the causes of a drought could be multiple, the on-set of a drought is usually caused by decrease in or absence of precipitation. A wet period is dominated by high precipitation and less dryness. For each event, the probability of occurrence and the magnitude (severity) act as the factors that are devoted to define each specifically (Udayanga and Najim, 2013). At present, many methods, procedures, indices etc. have been developed and are being employed to analyze the wetness and dryness and other weather extremes by using monthly precipitation data, where droughts are considered as precipitation deficits with respect to average values and floods as the opposite (Morid *et al*., 2006).

Among the numerous methods of extreme event predictions such as Effective Drought Index, Palmer Drought Severity Index, Surface Water Supply Index etc., the Standardized Precipitation Index [SPI] (McKee *et al*., 1993), outstands specifically due to its simplicity, flexibility, effectiveness and capability of acting as an objective measurement of meteorological droughts effectively in dry regions (Morid *et al*., 2006). The SPI also allows an analyst to determine the magnitude (severity) and the occurrence frequency of both droughts and anomalously wet events within a considered time scale for any region or a specific location that has continuous precipitation readings throughout consecutive number (usually for 25-30 years) of years. Thus, the SPI doesn't require complex land surface conditions and can be applied to different climate regions and at different time scales to predict short- and long-term drought conditions (McKee *et al*., 1993). SPI provides magnitude, period of occurrence and longevity of climate extremes identifying the trends of weather extremes (Lee *et al*., 2013).

The trends in rainfall seasonality represent one of the most important aspects of climatic variation, which is often not addressed in Southeast Asia. Meaningful comparisons of rainfall seasonality of different areas can be done via quantification of this aspect of rainfall regimes. The Seasonality Index (SI) developed by Walsh and Lawler (1981) is one of the widely used methods of rainfall seasonality analysis, which emphasizes on the relative seasonality of rainfall regimes or degree of variability in monthly rainfall throughout the year. Unlike the SPI, the SI assesses seasonal contrasts in rainfall rather than analyzing wet or dry and temporal patterns of Rainfall Seasonality. Studies of rainfall seasonality is vital for planning and management of water resources, adjust cropping patterns and to select and modify suitable cropping varieties (Udayanga and Najim, 2013).

Proper and well-coordinated planning and management of water resources is vital to withstand unfavorable weather extremes such as drought events that cause potential harmful impacts on agriculture and water resources. Thus, thorough, updated and localized study of climate patterns and prediction of climate extremes is vital (Udayanga and Najim, 2013). As the dry zones of tropical islands often face both temporal and spatial shortage of water, an analysis of the shifts, variations and trends of the climate patterns at present with respect to the past, focusing on dry and wet events and rainfall seasonality is highly important to assist the planning and management of water resources. Current, study applies SPI and SI to analyze trends in dryness, wetness and rainfall seasonality within the Northern and North Central regions of the DL_{1b} agro ecological zone of the dry zone of Sri Lanka, while providing adaptation measures to enhance climatic resilience.

Methodology

Study area

DL_{1b} agro-ecological zone covering the Northern and North Central regions located within the dry zone of Sri Lanka was selected as the study area. DL_{1b} is a prominant agro-ecological zone with a higher tank density, which is important as the major source of water for agricultural practices. The rainfall indicates a bimodal distribution pattern due to monsoons and the annual mean rainfall of this zone exceeds 900 mm and remains below 1750 mm (Udayanga and Najim, 2013). Rain dependent shifting cultivation is traditionally practiced within the DL_{1b} while paddy cultivation, mixed crop cultivation and agro forestry too are practiced. Yet severe crop failures can be experienced during the “off” season due to less rainfall often leading to drought events. This agro ecological zone has a high potential on the agricultural and water resources management aspects as most major and minor tanks are located within this zone (Punyawardena *et al*., 2003).

Data collection and analysis

Daily rainfall data covering the period from January 1961 to March 2018 of Anamaduwa, Anuradhapura, Kottukachchiya, Maradankadawala and Vavuniya rain gauging stations (Figure 1) located within the North Central region of the DL_{Ib} agro ecological zone were obtained from the Department of Meteorology, Sri Lanka. Monthly precipitation was computed based on the aggregated daily rainfall values for each station, under two approximately equal periods as 1961-1988 and 1989-2018.

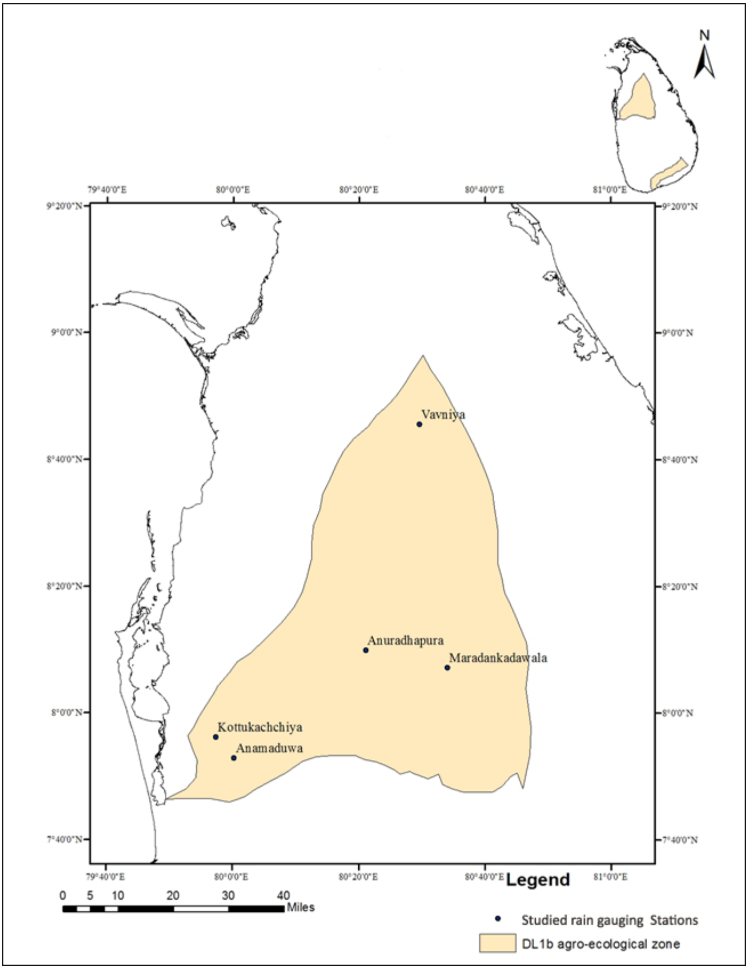

Figure 1: Spatial location of the studied rain-gauging stations in the DL_{Ib} agro ecological zone.

Standardized Precipitation Index (SPI)

SPI values for each month for the time intervals 1961-1988 and 1989-2018 were calculated at each station as the difference between precipitation on a time scale (x_i) and the mean value ($\bar{x}$), divided by the standard deviation (S), as given in the Equation 1.

$$\text{SPI} = \frac{x_i - \bar{x}}{s} \text{......................Equation 1}$$

Based on SPI range, dry periods were broadly classified into five classes as normally dry (0 to -0.49), mild drought (-0.50 to -0.99), moderate drought (-1.00 to -1.49), severe drought (-1.50 to -1.99), extreme drought (-2.00 or lesser) events (Liu *et al*., 2011). Drought length or duration (D) was taken as the number of consecutive months where SPI remains below -0.49. Similarly, the anomalously wet events were assumed to be present over a consecutive number of months, where SPI values remain over a threshold of 0.49. As recommended by Liu *et al*. (2011), the wet periods were also classified into five classes based on the SPI range, as normally wet (0 to 0.49), mild wet (0.50 to 0.99), moderate wet (1.00 to 1.49), severe wet (1.50 to 1.99) and extreme wet events (2.00 or higher).

Seasonality Index

As defined by Walsh and Lawler (1981), the Seasonality Index (SI) for 1961-1988 and 1989-2018 for each station was calculated as the simple sum of the absolute deviations of mean monthly rainfalls ($\bar{x}$) from the overall monthly mean, divided by the mean annual rainfall of the considered time period ($\overline{R}$) as indicated in the Equation 2.

$$SI = \frac{1}{\bar{R}} \sum_{n=1}^{n=12} \left| \bar{x} - \frac{\bar{R}}{12} \right| \text{ .... 2}$$

The mean SI values for each time period were calculated for each locality and were compared with each other to identify prominent trends in seasonality. According to Walsh and Lawler (1981), the value of the SI ranges from 0 to 1.83. The nature of the seasonality is defined as, very equable (0 - 0.19), equable but with a definite winter (0.20 – 0.39), rather seasonal with a short drier season (0.40 – 0.59), seasonal (0.60 -0.79), markedly seasonal with a long drier season (0.80 – 0.99), most rains received within 3 months or less (1.00 – 1.19) and extreme where all most all rain received within 1-2 months (1.20-1.83).

Data interpretation and analysis

The generated negative and positive values of SPI were categorized in accordance with the boundaries of different classes of drought and wet events, as proposed by Liu *et al.* (2011). The total number of events in both the periods were calculated and the percentage of each class of events were calculated separately and were statistically compared with respect to the classes of the events recorded during 1961-1988 and 1989-2018 by using the Chi-square test at 95 % level of confidence.

Results and discussion

Variations in dry and wet events

The percentage of climatic events belonging to each class that occurred within each time period at different localities are tabulated in Table 1. According to SPI, all the rainfall stations, denoted notable reductions in moderate, severe and extreme wet events within the 1989-2018 period compared to 1961-1988, suggesting a decrement in wetness. However, statistics of Chi-square test, emphasized that all the above trends were statistically non-significant ($X^2_{(df\ =\ 4)}$ <6.93; P>0.05) at 95 % level of confidence (Figure 2).

An increasing trend in mild, moderate, severe and extreme dry events were observed in all the localities within the recent year period (1989-2018), depicting an overall increase in dryness (Table 1). According to the results of Chi-square test, only the increment of dryness in Vavuniya remained significant ($X^2_{(df\ =\ 4)}$ =9.78; P=0.04) at 95 % level of confidence. According to De Silva (2006), the rainfall is predicted to decrease in several areas of dry zone such as Anuradhapura, Trincomalee and Batticaloa. Based on the SI values, all the study locations (0.95-0.97) were characterized with markedly seasonal climatic conditions with long drier seasons (0.80 – 0.99) as suggested by Walsh and Lawler (1981). Further, notable variations in rainfall seasonality were not observed among the two periods according to the SI (Figure 2).

Table 1: Percentage occurrence of dry and wet events at different study localities.

Event	SPI Value	Category	Kottukachchiya 1961-1988	Kottukachchiya 1989-2018	Anuradhapura 1961-1988	Anuradhapura 1989-2018	Vavuniya 1961-1988	Vavuniya 1989-2018	Maradankadawala 1961-1988	Maradankadawala 1989-2018	Anamaduwa 1961-1988	Anamaduwa 1989-2018
			Percentage Occurrence of Events %									
Wet Events	≥ 2.00	Extreme wet	5.3	3.1	5.5	2.1	4.7	4.3	1.3	1.1	3.5	1.9
	1.50 to 1.99	Severe wet	9.7	8.4	10.2	5.9	6.8	6.5	8.5	8.1	9.8	8.4
	1.00 to 1.49	Moderate wet	17.8	15.7	24.3	16.6	17.6	16.1	19.6	17.9	20.3	20.6
	0.50 to 0.99	Mild wet	32.7	34.9	29.5	31.9	34.5	34.3	33.3	32.4	30.8	29.5
	0 to 0.49	Normal wet	34.5	37.9	30.5	43.5	36.4	38.8	37.3	40.5	35.6	39.6
Dry Events	0 to -0.49	Normally dry	42.4	38.9	41.9	31.5	38.9	33.7	43.5	35.6	38.1	12.5
	-0.50 to -0.99	Mild droughts	32.1	30.6	30.3	32.9	33.1	43.2	29.8	33.1	31.9	43.2
	-1.00 to -1.49	Moderate droughts	18.2	19.8	14.8	19.7	17.9	12.3	17.6	20.7	19	24.6

	-1.50 to -1.99	Severe droughts	6.1	7.9	9	10.7	9.4	9.4	7.6	8.7	9.2	15.9
	≤ -2.00	Extreme droughts	1.2	2.8	3.9	5.2	0.7	1.4	1.5	1.9	1.8	3.8

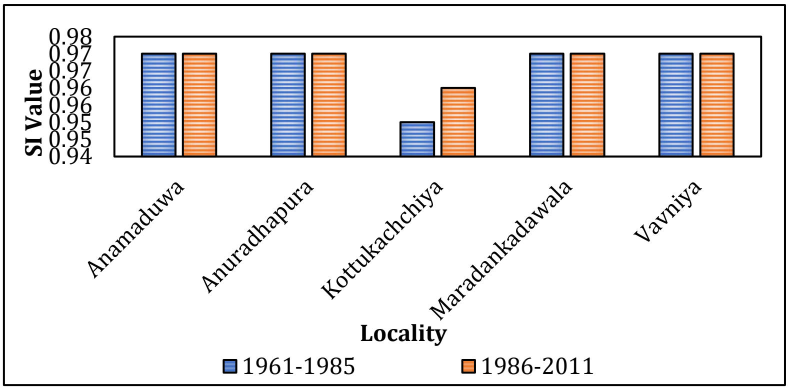

Figure 2: Variations in rainfall seasonality depicted by the SI index

A previous study conducted by Jayawardene *et al.* (2005) using a century-long rainfall dataset has also reported that regardless of increasing or decreasing trends in annual rainfall patterns in Sri Lanka, majority of those remains non-significant. In addition, several recent studies are also in agreement with the findings of the current study, suggesting an increase in overall dryness within areas such as Anuradhapura, Batticaloa, and Kurunegala (Naveendrakumar *et al.*, 2018).

Climate in tropical countries often exhibit significant spatial and temporal variations. Especially microclimate variations at regional levels could be often experienced in the climate patterns in tropical islands such as Sri Lanka. Thus, unlike most of the recent studies that have been conducted to investigate the trends and impacts of climate change at national level in tropical countries, the present study focuses on the variations and trends in climate at the regional level, which are of higher importance for many aspects such as the degree of bio diversity, agriculture-based economy etc. Even though many studies that were carried out in Sri Lanka (De Silva, 2006; De Silva *et al.*, 2007; Eriyagama *et al.*, 2010) predict significant alterations throughout the country in the severity and occurrence frequency of climatic events in the recent years, only the dry events of Vavuniya indicated significant alterations in accordance with the results of the SPI approach.

Adaptations for increasing dryness

The study area in the DL_{1b} agro-ecological zone covers, several major localities of Sri Lanka in terms of agriculture, due to its high contribution to the agricultural productivity of Sri Lanka. A network of tanks fed by the monsoon rainfalls have been used to cater to agricultural water requirements in the study area. Hence, any alteration in rainfall amount and seasonality, as suggested in the current study, could result significant impacts on the availability of water for agriculture. Thus, a decrease in severity and frequency of occurrence of rainfalls could bear severe consequences on the agricultural productivity.

According to De Silva *et al*. (2007), by the year 2050, a possible reduction in the quantity and spatial distribution of rainfall may lead to an increased irrigation water requirement for paddy by 13-23 % during the main season compared to that of 1961-1990. Enlargement and de-siltation of tanks to enhance the water holding capacity would be of importance. Therefore, renovating the existing tanks in the DL_{1b} agro-ecological zone would facilitate collection of excess rainfall, especially during the South West Monsoon (SWM) that could be used in dry periods. Encouraging the community towards rainwater harvesting at the household level would also be an efficient low-cost adaptation strategy to face the expected increasing dryness of the study area (Eriyagama *et al*., 2010). Government could support this process via provision of soft loans and required technical knowledge under a well-coordinated "National Rainwater Harvesting Policy". Shifting of crop species, from varieties with high water demands to varieties with low water demands, adjustment of the cropping seasons (Zougmoré *et al*., 2016), use of more efficient water smart irrigation methods such as drip irrigation (Fox *et al*., 2005), implementation of agro-forestry systems (Reij *et al*., 2009) and employment of Smart and Integrated Watershed Management Practices (SIWMP) etc. could also be recommended as potential measures to compensate the expected increments in dryness.

Sri Lanka and Western Ghats is considered as a sensitive and prominent biological hotspot in the world, which includes highly threatened diverse floral and faunal communities. The variations in climate triggered by the climate changes could significantly alter the environmental conditions of the diverse habitats on which many endemic species thrive upon, causing a significant impact on the distribution and survival of these flora and fauna (Garcia *et al*., 2014). The study area includes many dry deciduous monsoon forest patches with diverse vegetation structures and a rich biodiversity. Ritigala, one of the three Strictly protected Natural Reserves of Sri Lanka is also located within this region. In addition, Villpaththu, one of the most renowned national parks is also located very close to the border of the studied agro ecological zone. Extreme warming and drying events, are expected to mainly affect the tropical regions, causing severe threats on sensitive species (Garcia *et al*., 2014). Thus, the study of the recent trends in climate change play a crucial role in the conservation aspect of biodiversity. According to Garcia *et al.* (2014), improving habitat quality in areas shrinking climatically to help species adapt locally, or promoting landscape connectivity for species that need to move to track suitable climates through time, are sound conservation strategies. Hence, studying of such implications of climate change is essential for the drafting of policies, designing of management actions and plans etc. to preserve biodiversity and ecosystems.

Community involvement is a critical factor in successful implementation of any project. Thus, increasing the awareness of the community of the expected increments in dryness and appropriate adaptation measures and dissemination of technology know-how among selected groups in the community would be critical in enhancing the climate change resilience of the study area (Zougmoré *et al*., 2016). Findings of the current study could be used to identify the impacts of climate change and to develop proper adaptation plans to face the expected implications of climate change.

Conclusions

The results of this study suggest an increase in dryness within the DL_{1b} agro-ecological zone. Unlike the predictions of many studies that were carried out in Sri Lanka, which expect significant alterations in the severity and occurrence frequency of climatic events, significant increase in dryness was significant only in Vavuniya. The planning and management of the water resources and crop management practices in the DL_{1b} agro-ecological zone should be properly conducted based upon the observed present and expected future trends in climate patterns. In addition, the evaluation of the variations in climates is of potential importance in assessment of the future impacts of climate change on the rich biodiversity of Sri Lanka. Thus, rational and effective drafting of conservation strategies, biodiversity management and action plans etc. should be conducted taking such impacts of climate change into consideration.

References

De Silva C.S. (2006). Impacts of climate change on water resources in Sri Lanka. *32nd WEDC International Conference*, Colombo, Sri Lanka.

De Silva, C.S., Weatherhead, E.K., Knox, J.W. and Rodriguez-Diaz, J.A. (2007). Predicting the impacts of climate change—A case study of paddy irrigation water requirements in Sri Lanka. *Agricultural water management*, *93*(1-2): 19-29.

Eriyagama, N., Smakhtin, V., Chandrapala, L. and Fernando, K. (2010). *Impacts of climate change on water resources and agriculture in Sri Lanka: A review and preliminary vulnerability mapping* (Vol. 135). International Water Management Institute (IWMI).

Fox, P., Rockström, J. and Barron, J. (2005). Risk analysis and economic viability of water harvesting for supplemental irrigation in semi-arid Burkina Faso and Kenya. *Agricultural Systems*, *83*(3): 231-250.

Garcia, R.A., Cabeza, M., Rahbek, C. and Araújo, M.B. (2014). Multiple dimensions of climate change and their implications for biodiversity. *Science*, 344 (6183).

Intergovernmental Panel on Climate Change (IPCC) (2007). Climate change 2007: the physical science basis: summary for policymakers. Geneva*: IPCC*.

Jayawardene, H.K.W.I., Sonnadara, D.U.J. and Jayewardene, D.R. (2005). Trends of rainfall in Sri Lanka over the last century. *Sri Lankan Journal of Physics*, *6*.

Lee, T., Modarres, R. and Ouarda, T.B. (2013). Data-based analysis of bivariate copula tail dependence for drought duration and severity. *Hydrological Processes*, 27(10): 1454-1463.

Liu, C.L., Zhang, Q., Singh, V.P. and Cui, Y. (2011). Copula-based evaluations of drought variations in Guangdong, South China. *Natural Hazards*, 59(3): 1533-1546.

McKee, T.B., Doesken, N.J. and Kleist, J. (1993). January. The relationship of drought frequency and duration to time scales. *In*: *Proceedings of the 8th Conference on Applied Climatology*. 17(22): 179-183.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A. and Raper, S.C. (2007). Global climate projections. *Climate change*, 3495: 747-845.

Morid, S., Smakhtin, V. and Moghaddasi, M. (2006). Comparison of seven meteorological indices for drought monitoring in Iran. *International Journal of Climatology,* 26(7): 971-985.

Naveendrakumar, G., Vithanage, M., Kwon, H.H., Iqbal, M.C.M., Pathmarajah, S. and Obeysekera, J. (2018). Five decadal trends in averages and extremes of rainfall and temperature in Sri Lanka. *Advances in Meteorology*, 2018.

Punyawardena, B.V.R., Bandara, T.M.J., Munasinghe, M.A.K., Banda, N.J. and Pushpakumara, S.M.V. (2003). Agro-ecological regions of Sri Lanka. Natural Resource Management Centre, Department of Agriculture, Peradeniya, Sri Lanka.

Reij, C., Tappan, G. and Smale, M. (2009). Agroenvironmental Transformation in the Sahel: Another Kind of "Green Revolution" IFPRI Discussion Paper 00914. *Food Policy,* Washington DC, USA, p.52.

Udayanga, N.W.B.A.L. and Najim, M.M.M. (2013). Evaluation of the Trends in Climatic Change with Respect to Severity and Occurrence Frequency. *In*: *Proceedings of the Water Professional's Day – 2013*, Peradeniya, Sri Lanka, 51-62.

Walsh, R.P.D. and Lawler, D.M. (1981). Rainfall seasonality: description, spatial patterns and change through time. *Weather*, 36(7): 201-208.

Zougmoré, R., Partey, S., Ouédraogo, M., Omitoyin, B., Thomas, T., Ayantunde, A., Ericksen, P., Said, M. and Jalloh, A. (2016). Toward climate-smart agriculture in West Africa: a review of climate change impacts, adaptation strategies and policy developments for the livestock, fishery and crop production sectors. *Agriculture and Food Security*, 5(1): 26.