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Modeling Extreme Drought Events in Major Cocount Growing Agro-Ecological Regions in Sri Lanka

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Abstract: ***Coconut is one of the major plantation crops in Sri Lanka which is more sensitive to the climatic change. During past few years in Sri Lanka the climate change has been extensively discussed, because it is important to investigate the climate extremes in order to best address their impacts in the agriculture section in future. The main objective in this study is to identify rainfall patterns and forecasting the extreme drought events in major coconut growing agro-ecological regions (AERs) during the monsoon seasons and Yala/ Maha seasons. Daily rainfall data from 1932 to 2011in 14 rainfall stations from six AERs, DL3, WL2, WL2b, WL3, IL1 and IL3 were acquired from the climate database from Biometry division in Coconut Research Institute. Climate indices provide valuable information contained in daily rainfall data. In this study five descriptive extreme precipitation indices, which are defined by Expert Team on Climatic Change Detection and Indices (ETCCDI) were used to identify characteristic trend of extreme events. There are two types of extreme rainfall indices interested in this study, those are extreme frequency (R10mm, R20mm, R95p, R99p) and extreme intensity (Rx1day). Mann Kendall trend test used to identify trend of each indices. It was noted that trend analysis of extreme precipitation indices were revealed that the occurrence of drought events had a significant increase in WL2b region, Horakelle, Palugaswewa stations in IL1 region and Ambalantota station in the DL3 region. Standard Precipitation Index (SPI) was used as the drought-monitoring tool with three different time scales, those are SPI3, SPI6, and SPI12 time scale. SPI12 time scale was used to obtain the historical hydrological drought event. It was noted that all stations in WL2b region had highest drought duration and drought severity while Kekanadura station had highest drought duration with -96.58 drought severity with 35 month. SPI3 and SPI6 time scale values were used to analysis the drought events in monsoon seasons and Yala/Maha seasons respectively. To forecast future drought events in each stations Autoregressive Integrated Moving Average (ARIMA) and Seasonal Auto Regressive Integrated Moving Average (SARIMA) models were fitted in monsoon seasons and Yala/Maha season. To identify drought areas with similar characteristics in different seasons, cluster analysis for SPI3 and SPI6 time scale were performed separately. To identify most suitable time series modeling method the fitted time series models of the each station were compared with time series models of the clustered stations in WL2b region for SPI6 time. It was identified that fitting time series model to forecast extreme drought events in clustered station in WL2b region is more accurate than fitting time series models for individually in each station in this region. It was noted that WL2b region, Horakelle, Palugaswewa stations in IL1 region and Ambalanthota station in DL3 region are drought prone AER in Sri Lanka.***

Keywords: drought, agro-ecological regions (AERs), extreme rainfall indices, standardized precipitation index (SPI)

1. Introduction

Climate change has been extensively discussed throughout past few years in Sri Lanka, because of the expected shift of climate regimes to a warmer climate with more extreme events in the country. It is important to investigate the climate extremes in order to best address their impacts and implement adaptations and mitigation measures in the agriculture sector in future. The climatic pattern of Sri Lanka is determined by the generation of monsoonal wind patterns in the surrounding oceans. Period of rainfall in a year has been divided into four categories, those are, North east monsoon, first inter monsoon, south west monsoon and second inter monsoon. Agro-ecological regions (AERs) represent a particular combination of the natural characteristics of climate, soil and relief. Each agro-ecological region represents a uniform agro-climate, soils and terrain conditions and as such would support a particular farming system and for the crop production.

The main objective of this study is to identify rainfall patterns and forecasting the extreme drought events in major coconut growing agro-ecological regions (AERs) which are vulnerable to drought conditions during the monsoon seasons and *Yala/Maha* seasons (Waidyarathne et al, 2006).In this study, descriptive extreme rainfall indices were calculated using the ETCCDI (by Expert Team on Climatic Change Detection and Indices) standards which are important to gain a uniform perspective on observed changes in weather and climate extremes (Donat et al, 2013). Extreme indices based analysis was performed to the daily rainfall to identify the significance extreme events rather than studying the normal precipitation events.

Five extreme indices were calculated and characteristic of those indices in the past was identified by applying the Mann-Kendall trend test. There are two types of extreme indices considered in this study namely frequency based extreme indices and intensity based extreme indices.

Drought is a natural occurring phenomenon related to the significant decrease of the water availability for a long period of time. Drought forecasting is an essential tool for predict the coconut production in the future. It is very important concept in planning the water resources systems in field. There are several drought monitoring indices. McKee et al (1993) developed the Standardized Precipitation Index (SPI) which is used in this study for drought monitoring purpose, due to its capability of forecasting the drought events in different time scales.

2. Literature Survey

Shahid.S (2011) considered the variability of the extreme rainfall events in Bangladesh during the time period 1958-2007. Variability of the 15 annual and seasonal rainfall indices were examined in that study. In that study he used Mann-Kendall statistic to measure the trends and Sen's Slope to measure magnitude change of rainfall indices respectively. His results suggested that there is a significant increase of annual and pre-monsoon rainfall. Also there was an increasing trend in heavy precipitation days and decreasing trends in consecutive dry days over in the Bangladesh. Finally, he concluded that the significant change in most of the extreme rainfall indices are observed in the stations situated in Northwest Bangladesh.

Chirthranayana R.D and Punyawardene B.V.R (2008) were conducted the study in Sri Lanka to identify the drought areas in agro-ecological regions. This study they has attempted to identify the agro-ecological regions (AERs) which are vulnerable to drought conditions during Maha and Yala seasons, using a drought index based on the monthly Moisture Availability Index (MAI). Also they found that The Wet Zone does not exhibit droughts during Maha seasons except WL2b and WL3 regions which have a slight vulnerability for droughts. All AERs in the up country and mid country intermediate zone are generally free from droughts. All AERs of the low country intermediate zone are vulnerable to drought during Maha seasons except IL2 and IL1c. All AERs in the low country intermediate zone are vulnerable to droughts except the IL1a region. Excluding the AERs that adjoin the high rainfall receiving AERs of the wet zone, AERs in mid country intermediate zone are also prone to droughts. Furthermore results of this study showed that that all the AER of the dry zone are highly vulnerable to droughts. Also they found that to Yala seasons, almost all AERs of the dry zone are less experience droughts than Maha seasons except those located in the extreme northwestern and southeastern regions.

3. Materials and Methods

This study was conducted using daily rainfall data from 1932 to 2011 in 14 rainfall stations located across six major coconut growing AERs. In this study 5 out of 27 descriptive extreme indices were calculated and characteristic trends of those indices in each station were identified using the Mann-Kendall trend test. These five indices consist of two types of extreme indices, frequency based extreme indices and intensity based extreme indices. For this study the Number of heavy precipitation days(R10mm), very heavy precipitation days(R20mm), very wet days(R95p) and extremely wet days(R99p) were considered as frequency based extreme indices while monthly maximum one day precipitation (Rx1day) considered as the only intensity based index.

For drought monitoring purposes SPI3, SPI6, SPI12 time scale values were calculated. SPI3 and SPI6 time scale values were used for trend analysis, to forecast the drought events in station wise for monsoon seasons and *Yala/Maha* seasons respectively. SPI12 time scale values were used to identify the long term hydrological drought event in that particular location. Drought event is taken as the SPI values become negative or continuously less than the negative one value. When SPI values again reached to greater than the negative one drought event is terminated. Drought duration defined by the number of months in which the SPI values remained under this threshold value. Drought severity is defined as the cumulative sum of the monthly SPI values under a certain threshold (negative one).

Time series analysis was conducted to forecast the extreme drought events in each station. Stationary of time series data is checked by using Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test and Phillips-perron unit root test. There are several tentatively identified Box Jenkins models constructed for SPI data in station wise. Combinations of Autoregressive Integrated Moving Average (ARIMA) and Seasonal Auto Regressive Integrated Moving Average (SARIMA) models were fitted to forecast meteorological droughts in monsoon seasons and *Yala/Maha* seasons. Best fitted models for the each station were selected by using AIC/BIC criteria. Residual analysis of the best fitted model was performed and the fitted model was validated using data from 2005 to 2011. Then the forecast accuracy is measured for the each individual station by using Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). Cluster analysis for SPI3 and SPI6 time scale data were performed separately to identify drought areas with similar characteristics in the monsoon and *Yala/Maha* seasons respectively. Hierarchical clustering technique applies to cluster the data in station wise. Most suitable clustering method is selected using the highest value of Cophenetic correlation. Scree plot is used for determine the number of clusters in the data set. Time series models were fitted for one of the clustered stations in SPI6 time scales and it was compared with time series models of the each station in that cluster separately.

Table 1: Description of AERs and rain stations

AERs	*AERs*	*Rain Station*
DL3	Dry Zone Lower	Puttalama Ambalantota
WL2	Wet Zone Lower2	Dedigama
WL2b	Wet zone Lower2b	Galle Kekanadura Beddegama
WL3	Wet zone Lower3	Gampaha Katunayake
IL1	Intermediate zone Lower1	Horakelle Kurunegala, Palugaswewa Rathmalagara
IL3	Intermediate zone Lower3	Mediyawa Wariyapola

4. Results and Discussion

The p-value of Mann-Kendall trend test of the extreme precipitation indices suggested that the occurrence of drought events had a significant increase in WL2b region, Ambalantota station in the DL3 region and Horakelle, Palugaswewa in IL1 region. Also the results of trend analysis for the SPI data in three month time scale and six month time scale showed an evidence for a significant decreasing trend in the SPI values in WL2b region, Ambalantota in DL3 region and Horakelle, Palugaswewa in IL1 region. The highest drought duration and the highest severity drought events were found in WL2b region while Kekanadura station in WL2b region had the highest drought duration (35 month) with
-96.58 drought severity.

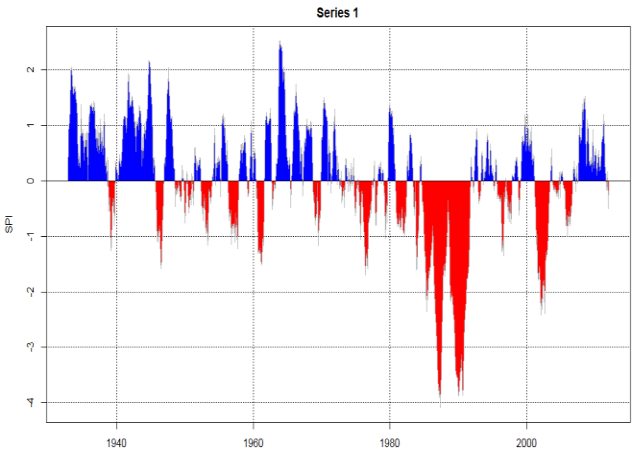

Figure 1: Highest drought duration and severity in Kekanadura station

Also it is noted that the highest significance of drought event occurred in all rain station located in the WL2b region with compare to the other stations. The summary of historical drought duration and severity in each station is shown in following table.

Table 2: Historical drought duration and highest severity

AERs	Rain Station	Duration (months)	Severity
DL3	Puttalama	22	-37.58
	Ambalantota	26	-44.93
WL3	Gampaha	14	-21.68
	Katunayake	15	-29.98
WL2b	Galle	24	-44.34
	Kekanadura	**35**	**-96.58**
	Beddegama	29	-40.36
WL2	Dedigama	19	-44.95
IL1	Horakelle	17	-27.06
	Kurunegala	13	-29.42
	Palugaswewa	8	-27.06
	Rathalagara	14	-31.48
IL3	Mediyawa	14	-23.24
	Wariyapola	13	-25.96

Time series models were fitted to forecast the future extreme drought events and the following table represents the resulted time series models for the SPI3 time scale, furthermore these fitted time series model can be used to forecast the future extremes in monsoon seasons in Sri Lanka.

Table 3: The fitted time series model for SPI3 time scale

AERs	Rain Station	SPI3 Time scale
DL3	Puttalama	SARIMA(0,0,2)(0,0,2)$_{12}$
	Ambalantota	SARIMA(1,0,2)(0,0,1)$_{12}$
WL3	Gampaha	ARMA(0,2)
	Katunayake	ARIMA(0,1,3)
WL2b	Galle	SARIMA(1,0,2)(0,0,1)$_{12}$
	Kekanadura	SARIMA(1,1,3)(0,0,1)$_{12}$
	Beddegama	ARIMA(2,1,3)
WL2	Dedigama	SARIMA(1,0,2)(0,0,1)$_{12}$
IL1	Horakelle	ARIMA(0,1,3)
	Kurunegala	ARIMA(2,0,2)
	Palugaswewa	ARIMA(1,1,3)
	Rathmalagara	SARIMA(1,0,2)(1,0,2)$_{12}$
IL3	Mediyawa	SARIMA(3,1,3)(2,0,2)$_{12}$
	Wariyapola	ARIMA(2,1,3)

Time series models were fitted for SPI6 time scale to forecast droughts events in main season (Yala & Maha). The following table represents the summary of fitted time series models for the each station.

Table 4: The fitted time series model for SPI3 time scale

AERs	Rain Station	SPI6 Time scale
DL3	Puttalama	SARIMA(0,0,5)(0,0,2)$_{12}$
	Ambalantota	SARIMA(3,1,3)(1,0,0)$_{12}$
WL3	Gampaha	SARIMA(1,0,5)(0,0,2)$_{12}$
	Katunayake	SARIMA(1,0,5)(0,0,2)$_{12}$
WL2b	Galle	ARIMA(2,1,3)
	Kekanadura	SARIMA(1,0,4)(1,0,0)$_{12}$
	Beddegama	ARIMA(0,1,4)
WL2	Dedigama	SARIMA(5,0,5)(0,0,1)$_{12}$
IL1	Horakelle	SARIMA(0,0,5)(0,0,1)$_{12}$
	Kurunegala	SARIMA(1,0,5)(0,0,2)$_{12}$
	Palugaswewa	SARIMA(0,0,5)(0,0,1)$_{12}$
	Rathmalagara	ARIMA(4,0,5)
IL3	Mediyawa	ARIMA(0,1,4)
	Wariyapola	SARIMA(1,0,5)(0,0,1)$_{12}$

Clustering technique is used for identify those similar behaved stations in SPI3 time scale and SPI 6 time scale. In this study hierarchical agglomerative clustering method is used for the cluster stations. The results of the clustering procedure are illustrated by using a dendrograme. Cophenetic correlation is used to selecting the most suitable clustering method, the best clustering method is selected according to the highest value of cophenetic correlation and number of clusters is determined by using the scree plot. The results of following table confirmed average linkage clustering method is preferable to cluster stations in both time scales.

Table 4: The cophentic correlation values for SPI time scales

Time scale	**Average linkage**	Complete linkage	Single linkage	Ward method
SPI3	**0.937**	0.928	0.917	0.800
SPI6	**0.905**	0.888	0.873	0.795

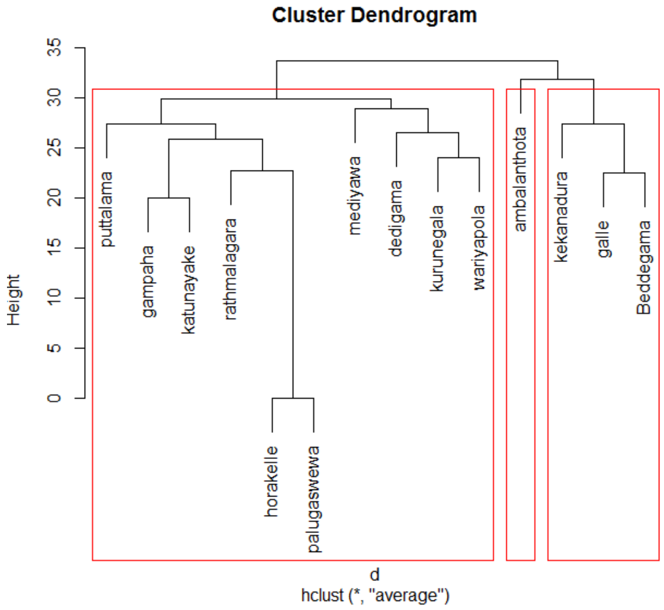

Figure 2: Cluster dendograme for SPI 3 time scale

The results of dendrograms revealed that all the stations in WL2b region and Ambalanthota station had similar dry and wet climatic patterns in monsoon season and Yala maha seasons.

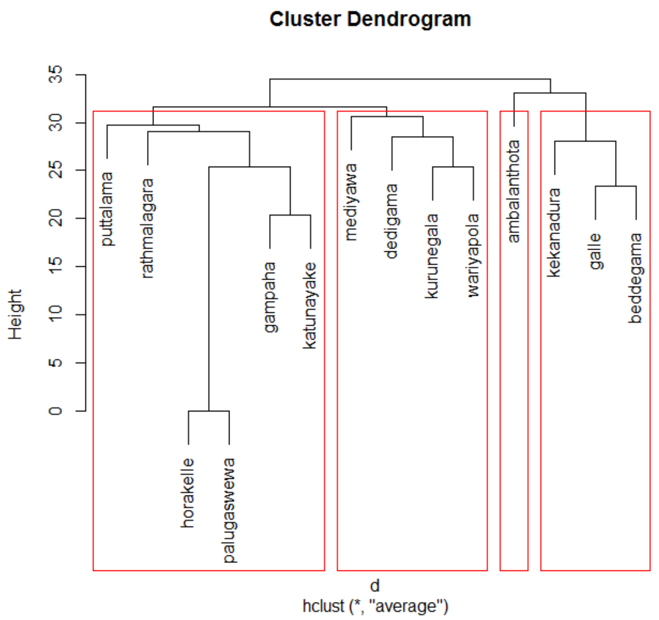

Figure 3: Cluster dendograme for SPI6 time scale

One of the clustered stations was considered in SPI6 time scale and time series model was fitted to the clustered station by using the Box Jenkins criteria, and then compares that fitted model with fitted individual time series models in the cluster. It was confirmed that time series model in clustered stations had the maximum log likelihood value and the minimum AIC and BIC values. Also the accuracy of the time series model of fitted clustered models for WL2b region was higher than the individual models in SPI6 time scales.

Table 6: The fitted time series model for SPI6 time scale

Station	*Time Series model*	*Log Likelihood*
Galle	*ARIMA(2,1,3)*	*-857.57*
Kekanadura	*SARIMA(1,0,4)(1,0,0)$_{12}$*	*-609.06*
Beddegama	*ARIMA(0,1,4)*	*-600.55*
Cluster model	***SARIMA(4,0,5)(0,0,1)$_{12}$***	***-506.81***

Table 7: The AIC and BIC values in fitted time series model

Station	*AIC*	*BIC*	*MAE*	*RMSE*
Galle	*1727.14*	*1755.85*	*0.49*	*0.64*
Kekanadura	*1234.12*	*1272.39*	*0.38*	*0.48*
Beddegama	*1221.1*	*1268.92*	*0.36*	*0.48*
Cluster model	***1037.63***	***1095.03***	***0.32***	***0.41***

Therefore the results revealed that fitting time series model to clustered station in WL2b region is more accurate than fitting time series models for individually in each station for SPI6 time scale.

5. Conclusions

The extreme indices calculation suggested that the occurrence of drought events had a significant increase in all the selected stations of WL2b region, Ambalantota station in DL3 region and Horakelle, Palugaswewa stations in IL1 region. Also trend analysis of SPI showed a negative trend that revealed an increase of drought condition in the above mentioned regions. It was found that fitted time series ARIMA and SARIMA models forecast the future drought events in inter monsoon and Yala/Maha seasons more accurately. According to cluster analysis WL2b and Ambalantota had similar characteristic of extreme drought events in inter monsoon seasons and main seasons. Then the results were confirmed that fitting the model for cluster is more accurate than fitting the individual time series models. It was very useful information to the develop the future research works, because of the individual time series modeling process was longer and difficult when had the large number of stations. So initially perform the cluster analysis to stations and then fitting models to each cluster were more effective in the further works regards to forecasting the drought events. It was noted that the coconut growing areas located in Ambalanthota, Horakelle, Palugaswewa and WL2b region are drought prone AERs in monsoons and Yala/Maha seasons in the Sri Lanka.

6. Future Scope

When using the rainfall data it is difficult to dealing with the series of missing rainfall values. When monitoring the drought event it is better to consider the effect of the temperature also expect to the considering the rainfall. SPI is based on precipitation only. So choosing the drought index it is suitable select SPEI index in future.

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