Rainfall Trends for El Niño Seasons over Malawi from 1970 to 2016 and its Impact on Crop Yield and Hydropower Generation

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Abstract- The purpose of this study was to evaluate the rainfall trend for El Niño seasons over Malawi and its impact on electricity and agricultural production from 1970 to 2016. Monthly and annual rainfall time series of over 45 year period to 15 meteorological weather stations across Malawi were constructed for all El Niño rainfall seasons. This study reveals a high variability of both monthly and seasonal El Niño rainfall seasons. From the selected rainfall stations, 34.7% had rainfall above normal in the south, 39.2% in the central and 52.6% in the north. Substantial rainfall was recorded in the months of December, January, February and March. 70.4% of the stations in the southern half Malawi showed decreasing November rainfall, while the northern half of the country had decreasing December rainfall for 63.7% of stations therein. April rainfall was gaining importance as its contribution to seasonal rainfall was increasing in 68% of the seasons over central and north of Malawi. 65% of the stations in the south had Onsets in November. Similarly, 73% rainfall stations in the northern Malawi experienced rainfall Onset in December. El Niño seasons had a fluctuation decreasing rainfall average trend of 972.4±53 mm. However, the stations in the north of the country had an average increasing rainfall trend of 105±13 mm under El Niño rainy seasons. Total trend of an average number of rainy days was decreasing under El Niño seasons, 75.3% in the south, 81.3% in the central and 43.7% rainfall stations in the north had a decreasing trend in rainy days. The length of the El Niño seasons had a gradually reducing tend by an average of 103±14 days. Within the progression of El Niño rainfall seasons, longer spells were experienced in southern parts of Malawi with an average of 6±2 days. 75% of the "cessation" of the El Niño rainfall seasons were from the months of March over the south, and April over the north with a trend of shifting to the next months in both parts of the country respectively. The El Niño borderline conditions led to extensive rainfall deficits, resulting in widespread drops in crop production. The study underscores the clear link between El Niño events and drops in national maize yield as well as low Shire river flow rate leading in mean lower amounts of water flow to the dams that produce electricity in Malawi.

Index Terms- El Niño season, Rainfall trends, Climate change, Malawi, Onset, Progression and Cessation

I. Introduction

El Niño is a term given to a warming of at least 0.5°C for at least 5 months in a row of the eastern tropical Pacific occurring every few years, which alters the weather pattern of the tropics [1]. The El Niño-Southern Oscillation (ENSO) is a naturally occurring phenomenon that involves fluctuating ocean temperatures in the equatorial Pacific. The Malawian summer (October to April) rainfall is very crucial for the economic development, electricity generation, disaster management and hydrological planning for the country [2]. Annual rainfall and run-off averages show that overall water resources are abundant, ranging from 725 mm to 2 500 mm. with Lilongwe having an average of 900 mm, Blantyre 1127 mm, Mzuzu 1289 mm and Zomba 1433mm [3]. The resulting mean annual runoff of Malawi, minus evaporation, is estimated at 588 m^3/s or 18 480 x 106 m^3. The mean annual runoff over the land area of the whole country is 196 mm (i.e. an equivalent of 588 m^3/s), and this constitutes 19% of the mean annual rainfall [4].

The main rains start from November in the south and progressively spreading northwards. During this period, the main rain bearing systems that influence rainfall over Malawi include the Inter-Tropical Convergence Zone (ITCZ), Congo air mass, Easterly Waves and Tropical Cyclones [4]. The key driving factors on rainfall systems over Malawi include the Sea Surface Temperatures (SSTs) over the Pacific, Indian and Atlantic tropical Oceans. La Niña, unusual cooling of waters over the Eastern and Central Equatorial Pacific Ocean, affects rainfall pattern over the world including Southern Africa and Malawi [5].

In the context of climate change, it is pertinent to ascertain whether the characteristics of Malawian rainfall pattern also are changing. Serious concerns are mounting that Malawi might continue facing low hydropower generating and poor crop harvest, possibly a disastrous ones. For Malawi, El Niño usually means less annual rainfall [6]. The impacts of El Niño, with poor rainfall being observed across the country (in some areas less than 25% of the average seasonal rainfall), and at times leading to declaring drought emergencies in the country [7]. Right Now, 90% of Malawians rely on rain-fed sources of water, which are heavily impacted by floods and droughts. Future climate change risks in insufficient hydropower, rising temperatures, increased risk of drought, and late onset of rains will affect food production and increase food poverty [8]. Seasonal forecasts for the past El Nino seasons were optimistic, providing indications of wide spread lower than average rainfall for the duration of the season in Malawi. The past performances of the rainfall may give an indication of the future scenario.

This study aimed at evaluating the trend in rainfall for El Nino seasons over Malawi from fifteenth selected areas across the country by analyzing the rainfall season variability in terms of onset, progression, cessation, length and dry spells occurrence in relation with the normal (monthly and seasonal) rainfall at each station. It also overlays the impacts brought by El Nino rainfall seasons on crop yield and hydropower generation in Malawi. The study used acceptable data from The Department of Climate Change and Meteorological Services (DCCMS) to provide reliable estimate rainfall climatology for Malawi. The rainfall station network in Malawi is of higher density (approximately 28 Principal Meteorological Stations in total), where rainfall is recorded once per day at 08:00 UTC [2]. Daily totals recorded each morning at 08:00 are attributed to the previous day e.g. a rainfall reading of 20mm made at 08:00 on the 18th is the actual total for a 24hr period beginning at 08:00 on the 17th and is attributed to the 17th. These data are communicated to Meteorological department of Malawi by post and digital methods at the end of every two weeks. They are then quality controlled and entered into the rainfall database [9]. For the purpose of this study, the quality control and database entry from 1970 in the target stations was thoroughly revisited at DCCMS.

II. MATERIALS AND METHODS

This study used quantitative data collection method based on one stage sampling technique. Such triangulation is important for ensuring objectivity and representativeness of data. However, for a season to be regarded as an El Niño, it had to cover, strong or very strong thresholds, as such all weak and moderate El Niño season were excluded. Table 1 below shows all El Niño rain fall season that occurred between 1970 and 2017.

Table 1: Analogue Rainfall Seasons over Malawi

Type of the Rainfall Season	Duration				
El Niño	1972/73	1982/83	1986/87	1987/88	1991/92
	1997/98	2002/03	2009/10	2014/15	

Source; www.metmalawi.com

A. Epochal patterns of Malawian rainfall

It is well known that Malawian rainfall displays multi-decadal variations in which there is a clustering of rainfall anomalies [10]. To examine the epochs of above and below normal rainfall, 30-year running means Malawian rainfall was calculated to determine frequency behavior. These epochs of above and below normal rainfall are shown in appendix 1. To understand the epochal behavior of rainfall series for different months, the researcher had calculated 30-year running mean of each of the seasonal month. In order to examine further, whether the contribution of each month's rainfall in the annual rainfall showed any significant trend, the researcher prepared a time series of contribution of rainfall for each month towards the annual total rainfall for rainfall season in actual rainfall amount (mm). Trend analyses were carried out for each month and for all the 15 weather stations.

B. Description of sample

To have a better estimate of rainfall trends over Malawi, it was necessary to select rainfall stations across the country. This report contains an analysis of 15 rainfall stations in Malawi (at least 5 from each region), namely: Nsanje, Nchalo, Chikwawa, Bvumbwe, Liwonde, Mangochi, Nkhotakota, Chitedze, Mchinji, Dowa, Mzimba, Chikangawa, Bolero, Karonga, and Misuku which are full weather observing stations. Most rainfall station had had reported 100% daily rainfall report from 1970 up to 2016.

Table 2: Name, elevation (meters), location, length record (years), and the completeness (%) For the daily rainfall databases on Malawi

Name of Site	Elevation (m)	Location (lat)	Location (long)	Length (yrs.)	Complete %
NSANJE	55	-16.92	35.26	1940-Current	100
NCHALO	74	-16.26	38.087	1965-Current	100
CHIKWAWA	106	-16.03	34.38	1948-Current	100
BVUMBWE	1149	-15.67	35.07	1923- Current	100
LIWONDE	499	-15.07	35.23	1900- Current	100
MANGOCHI	482	-14.47	35.25	1947- Current	100
NKHOTAKOTA	500	-12.92	34.28	1965- Current	100
CHITEDZE	1149	-13.97	33.63	1968- Current	100
MCHINJI	1186	-13.80	32.88	1922- Current	98
DOWA	1361	-13.65	33.94	1961- Current	97
MZIMBA	1349	-11.84	33.60	1948- Current	100
CHIKANGAWA	1729	-11.84	33.80	1953- Current	98
BOLERO	1108	-10.97	33.74	1953- Current	96
KARONGA	529	-9.88	33.95	1949- Current	100
MISUKU	1413	-9.67	33.53	1946- Current	98

NB: Current is referred to as the time when this report was written (2017)

Figure 1 showing 15 sites on Map of Malawi (*Source; Google earth*)

C. Data

The rainfall data were obtained from the DCCMS, and also from Global Historical Climatological Network (GHCN). Historical annual crop harvest datasets were obtained from Food and Agriculture Organization (FAO) and MAFS data base. Additional datasets for production of electricity was extracted from Electricity Supply Cooperation of Malawi (ESCOM) and Energies Africa portal.

D. Data analysis

The quantitative data was organized using Microsoft Excel (2007). IBM SPSS version 20 was used to work on daily rainfall data and coming up with monthly rainfall values, the monthly readings were summed up to yearly rainfall values. The qualitative data was analyzed by organizing the information and identifying the pattern, developing relevant themes and drawing conclusions. Rainfall values of the stations were then compared to show the trends.

E. Starting dates of the rain season

For this study, the beginning of the rainy season was evaluated with the following parameters: 0.3 mm and above is regarded as a rainy day (this value is also regarded as a rainy day by DCCMS) [2]. The beginning of the rainfall season had to reach the following threshold; the rainfall station had to record an average of ≥ 12.6mm of rainfall within 7 days, also, there must not be a dry spell of more than 3 days within the given days. Furthermore, within those 7 days, the precipitation should not equal to evaporation such that the soils must retain enough moisture to sustain seed germination for agricultural purposes [11]. The months of October, November and December were mostly focused because the ITCZ shifts from northern to southern hemisphere, thus brings the rains with it [7]. The rain season was expected to start (**"onset"**) during this period. Instat software application is used in seasonal Onset analysis.

F. Duration of the rain season

The duration of the season is the number of all days that lay from the date of the beginning of the rain season (season Onset), to the day when the season has to end. In these months, the rainfall was expected to be in **"progression"** period. The last date of rainfall recorded, which is followed up to 15 days of no rainfall recorded (**cessation)**. This meant that the rainfall season was leaving over Malawi.

G. Trends in monthly and annual (seasonal) rainfall patterns

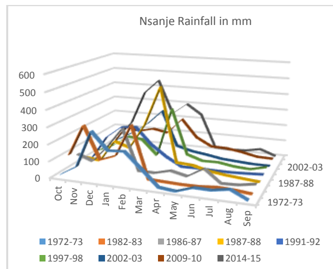
Monthly totals were the sum of the daily values. The analyses were done similarly to each rainfall station. Discrepancies were discussed, resolved into a single consensus analysis. Each month from all the stations was analyzed on how much rainfall reported since 1970 to 2016. The monthly rainfall values were summed up to give seasonal rainfall records which ranges from October to September (12 Months).). Graphs were plotted to portray the trends for monthly and seasonal rainfall since 1970 to 2016 under El Niño events. IBS SPSS version 20 and Microsoft excel was used in this analysis.

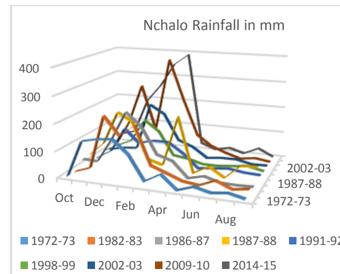
H. Patterns of dry spells

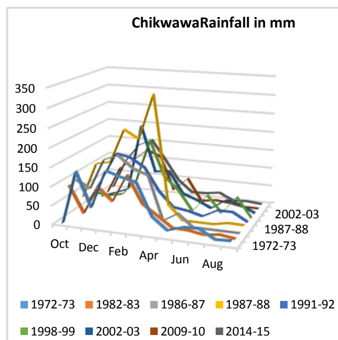
Dry spell incidences were determined on how each rainfall El Niño season at every station especially in the months of January to March. In these 3 months, the rainfall season is expected to be in "progression" period because the rainfall bearing system is well established over Malawi [4]. The pattern in which dry spells behaved from 1970 to 2016 (in days) was analyzed using Instat application so as to come up with the number of days and then Microsoft excels to show the trends in graphs.

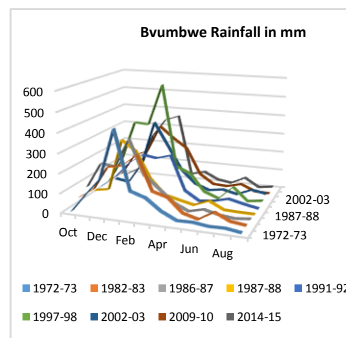
III. RESULTS AND DISCUSSIONS

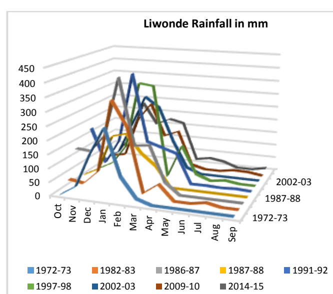
A. Onset, Cessation and Monthly rainfall trends under El Nino seasons

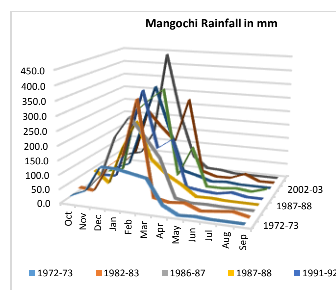


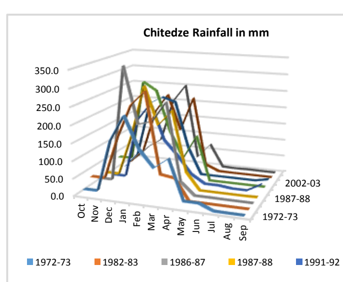


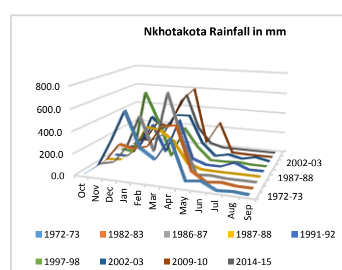


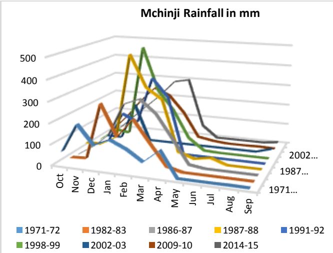


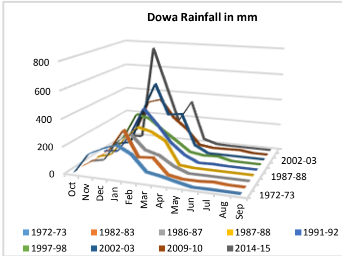


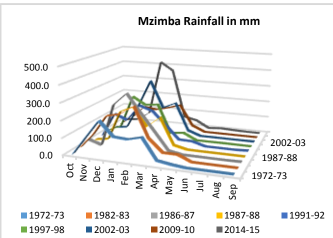


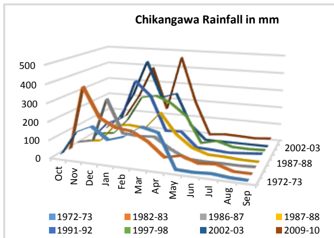


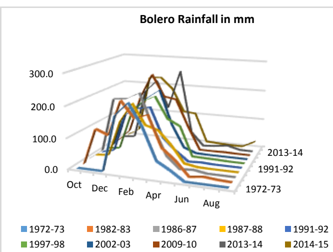


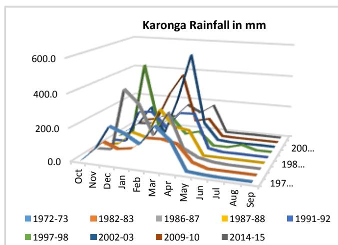


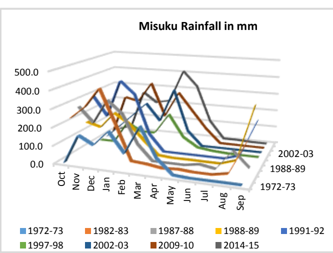






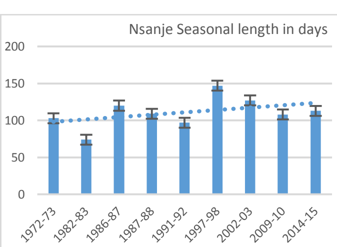


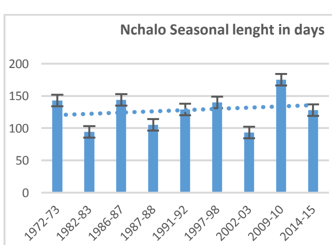


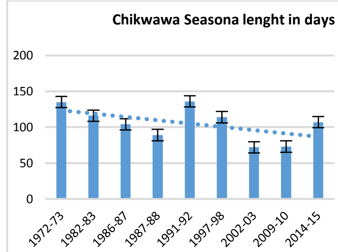


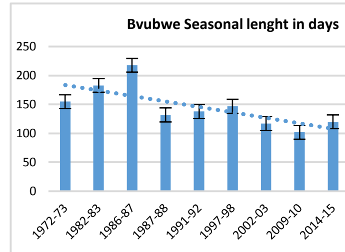
The rainfall season had been starting from the southern region of the country and gradually moving to the north. The El Niño precipitation of the month of January recorded highest rainfall values in 83% stations. On average, the "onset" of the El Niño rainy season was found to be the month of November which was shifting to December from stations in the southern part of Malawi. 65% of the El Niño station in the south had Onsets in November which was shifting toward December. Similarly, 69.7% of the stations in the northern Malawi experienced rainfall Onset in December, which was also shifting toward January. The months of January and February (with a rag of one month to the north part of the country) recorded seasonal rainfall "progression" phase over the country.

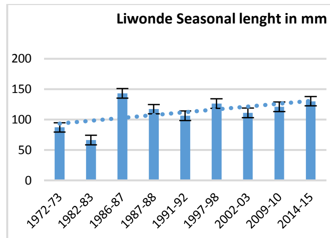
B. Length of the rainfall seasons.

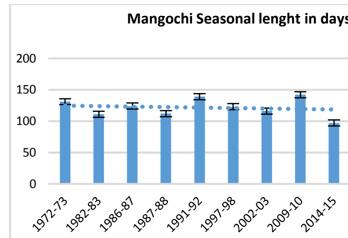


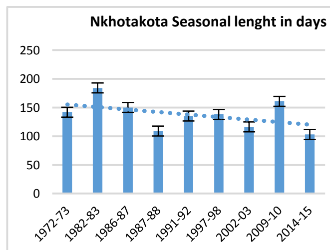


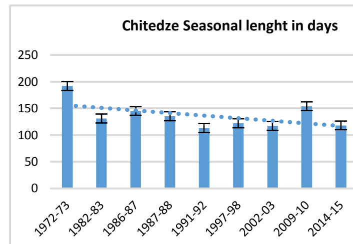


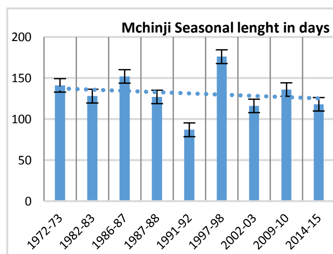


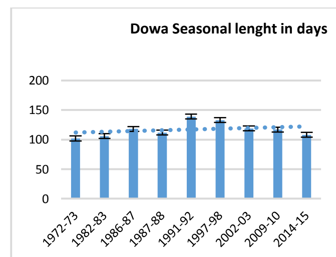


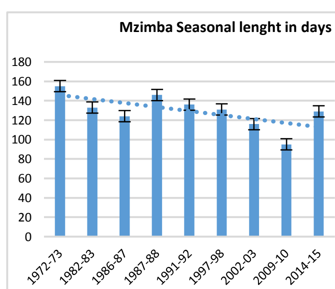


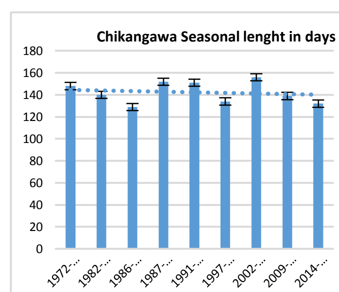


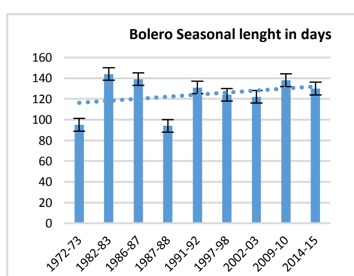


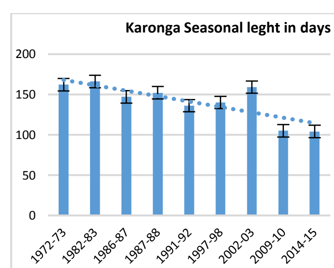


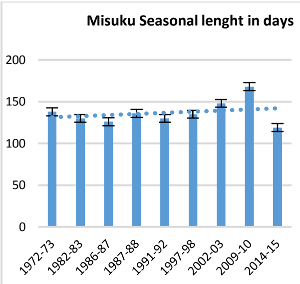






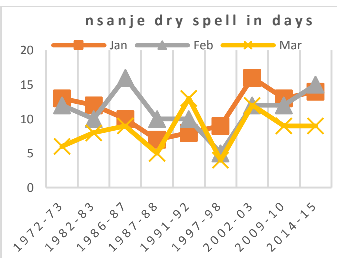


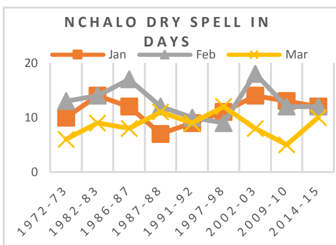


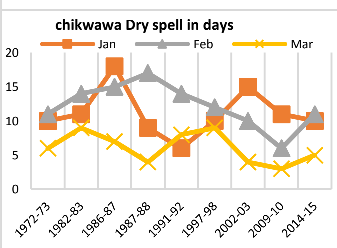


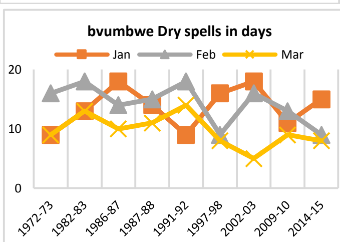
The total trend of average number of rainy days was 103±14 and was narrowly decreasing (within the El Niño rainfall season progression) over the country. Under El Niño seasons, 75.3% in the south, 81.3% in the central and 43.7% stations in the north had a decreasing trend in rainy days. 75% of the “cessation” of the El Niño rainfall seasons were from the months of March over the south, and April over the north with a trend of shifting to the next months in both parts of the country respectively.

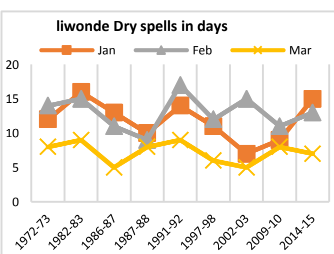
C. Dry spell occurrences trends under El Nino

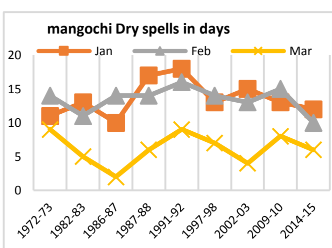


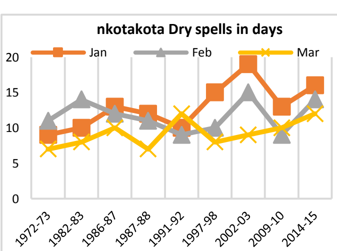


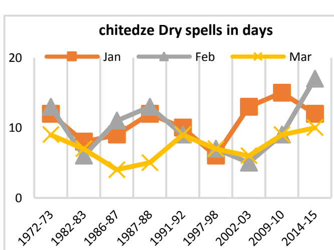


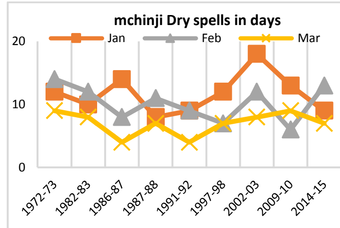


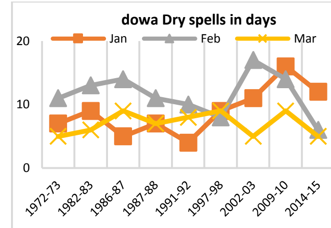


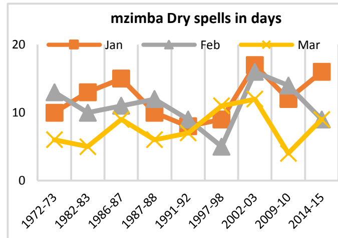


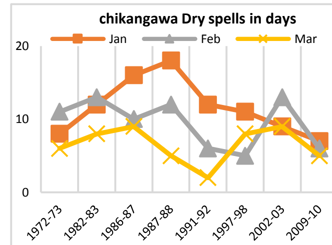


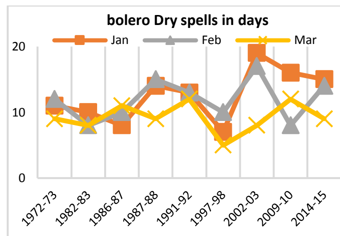


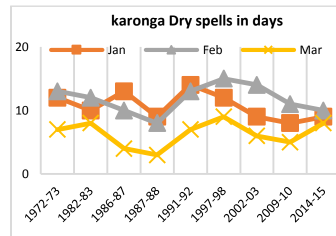


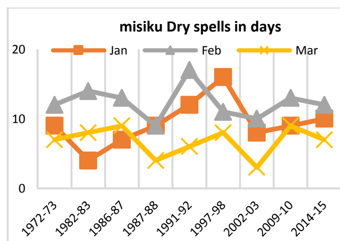






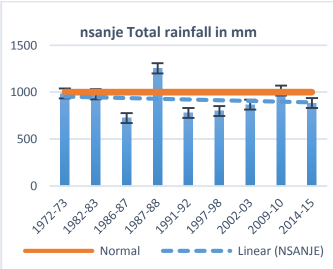


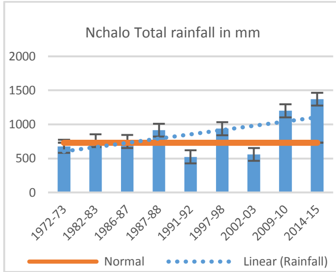


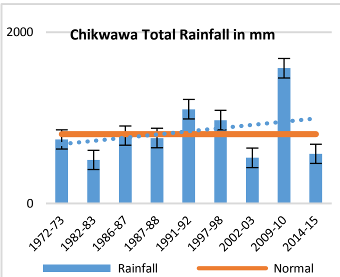


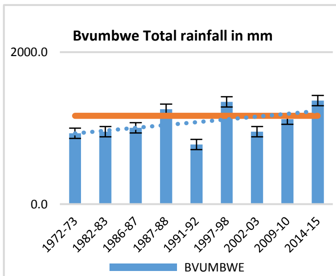
Within the progression of El Niño rainfall seasons, longer spells were experienced in southern parts of Malawi with an average of 6±2 days at the onset of seasons. Unlike in the south, longer dry spells in the northern half was due to late establishment of the season (late onset). Longer dry spells were experienced across the country in January in El Niño seasons with an average of 10 days with the south and central region being more vulnerable. In February, dry spells of about 11±3 days were experienced, more common in the Shire Valley region (N’gabu, Liwonde and Mangochi) and over some parts in northern Malawi (Bolero and Misuku). In March, longer dry spells were also observed in the central and north of Malawi under El Niño seasons of up to 9±2 days. Longest spells were experienced over central areas in 1983-84 El Niño season. On average, dry spells of about a week were more likely in the middle of the season in various parts of the country. These early rainfall deficits led to widespread dryness at the start of the El Niño season and resulted in delays to the start of the crop growing season.

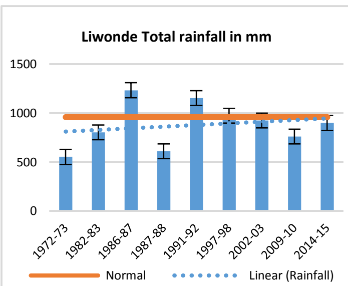
D. Total seasonal Rainfall trends under El Nino seasons.

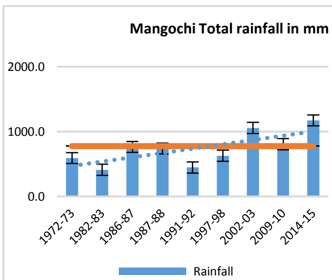


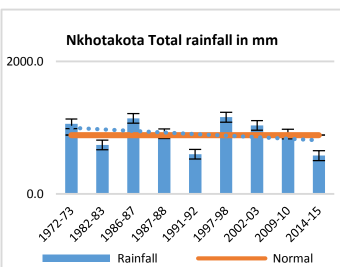


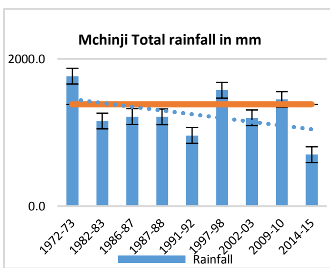


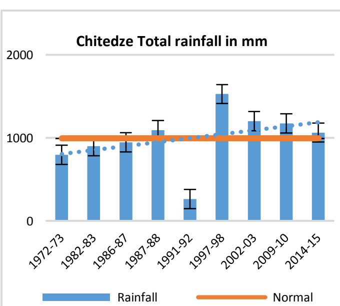


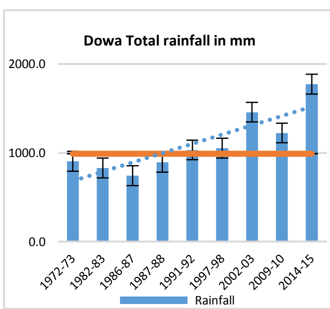


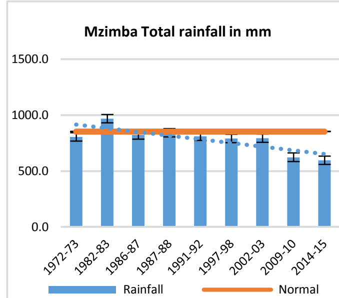


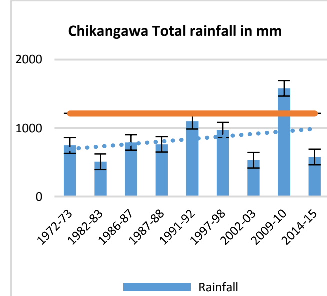


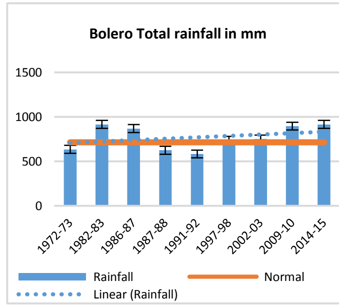


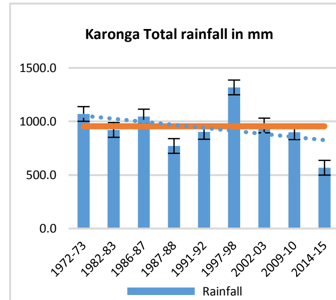


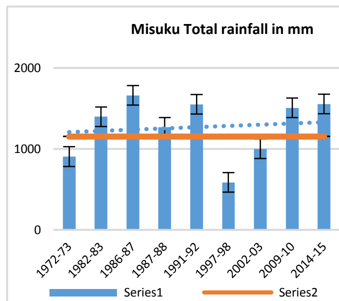












From 15 selected rainfall stations, the total El Niño rainfall trend from 1970 to 2016 was decreasing with an average of 972.4±53mm. However, the stations in the north of the country had an increasing rainfall trend of 105±13 mm. Under El Niño seasons, 34.7% of the stations had rainfall above normal in the south, 39.2% in the central and 52.6% in the north. The rainfall pattern in Malawi suggests that local factors like topography and location have a dominant role in the spatial distribution of rainfall.

E. Poor Maize performance during the El Niño growing season

The El Niño growing season of 1970 to 2016 were characterized by extensive rainfall deficits during its key stages. These should have led to a delayed start of the season and dry spells during the flowering and grain filling stages of the staple maize crop. This implies short seasonal cropping seasons and major risks to dry spells which were exacerbated under climate change. This resulted in crop production deficits across the country which were particularly acute in 1991/92 and 2002/03 (as shown in table 3 below) impacted very severely on agriculture in Malawi which accounts for the major part of maize production. The El Niño rainfall variability Periods of below average or erratic rainfall were less extreme and less general in their impacts in the 1970s and 1980s than in the 1990s and 2000s

F. Evidence from Agricultural Statistics in Malawi and other neighboring countries during El Nino rainfall seasons

Historical crop statistics (1961 to 2016, from FAO-STAT) clearly reflect the impact of El Nino events on regional maize production. El Niño seasons have led to low and unstable maize prices - very pathetic in Malawi where the majority of households are net consumers, and food accounts for over 60 percent of household income. Since then, the country has managed to have a food deficit in most season. National maize yield data for the country, when expressed as variations from its thirty five year average, show a clear relationship with El Nino. Negative variations in maize yield (values below 0%) are mostly associated with El Nino events as shown in table 4 below.

G. Hydropower in Malawi

Malawi's electricity generation relies predominantly on large hydro, which accounts for 97% of the total installed capacity. There is already a current 860 MW power deficit and the Electricity Supply Commission of Malawi (ESCOM) has implemented power rationing/load shedding in the country since 1970s. Malawi experiences deep deficit regarding electricity production from the drought conditions that are as a result of El Niño rainfall seasons as depicted on table 5 below. The effects of El Niño rains results in low Shire river flow rate leading in mean lower amounts of water flow to the dams that produce electricity, impacting on the power supply for Malawi as show in the table 5. At present, the basin has 285.82MW (thus 281.5MW for main hydro, and 4.32MW of mini-hydro Wovwe) of installed hydropower generation capacity along the main trunk Shire River, but the generation is at its lowest during El Niño seasons and is of decreasing trend.

Table 3: Food surplus/deficit 1960-2016

					El Niño Season				
	72/73	**82/83**	**86/87**	**87/88**	**91/92**	**97/98**	**02/03**	**09/10**	**14/15**
Surplus (Metric Tons)	0.4	0.1	1.3	0.3	-3.7	1.3	-2.8	-1.1	0.2

*Source: MAFS, 2016; * based on April 2016 Second Round Crop Estimates*

Table 4: All cereal production (in Metric tons) vs 35 year average.

Country					**Rainfall season**					**35yr Avg**	**Ratio**
	72/73	**82/83**	**86/87**	**87/88**	**91/92**	**97/98**	**02/03**	**09/10**	**14/15**		
Angola	673	864	557	568	67	1351	979	451	1749	1110	58%
Botswana	852	1004	579	712	67	934	1370	456	15	62	-75%
Lesotho	235	104	54	97	227	49	337	114	81	92	-12%
Malawi	**874**	**967**	**753**	**1007**	**1186**	**1976**	**3005**	**2745**	**2945**	**3883**	**-24%**
Mozambique	996	1032	2100	917	2001	1894	1973	2967	2255	2338	-4%
Namibia	109	60	105	89	48	71	56	88	51	126	-60%
RSA	9731	8734	6793	10254	7593	12486	10653	9286	13149	14420	-9%
Swaziland	27	56	53	70	109	95	83	99	82	78	5%
Tanzania	3904	4200	3980	5098	4278	6430	7351	5893	7382	6973	6%
Zambia	698	900	1056	1472	692	2963	1084	3481	2846	2943	-3%
Zimbabwe	1045	487	1162	2714	1046	762	2071	1090	800	1373	-42%

Source: *SADC figures-2017*

Table 5: Generation Installed Capacity

Name	River	Plant Type	Discharge (m^3/s)	Capacity (MW)	Expected Generation (GWh/year)	Generated in El Niño year(GWh/year								
						1973	1983	1987	1988	1992	1998	2003	2010	2015
Nkula A + B	Shire	RoR	246	124	582	365	401	205	367	297	368	297	476	376
Tedzani I + II + III	Shire	RoR	276	92.7	502	205	374	287	306	274	315	308	442	397
Kapichira	Shire	RoR	135	129.6	210	189	153	193	103	95	183	83	126	118
Wovwe	Rukuru	RoR	76	4.56	113	76	83	74	69	84	56	75	89	61

Source: MERA and ESCOM (2016)

IV. CONCLUSION

The inter-seasonal and monthly fluctuation of El Niño rainfall over a 45 year period was studied in 15 sites of Malawi. This study reveals a high spatial variability of both monthly and seasonal rainfall under El Niño seasons, where 34.7% of the seasons had rainfall above normal in the south, 39.2% in the central and 52.6% in the north. Substantial rainfall was recorded in the months of December, January, February and March. November rainfall was decreasing for 70.4% stations of southern half Malawi, while December rainfall was also decreasing for 63.7% stations of the northern half of the country during El Niño seasons. However February and March rainfall is increasing for the central parts of the country. April rainfall was getting importance as its contribution to El Niño seasonal rainfall was increasing in 68% of the seasons over central and north of Malawi. 65% of the El Niño seasons in the south had Onsets in November. Similarly, the stations in the northern Malawi experienced rainfall Onset in December. El Niño seasons had a fluctuation decreasing rainfall average trend of 972.4±53 mm. However, the stations in the north of the country had slightly increasing rainfall trend of 105±13 mm under El Niño seasons. Total trend of an average number of rainy days was decreasing under El Niño seasons, 75.3% in the south, 81.3% in the central and 43.7% rainfall stations in the north had a decreasing trend in rainy days. Within the progression of El Niño rainfall seasons, longer spells were experienced in southern parts of Malawi with an average of 6±2 days at the onset of seasons. 75% of the "cessation" of the El Niño rainfall seasons were from the months of March over the south, and April over the north with a trend of shifting to the next months in both parts of the country respectively. The El Niño borderline conditions led to extensive rainfall deficits, resulting in widespread drops in crop production. The overall finding was that the length of the El Niño seasons is gradually reducing in Malawi. These patterns typically resulted from significant dry spells during the El Niño periods, which had severe impacts on maize crop production in Malawi. The study underscored the clear link between El Niño events and drops in national maize yield in Malawi. The relationship throughout Malawi between maize and electricity production volatility and El Niño events was striking. Climatic variability and the Malawi economy Periods of below average or erratic rainfall were less extreme and less general in their impacts in the 1970s and 1980s than in the 1990s and 2000s. Maize production declined by around 60% in 1991/92 to the equivalent of only 45% of average production levels for the previous five years. The low rainfall and more dry spell pattern in 1997/98 and 2002/03 with the very strong ENSO event led severe drought in Malawi and very low crop yields. The effects of El Niño rains contributes in low Shire river flow rate leading in mean lower amounts of water flow to the dams that produce electricity, impacting on the power supply for Malawi. Focusing on rainfall and output has provided better understanding of the consequences of climatic variability historically and in the future – with implications for food security, hydropower generation and economic policy in Malawi.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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