Drought and El Nino Phases in Zimbabwe

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Abstract

The desk study was carried out to assess the frequency of drought associated with the various phases of the El Nino. Southern Oscillation index (SOI) values were analysed to determine El Nino or La Nina years. Three meteorological definitions of drought were used to establish one which correlates best with the El Nino or La Nina years. Annual mean rainfall data from the meteorological department ranging from 1901 to 1997 saved as the data base for the study. The corresponding annual mean SOI values for the same period were obtained from the Australian Weather Bureau website. For a particular year, the annual mean rainfall was correlated to the previous and current monthly mean SOI values. Analysis of the SOI values revealed that the probability of El Nino occurrence is 47 % and that of La Nina is 49 %. Results from the definitions of drought revealed that the probability of the occurrence of El Nino induced drought was 34% and the probability of the occurrence of La Nina induced wet years was 30 % . The study recommends that more detailed research be carried out on the association of ENSO phases and Zimbabwe's rainfall pattern to improve the precision of the current seasonal rainfall forecasting model.

Key words : Drought, Southern Oscillation Index (SOI), EL Nino, annual mean rainfall, EL Nino Southern Oscillation (ENSO).

Introduction

Zimbabwe has an Agro-based economy therefore the occurrence of drought negatively affects agriculture and all other industry that utilize agricultural products as inputs. Anomalous extreme weather events such as droughts,

floods and heat waves are becoming more frequent resulting in large losses in human lives, livestock and infrastructure. The upsurge of extreme weather events, widely blamed on climate change calls for further research to be carried out. A number of studies have revealed a significant correlation between the El Nino Southern Oscillation (ENSO) and annual rainfall amounts over the tropics and the middle latitudes(Rasmussen and Carpenter,1982; Ogallo,1988).In a recent study, Chifurira and Chikobvu (2010) also used the ENSO to predict meteorological drought and established that there was a correlation between SOI and the annual rainfall pattern. Makarau and Jury (1997)also carried out a similar study using meteorological data stretching over a period of forty one years and they obtained the highest correlation between SOI and the Zimbabwean summer rainfall. Matarira (2006) confirmed this when he showed that regional distribution of rainfall was significant and coherent over much of eastern and south eastern areas of Zimbabwe. Sea surface temperatures in the pacific are also used to determine El Nino phases. Cane, Eshel and Buckland (1994) found a correlation of 0.64 between Pacific Ocean Surface Temperatures (SST) and Zimbabwe's rainfall.

In the current study, the frequency of occurrence of drought years, years with normal rainfall and years with above rainfall from 1901 to 1997 were analysed using three versions of the definitions of drought that were obtained by varying the threshold of meteorological droughts .Zimbabwe's annual rainfall pattern was studied to establish the relationships between the annual rainfall and annual mean SOI values for the previous year and the current year.

Walker Circulation

According to Barry and Chorley (2003), ENSO phases can best be understood by understanding the Walker circulation. The Walker circulation is named after Sir Gilbert Walker who did extensive research on wind circulation patterns in the Pacific Ocean. Barley and Chorley (2003) argue that according to Sir Gilbert Walker air circulation assumes a complete loop, where under normal weather conditions there is a dominantly easterly trade wind component in the region .Under this situation, high pressure prevails over the eastern Pacific. The easterly trade wind is associated with subsidence over the eastern Pacific and at the same time a low pressure establishes itself

over Indonesia, where massive air uplift occurs, resulting in the formation of towering cumulonimbus clouds. Barry and Carleton (2001) further argue that the upper portion of this circulation starts from the Indonesian low pressure to the eastern Pacific where the descending limb of the circulation is found and it gives fine weather. Occasionally, this circulatory pattern varies when the reverse situation is established. The reverse situation gives low pressure to the eastern pacific and high pressure over Indonesia. A strong westerly wind component prevails on the surface and weather patterns change. Towering clouds appear over the eastern Pacific and dry weather over Indonesia and eastern Australia, (Barry and Chorley, 2003).

The El Nino and La Nina.

El Nino

El Nino comes from a Spanish word meaning 'boy child'. According to Ahrens (2003), Peruvian fishermen had long noticed occasional appearance of warm ocean currents adjacent to the area near Ecuador. They discovered that when the waters warmed, their fish harvest plummeted. This phenomenon occurs around Christmas in December hence it was called 'Christ child'. During normal years, that is when a strong easterly wind dominates over the eastern Pacific, the upwelling cold waters bring nutrient rich plankton to the surface, promoting good fish harvests. When the upwelling weakens during warm episodes, warmer nutrient deficient waters spread to this region and the fish harvests are drastically reduced. Usually El Ninos occur every four to seven years so El Nino is a situation when there are warmer than normal sea surface temperatures over eastern Pacific, (Ahrens, 2003).

La Nina

After the occurrence of warmer than normal sea surface temperatures over eastern Pacific (EL Nino), due to weakened trade winds, normal strong trade winds establish themselves and the waters become colder than normal. This situation is the opposite of El Nino and is called the La Nina, (Ahrens, 2003).

Southern Oscillation

Usually when the pressure is high over the eastern tropical Pacific, it is low over Indonesia and Australia, and vice versa. This see –saw changing pressure

pattern was noticed by Sir Gilbert Walker in 1924, and it is what is now called the Southern Oscillation. There is a close relationship between the Southern Oscillation and the Walker Circulation, when the Walker circulation strengthens east tropical Pacific waters cool and vice-versa, (Barry and Chorley, 2003).

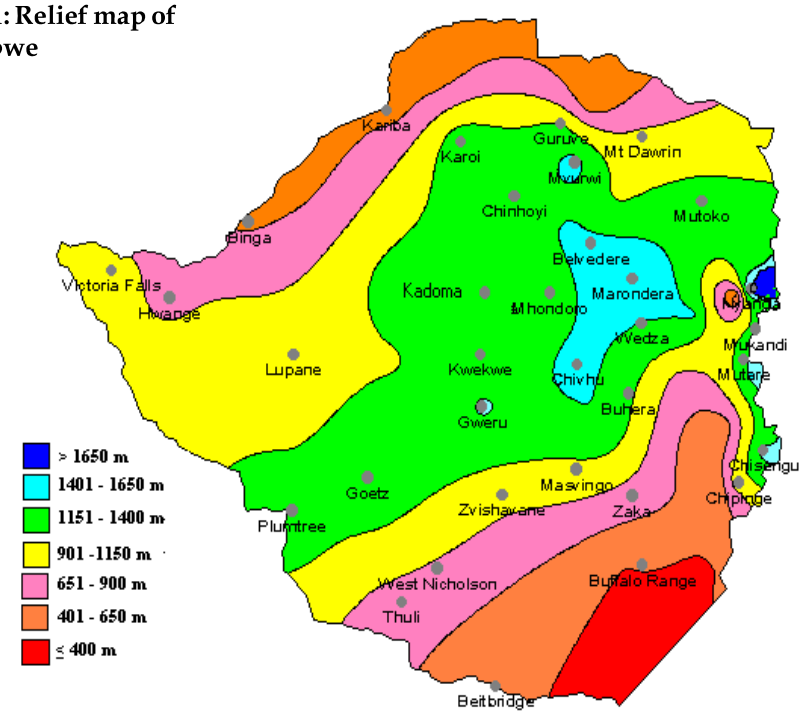
Study Area

Physical Setting of Zimbabwe

Zimbabwe is a land locked country whose area is approximately 400 000 km^2. It extends from 15 °S to 22.5° S (indicating that the country's climate is both tropically and extra-tropically influenced) with an east-west extent of 25 °E to 34 °E. The country has nearest proximity to the sea at its eastern boundary which is just less than 200 km from the Mozambique Channel.

Figure 1 is a general topographic map of Zimbabwe. It also shows all the reference climatological stations used by the Department of Meteorological services most of which have been used in this study.

Figure 1: Relief map of Zimbabwe



Altitude ranges from less than 300 m in the Save valley exceeding 2000 m in the eastern border mountains. According to Moyo et al (1993), Zimbabwe is physiographically divided into four zones based on altitude which are:

(a) low veld, below 600 m

(b) middle veld, 600-1200 m

(c) high veld, 1200-1500 m, and the

(d) Eastern Highlands, above 1500 m.

The drainage pattern (not shown) is controlled by the watershed oriented SW-NE over the central parts of the country and the Eastern Highlands. Rivers north of the country flow into the Zambezi River. The majority of the rivers over the south- east flow into the Save and Limpopo Rivers.

Statement of the problem

People perceive drought differently. The means of livelihood determines the perception of drought to an individual. There are many variations of drought definitions and three variations of drought definitions are used in this study. The levels of association between the ENSO phases and these drought definitions are unknown. Therefore this research sought to establish the probability of occurrence of drought and wet years in the data set for the three definitions.

Aim of the study

The main aim of this study was to establish whether the association between El Nino and drought and La Nina and wet years is dependent on the drought definition that is used.

Objectives of the study were to

- Determine the frequency of droughts and wet years during the period under study using the three definitions

- Assess the level of association between droughts and wet years, and El Nino, La Nina and Neutral years.
- Develop a simple model of monitoring the annual trend of ENSO phases from which seasonal rainfall forecasts can be derived.

Significance of the study

Zimbabwe's economy depends on rain fed agriculture. The country experiences erratic rainfall patterns and frequent droughts. Since rainfall is one of the most important climatic variables affecting agriculture, food security for the country is adversely affected when rains fail. Research has established that El Nino and La Nina are associated with rainfall variations in Zimbabwe. So it becomes necessary to study the interrelationships of Zimbabwe's annual rainfall and the ENSO phases. The findings will go a long way in improving rainfall forecasts, agricultural making decision processes and in promoting food security in Zimbabwe. The simple model for monitoring El Nino and La Nina droughts and wet years using SOI indices will enhance the seasonal rainfall forecasting process.

Methods and Materials

This was a desk study in which the mean annual rainfall for Zimbabwe and Southern Oscillation index values for the period 1901 to 1997 were used. EL Nino and La Nina years were obtained from the SOI values for the afore mentioned period. The Southern Oscillation Index (SOI) values for the corresponding period were obtained from the Australian Weather Bureau (2011). According to the Australian Weather Bureau (2011) ,SOI values are calculated using the following formula:

SOI = 10 [Pa (Tahiti) – Pa (Darwin)]/Std.Dev.Diff, where Pa is the pressure anomaly= monthly mean minus the long term mean while Std.Dev.Diff = Standard deviation of the difference. According to this formula, an annual mean SOI value of 10 means that the SOI is one standard deviation on the positive of the long term mean.

Frequency of occurrence of El Nino and La Nina years using SOI values for the period 1901 – 1997 was calculated. Using threshold values from each of the drought definitions, drought, and normal and above normal rainfall years were identified and their frequency calculated on Excel spread sheet. The frequency of drought associated with ENSO phases (i.e. EL Nino, La Nina and Neutral) were calculated and the same was done for wet years. For a particular year, the annual mean rainfall was correlated to the SOI values of the previous year, same year and two years back.

Finally a trend graph to monitor ENSO phases was drawn for the period January 2010 to February 2011.

Results and Discussion

Drought Definition (a) Drought is when the annual mean rainfall is one standard deviation below the normal and normal year is when the annual rainfall is within one standard deviation of the mean annual rainfall. A wet year is when the annual mean rainfall is one standard deviation above the normal. Using this definition threshold values were;
Standard deviation = 173.6mm, mean or normal = 662mm.

Drought = one standard deviation below the mean =662-173.6mm=488.4mm
From the above definition drought years were:
1912= 433mm, 1914= 473mm, 1916= 394mm, 1922= 385mm, 1947= 365mm
1960=483mm, 1964=467mm, 1968=404mm, 1973=371mm, 1982=439mm, 1983=403mm
1984= 464mm, 1987= 422mm, 1992=335mm, 1995=418mm **(16 cases of drought)**

Normal year = rainfall from 489 – 834 mm **(68 occasions of normal years)**
Above normal or wet year (a) 1 standard deviation above the mean rainfall i.e. 662mm + 173.6mm = 835.6mm.

Using the above definition the wet years were:

1902=879mm, 1915=953mm,1918=1118mm,1923=936mm,1925=1192mm

1929=851mm,1939=976mm,1953=908mm,1955=1012mm,1974=1003mm

1978=980mm,1981=860mm **(12 occasions of wet years).**

From the mean annual rainfall provided for the period 1901-1997 , the worst droughts on record in terms of rainfall amounts occurred in 1992 (335mm),1947 (365mm) , 1973 (371mm) , 1982(439mm) and 1983(403mm). The 1982-83 drought was the most devastating because it stretched for two consecutive years.

Data analysis gives the probability of drought for any year as 16.6% and that of an above normal (wet) year as 12.5% . The probability of a normal year is 70% , then that of normal to above normal is 83% .The high probability of a normal to wet year might be due to the fact that the threshold of drought (488mm) is too high.

Table 1. EI Nino and Drought Analysis using Drought definition (a)

Category /Phenomenon	**Probability of occurence**
Drought with EL Nino years where R<488mm	13.5%
EL Nino and normal to below normal	43.7%
EL Nino and above normal or wet: R>835mm	3%
EL Nino and normal to above normal	33%
E Nino and normal rainfall	30%

Table 2. La Nina and Drought Analysis using Drought definition (a)

Category/Phenomenon ***Probability of occurrence***

Category/Phenomenon	*Probability of occurrence*
La Nina and drought	3%
La Nina and above normal	8%
La Nina and normal	37.5%
La Nina and normal to above normal	45.8%
Neutral (no La Nina or EL Nino) but drought	0%
Neutral and normal	3%
Neutral and above normal	1%

Table 1 and table 2 reveal that the drought threshold is too high. This means that only severe cases of drought are captured at the expense of mild and moderate droughts Using drought definition (a) results in reduced documented cases of droughts. However the normal to above normal cases were enhanced for both analyses with ENSO and without ENSO. These were 45.8 % and 83 % respectively. This version of drought definition overestimates La Nina induced normal to above normal rainfall and underestimates the number of El Nino induced droughts.

Drought definition (b) : Drought is defined as when the annual rainfall falls below 10 % of the normal, and normal rainfall year is when the annual rainfall is within 10 % of the normal and above normal or wet year is when the annual rainfall is more than the normal by 10 % of normal.

Note: 10% of normal = 66.2mm, Normal is 662mm.
Droughts (below normal) :38 occasions (rainfall equals or less than 594mm)
Wet years (above normal) : 32 occasions (rainfall equals or greater than 729mm)

normal years :26 occasions (rainfall from 595mm to 728mm)
normal to **above normal**: 58 occasions.

Table 3 Analysis without ENSO Phases(El Nino/ La Nina) using drought definition (b)

Category	**Probability of occurrence**
Drought(below normal)	39.5%
Normal	27%
Above normal	33%
Normal to above normal	33%
EL Nino	46.8%
La Nina	48.9%
Neutral Phase	4%

Table 4. Analysis with EL Nino

Category /Phenomenon	**Probability of occurrence**
EL Nino with drought	28%
EL Nino and normal rainfall	9%
EL Nino and above normal (wet)	9%
EL Nino and normal to below normal	18.7%

Table 5.Analysis with La Nina

Category/phenomenon	Probability of occurrence
La Nina and normal	16%
La Nina with normal to above normal	37.5%
La Nina and drought (below normal)	11%
La Nina and above normal (wet)	22%
Neutral and below normal	0%
Neutral and normal	2%
Neutral and above normal	2%

If drought definition (b) is used droughts have a 39.8 % probability of occurrence and normal to above normal years have a probability of 60% occurence. Findings on table 4 point to the fact that analysis with ENSO phases indicate that the probability of occurrence of an El Nino related drought was 28%, implying that 10% is accounted for by other predictors. According to table 5, the probability of occurrence of a La Nina related normal to above normal rainfall was 37.5 % implying that 22 % is also accounted for by other climatic factors.

Drought definition (c) Drought is when annual rainfall is below the annual mean (662mm) and normal or wet year is when the annual rainfall is 662mm and above.Table 6 and table 7 show the probability of drought occurrences without ENSO phases and probability of drought occurrence with ENSO phases.

Table 6.Drought Analysis without ENSO Phases

Category/ Phenomenon	**Probability of occurrence**
Above normal (wet)	46.8%
Below normal (drought)	53%
EL Nino	46.8%
La Nina	48.9%

Table 7. Analysis of ENSO phases with drought and wet years.

Category/Phenomenon	Probability of occurrence
Drought years with EL Nino were :	34%
EL Nino and wet years	12.5%
La Nina and drought	18.7%
La Nina and wet years	30%
Neutral (no La Nina / EL Nino) and drought	0%
Neutral and wet year:	4%

Table 6 shows that when drought is defined as mean annual precipitation of less than 662mm and normal to above normal as precipitation equal to annual rainfall amounts of 662mm and above, then the probability of occurrence of drought is 53% and that of normal to above normal is 46,8%.Analysis with ENSO phases revealed that El Nino related droughts had a probability of occurrence of 34% (see table 7), implying that 19% was accounted for by other weather predictors. La Nina related normal to above normal rainfall had a probability occurrence of 30% implying that 16% is accounted for by other weather factors. The definition's lower threshold value of 662mm seems to have reduced the number of normal to above normal rainfall years.

Table 8: Correlation of the annual mean rainfall with the monthly SOI Values.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Same year (R)	0.2096	0.2380	0.1834	0.1716	0.0191	0.0246	0.1732	-0.0012	-0.0041	0.0608	0.0401	0.0309
Previous Year (R)	0.1819	-0.0556	0.1652	0.2090	0.2553	-0.1618	0.0496	-0.0537	-0.1253	-0.2082	0.1680	0.0831
Two Years Back (R)	0.0026	0.0579	-0.1176	-0.1825	-0.1819	-0.0671	-0.1145	-0.1697	-0.0612	0.0210	0.1415	-0.0226

Same Year correlations

Table 8 shows that highest monthly correlation (R) values of 0.2096 and 0.2380 occurred in January and February respectively. Of significance is that the annual R value is positive implying that an increase in SOI values means an increase in annual mean rainfall and vice versa. This result is of little use in weather prediction. However the result can be used in studies of past climates.

Previous Year correlations

Table 8 shows that the highest monthly R values were in April (0.2090) and May (0.2553). These results also indicate that as R values increase , the mean annual rainfall also increases and vice versa. These results can be utilized in seasonal rainfall forecasts. SOI values and trends for May and April can be monitored to infer rainfall amounts for the next rainfall season.

Two years back

According to table 8 monthly SOI values for this period indicate no significant correlation with annual mean rainfall and the point to note is that use of the SOI values should be limited to the previous year.

Model for tracking the ENSO phases

From the results, it is apparent that ENSO phases can save as tools in seasonal rainfall forecasts. Monitoring the ENSO trend on a monthly basis as the year progresses can be useful since the quality of the rainfall season can be inferred from this trend. A graph (Figure 2) was drawn to monitor the ENSO phases from January 2010 to March 2011. The graph was provided to show how one can monitor ENSO phases for any given period.

Figure 2: El Nino Southern Oscillation (ENSO) trend for the period January 2010 to February 2011

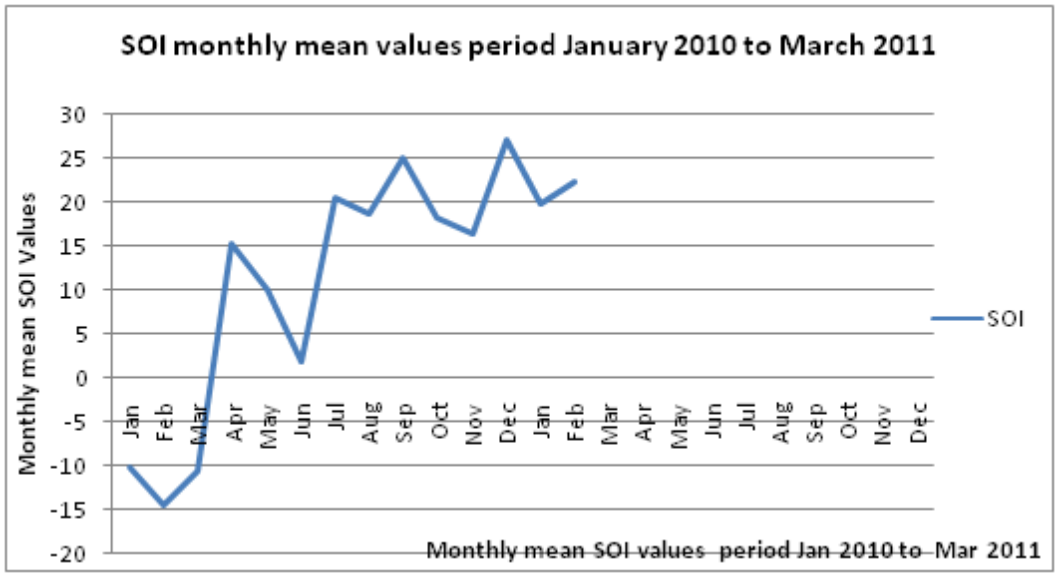


Figure 2 shows that from January to March 2010, the El Nino phase prevailed, then from April 2010 to March 2011 the La Nina phase dominated. On the whole the period experienced a La Nina. It is reasonable to attribute the above normal rainfall in December 2010 and January 2011 to the La Nina.

Conclusion

The three drought definitions reveal that the association between drought and El Nino phases depends on the threshold values of drought. The highest correlation for drought and El Nino was obtained from definition (c) (34%)and that of normal to above normal was obtained from definition (b) (38%).From the analysis, it can be observed that all El Nino years were not drought years and all La Nina years were not normal to above normal years. Droughts can occur in association with La Nina while normal to above normal can also occur during El Nino phases.

Recommendations

The study recommends that:

- Further research using other definitions of drought such as hydrological and agricultural drought be carried out to determine whether El Nino and La Nina drought and wet years will correspond with the drought definition used.
- Principal component analysis be used to establish specific agro-ecological regions in Zimbabwe that have the best correlation with ENSO phases.
- A similar study be carried out using Zimbabwe's annual mean rainfall up to 2010.
- Research focusing on SOI values prior to the onset of the rainfall season and the association between Zimbabwe's rainfall and ENSO phases be carried out.

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