INSTITUTE FOR METEOROLOGICAL TRAINING AND RESEARCH (IMTR), NAIROBI, KENYA

Towards Improved Seasonal Rainfall Forecast over Malawi

RESEARCH REPORT FOR
WMO CLASS II 2005 TO 2006

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A Project submitted in partial fulfillments of
the requirements for the class II, WMO

DECLARATION

I declare that this is my original work and has not been presented for examination for Class II or any other level in this or any other meteorological institute.

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Thanks to the lord our saviour who has been a source of strength, piece and joy during this period. I give all the glory and honour to Him for granting me wisdom and good health in order to accomplish my task.

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DEDICATION

I dedicate this work to my entire family, my beloved wife Victoria and son Francis for their prayers, patience and for missing me during my absence.

I also dedicate this work to my Mum, brothers, uncles and not forgetting my niece Judith for the support they extended to me during the period of study in this Institute. Words and emotions can hardly express the sense of gratitude and love I constantly received from them during the study period.

ABSTRACT

Extreme climate events such as floods and droughts have devastating socio-economic impacts associated with food shortages, famine, lack of energy, water, shelter and other major basic needs. Because these events are recurrent in nature, effective, accurate and timely prediction and early warning of these events can enable Governments and other stakeholders to put into motion appropriate actions for mitigating or alleviating their adverse impacts.

In this study, the relationship between seasonal rainfall and global Sea Surface Temperature anomalies was examined. The analysis was based primarily on empirical statistical modeling using observed rainfall data from 9 meteorological stations spread over the entire Malawi spanning 35 years i.e. 1970-2005. The missing data in some stations were estimated using correlation and regression methods while single mass curve technique was employed to check the homogeneity of the rainfall data for all stations. Other methods employed in the study include correlation analysis, standardization, regression analysis, analysis of variance (ANOVA) and model verification technique.

Multiple linear regression expressing seasonal rainfall as a function of SST anomalies, Southern Oscillation Index (SOI), Indian Ocean Dipole (IOD) and Niño indices were formulated using stepwise regression analysis techniques.

The results of this study indicated that November - April seasonal rainfall over the study area has significant relationships with SSTs in the Pacific, Atlantic and the Indian Ocean. It was further observed that the SOI and seasonal rainfall over the study area are always in phase and amplitude thus suitable phenomenon for seasonal rainfall prediction.

The formulated models showed reasonable simulation of the seasonal rainfall with tested skills during forecasting period indicating highest skillful prediction of above and below normal rainfall over the study region.

This study would be useful in enhancing the seasonal forecasting techniques not only for Malawi as a country but also for the regional forecasting outlook done annually by the Drought Monitoring Center (DMC) in Harare, Zimbabwe. It would also contribute towards improved planning and management of climate sensitive activities such as agriculture and water resources, hydroelectric power supply and tourism among others.

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List of acronyms

SST -	Sea Surface Temperature
SOI-	Southern Oscillation Index
IOD-	Indian Ocean Dipole
NINO 3.4-	NINO region 3.4
NINO 3.0-	NINO region 3.0
NINO 4.0-	NINO region 4.0
PC-	Pacific Ocean
AT-	Atlantic Ocean
IND-	Indian Ocean
NKO-	Nkhotakota
MIM-	Mimosa
MAN-	Mangochi
KAL-	Kalonga
CHT-	Chitedze
SOND-	September, October, November, December

1. INTRODUCTION

1.1 Background

Malawi like many other countries in eastern and southern Africa is prone to extreme climate events such as floods and droughts. These extreme events have severe negative impacts on key socio-economic activities in the country such as agricultural production that often results into widespread food shortage and considerable hardship among the poor. Floods have negative impacts such as damages of houses and properties (mainly over low-lands), loss of life and eruption of weather related epidemics such as Malaria and Cholera. Some suffering that follow an extreme weather/climate events could be mitigated or minimized through tangible advance planning based on reliable long range (seasonal) rainfall forecast.

Agriculture is by far the most important sector of Malawi's economy for example, in 2003, it contributed 37.6 percent to the country's GDP of one 700 million US$. Agriculture accounts for about 90 percent of the country's export earnings, with tobacco alone accounting for 60 percent, and provides employment for 81 percent of the economically active population.

Malawi's agricultural sector is characterized by a dualistic structure: a low input/low productivity smallholder sector and high input/high productivity estate sector. The smallholder sub-sector comprises a very large number of small-scale farmers growing mainly food crops for their own consumption but they also grow some cash crops such as coffee, tobacco, macadamia and cotton. The estate sector comprises a much smaller number of large-scale farmers, producing almost entirely for the export market. In 2001, the cultivated area was about 2.34 million ha (25 percent of the land area) with just over half occupied by agricultural estates.

The main food crop is maize, which accounts for nearly 90 percent of the cultivated land, supplemented by sorghum, millet, pulses, rice, root crops, vegetables and fruits. Industrial export crops grown by smallholders include cotton, rice, groundnuts, coffee, macadamia and tobacco. The main estate-grown crops are tobacco, coffee, tea and sugar. Malawi is the second largest producer of tobacco in Africa after Zimbabwe.

Food demand in Malawi has been increasing steadily because of the absolute increase in population. In addition, droughts like the one of 1991/92, partially of 1996/97 and 2001/02 cause low yields and countrywide crop failures. The country is currently not able to meet its food requirements, particularly in cereals.

There is therefore need to minimize the negative impacts caused by extreme climate events, and to take advantage of the good years, brought about by favorable climate conditions through accurate and timely seasonal rainfall forecast in the country.

1.1 OBJECTIVE OF THE STUDY

The general objective of this study is to establish the relationship between global Sea Surface Temperatures (SSTs) anomaly and seasonal rainfall with an aim of developing improved statistical modeling tool for seasonal rainfall forecast over Malawi. In order to achieve the above objective, the following specific objectives were undertaken.

a) Determination of the correlation between rainfall over the study region and global SSTs
b) Develop regression model using global SSTs, Southern Oscillation Index (SOI), Indian Ocean Dipole (IOD) and Niño’s as predictors of seasonal rainfall.

1.2 JUSTIFICATION OF THE STUDY

The socio-economic activities of Malawi largely depend on the performance of the seasonal rainfall which has been affected by the recurrent drought for a long time. Starting from the peasant farmer in the village to the commercial farmer, the hydro power generating companies, most of the manufacturing industries, the mining industries, the health sector all need rainfall performance forecast to cushion the impacts in times of drought, flooding and normal rainfall seasons.

The severe impacts associated with extreme climate events can be reduced through a good understanding of the climate of the previous events, enhanced monitoring and timely early warning as well as improved awareness of the usefulness of climate information and prediction products in decision making.

Currently Sea Surface Temperatures (SSTs) and the ENSO phenomenon, the southern oscillation, among others are used as the predictors of rainfall anomalies in the neighboring regions such as East Africa. Thus, there is a need to extend this and evaluate if it is associated with seasonal rainfall over Malawi.

1.4 DOMAIN OF STUDY REGION

Figure 1: Location of Malawi with respect to Africa

Malawi is a landlocked country - surrounded entirely by land- lying in Southern Africa between latitudes 9°22’S and 17°03’S and longitudes 33°40’E and 35°55’E (Figure 1). It is bordered by the United Republic of Tanzania to the north and northeast, Mozambique to the east, south and southwest, and Zambia to the west. It is 855 km long, with varying widths from 10 km to 250 km, covering a total area of 118484sq km, of which over 24000sq km is fresh water - Lake Malawi, minor lakes and rivers. Lake Malawi water surface area is 28760 sq km.

1.4 PHYSICAL FEATURES OF THE STUDY AREA

Malawi's topography is characterized by extremely diverse physical features. It is divided into four major physiographic zones. The highlands of Mulanje, Zomba and Dedza in the southern part of the country; the plateau of the central and northern regions; the rift valley escarpment and the rift valley plains along the lakeshores of Lake Malawi, the Upper Shire and Lower Shire Valleys.

The geographical character of Malawi is dominated by Lake Malawi, which stretches 568km along the spine of the country, with varying widths from 16km to 80km. Lake Malawi is the third largest in Africa, and the thirteenth largest in the world. To the west of the lake, the country's plateau rises to a general height of between 915m and 1220m. Rising above these fairly cool highlands are the higher plateau of Dedza, Viphya and Kirk Range that, in places, reach between 1524m and 2440m. In the Southern Region of Malawi, the 2134m high Zomba Mountain dominates the Shire highlands. The highest peak in Malawi is Sapitwa on Mulanje Mountain (3050m high) located in the southern part of the country.

1.5 CLIMATOLOGY OF MALAWI

Malawi has a sub-tropical climate, which is relatively dry and strongly seasonal. The warm-wet season stretches from November to April, during which 95% of the annual precipitation takes place. Annual average rainfall varies from 725mm to 2,500mm with Lilongwe having an average of 900mm, Blantyre 1,127mm, Mzuzu 1,289mm and Zomba 1,433mm. Extreme conditions include the drought that occurred in 1991/92 season and floods of 1988/89 season. The low-lying areas such as Lower Shire Valley and some localities in Salima and Karonga are more vulnerable to floods than higher grounds.

A cool, dry winter season is evident from May to August with mean temperatures varying between 17 and 27 degrees Celsius, with temperatures falling between 4 and 10 degrees Celsius. In addition, frost may occur in isolated areas in June and July. A hot, dry season lasts from September to October with average temperatures varying between 25 and 37 degrees Celsius. Humidity ranges from 50% to 87% for the drier months of September/October and wetter months of January/February respectively.

•The main rain bearing system in Malawi is the Inter-Tropical Convergence Zone (ITCZ). This is a broad zone in the equatorial low-pressure belt, towards which the northeasterly and southeasterly trade winds converge. This system is responsible for most of the rain received in the country.

Other rain bearing systems affecting Malawi are:

•Tropical cyclones, which are essentially intense low-pressure cells that originate in the Indian Ocean and move from east to west, bringing widespread heavy rainfall mostly in southern Malawi, which can cause serious flooding.

•The Convergence Ahead of Pressure Surges (CAPS) system, which develops as high-pressure cells continue to move over the southern tip of the sub-continent. This leads to the convergence ahead of the pressure surges causing isolated but locally heavy rains that normally precede the onset of the rainy season.

•The easterly waves system, which is mostly active towards the end of the rainy season (March/April). The existence of easterly waves in the atmosphere causes isolated but locally heavy rains in some parts of the country.

Temperatures are greatly influenced by the topography and decreases with increasing altitude. The mean maximum and minimum temperatures are 28 °C and 10 °C respectively in the plateau areas, and 32 °C and 14 °C respectively in the rift valley plains. The highest temperatures occur in October/November while the lowest temperatures are experienced in June/July.

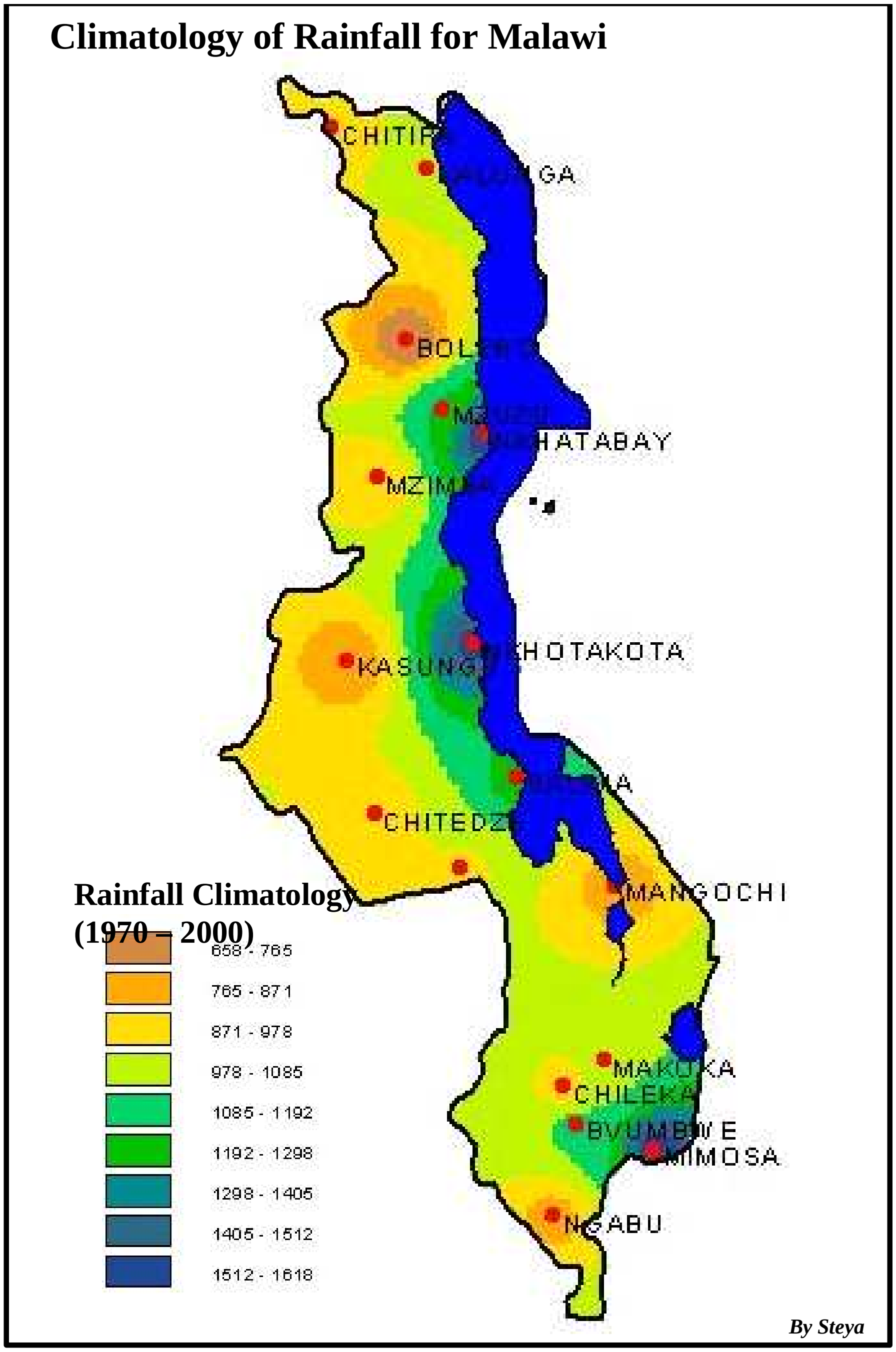

Figure 2: Climatology of rainfall for the study region

1.6 Methodology and Data Used In the Study

1.6.1 Data Used

The data used for the study included monthly rainfall from November to April for 9 Meteorological stations spread over the country (Figure 3) for the period 1970 – 2005, Sea Surface temperatures (SSTs) Indices, Southern Oscillation Index (SOI), Indian Ocean Dipole (IOD) and Niño Indices. The monthly rainfall was obtained from Malawi Meteorological Department while the SST indices, Nino Indices, Indian Ocean Dipole, SOI obtained from National Oceanic and Atmospheric Administration (NOAA) / Climate Diagnostics Center (CDC) Optimum Interpolation (OI) Sea Surface Temperature (SST) Version 2. The SSTs data are on 1.0^0 x 1.0^0 grid point resolutions.

1.6.2 Methods Used In the Study

This section discusses the various methods that were employed to address the overall and specific objectives of the study. These include standardization of rainfall anomalies; cumulative mass curve; simple correlation analysis and regression analysis. Details of these are highlighted in the following sub-sections.

1.6.2.1 Estimation of Missing Data and Quality Control

Prior to presenting methods and results, it is important to discuss a number of significant uncertainties that are associated with the analysis of precipitation data. Uncertainties are mainly attributed to precipitation measurements associated with significant human and instrument errors. Error in data collection is hampered by site and instrument changes which are often poorly documented and seldom considered in analyses. Changes over a period of time in the wind environment around a measurement site due to long-term growth or cutting of trees, erection of structures among others may reduce wind speed, increase turbulence, increase catch in rain gauges, and therefore produce a fictitious upward trend in precipitation. Errors can also occur in the transcription of data from handwritten records or strip charts into digital form such as was found in this study.

The missing data were estimated using correlation and regression methods based on the cross correlation between the rainfall observations over the stations and the ratio of the climatological values of rainfall over the stations. The cross correlation between the station rainfall (r_{xy}) is given by:

$$r_{xy} = \frac{\frac{1}{n}\sum_{i=1}^{n}\left[(x_i - \overline{x})(y_i - \overline{y})\right]}{\left[\ \frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2 \frac{1}{n}\sum_{i=1}^{n}(y_i - \overline{y})^2\ \right]^{\frac{1}{2}}} \qquad \text{…………………..……………..} (1)$$

Correlations between all the stations were computed by taking a block of data over a sub-period where most of the data was available.

If station Y_i had a missing value in a certain year, and the station is best positively correlated with station X with available data (X_a), the formula used to estimate Y_i was:

$$Y_i = X_a \frac{\overline{Y_i}}{\overline{X_a}} \qquad \text{………………………………………………………………} (2)$$

Where, Y_i = the missing data

X_a =the available data of the station with the highest correlation with station whose data is missing.

$\overline{X_a}$ = Mean value for the station with complete data

$\overline{Y_a}$ = The mean value for the station with missing data

The estimated data were, however, less than 10% of the record at any given location. Stations with more than 10% of the record missing were not used. Only stations with an interstation correlation coefficient of at least 0.6 were used to estimate missing data.

1.6.2.2 Data Quality Control

Data quality control was necessary for detection of errors in data and ensured that the data sets were free from errors. Several methods can be used to detect errors in the data set (WMO 1966). The cumulative mass curve technique was used in this study.

The cumulative mass curve technique involved accumulating monthly and seasonal records for each station and plotting these values against time. A single straight line indicates a homogeneous record whereas heterogeneity tendency is indicated by existence of more that one line fitted to the graphical plots of the cumulative data.

1.6.2.3 Standardized Anomaly Indices

The two most common parameters that have been used in normalizing time series observations are the mean and the variance. The standardized rainfall anomaly was adopted in this study. The standardized anomaly, *z*, was computed as follows:-

$$z = \frac{X - \overline{X}}{S_x} = \frac{X'}{S_x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where X is the observed data, $\overline{X}$ is the mean and S_x the standard deviation.
The value of Z provides immediate information about the significance of a particular observation from the mean.

1.6.2.4 Correlation Analysis

Correlation analysis examines the relationship between pairs of variables. Simple correlation analysis examines the relationship between pairs of variables namely the dependent variable (Y) and the independent variable (X). The degree of relationships between the pair of variables Y and X is often quantified using correlation coefficient. This simple correlation coefficient r may be expressed as:

$$r = \frac{\sum_{i=1}^{N}(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\left[\sum_{i=1}^{N}(X_i-\bar{X})\right]\left[\sum_{i=1}^{N}(Y_i-\bar{Y})\right]}}$$

…………………..………………………………………… (4)

where r is the correlation coefficient and X_i and Y_i are i^{th} observations of variables X and Y respectively, while $\bar{X}$ and $\bar{Y}$ are means of the variables with sample sizes N. In this study, X and Y are rainfall observations from different observation stations. The value of r lies between -1 and +1. The value of r equals +1 when X and Y are perfectly related, while it is zero when there is no relationship between the variables. Negative and positive values of r reflect negative (one increases as the other decreases) and positive (both increase and decrease simultaneously) relationships between X and Y.

In this study, correlation between SST, SOI, Niño's, and IOD's indices and seasonal rainfall were investigated in order to identify their association at seasonal time scales.

1.6.2.5 Regression Analysis

For any pair of variables, which have a significant correlation coefficient (r), the next step is to determine the nature of the relationship. This is done by determining the best regression equation governing the relationship. A linear relationship model expressing rainfall ($\mathbf{Y}_t$) as a function of SST ($\mathbf{X}_{t1}$), SOI ($\mathbf{X}_{t2}$), IOD ($\mathbf{X}_{t3}$), NINO ($\mathbf{X}_{t4}$), may be expressed as;

$\mathbf{Y}_t = a + \mathbf{b}\mathbf{X}_{t1} + \mathbf{c}\mathbf{X}_{t2} + \mathbf{d}\mathbf{X}_{t3} + \mathbf{e}\mathbf{X}_{t4}$ ………………………………………………….. (5)

Where **a** is the regression constant b and c are regression coefficients respectively, which can be determined from available records.

In this study, functional relationships between seasonal rainfall, SST SOI, IOD and NINO indices were developed to predict rainfall over Malawi. Details of regression analysis can be obtained from various standard statistical texts.

2.2.3 Multiple linear regression analysis

Multiple linear regression (MLR) analyses aim to produce predicted values of a dependent variable from a linear set of principal predictors that efficiently describe the collective variability of independent variable. To create a statistical forecast system, one must first identify the potential predictors (*mutually uncorrelated*) that are strongly related to the predictant. Then statistical forecast models are developed by relating the pre-season values of the predictors to the observed seasonal rainfall anomaly. MLR is the most used statistical technique. The forecast standardized rainfall anomaly R, is given in the model by:

$$R = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \Lambda + \beta_p X_p + \varepsilon \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

Where X_i is the value of the ith predictor, β_i the model regression parameters for predictor i, p the number of predictors in the model and ε the unmodelled variance in the rainfall series (ε assumed to be distributed normally). The β_i values are estimated from the "training period" data. It is useful that all predictors and predictant series are expressed as standardized anomalies relative to the developmental data, so that the model coefficients give an indication of the relative contribution of each predictor.

The regression equations are usually derived using stepwise MLR, in which each potential predictor variable is evaluated for its individual significance level before being included in the equation and, with each addition, each variable within the equation is then evaluated for its significance as part of the model.

2.2.4 VERIFICATION OF THE FORECAST

To assess the true skill of a forecast system, it is vital to minimize the risk of artificial skill that arises because the system has information that would not be available in real-time application. The safest solution is to define a period for model development and a completely independent period for model testing. It is desirable that the development period be as long as possible to increase the reliability of the statistical analysis. Overfitting the model results from the use of too many predictors while under-fitting the model results from use of too few predictors. It is desirable to use average number of predictor giving average model efficiency (R^2).

Statistics used to assess the forecast skill from MLR include the standard correlation between the forecast (f) and observed (v) variable from equation (7), F-ratio and the p-values. Summaries of the model forecasts and observed scores are presented in the form of contingency tables for each station. Table 1 shows a sample of a contingency table with arbitrary scores for both forecasts and the observations.

Table 1: Contingency table for observed and forecasted model

		Forecast			
		Dry	Normal	Wet	Total
Observation	Dry	a	b	c	J
	Normal	d	e	f	K
	Wet	g	h	I	L
	Total	M	N	O	T

Percent Correct $= \frac{a+e+i}{T} \times 100\%$

Post Agreement $= \frac{a}{M}, \quad \frac{e}{N}, \quad \frac{i}{O}$ for Dry, Normal and Wet categories.

False Alarm Ratio (FAR) $= 1 - \frac{a}{M}$ or $= 1 - \frac{i}{O}$ for extreme (Wet or Dry) cases.

Other statistics that may be used include the root-mean-square error $(RMSE)$, the absolute error $(ABSE)$, and the bias $(BIAS)$:

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (f - v)^2 \right]^{1/2} \tag{7}$$

$$BIAS = \frac{1}{N} \sum_{i=1}^{N} (f - v) \tag{8}$$

$$ABSE = \frac{1}{N} \sum_{i=1}^{N} \left| f - v \right| \tag{9}$$

Where the summation extends over the N forecast years. It is worth mentioning that RMSE and BIAS do not measure skill relative to reference score.

2.0 RESULTS AND DISCUSSION

This section presents and discusses the results that were obtained from the various methods that were used to address the objectives of this study. These methods include data quality control, standardized anomaly, correlation analysis and regression analysis.

2.1 STATIONS USED IN THE STUDY

The representative synoptic stations chosen for the study are given in Tables 1 while Figure 3c shows their spatial distribution over the study area. All these stations are currently operational in Malawi.

Table 1: Latitude and longitude of the stations used in the study

	STATION	LATITUDE	LONGITUDE
1	KALONGA	-9.95	33.88
2	CHILEKA	-15.68	34.97
3	MANGOCCHI	-14.43	35.25
4	BOLERO	-11.02	33.78
5	NKHATA BAY	-11.6	34.3
6	CHITEDZE	-13.98	33.68
7	NKHOTAKOTA	-12.92	34.27
8	SALIMA	-13.75	34.58
9	MIMOSA	-16.08	35.58

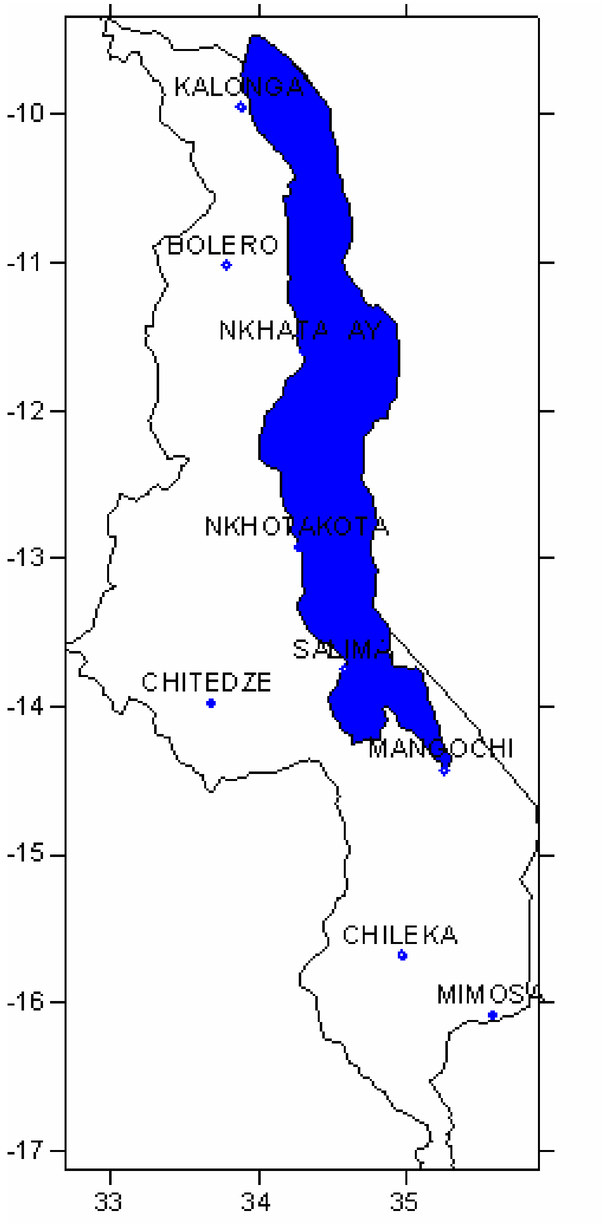

Figure 3: Distribution of representative stations used over the study region

The results obtained when the rainfall data set was subjected to quality control method are discussed in the next sub section.

2.2 DATA QUALITY CONTROL RESULTS

Few missing data were estimated using correlation and regression methods as discussed in section 1.6.2.1. The estimated data were less than 10% of the total records in all locations and were not consecutively following each other. Mass curve analysis was used to assess the quality of the estimated and other records used in the study.

Results from the mass curves indicated that in general only almost straight single lines could be fitted to most of the cumulative seasonal rainfall records for most of the stations, which is indicative of homogeneity of the records used in the study. Examples of the derived mass curves are shown in figure 4. The results were indicative of good quality of rainfall records. These data formed the foundation of the data used in this study.

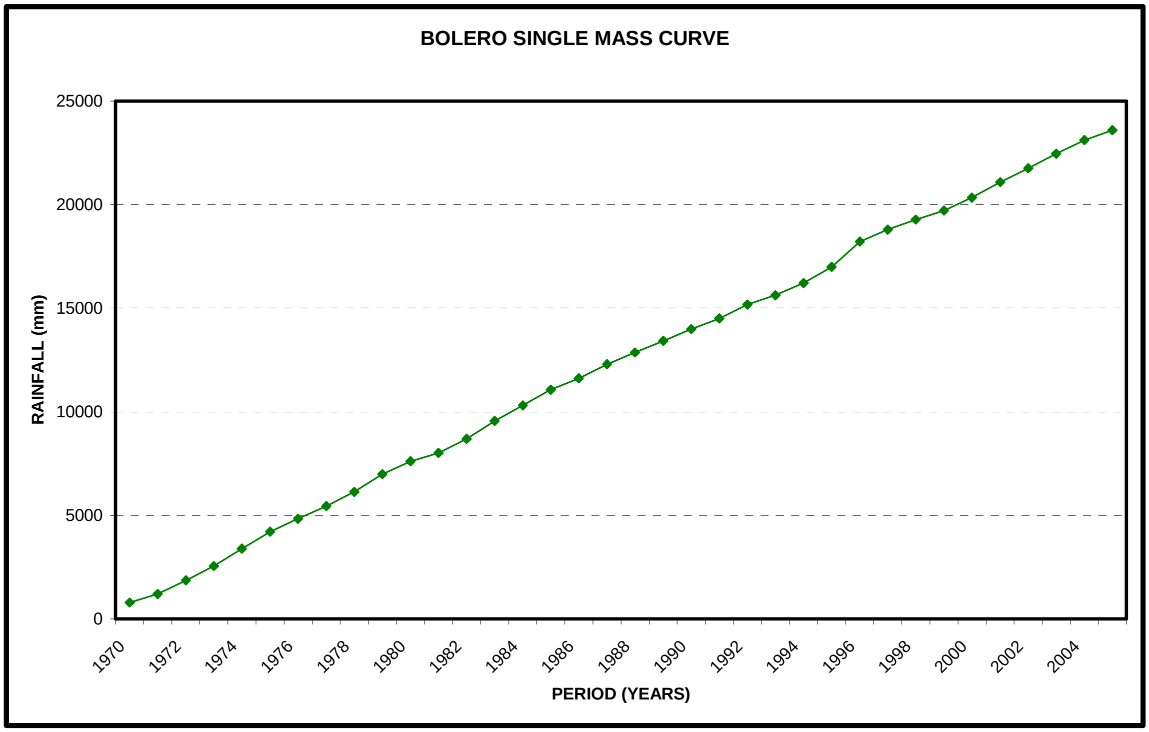

Figure 4a: Cumulative November – April (NDJFMA) seasonal rainfall totals for Bolero

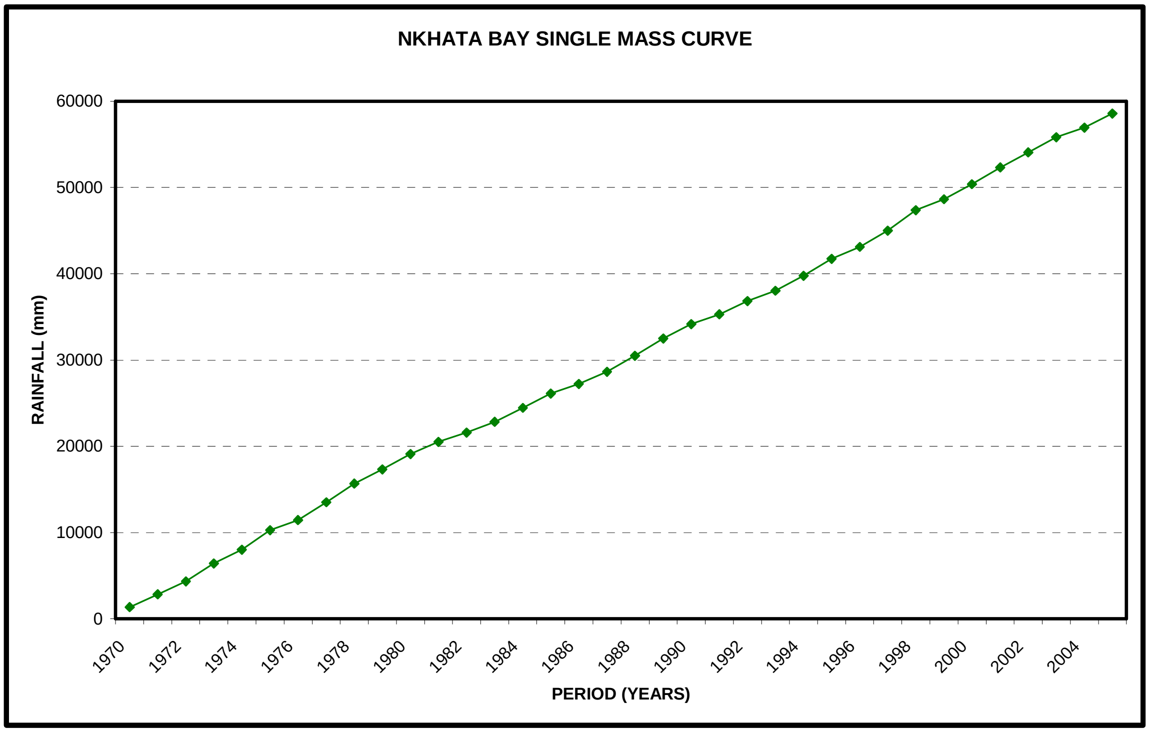

Figure 5b: Cumulative November – April (NDJFMA) seasonal rainfall totals for Nkhatabay

2.3 RESULTS FROM SIMPLE CORRELATION ANALYSES

2.3.1 TEMPORAL CORRELATION ANALYSIS

Table 2 highlights some summary results that were obtained from the temporal correlation analysis of seasonal rainfall variability and SST's, IOD's, Niño's and SOI indices. Results from this study showed statistically significant association between rainfall over Malawi and global SSTs. All the stations had significant correlation with the SSTs from all the three basins when lagged by three months. These therefore show that SSTs influence seasonal rainfall over Malawi more than any of the indices used in this study.

Table 2: Correlation coefficients between seasonal rainfall totals and the indices

	PREDICTORS								
STATION	SST	SST	IOD	IOD	SOI	SOI	SOI	NINO	NINO
BOLERO	**(P)** **0.468**	**(I)** **-0.520**	(11) -0.280	(12) -0.119	(9) 0.228	(6) 0.180	(8) 0.161	(3.4_10) -0.176	(3.4_1) -0.157
KALONGA	**(I)** **0.507**	**(A)** **-0.522**	(6) 0.285	(7) 0.153	(9) 0.203	(7) 0.185	(11) 0.185	(3.4_7) -0.185	(3.4_6) -0.148
NKHATABAY	**(P)** **0.527**	**(P)** **-0.419**	(7) -0.207	(8) -0.239	**(1)** **0.448**	**(7)** **0.431**	**(9)** **0.402**	**(3_6)** **-0.404**	**(3.4_6)** **-0.415**
NKHOTAKOTA	**(I)** **-0.601**	**(P)** **-0.517**	(8) -0.336	(9) -0.265	**(8)** **0.403**	(1) 0.233	(9) 0.292	(3_6) -0.353	(3_7) -0.307
CHITEDZE	**(P)** **0.512**	**(P)** **0.509**	(7) -0.384	(8) -0.344	**(9)** **0.435**	(8) 0.338	(10) 0.393	(3.4_11) -0.307	(3.4_12) -0.360
SALIMA	**(P)** **-0.441**	**(A)** **0.506**	(6) -0.125	(12) 0.273	(9) 0.255	(12) 0.246	(8) 0.209	(3_6) 0.277	(3_1) -0.126
MANGOCHI	**(P)** **-0.472**	**(P)** **0.482**	**(9)** **0.411**	**(10)** **0.422**	**(1)** **0.420**	**(8)** **0.522**	**(9)** **0.492**	**(3_1)** **-0.509**	**(3_10)** **-0.449**
CHILEKA	**(P)** **-0.504***	**(P)** **-0.406**	**(6)** **-0.408**	(7) -0.169	(6) -0.227	(8) -0.189	(9) -0.189	**(3_12)** **-0.406**	**(34_12)** **-0.429**
MIMOSA									

KEY

*** Statistically significant correlation**

2.3.2 SPATIAL CORRELATION ANALYSIS

Figure 6 shows some examples of significant spatial correlation between specific station rainfall and grid point global SST anomalies while Tables 3a to 3d show areas with correlation coefficient greater than 0.4, which were subsequently used as predictor indices in the model development, discussed in section 2.6.

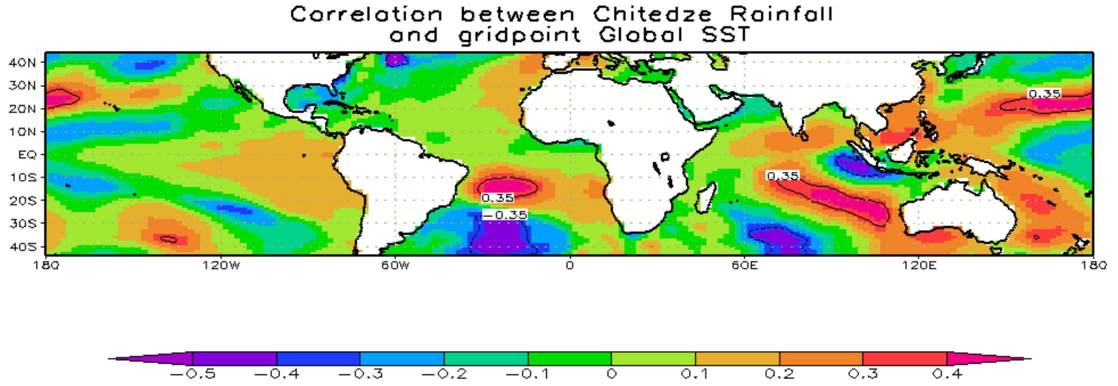

Figure 6a: Significant spatial correlation of station rainfall and global SST as depicted by Chitedze

Table 3a: Chitedze with the specific SST predictor areas

CHITEDZE	**PREDICTOR**	**OCEAN**	**LONGTUDE**	**LATITUDE**
	CHT_AT1	ATLANTIC	30 – 18W	42 – 30S
	CHT_IND1	INDIAN	70 – 75E	44 – 34S
	CHT_PC1	PACIFIC	162 – 175E	20 – 24N
	CHT_IND2	INDIAN	94 – 99E	23 – 20S

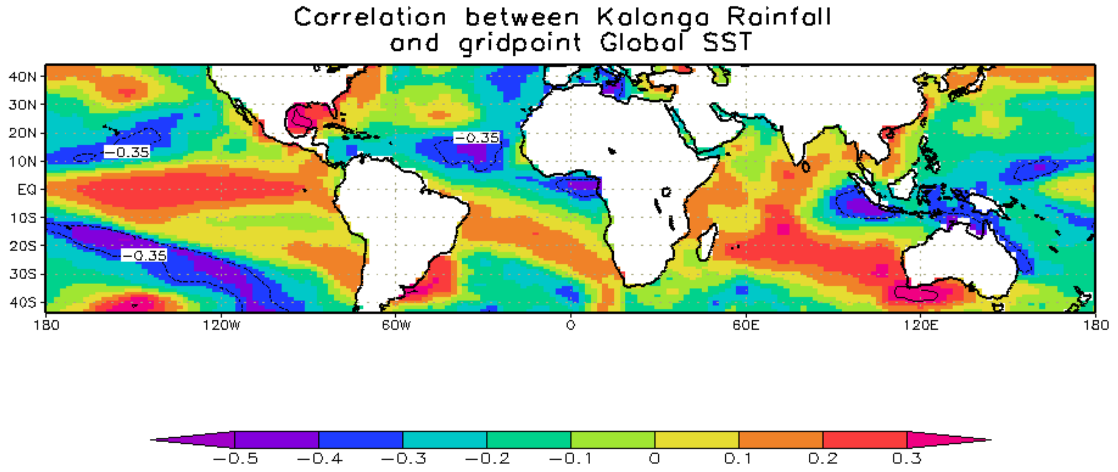

Figure 6b: Significant spatial correlation of station rainfall and global SST as depicted by Kalonga

Table 4b: Kalonga with the specific SST predictor areas

	PREDICTOR	**OCEAN**	**LONGTUDES**	**LATITUDES**
KALONGA	KAL_AT	ATLANTIC	40 – 28W	10 – 16N
	KAL_PC	PACIFIC	166 – 156W	20 – 16S
	KAL_IND1	INDIAN	117 – 124E	39 – 36S
	KAL_IND2	INDIAN	100 – 106E	10 – 06S

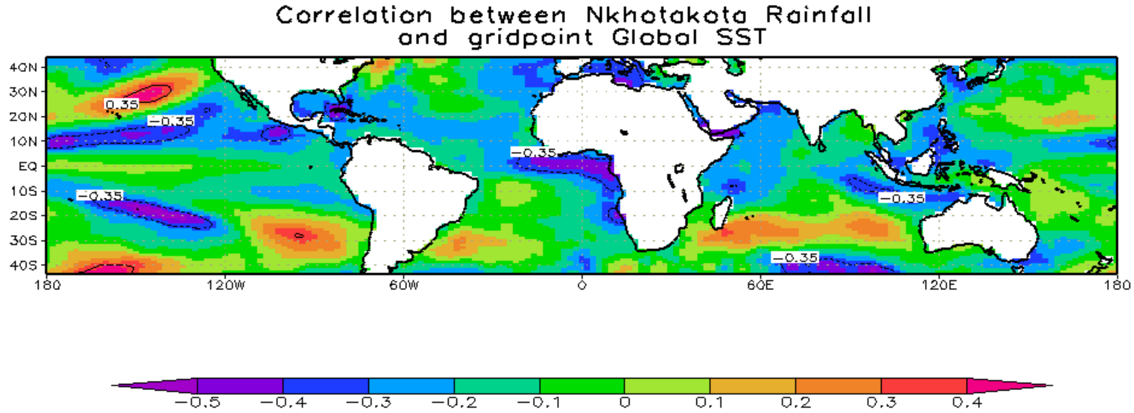

Figure 6c: Significant spatial correlation of station rainfall and global SST as depicted by Nkhotakota

Table 5c: Nkhotakota with the specific SST predictor areas

NKHOTAKOTA	PREDICTOR	OCEAN	LONGTUDES	LATITUDES
	NKO_AT	ATLANTIC	10 – 05W	02S – 02N
	NKO_PC1	PACIFIC	150 – 143W	20S – 16S
	NKO_PC2	PACIFIC	176 – 170W	08 – 12N

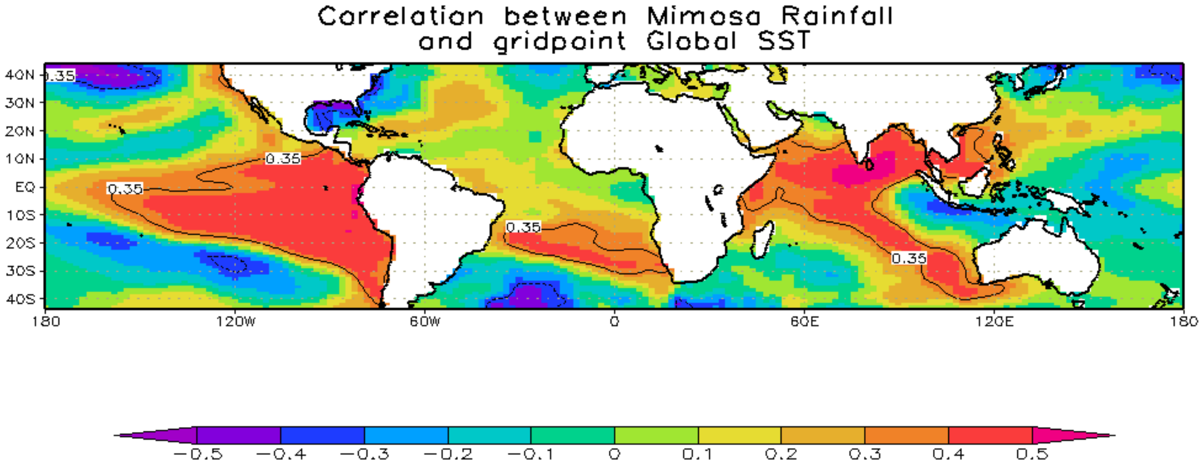

Figure 6d: Significant spatial correlation of station rainfall and global SST as depicted by Mimosa

Table 6d: Mimosa with the specific SST predictor areas

MIMOSA	**PREDICTOR**	**OCEAN**	**LONGTUDES**	**LATITUDES**
	MIM_PC1	PACIFIC	110 – 80W	20S – 06W
	MIM_IND1	INDIAN	70 – 80E	00 – 09N
	MIM_PC2	PACIFIC	172 – 164W	40 – 44N
	MIM_AT1	ATLANTIC	16 – 10W	25 – 22S

2.4 RESULTS FROM NINO / RAINFALL RELATIONSHIP

Figure 10 shows the NINO regions (boxes) used as predictor indices that showed significant correlations with the seasonal rainfall over Malawi (Table 2). The results showed that Nino 3 and 4 regions had significant correlations with stations in central and southern parts of the country especially between Octobers to December.

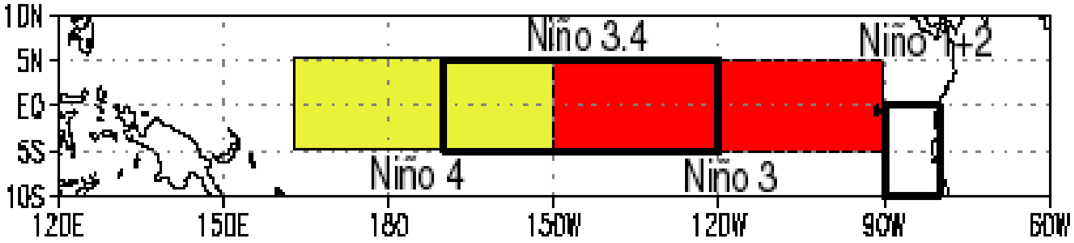

Figure 7: Map showing the position of NINO areas in the Equatorial Pacific Ocean

2.5 RESULTS FROM SOI / RAINFALL RELATIONSHIP

Results from the study between SOI and seasonal rainfall showed statistically significant positive association between rainfall over the central and southern parts of the study region. Figure 11 shows some examples of stations with significant correlation between rainfall and SOI as depicted by Chitedze and Mimosa.

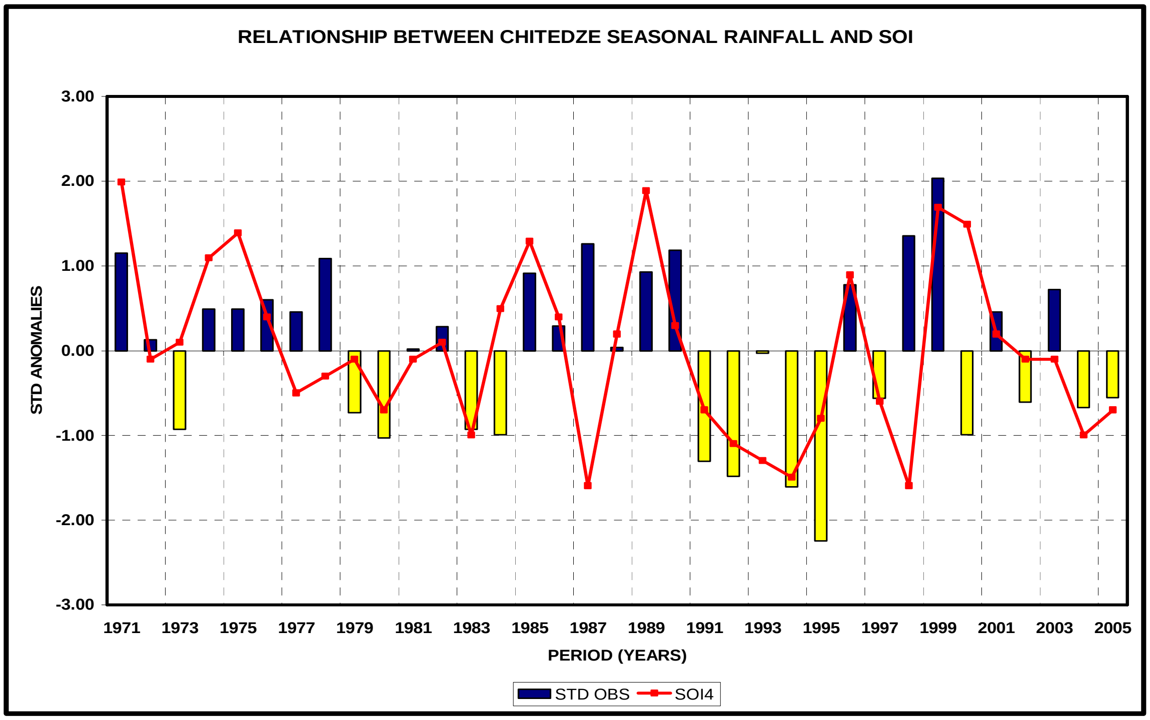

Figure 8a: Relationship between seasonal rainfall anomaly and SOI as represented by Chitedze

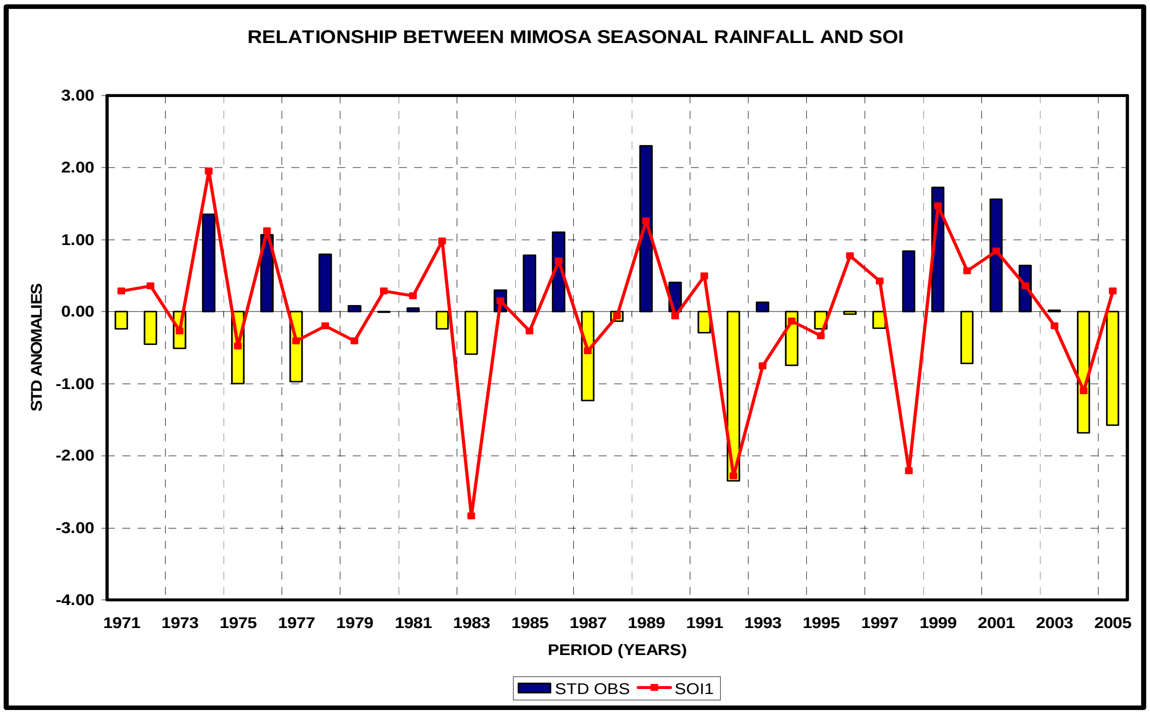

Figure 8b: Relationship between seasonal rainfall anomaly and SOI as represented by Mimosa

2.6 RESULTS FROM GRAPHICAL METHODS

2.6.1 REGRESSION ANALYSIS

An attempt was further made to make seasonal rainfall forecast for Malawi using multiple linear regression. The regression models were developed using the SST, IOD, NINO and SOI indices as predictors. Most predictors captured in the analyses were mostly areas within the Pacific and Indian Oceans. However, SOI was also captured by stations in the central and southern parts of the study region. The predictors, which contributed more than 15% to the regression in the stepwise analysis, were used in model development. Some of the graphical results obtained from the regression models are as shown in figure 13 for Mimosa, Nkhotakota and Mangochi respectively. The statistical summary on Analysis of Variance (ANOVA) for each respective station is as given in Tables 3a to 3c.

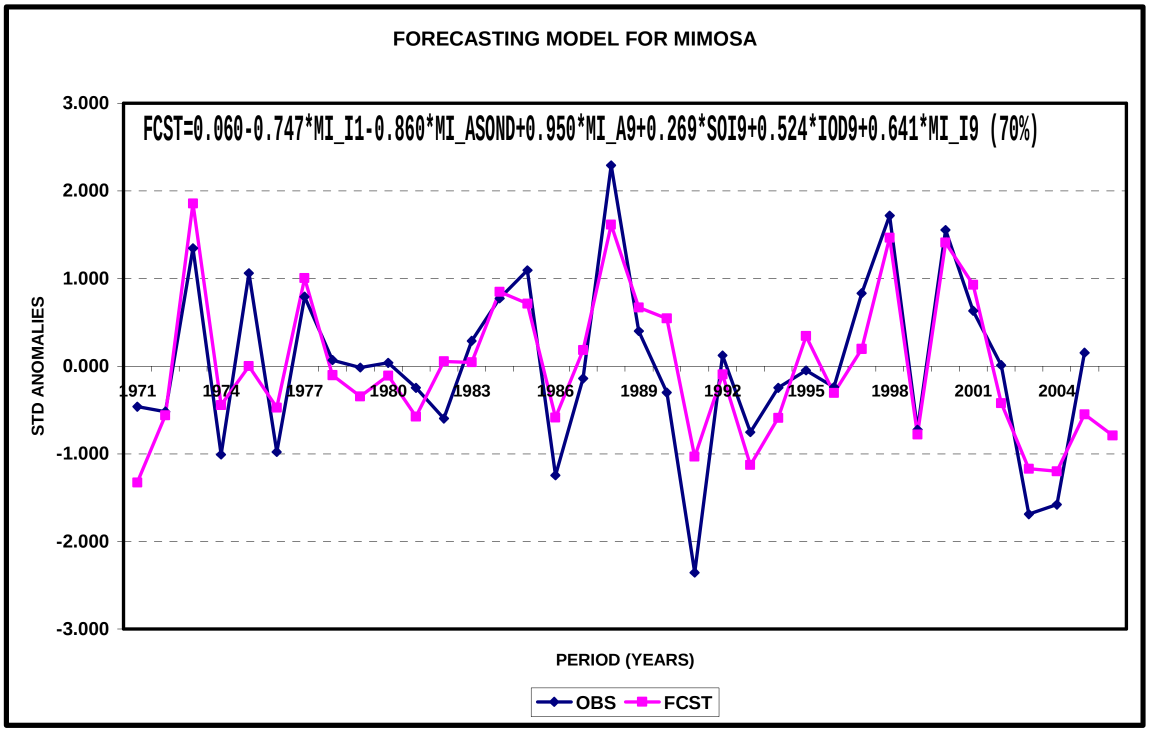

Figure 9a: Regression model for Mimosa

Table 7a: Statistical Summary (ANOVA) for Mimosa

R² =	Analysis of Variance				
Source	Sum-of-Squares	df	Mean-Square	F-value	P-value
Regression	19.855	6	3.309	9.324	0.000
Residual	8.163	23	0.355		

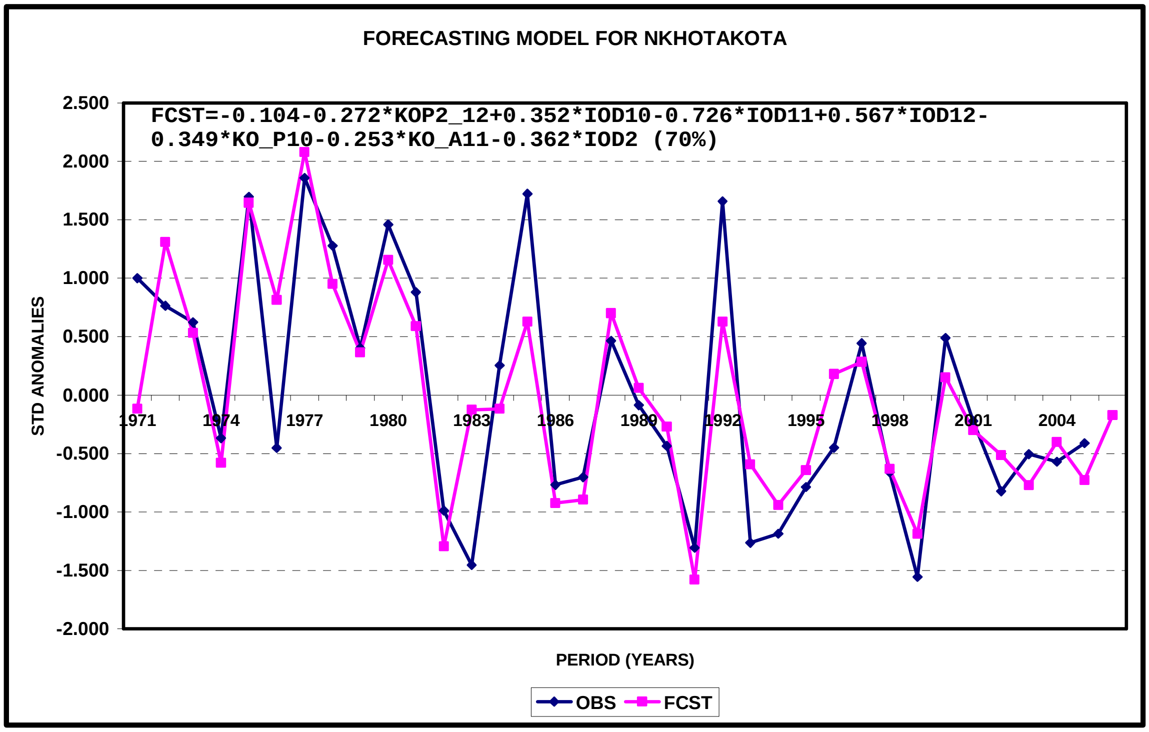

Figure 9b: Regression model for Nkhotakota

Table 7b: **Statistical Summary (ANOVA) for Nkhotakota**

R² =	Analysis of Variance				
Source	Sum-of-Squares	df	Mean-Square	F-value	P-value
Regression	22.751	7	3.250	7.481	0.000
Residual	9.558	22	0.434		

Table 4 shows the statistical summary that was used to develop a regression model for forecasting seasonal rainfall over Malawi. Predictor SSTs from areas within the global oceans that were highly correlated to the rainfall were used.

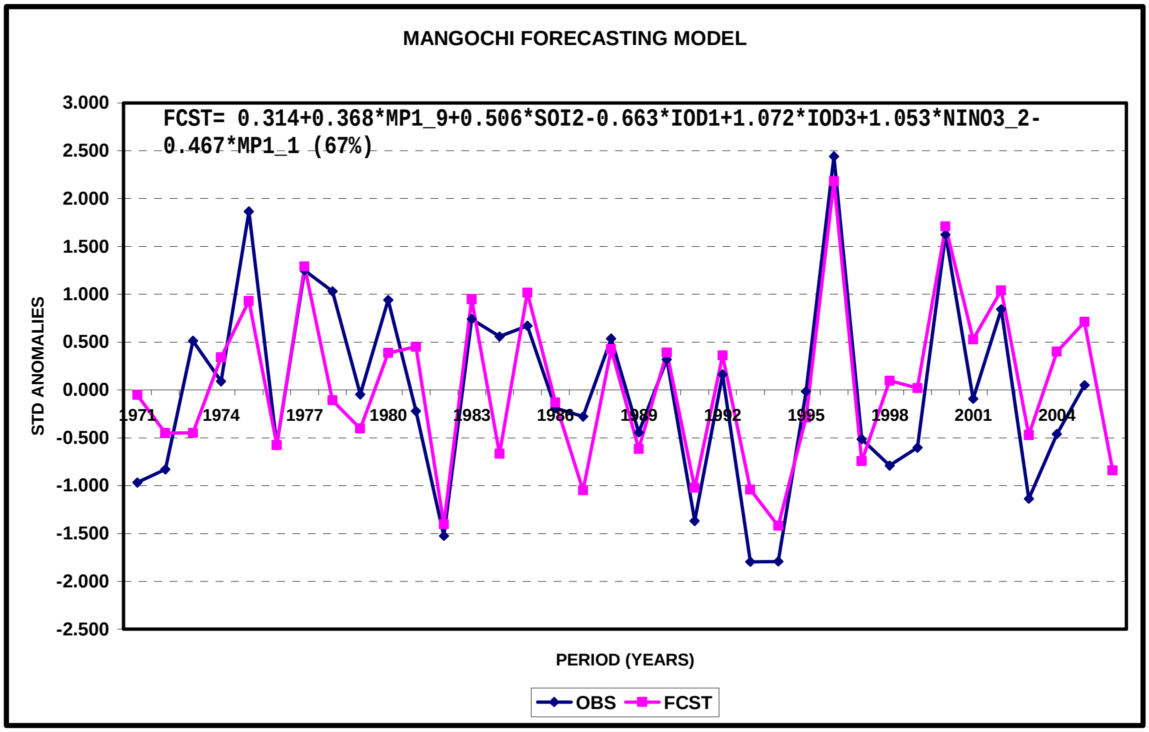

Figure 7c: Regression model for Mangochi

Table 7 c: Statistical Summary (ANOVA) for Mangochi

$R^2 = 67\%$	Analysis of Variance				
Source	Sum-of-Squares	df	Mean-Square	F-value	P-value
Regression	21.246	6	3.541	7.750	0.000
Residual	10.509	23	0.457		

It was noted from the regression models that the forecast simulated the seasonal rainfall well and therefore could provide good skill for forecasting rainfall over Malawi. The next section highlights on the tests on the performance of the models that were developed.

2.6. RESULTS FROM VERIFICATION OF THE FORECAST

The skills of the November-April models were determined by constructing Contingency table for each station and several skill scores calculated for both the training and verification periods. The percentage correct forecast in all categories was found to be above average in all station at between 49% and 80% (Table 7). In post agreement scores, the models were found to be biased towards forecasting extremes-Above or below normal. The highest correct Percentage for forecasting dry was 100%, while highest for normal was 63% and 100% for wet. Figure 17 shows some of graphs of the forecast verification.

Table 8: Model Skill from Contingency Tables

			Post-agreement			**False-alarm-Ratios**	
NO	STATION	**% correct**	**% correct-below**	**% correct-normal**	**% correct-above**	**O-Below &F-Above**	**O-Above &F-Below**
1	BOLERO	68.7	70.0	61.5	75.0	30.0	25.0
2	CHITEDZE	60.0	75.0	50.0	66.7	25.0	33.3
3	KALONGA	48.6	33.3	30.8	76.9	66.7	23.1
4	MANGOCHI	62.9	66.7	52.9	77.8	33.3	22.2
5	MIMOSA	80	75	0.00	100.0	25.0	0.0
6	NKHATABAY	60.0	100.0	50	50	0.0	50
7	NKHOTAKOTA	71.4	75.0	61.5	80.0	25.0	20.0
8	SALIMA	62.9	63.6	42.9	90.0	36.4	10.0
9	CHILEKA	65.7	100.0	52.6	70.0	00.0	30.0

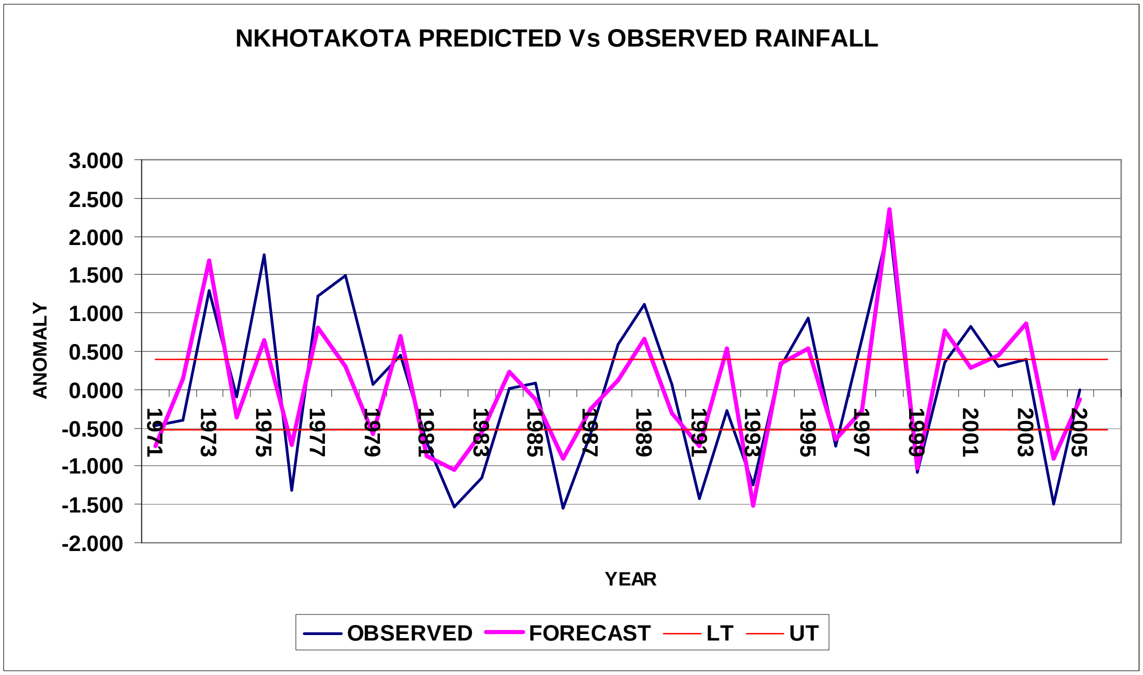

Figure 10a: Forecast verification as represented by Nkhatabay

Table 9a: Contingency table for forecast verification of Nkhatabay

		FORECAST			
		B	N	A	M-Totals
OBSERVED	B	1	0	0	1
	N	0	1	1	2
	A	0	1	1	2
	M-Totals	1	2	2	5

PERCENT CORRECT	60.0	B	N	A
POST AGREEMENT(%)		100.0	50.0	50.0
FAR(%)		0.0		50.0
POD - HIT RATE(%)		100.0	50.0	50.0
BIAS		1.00	1.00	1.00
CSI		1.00	0.33	0.33
HSS		0.375		

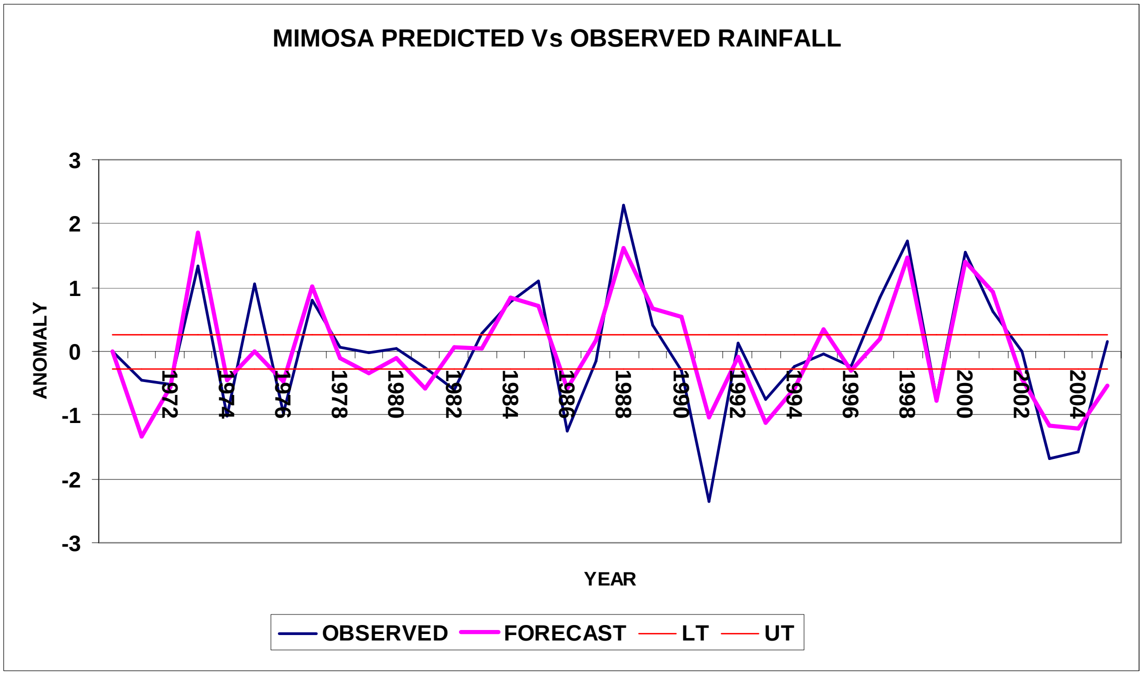

Figure 8b: Forecast verification as represented by Mimosa

Table 9b: Contingency table for forecast verification of Mimosa

		FORECAST			
		B	N	A	M-Totals
	B	3	0	0	3
OBSERVED	N	1	0	0	1
	A	0	0	1	1
	M-Totals	4	0	1	5

PERCENT CORRECT	80.0	B	N	A
POST AGREEMENT(%)		75.0	0.0	100.0
FAR(%)		25.0		0.0
POD - HIT RATE(%)		100.0	0.0	100.0
BIAS		1.33	0.00	1.00
CSI		0.75	0.00	1.00
HSS		0.583		

2.7. SEASONAL FORECAST FOR 2006/2007

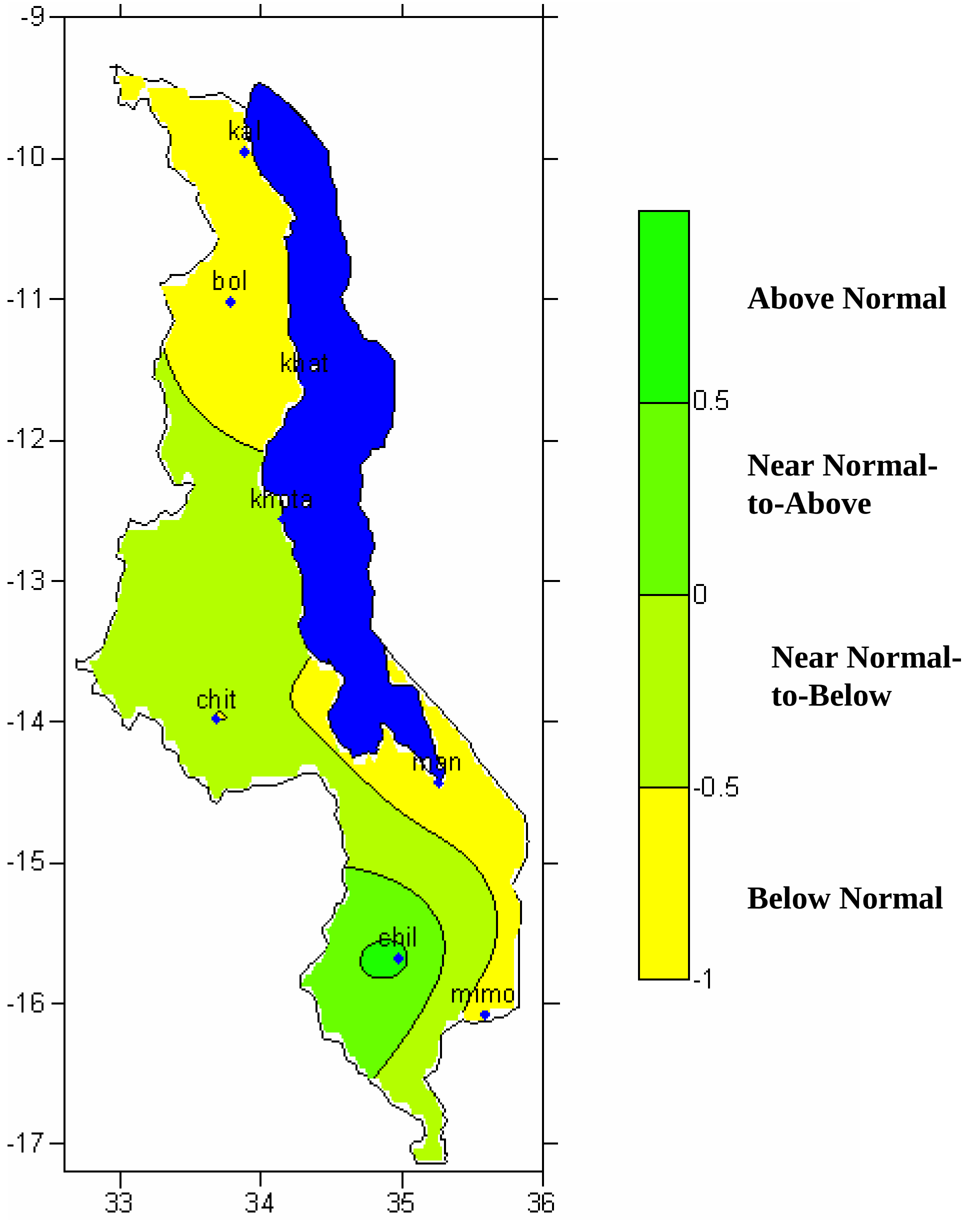

Figure 9: Forecast for November – April Seasonal rainfall for 2006/2007 over Malawi

Results from regression models indicated that the northern (Kalonga, Bolero, Nkhatabay) and southeastern (Mangochi, Mimosa) regions would receive near normal to below normal rainfall. Central (Nkhotakota, Chitedze) part of the country would be expected to receive near normal rainfall while the southwestern (Chileka) near normal to above normal rainfall (Figure 19).

2.8. CONCLUSION

The November - April seasonal rainfall over the study area was found to have significant relationships with SSTs in the Pacific, Atlantic and the Indian Ocean. It was further noted that the SOI and seasonal rainfall over the study area are always in phase and amplitude thus suitable phenomenon for prediction.

The developed regression models were found to be skillful in predicting above and below normal rainfall over the region studied.

2.9. RECOMMENDATIONS

The recommendations of this study are geared towards future research scientists, Malawi Meteorological Department and the policy makers of Malawi government.

- There is need to use more predictors such as the Quasi-Biennial Oscillation (QBO), Inter Tropical Convergence Zone (ITCZ), the subtropical high pressure cells e.t.c. that directly affect rainfall over the tropical region.
- To obtain precise and accurate forecast, there is need to incorporate both statistical and dynamical modeling techniques.
- More resources should be invested for research to investigate more on factors affecting seasonal over Malawi
- The policy makers and planners can now improve on the long term planning by using the products of this study and put in place mitigation and/or adaptation measures in infrastructure and advocate for changes in policy incase of potentially large magnitude of the effects of seasonal rainfall anomalies.

3.0 REFERENCES:

Malawi Meteorological Department website. metdept@metmalawi.com

Anyamba, A. (1994) Retrieval of the ENSO Signal from Vegetation Index Data. *The Earth Observer*. 6 (3): 24-26.

Anyamba, A. , EASTMAN, J. R. and FULK, M. A. (1995) NDVI Time Series as an Indicator of Climate Variability.

Cane, M. A. (1992) Tropical Pacific ENSO models: ENSO as a mode of the coupled system. In: K. E. Trenberth (Ed) *Climate System Modeling.* Cambridge University Press, New York. 583-614.

Diaz, H. F; Kiladis, G. N. (1992) Atmospheric teleconnections associated with extreme phases of the Southern Oscillation. In: H. F. Diaz and V. Markgraf (eds) *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation.* Cambridge University Press, New York. 7-28.

Eastman, J. R. and Fulk, M .A. (1993a): Time Series Analysis of Remotely Sensed Data Using Standardized Principal Components Analysis: *Proceedings 25th International Symposium on Remote Sensing and Global Environmental Change, Volume I.* April, 4-8, Graz - Austria. I485-I496.

Eastman, J. R. and FY, M. A. (1993b) Long Sequence Time Series Evaluation Using Standardized Principal Components. *Photogrammetric Engineering and Remote Sensing.* 53(12): 1649-1658

Hastenrath, S. (1991) *Climatic Dynamics of the Tropics.* Chapter 6: Regional Circulation Systems. Kluwer Academic Publishers. Dordrecht. 202-303.

Philander, S. G. (1990) *El Niño, La Niña, and the Southern Oscillation.* Academic Press, San Diego.

Ogallo, L. J., 1988: Relationships between seasonal rainfall in East Africa and the Southern Oscillation. *J. Climatol.*, 8, 31 – 43

Rasmusson, E. M., and Carpenter T. H, 1983: variation in tropical sea surface temperature and surface winds associated with the southern oscillation/El Niño. *Monthly Weather Review*, 110, 354-384.

WMO (1987) the Global Climate System: Autumn 1984 - Spring 1986. World Meteorological Organization, Geneva, Switzerland. 20-21.

WMO, 1966: *Climate change*. WMO Tech. Note No. 79, Geneva: WMO