STUDY OF DROUGHT IN MACHAKOS AND MAKUENI COUNTIES AND THEIR ASSOCIATION WITH GLOBAL TELECONNECTIONS

BY

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DECLARATION

This research project is my original work and has not been submitted for degree in any other university.

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This research project has been submitted for examination with our approval as university supervisors

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ABSTRACT

Extreme weather, including drought episodes, causes a lot of socio-economic losses. Drought is a cause to serious hydrological imbalances resulting in unusual dry conditions and is normal feature of the climate system. Understanding drought occurrences serves as early warning and provides approaches linked to mitigation of its impacts. Drought is also often linked to various global, regional and local climatic systems.

Kenya has had its fair share of drought episodes over the past five decades. It is in view of this that the study investigates drought frequency in Machakos and Makueni counties and their association with global teleconnections. The teleconnections considered are Nino 3.4 and Southern Oscillation index for the period 1965 to 2011 in relation to the rainfall amounts recorded in the two Counties.

The study utilised Standard Precipitation Index to study drought in the region and correlation analysis to investigate the relationship between rainfall and the global teleconnections. Based on Principle Component Analysis of the rainfall data, the region was divided into 4 and 3 homogeneous zones for MAM and OND respectively.

Results obtained indicate both indices have positive and negative correlation ranging from -0.51 to +0.27 for OND and -0.30 and +0.22 for MAM respectively. In terms of the zones Mbooni for OND and Makindu for MAM have the highest correlation with the global teleconnections. The drought and wet years were identified. The study recommends a continuous assessment of the drought situation in the region for the benefit of socio economic planning for mitigation purposes.

DEDICATION

I dedicate this study to God for giving me the opportunity to undertake this study, it was by His Grace that I have come this far. May all glory and honour go back to Him. Secondly I dedicate this study to my family, my husband Benjamin and our two daughters Sharon and Desmar for their encouragement, physical, moral and financial support.

I also wish to thank all who contributed to completion of this project especially my supervisors, Professor F. Mutua, Professor J. Ininda and the late Dr.R.E.Okola for guiding me. May God almighty bless and reward them abundantly as Dr.R.E.Okolla's soul rest in eternal peace.

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CHAPTER ONE

1.0 INTRODUCTION

Drought is a deficiency in precipitation over an extended period usually a season or more, resulting in water shortage, causing adverse impacts on vegetation, animals and people. It's a period in which an unusual scarcity of rain causes a serious hydrological imbalance in which water supply reservoirs become empty, wells dry up and crop damage ensues. The impacts of drought are higher in many developing countries, especially in Africa. Drought creeps in very slowly and is often very difficult to detect its onset until its major impacts such as lack of water, food, etc. start to be discernible. Its effects are cumulative. There is no universal definition of drought because it is a creeping phenomenon with either no distinct start or finish. Despite the confusion about drought concept, it is obvious that any form of drought originates from deficient rainfall (Mwangi et al., 2014).

Studies have shown that drought occurs frequently within the horn of Africa (Balint et al., 2013). The study further indicates that drought is common in many sub Saharan regions sometimes causing conflicts. Drought occurrence is a natural phenomenon in the climate system. It mainly occurs in arid and semi-arid areas. In Kenya this includes the parts of eastern and northeastern. The area of the present study, Machakos and Makueni counties are located in the eastern part of Kenya.

Ordinarily, such arid areas are already vulnerable to the impacts of droughts as there is shortage of resources. This results in difficult living conditions for the affected populations as agricultural activities are reduced or decimated. Drought leads to migration of communities in search of greener pastures and water, sometimes causing conflicts between communities.

Understanding drought occurrences serves as early warning and provides approaches linked to mitigation of its impacts (Mwangi et al., 2014). Drought is also often linked to various global, regional and local climatic systems (Sheffield et al., 2012). Kenya has had its fair share of drought episodes over the past five decades. The recently documented droughts occurred during 2008/2009 and 2010/2011, hitting the arid and semi-arid regions of the county hard (Zwaagstra et al., 2010).

Droughts are major hindrances to economic and social developments in many parts of the world especially in developing Nations like Kenya. In Machakos and Makueni counties of Kenya, drought is prevalent particularly in remote areas of the region. The communities in the region are mainly dependent on subsistence cropping and animal farming and drought occurrences lead to great economic losses. It is therefore important to improve on the ability to make accurate drought forecasts, with sufficient lead-time (Mwangi et al., 2014).

Drought may be defined basing on Meteorology, Hydrology and Agriculture. Meteorological drought is principally defined by deficiency of precipitation from expected or "normal" over an extended period of time. Hydrological drought is best defined by deficiencies in surface and subsurface water supplies. Agricultural drought is best characterized by deficiency in soil moisture (critical factor in defining crop production potential)

Global teleconnections are climate indices linked remotely to weather patterns in various part of the world.

1.1 Problem statement

Attempts have been made to understand drought occurrence over various parts of Kenya (onyango, 2014; ngaina et al., 2014). However, the drought phenomenon has not been fully understood. Drought occurrence displays variability in space and time and this variability greatly affect the social and economic lives of many people in Kenya (GoK, 2013). Often it results in societal conflicts, spread of communicable diseases, human wildlife conflict and general poverty. National studies show that persistent droughts reduce national food production and leads to commitment of massive resources in mitigating their effects (DMC, 2002).

In the region under study, many inhabitants dependent on subsistence cropping and animal farming that are vulnerable to droughts. Managing droughts will therefore require consistent study for evidence and objective assessment of the situation in Machakos and Makueni counties of Kenya. This study, therefore, provides reliable information for decision making in the region.

1.2 Objectives;

1.2.1 Main objective;

The main objective is to study the characteristics of droughts in Machakos and Makueni counties

1.2.2 Specific objectives

1. To determine the temporal and spatial characteristics of drought occurrences in Machakos and Makueni counties.
2. To determine linkages between drought and Global teleconnections in Machakos and Makueni counties.

1.3 Justification

There is not sufficient studies and research work done to understand the occurrence of droughts in lower eastern Kenya, particularly Machakos and Makueni counties. Information on spatial and temporal characteristics of droughts is important in planning activities that are affected by weather activities and helps in mitigation against adverse climatic conditions (Onyango, 2014; Ngaina et al., 2014). The search for governance options, particularly in the now devolved units will require studies such as this at county levels for more detailed information.

1.4 Area of study

The study is to be centred over the two counties of Machakos and Makueni. The following table 1 shows the geographical location and population of the two counties.

Table 1: Longitudes and latitudes of study area

County	Latitude	Longitude	Population	Population/km2
Machakos	0 45’& 1 31’S	36 45’ & 38 30’E	1,098,584	177
Makueni	1 35’& 3 00’S	3710’& 38 30’E	884’527	110

These region is home to a population of about 2 million inhabitants with different tribes namely Akitutu, Akitondo, Aombe, Amiw’a, Atangwa, and Aambua among many others. The two counties experiences varied climatic conditions ranging from dry to semi-arid and arid conditions. Thus both counties experiences erratic and unpredictable rains with short rains in October to December and long rains from late March to May. Figure 1: shows the counties and the location of the rainfall stations to be used in the study.

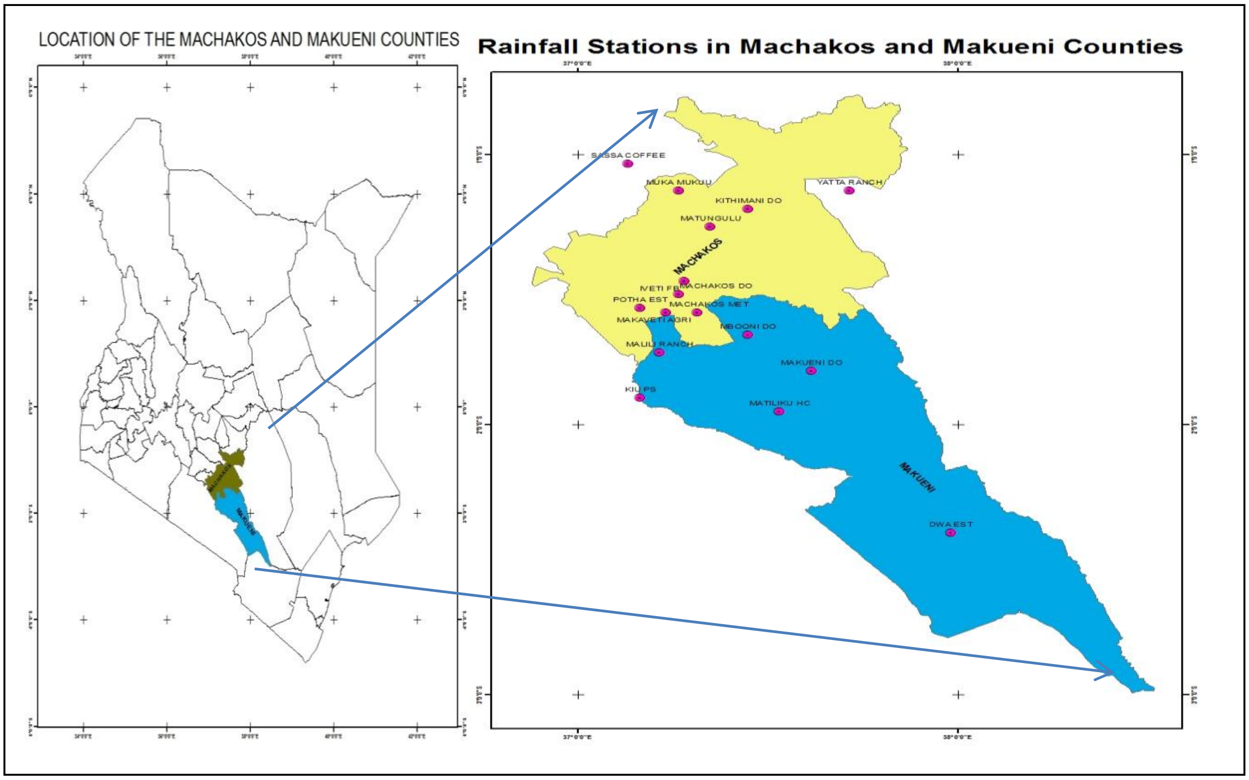

Figure 1; Area of study

Table 2; shows the rainfall stations to be used in the study

No.	Name	Stn No.	Lat	Long	Height(ft)
1	Sassa	9137002	1^0,2'S	37^o,08'E	4880
2	Malili	9137003	1^0,,44'S	37^o,13'E	6080
3	Mbooni Forest	9137099	1^0,38'S	37^o,27'E	6000
4	Kiu Pry School	9137012	1^0,54'S	37^o,10'E	4870
5	Machakos Potha	9137014	1^0,34'S	37^o,10'E	5500
6	Machakos Matungulu	9137040	1^0,16'S	37^o,21'E	5000
7	Machakos Iveti Forest	9137045	1^0,28'S	37^o,17'E	6200
8	Mukamukuu Farmers	9137055	1^0,8'S	37^o,16'E	4950
9	Machakos Matiliku Health Centre	9137028	1^0,57'S	37^o,32'E	3600
10	Machakos Makaveti Agri Camp	9137071	1^0,35'S	37^o,19'E	3650
11	BZ Yatta Ranching	9137076	1^0,8'S	37^o,43'E	4100
12	Makueni unoa hill	9137056	1^0,48'S	37^o,37'E	3950
13	Machakos Katumani	9137089	1^0,35'S	37^o,14'E	5250
14	Kibwezi DWA plantation	9237002	2^0,24'S	37^o,59'E	3000
15	JKIA	9136168	1^0,19'S	37^o,55'E	5329
16	Makindu Met	9237000	2^0,17'S	37^o,50'E	3280

CHAPTER TWO

2.0 LITERATURE REVIEW

Weather and climate variability affects all socio-economic development, thus, extreme weather causes a lot of socio-economic loss. Drought is a period of abnormally dry weather, prolonged for lack of water / precipitation that cause serious hydrological imbalances. According to studies, periods of unusually dry conditions are a normal feature of the climate (Mwangi et al., 2014; Ngaina et al., 2014; Onyango, 2014). Droughts can be classified in various categories; Meteorological, hydrological, agricultural. The definition and meaning of drought varies from discipline but a generally accepted definition of drought is a temporary reduction in water or moisture availability significantly below the normal or expected amount (norm) for a specified period. In this definition the following assumptions are made;

a) That the reduction is temporary,

b) That the reduction is significant,

c) That the reduction is defined in relation to a norm,

d) That the period taken as the basis for the norm is specified.

The Greater Horn of Africa is prone to extreme climate events such as droughts and floods. Droughts have been there from time in memorial (Sambuca et al., 2014). Drought is a potential hazard for agriculture in nearly all of Kenyan counties because over three quarter of its area, evapo-transpiration rates exceed available moisture (Zwaagstra et al., 2010). According to Nyamwange (1995), the 1984/85 drought was the worst in the last one hundred years.

In Kenya drought affects mostly Eastern, Coast, North Eastern and parts of Rift Valley counties. Most of these counties experience dry weather conditions causing pressure on the existing pastures and water resources on which the communities depend for survival.

2.1 Types of droughts

Literature distinguishes various forms of drought, mostly depending the sector concerned (Onyango, 2014; Ngaina et al., 2014).

2.1.1 Meteorological drought

Meteorological drought describes a reduction in rainfall for a specified period, below an agreed statistical amount of the long-term average for the specified time period. Its definition involves only precipitation statistics (Wambua et al., 2014). It is a simple absence or deficit of rainfall from the normal. It is the least severe form of drought and is often identified by sunny days and hot weather.

2.1.2 Hydrological drought

Hydrological drought occurs where the water in natural and manmade reservoirs fall below a certain threshold in a given period of time, often leading to reduction of natural stream flows or ground water levels (streams, rivers, lakes, aquifers), plus stored water supplies. The main impact is on water resource systems. Hydrological droughts tend to show up more slowly because it involves stored water that is used with less replenishing (Sheffield et al., 2012)

2.1.3 Agricultural drought

To the agriculturists this form of drought occurs when moisture level in soil is insufficient to maintain average crop yields. Initial consequences are in the reduced seasonal output of crops and other related production. An extreme agricultural drought can lead to a famine, which is a prolonged shortage of food in a restricted region causing widespread disease and death from starvation. Agricultural drought is the impact of meteorological and/or hydrological droughts on crop yields. Crops have particular temperature, moisture and nutrient requirements during their growth cycle in order to achieve optimum growth. If moisture availability falls below the required amount during the growth cycle then crop growth will be impaired and yields reduced.

Agricultural drought may also occur due to low or prolonged lack of precipitation (Wilhite and Blintz 1985). The parameters that determine the agricultural drought are: precipitation, evapotranspiration, available soil moisture, moisture requirements of the plants. Therefore, agricultural droughts link the various characteristics of meteorological drought to agricultural production. While it is generally associated with arid and semi-arid climates, this drought can occur in areas that normally enjoy adequate rainfall and moisture levels. This can result if there is lack of enough water to the plants due to; lack of supply of the water, inadequate storage or conveyance facilities, or abnormal demand. In most cases the drought is accompanied by hot, dry, winds and may be followed by damaging floods (Wambua et al., 2014).

2.1.4 Socio-economic drought

Socio-economic drought correlates the supply and demand of goods and services with the three above-mentioned types of drought. When the supply of some goods or services such as water and electricity are weather dependant then drought may cause shortages in supply of these economic goods.

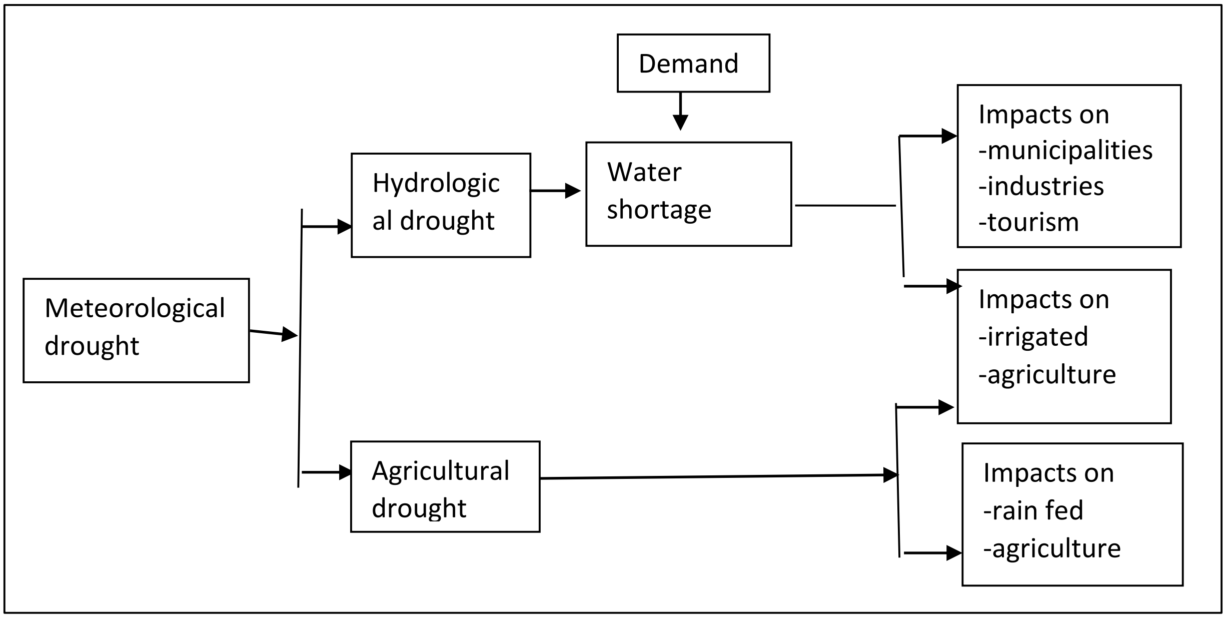

Figure 2; Social drought sequence, figure modelled along Wambua et al (2014)

Droughts are caused by various factors. The immediate cause is shortage of rainfall. Over eastern Africa shortage of rainfall is caused by absence of available moisture in the atmosphere; large scale subsidence (downward movement of air within the atmosphere) which suppresses convective activity; and the absence or non-arrival of rain-bearing systems (Sheffield et al., 2012). Changes in such factors involve changes in weather systems on many spatial scales ranging from local to regional to global. In summary some of the causes of drought include;

- Short term periodic fluctuations in rainfall levels,
- Long term climatic changes
- Desertification caused by loss of vegetation
- Subsequent land erosion caused by combination of drought overgrazing and poor land management.
- Deforestation
- Improper land use
- Extreme climatic events

2.2 Associated Impacts of drought conditions

Droughts affect large geographical areas, often covering countries or parts of continents and may last for several months and, in some cases, several years. Droughts cause heavy loss of livelihoods and paralyzed economic activities in sectors such as agriculture (DMC, 2002), pastoralism, power generation, tourism, horticulture and others. This often leads to poor health, hunger, vulnerability to diseases, leading to deaths especially for the children and the aged. Over the larger Ukambani counties droughts results in general poverty, dependence on relief supplies from the Government, and non-governmental organisations, NGOs. Occasionally there are increased human and wildlife conflicts due to diminished water and food resources. Many communities may resort to migration and displacement of families into areas with food supplies or relief foods. Even on the trading markets, the few available commodities face price hikes while prices of livestock depreciate drastically due to their emaciated conditions. There is lack of social amenities like water and sanitation services.

Historically, scientists have classified the intensity and variation of weather based on SSTs anomalies exceeding a pre-selected threshold in a certain region of the equatorial Pacific. The most commonly used region is the Niño 3.4 region and the most commonly used threshold is a positive SST departure from normal greater than or equal to +0.5°C. Since this region encompasses the western half of the equatorial cold tongue region, it provides a good measure of important changes in SST and SST gradients that result in changes in the pattern of deep tropical convection and atmospheric circulation. This criterion is often used to classify El Niño episodes, which have impact on rainfall performance in Kenya and the study area.

Studies have shown that a necessary condition for the development and persistence of deep convection (enhanced cloudiness and precipitation) in the tropics is that the local SST be 28°C or greater. Once the pattern of deep convection has been altered due to anomalous SSTs, the tropical and subtropical atmospheric circulation adjusts to the new pattern of tropical heating, resulting in anomalous patterns of precipitation and temperature that extend well beyond the region of the equatorial Pacific. An SST anomaly of +0.5°C in the Niño 3.4 region is sufficient to reach this threshold from late March to mid-June. During the remainder of the year a larger SST anomaly, up to +1.5°C in November-December-January, is required in order to reach the threshold to support persistent deep convection in that region.

CHAPTER THREE

3.0 DATA AND METHODOLOGY

The data used in the study was monthly rainfall values for selected rainfall stations in Machakos and Makueni counties for the period 1965 – 2011 from Kenya Meteorological Department (KMD).

3.1 Data quality control

The data collected was subjected to various data quality control procedures and techniques. The data quality control helped check and detect errors in the data sets. The data quality check was done by checking the missing values, and estimating the missing values using the arithmetic mean method. The form of the equation to estimate missing data was given by;

$$X_m = \frac{\overline{X}_m}{\overline{X}} X \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where; X_m is the station with missing data, X station which is highly correlated with missing data, $\overline{X}_m$ is the mean of the missing station and $\overline{X}$ is the long-term mean of the station

3.2 Methodology

These are the techniques that were employed in achieving the set objectives.

3.2.1 Principal Component Analysis

Principal Component Analysis (PCA) was used to reduce data dimensionality by performing a covariance analysis between factors. It was used because it is suitable for data sets in multiple dimensions.

3.2.2 Standard precipitation Index (SPI)

To facilitate the assessment of drought special indices were developed. Standard Precipitation Index (SPI) is among many others that are most popular indices used for assessing the severity of meteorological drought. Apart from the severity indices selected to represent drought severity, the other dimensions of drought include the areal extent and duration. SPI was developed to enhance detection of drought. It involved probability of precipitation for a given period and is negative for drought, and positive for wet conditions. SPI is a probability index that considers only precipitation. SPI is flexible to measure drought at different time scale and was used for detection and monitoring capabilities. Due to the normal distribution of SPI, the frequencies of extreme and severe drought classifications for any location and any timescale are consistence. SPI was developed by McKee et al. (1993) and was based just on precipitation therefore requires less data input and calculation effort. A long-term precipitation record at a desired station is fitted to a probability distribution, and then it's transformed to normal distribution so that mean for SPI is zero. From the wide array of the drought indices, SPI is the most recognized and applied in both research and operational activities (Onyango, 2014; WMO 2012)

3.2.3 Time series analysis

A time series of the data collected was plotted. The time series showed the distribution of rainfall as a function of time. This helped analyse the temporal variability of the rainfall and hence identifying the wet and dry years.

3.2.4 The global teleconnections.

SSTs indices were studied in order to determine the phases that are associated with the meteorology and dry episodes in the Makueni and Machakos counties. Complete correlation between the rainfall and the SST indices was done. The SST indices that were used in the study include the NINO 3.4 and SOI from National Oceanic and Atmospheric Administration (NOAA). The National Climate Centre has a revised SOI calculation though equation 3.

$$SOI = 10 \times \left[\frac{PA(Tahiti) - PA(Darwin)}{std\ dev\ diff}\right] \text{ .... (3)}$$

Where: PA = the Pressure Anomaly; monthly mean minus long-term mean

STD dev. diff. = Standard deviation of the difference

3.2.5 Coefficient of variability

Equation 4 and 5 were used to study the reliability of rainfall.

$$\frac{SD}{Mean} x\ 100 = cofficient\ of\ variability \text{ ....(4)}$$

$$100 - Cov = Reliability \text{ .... (5)}$$

CHAPTER FOUR

4.0 RESULTS.

4.1 Significant Eigen Vectors for MAM and OND

The Latent Roots (Eigen values) results are presented in table 3, 4 and 5. There are three significant values (table 3, 4 and 5); i.e. values measuring more than one. The values were 11.02, 1.454 and 1.092 for MAM respectively. For OND, there are two significant values measuring greater than one; 11.451 and 1.437 respectively. This is as depicted in the two scree plots as in figure 3 and 4. Component loadings (figure 5) were derived from the first three Eigen values for MAM and first two Eigen values for OND respectively. MAM explains a variance of 61.223%, 8.076% and 6.066% of the data used over the study area giving a total of 76.365% while OND explain a variance of 63.165% and 7.982% of the data used over the study area giving a total of 71.147%.

Table 3; Latent Roots (Eigen values) for MAM and OND

No.	**1**	**2**	**3**
MAM	11.02	1.454	1.092
OND	11.451	1.437	-

Table 4; Variance Explained by Components

	Variance explained			
	1	2	3	
MAM	11.02	1.454	1.092	
OND	11.451	1.437	-	
	Percent of Total Variance Explained			
	1	2	3	total
MAM	61.223	8.076	6.066	75.365
OND	63.165	7.98	-	69.245

This entailed transformations of rainfall data from the various stations into different components. These transformations could be out of the influence of the systems that bring about rainfall in the two counties. The first transformation of MAM period gave the latent roots (Eigen values) from which only three were used to obtain the component loadings. From the second transformation (OND) only two latent roots (Eigen values) were used to obtain the component loadings. The total variance explained in % from the first three latent roots added up to 75.365% for MAM and 69.245% for OND.

Table 5; Component loadings

	MAM				OND	
Rainfall stations	1	2	3		1	2
Sassa	0.804	0.021	-0.122		0.736	0.472
Malili	0.884	0.193	0.143		0.878	-0.172
Kiu pry sch	0.724	-0.032	0.114		0.791	-0.489
Mks potha	0.927	0.058	0.141		0.852	0.109
Matiliku	0.858	-0.106	-0.255		0.831	0.026
Matungulu	0.803	-0.344	-0.143		0.892	-0.041
Mks iveti	0.551	-0.661	0.03		0.678	-0.557
Mukamukuu	0.727	-0.509	0.113		0.805	-0.063
Makueni	0.75	0.532	0.032		0.733	-0.269
Makaveti	0.83	0.044	0.129		0.677	0.439
Yatta bz	0.549	0.34	-0.602		0.509	0.475
Mbooni	0.823	0.38	0.133		0.799	0.225
Katumani	0.606	0.152	0.461		0.816	-0.127
Kibwezi dwa	0.839	-0.032	0.061		0.845	0.103
Jkia	0.787	-0.043	-0.365		0.822	0.053
Makindu met	0.905	0.003	-0.163		0.923	0.019

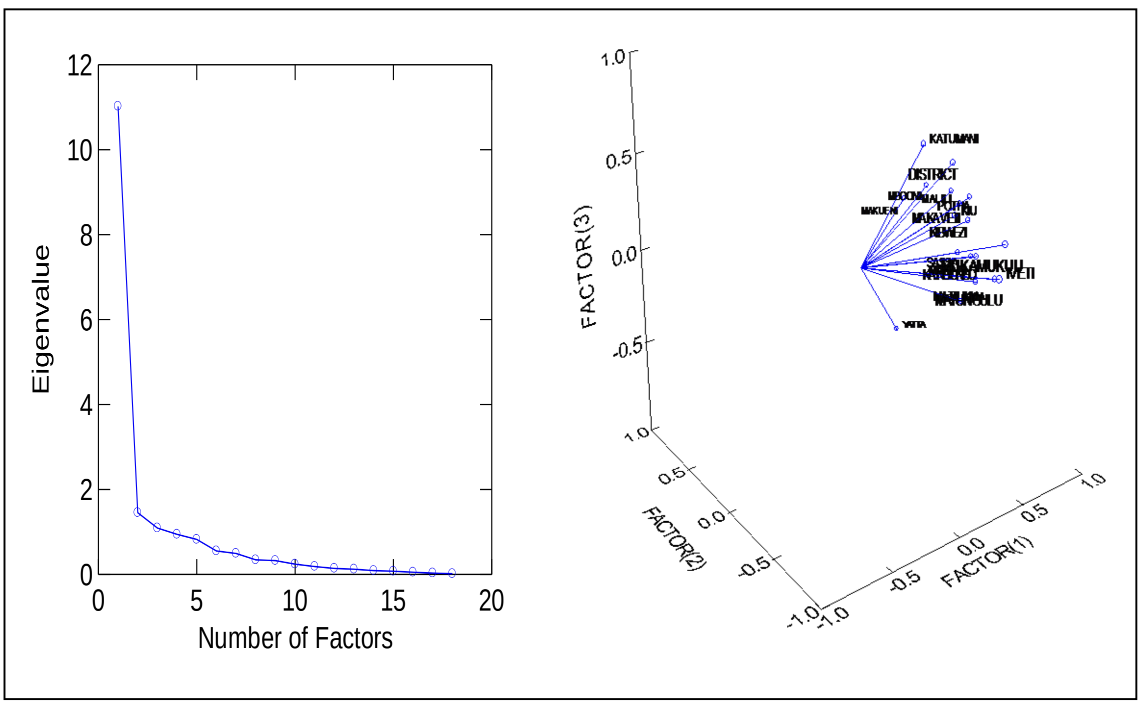

Figure 3: Scree plot and factor loading plot for MAM period.

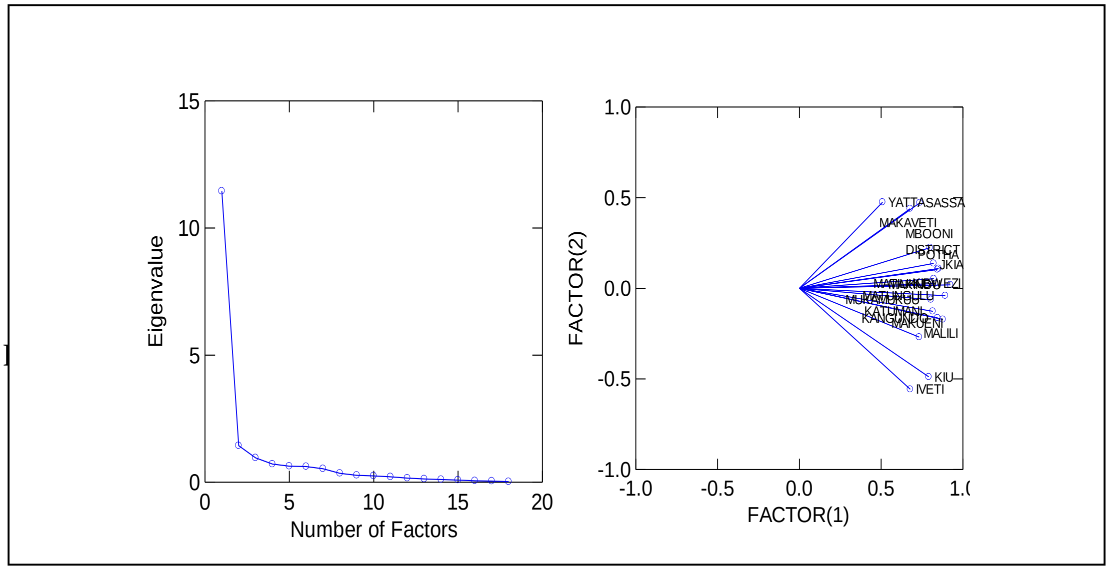

Figure 4: Scree plot and factor loading plot for OND period.

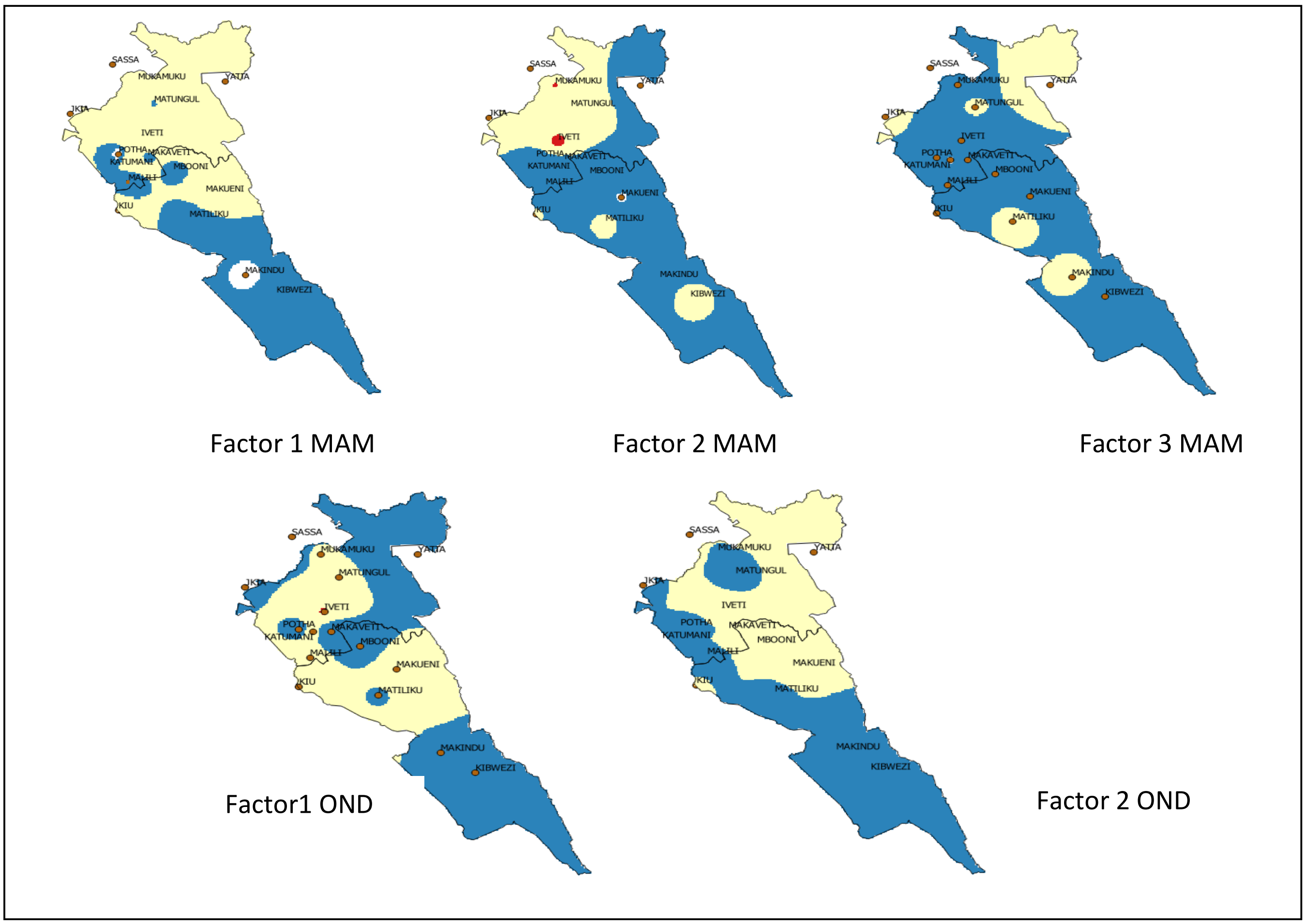

Figure 5; Factor loadings for MAM and OND.

Figure 6 and table 6 shows the identified homogeneous zone based on the 47 years rainfall data sets. The zones were gotten from taking the station with highest communality in each zone. The zones were then grouped to represent seven climatic areas which are analysed in the study. Major factors contributing to the zoning differences were topography, vegetation, rainfall distribution among others.

The homogenous zones were as a result of scales of motion such as planetary features, synoptic, meso-scale and local scale features. During MAM the global teleconnections are weak, thus the main driving forces are synoptic and meso-scale features which may have contributed to the resultant of more homogeneous zones. While during the OND period the global teleconnections are intense thus contributing to the three resultant zones.

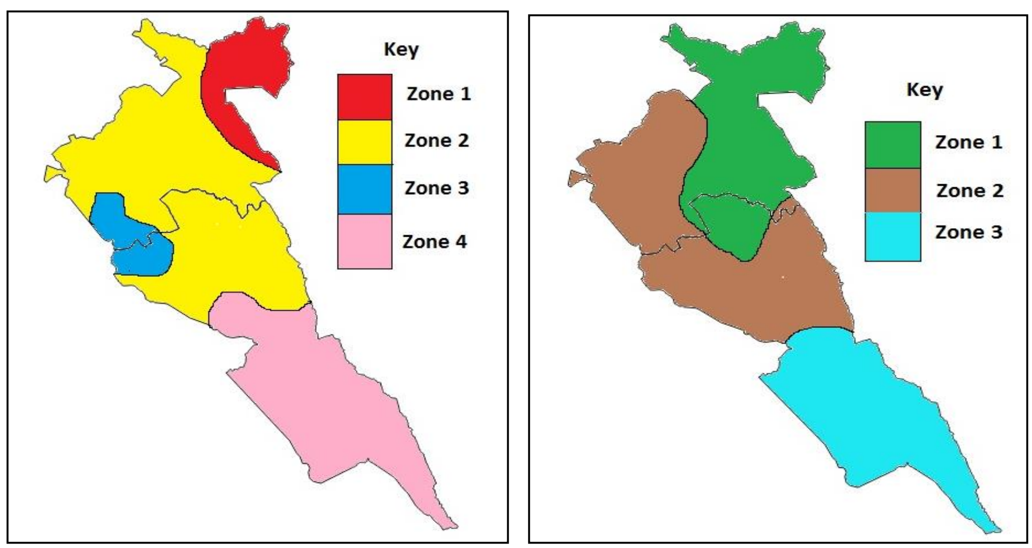

Fig 6a MAM zones Fig 6b OND Zones

Figure 6: homogeneous zone for both MAM and OND.

Table 6 shows the identified zone for MAM and OND

Zones	MAM	OND
Zone 1	Yatta	Mbooni
Zone 2	Potha	Kiu
Zone 3	Malili	Makindu
Zone 4	Makindu	-

4.2 Results for Standardized Precipitation Index (SPI)

4.2.1 Results for SPI index for MAM

The following table shows the SPI values used in this study. Normalized data was plotted and SPI scale (table 7) used to identify severity of drought. Table 7 shows the color codes for drought, adapted from WMO 2010. This was used as the reference table for the interpretation of the wet and dry years in all the zones.

Table 7; Colour bar on the SPI Index analysis

Scale	Color bar	Drought levels
2.00+	Dark Blue	Extremely wet
1.50 – 1.99	Light Blue	Very wet
1.00 – 1.49	green	Moderately wet
-0.99 – 0.99	No color	Near normal
-1.00 - -1.49	yellow	Moderately dry
-1.50 - -1.99	Magenta	Very dry
-2.00 and less	Brown	Extremely dry

Results in figure 7 indicates that most of the years fall between moderately dry to moderately wet. However, 6 and 5 years were found to be very wet and very dry respectively. Only one year, 2009 was found to be extremely dry. The drought analysis for Makindu is shown in table 8.

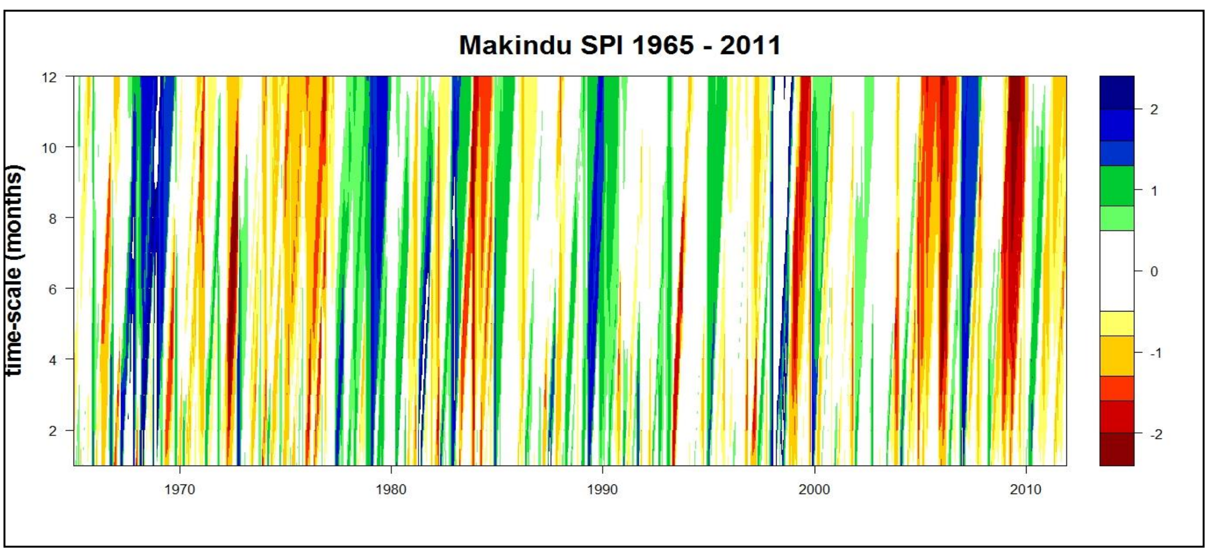

Figure 7: SPI plot for Makindu Zone 4; MAM

Table 8: Wet and dry years for Makindu Zone 4; MAM

Drought	Years
Extremely wet	nil
Very wet	1969,1970,1979,1989,1998,2007
Moderately wet	1996,1968,1978,1981,1983,1985,1988,1990,1993,1995,1997,2000,2002
Near normal	1967,1972,1973,1980,1987,1991,1992,1996,2001,2003,2004,2008,2010
Moderately dry	1965,1971,1974,1975,1976,1982,1986,1994,2011
Very dry	1977,1984,1999,2005,2006
Extremely dry	2009

Results in figure 8 indicates that there were 5 very wet years, 7 years were very dry while most of the years fall between moderately wet and near normal.However,9 years were found to be moderately dry with one extremely dry year i.e. 2009. The drought analysis for Yatta is shown in table 9.

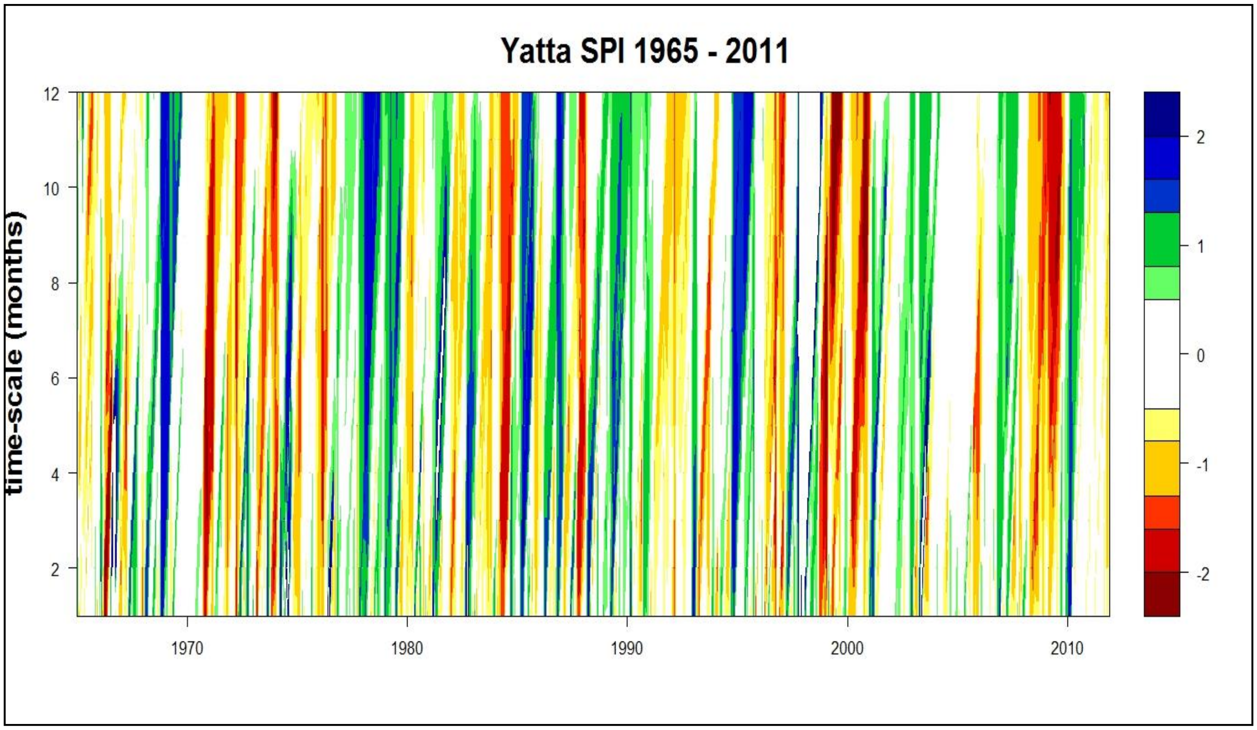

Figure 8: SPI plot for Yatta Zone 1; MAM

Table 9: Wet and dry years for Yatta Zone 1; MAM

Drought	Years
Extremely wet	nil
Very wet	1969,1978,1985,1995,1998
Moderately wet	1965,1977,1979,1982,1987,1989,1990,1997,2001,2003,2006,2007,2010
Near normal	1967,1968,1970,1973,1975,1981,1986,1991,1993,1994,2002,2004,2005
Moderately dry	1966,1971,1976,1980,1983,1992,2008,2011,
very dry	1972,1974,1984,1988,1996,2000,2009
Extremely dry	1999

Result in figure 9 indicates that most of the years fall under near normal. We also have 10 very wet years and 8 very dry years with only two extremely dry years 1984 and 2002. The drought analysis for Potha is shown in table 10. Figure 8 shows the obtained results for Potha.

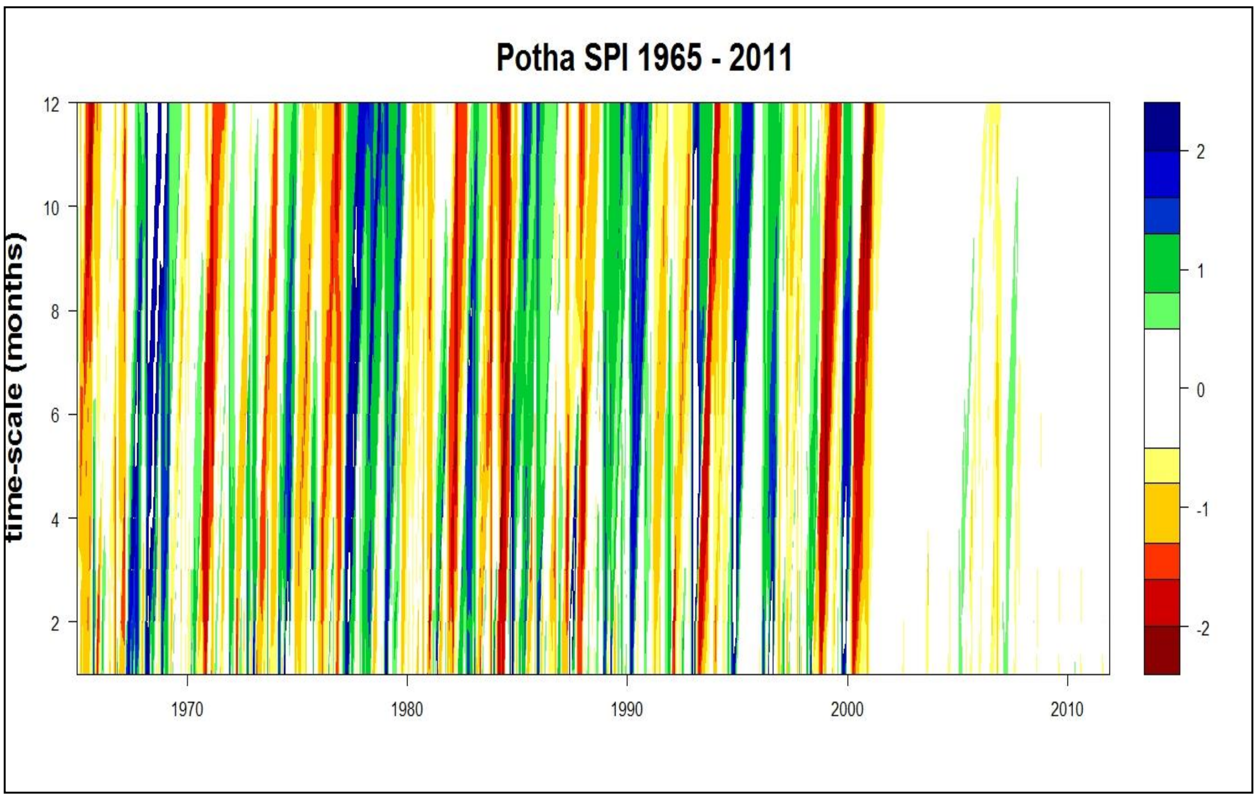

Figure 9: SPI plot for Potha Zone 2; MAM

Table 10: Wet and dry years for Potha Zone 2; MAM

Drought	Years
Extremely wet	nil
Very wet	1968,1979,1985,1991,1996
Moderately wet	1969,1973,1975,1983,1986,1990,1993,1998,2001,2008
Near normal	1965,1967,1970,1972,1981,1987,1997,1999,2004,2005,2007,2009,2010,2011
Moderately dry	1976,1977,1980,1989,1992,1995,2003,2006
very dry	1966,1971,1974,1978,1982,1988,1994,2000
Extremely dry	1984,2002

Results in figure 10 indicate that most of the years fall under near normal and moderately wet. We also have 4 very wet years and 7 very dry years with only one extremely dry year i.e. 1984. The drought analysis for Malili is shown in table 11 with Figure 9 showing the SPI results.

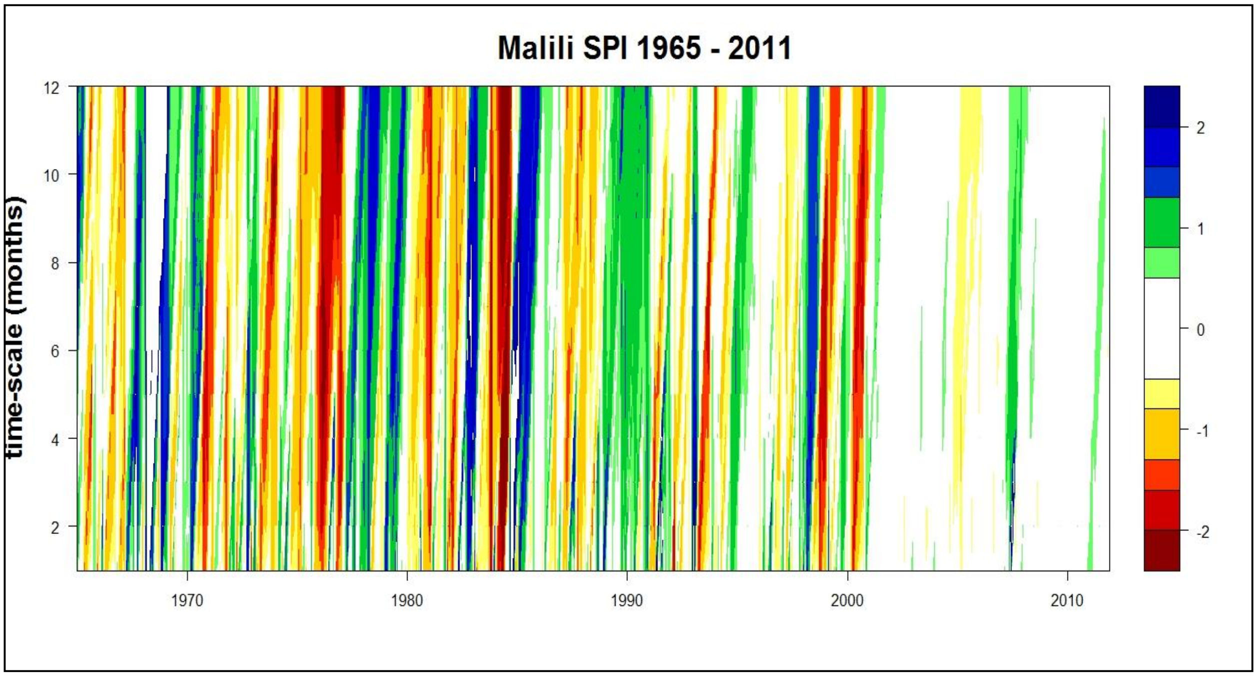

Figure 10: SPI plot for Malili Zone 3; MAM

Table 11: Wet and dry years for Malili Zone 3; MAM

Drought	Years
Extremely wet	nil
Very wet	1978,1982,1985,1998
Moderately wet	1965,1968,1970,1973,1979,1983,1986,1990,1991,1996,2007,2011
Near normal	1969,1975,1987,1992,1993,1997,2000,2002,2003,2004,2006,2008,2009,2010
Moderately dry	1966,1967,1972,1976,1981,1988,1989,1995,2005
very dry	1971,1974,1977,1980,1994,1999,2001
Extremely dry	1984

4.2.2 Results for SPI index for OND

Results in figure 11 indicates that most of the years fall under near normal with two very dry years 2002 and 2005.Only one year was found to be extremely dry i.e. 2009. The drought analysis for Mbooni is shown in table 12.

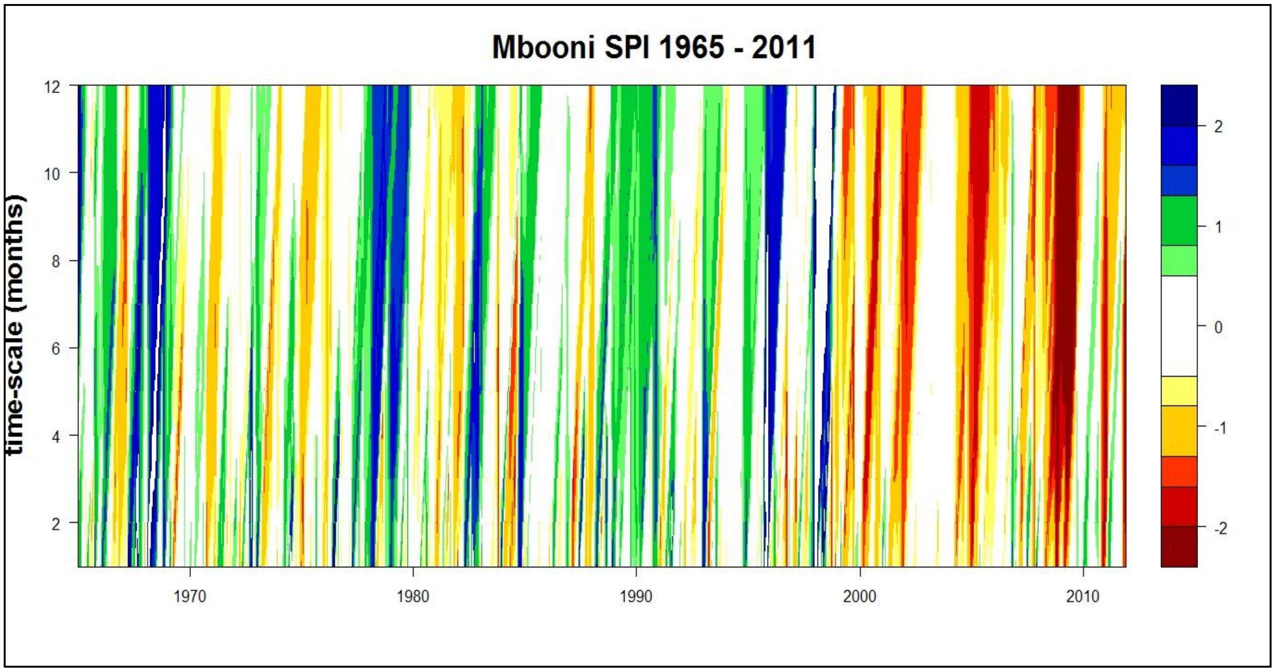

Figure 11: SPI plot for Mbooni Zone 1; OND

Table 12: Wet and dry years for Mbooni Zone 1; OND

Drought	Years
Extremely wet	nil
Very wet	1969,1979,1980,1991,1996
Moderately wet	1965,1967,1974,1978,1983,1985,1989,1990,1993,1995,1998
Near normal	1966,1968,1970,1972,1973,1975,1977,1981,1984,1986,1987,1988,1992,1994,1997,1999,2003,2007,2010
Moderately dry	1971,1976,1982,2000,2001,2004,2006,2008,2011
Very dry	2002,2005
Extremely dry	2009

Results in figure 12 indicate that there was only one very dry year 1984 with most of the years falling under moderately dry and moderately wet. We also have 6 very dry years. The drought analysis for Kiu is shown in table 13.

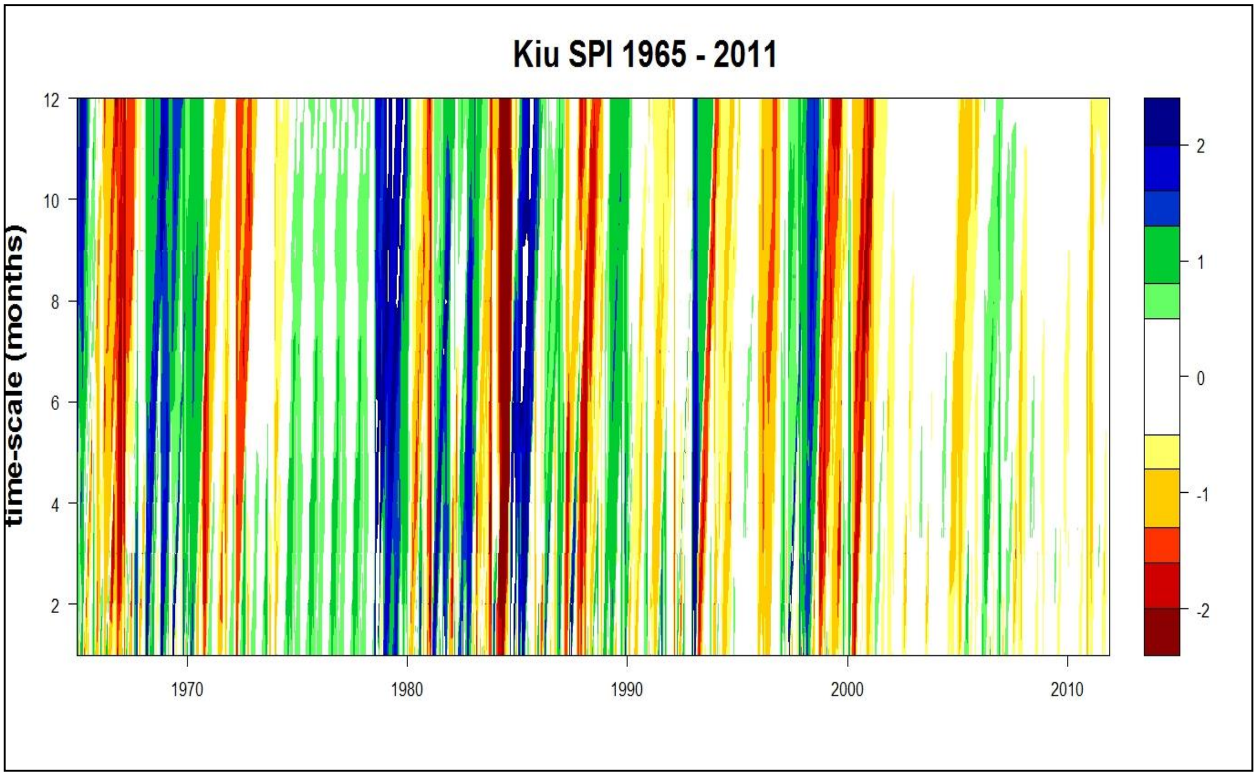

Figure 12: SPI plot for Kiu Zone 2; OND

Table 13: Wet and dry years for Kiu Zone 2; OND

Drought	Years
Extremely wet	nil
Very wet	1965,1969,1979,1980,1985,1988
Moderately wet	1968,1970,1976,1977,1978,1982,1983,1986,1990,1994,1999,2008
Near normal	1971,1974,1991,1993,1996,2003,2004,2005,2007,2009,2010
Moderately dry	1966,1972,1975,1981,1987,1992,1995,1997,2001,2006,2011
very dry	1967,1973,1988,1989,2000,2002,
Extremely dry	1984

Results in figure 13 indicates that there were 7 very wet years and 7 very dry years while most of the years fall between moderately wet and moderately dry.However,9 years were found to be moderately dry with one extremely dry year i.e. 2009. The drought analysis for Makindu is shown in table 14.

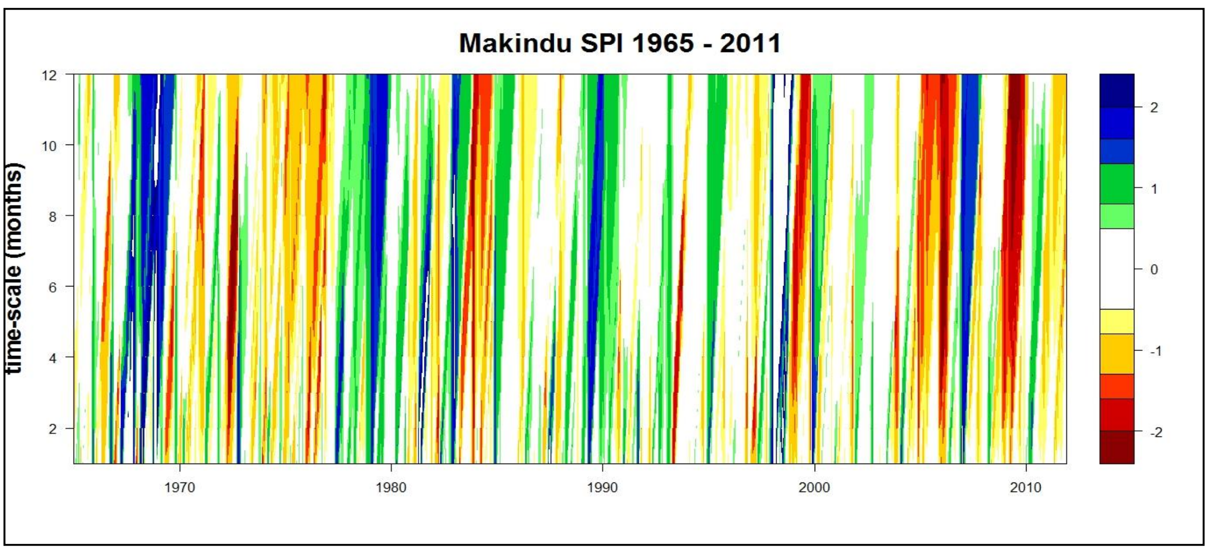

Figure 13: SPI plot for Makindu Zone 3; OND

Table 14: Wet and dry years for Makindu Zone 3; OND

Drought levels	years
Extremely wet	nil
Very wet	1969,1970,1980,1982,1986,1991,2008
Moderately wet	1966,1968,1979,1983,1990,1992,1995,1998,2001,2003,2010
Near normal	1965,1973,1978,1981,1988,1989,1993,1994,1999,2002,2004,2005
Moderately dry	1967,1971,1972,1974,1975,1976,1987,1996,1997,2011
Very dry	1977,1984,1985,2000,2006,2007,2009
Extremely dry	nil

4.3: Results for global Teleconnections

Figure 14 and 15 shows the time series for the SSTs (Southern Oscillation Index and Nino 3.4) used in the study. The indices are highly variable in time. Some of the SOI index peak years coincide with wet periods over the four zones. SOI performs better as compared to Nino 3.4 in terms of relation to the wet seasons over the region.

The dry spells are well represented with the Nino 3.4 and SOI low peaks. These indices could be used to estimate the dry periods and hence identify drought for better management. Table 15 and 16 indicate the high peak and low peak years of the considered indices.

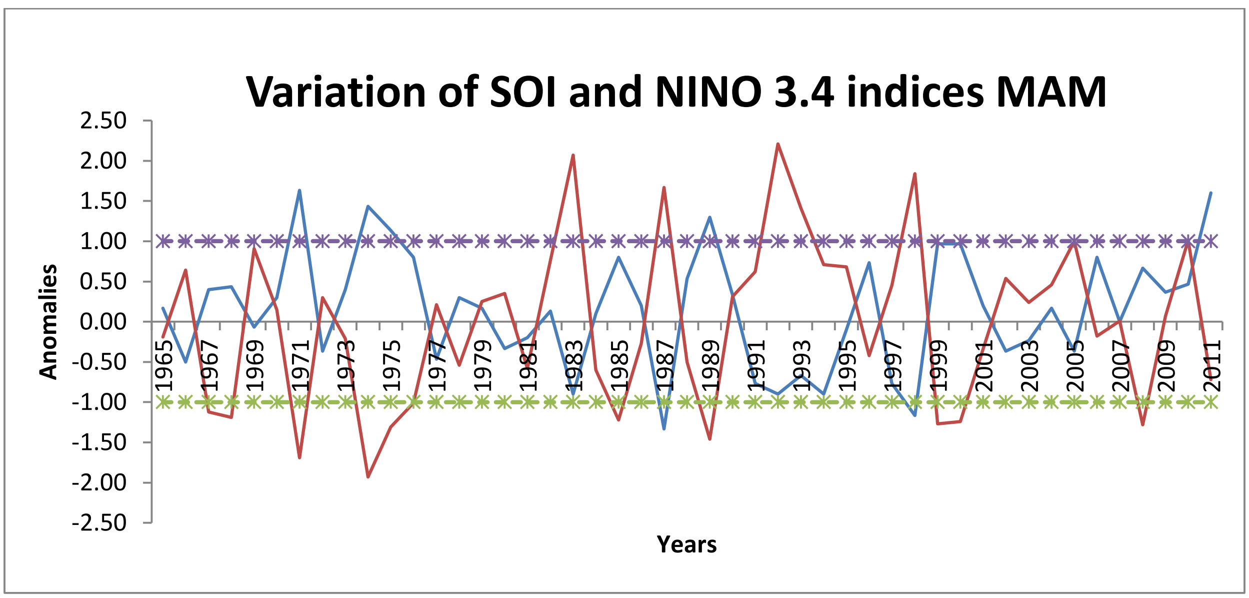

Figure 14; Time Series for SOI and NINO 3.4 during MAM

Table 15: low and high peaks for considered SSTs during MAM

SOI	High	1971	1974	1975	1989	2011						
	Low	1987	1998									
NINO3.4	High	1983	1987	1992	1993	1998	2005	2010				
	Low	1967	1968	1971	1974	1975	1976	1985	1989	1999	2000	2008

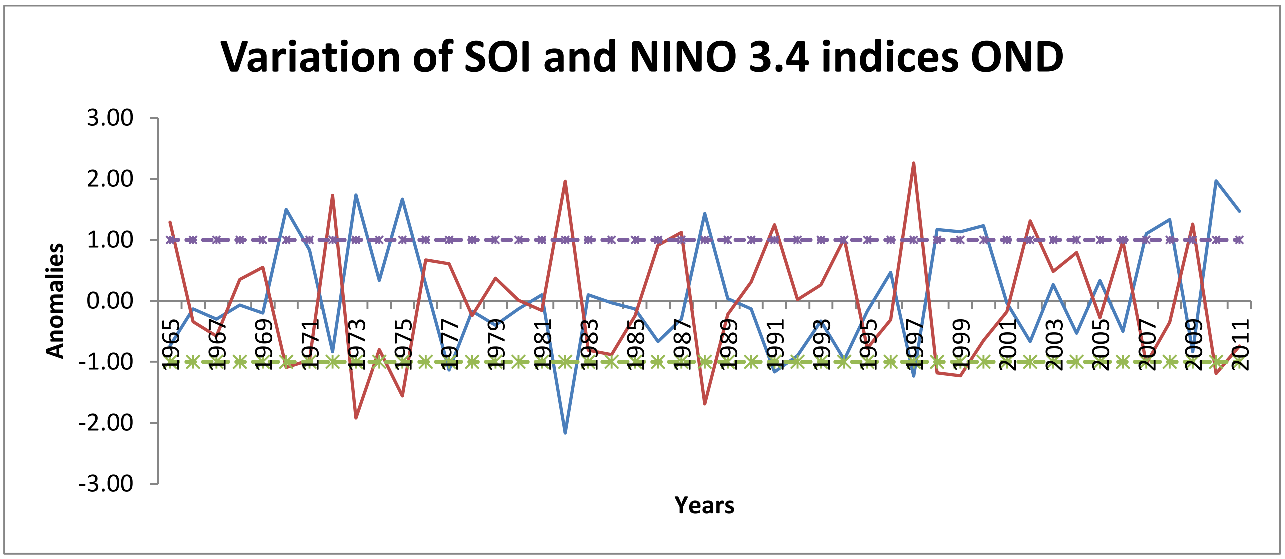

Figure 15; Time Series for SOI and NINO3.4 during OND

Table 16: low and high peaks for considered SSTs during OND

SOI	High	1970	1973	1975	1988	1998	1999	2000	2007	2008	2010	2011
	Low	1977	1982	1991	1997							
NINO3.4	High	1965	1972	1982	1987	1991	1994	1997	2002	2009		
	Low	1970	1973	1975	1988	1998	1999	2007	2010			

4.3.1Results for correlation

The rainfall data was correlated with the two indices. The results obtained are shown in table 17. A null hypothesis was developed as follows; $\varrho = 0$ then there is no significant correlation and alternative hypothesis was $\varrho \neq 0$ the there is significant correlation. If P value < 0.05 then we reject the null hypothesis. Southern Oscillation Index (SOI) is the pressure difference between

Tahiti (East) and Darwin (West) while NINO 3.4 is found between 5°n - 5°s, and 170°w - 120°w of the eastern pacific ocean. Warm temperatures are associated with low pressure. Table 17 shows –ve index values for SOI (low pressure) and +ve index values for NINO3.4 (warm temperatures) for all OND zones correlation. On the contrary from table 18, SOI index is +ve (high pressure) with –ve index for NINO 3.4(low temperatures) in all the zones for MAM correlation.

Table 17; Correlation between rainfall and global teleconnections during OND

	RAINFALL		
INDEX	ZONE1 (Mbooni)	ZONE2 (Kiu)	ZONE 3 (Makindu)
SOI	-0.51*	-0.31*	-0.34*
NINO 3.4	0.27	0.16	0.22

Table 18; Correlation between rainfall and global teleconnections during MAM

	RAINFALL			
INDEX	ZONE1 (Yatta)	ZONE2 (Potha)	ZONE3 (Malili)	ZONE4 (Makindu)
SOI	0.08	0.17	0.16	0.22
NINO 3.4	-0.17	-0.24	-0.19	-0.30*

*- Zones with significant indices

4.3.2 Relationship between SOI and NINO 3.4 with the seasonal rainfall

Figure 16 and 17 presents' results for variation of the indices that had the highest correlation with rainfall over the stations. For OND period, Mbooni had the highest correlation while for MAM Makindu had the highest correlation.

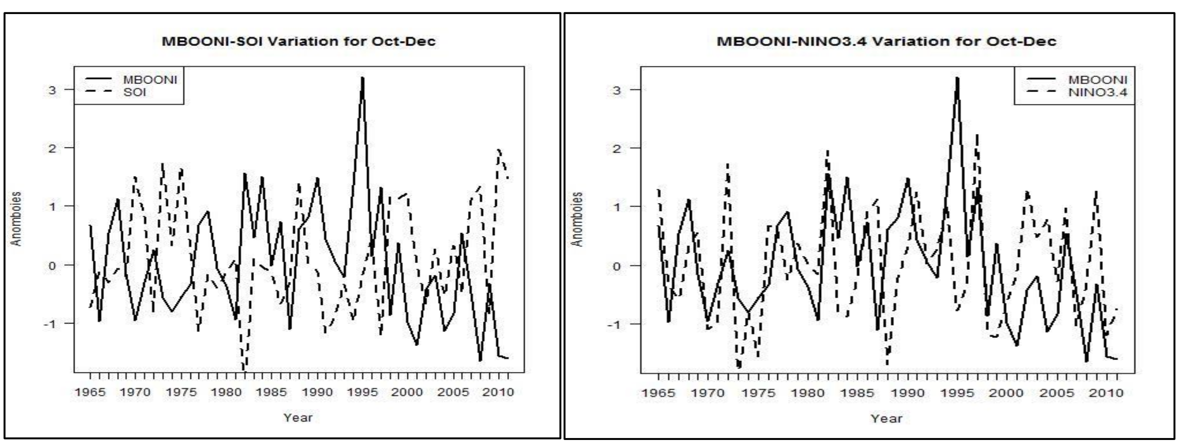

Figure 16; Time series for SOI and Nino 3.4 for Mbooni rainfall, MAM

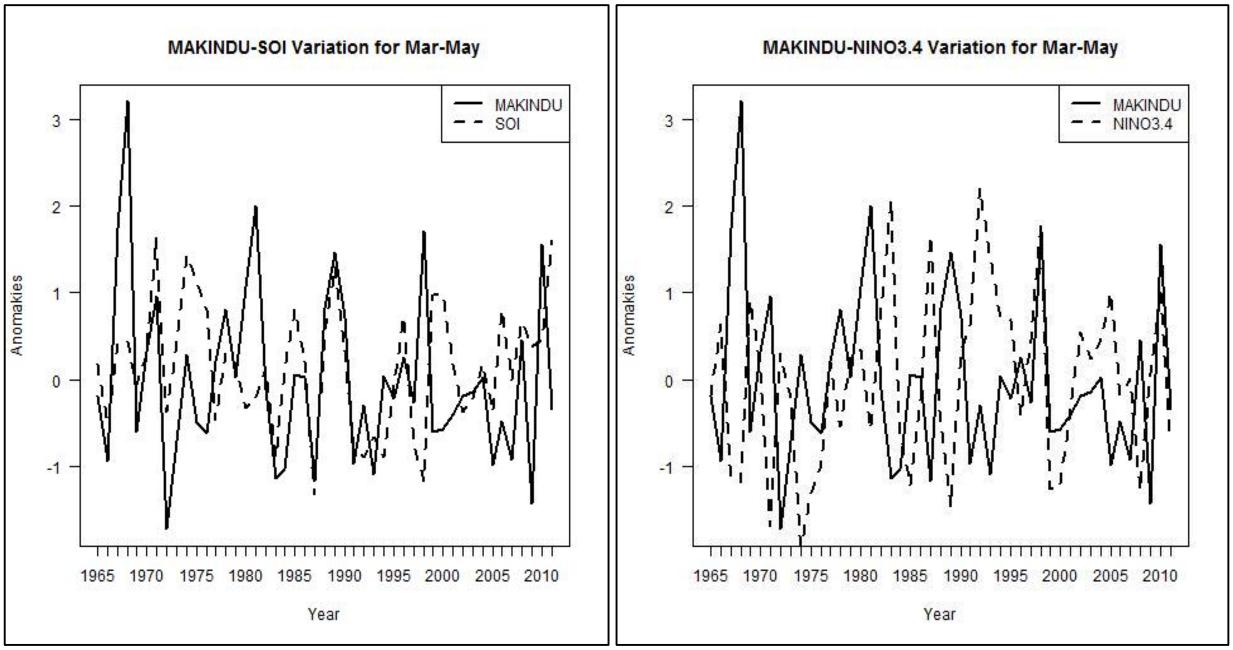

Figure 17; Time series for SOI and Nino 3.4 for Makindu rainfall

4.3.3 Results for reliability of rainfall

Using equation 4 and 5, table 19 shows that OND rainfall is more reliable than MAM rainfall with highest reliability in the southern part.

Table 19; Rainfall reliability

MAM		OND	
ZONE	RELIABILITY (%)	ZONE	RELIABILITY (%)
ZONE1 (Yatta)	39	ZONE1 (Mbooni)	49
ZONE2 (Potha)	43	ZONE2 (Kiu)	27
ZONE3 (Malili)	41	ZONE 3 (Makindu)	59
ZONE4 (Makindu)	51		

CHAPTER 5

5.0 Conclusion and Recommendation

5.1 Conclusion

5.1.1 Homogeneous zones

There were four zones identified for MAM and three zones identified for OND which reflected the different systems that influence weather in the region.

5.1.2 Standardized precipitation index

Moderate droughts are frequent than extreme .There is indication of high frequency of drought in the recent years.

5.1.3 Global Teleconnections

Negative phase of ENSO is associated with drought in OND while the positive phase tends to be associated with suppressed rainfall during MAM.

5.1.4 Rainfall reliability

OND rainfall was found to be more reliable than MAM rainfall with highest reliability in the southern part.

5.2 Recommendation

There were four and three zones identified for MAM and OND respectively. The refined zones can be used for future forecasting in the region. There is more frequency of droughts in the region hence there is need to provide information to the community so that they can align to this. The community should optimize by appropriate farming. The Global Teleconnections shows a strong relationship between SOI and OND rainfall. Nevertheless, more studies should be carried out to indentify other causes of drought. The rainfall reliability can be used by the county Government through the Kenya Meteorological County Director in the respective counties in their development plan. The county Government and other stake holders should assist farmers indentify appropriate mitigation strategies.

REFERENCES

Balint, Z., Mutua, F., Muchiri, P., & Omuto, C. T., (2013) Monitoring Drought with the Combined Drought Index in Kenya.

Drought Monitoring Centre, DMC, (2002), Factoring of Weather and Climate Information and Products into Disaster Management Policy for Kenya, A contribution for disaster strategies for Kenya, pp.152-206, IGAD Climate Prediction Centre, Nairobi, Kenya

Government of Kenya, (2013), National Climate Change Action Plan, 2013-2017, Executive Summary, Ministry of Environment Water and Natural Resources, Nairobi, Kenya.

Mwangi, E., Wetterhall, F., Dutra, E., Di Giuseppe, F., & Pappenberger, F. (2014). Forecasting droughts in East Africa. *Hydrology and Earth System Sciences*, *18*(2), 611-620.

Ngaina JN, Mutua FM, Muthama NJ, Kirui JW, Sabiiti G, Mukhala E, Maingi NW, Mutai BK (2014) Drought monitoring in Kenya: A case of Tana River County. International Journal of Agricultural Science Research, 3(7): 126-135.

Nyamwange, M. (1995). Famine mitigation in Kenya: Some practices, impact and lessons. *Middle States Geographer*, *28*, 37-44.

Onyango OA (2014) Analysis of Meteorological Drought in North Eastern Province of Kenya. J Earth Sci Clim Change 5: 219. soi:10.4172/21577617.1000219

Sheffield, J., Wood, E. F., & Roderick, M. L. (2012). Little change in global drought over the past 60 years. *Nature*, *491*(7424), 435-438.

Wambua RM, Mutua BM, Raude JM (2014) Drought Forecasting Using Indices and Artificial Neural Networks for Upper Tana River Basin, Kenya-A Review Concept. J Civil Environ Eng 4: 152. doi:10.4172/2165-784X.1000152 Zwaagstra L, Sharif Z, Wambile A, de Leeuw J, Johnson N, Njuki J, Herrero M (2010) An assessment of the response to the 2008-2009 drought in Kenya- A report to the European Union Delegation to the Republic of Kenya. *Nairobi: International Livestock Research Institute*.