DROUGHT ANALYSIS IN SOUTHERN HIGHLAND AND CENTRAL TANZANIA

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DECLARATION

This research project is my original work and it has not been presented for a degree in any other University

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DEDICATION

I dedicate this work to my family and to all Tanzania Meteorological Agency (TMA) workers

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ABSTRACT

Temporal characteristics of meteorological drought were investigated to provide a frame work for sustainable water resources in the southern highland and central Tanzania. These regions are intensely productive in agricultural activities which makes more important for drought analysis in order to overcome drought risks. Using Precipitation drought index (PDI) drought characteristics for the period 1978 to 2008 were assessed using decadal rainfall and probability drought analysis method were used to analyze drought persistence. Findings showed that drought category that occurred in both regions were mild (low) and Moderate droughts, and most of the drought that occurred persisted for only one year except those that occurred in 1983, 1993, 2003 and 2005 respectively which persisted for at least three years and caused serious human hazards including, food and Hydroelectric power crisis in most of the regions.

CHAPTER ONE

1.0 INTRODUCTION

Drought is the natural phenomenon, which has been recognized as one of the most insidious causes of human misery, and being the natural disaster that claims the most victims in the world. Its ability to cause widespread misery is actually increasing (Perez et al 1995). Previous Studies have showed that drought is a temporal recurring natural disaster, which occurs due to lack of precipitation, causing significant economic losses. The recurrence interval of drought is normally greater than the drought durations (Gregory, 1989, Dracup, et al.1980a, Ponce, et al 2000, Pandey, et al, 2001) depending on the climatic condition of the region. No one knows when the drought creeps in and when it will end, and its magnitude. Drought has extensive spatial dimension and thus can have serious implications on social-economic stability of the entire region.

Drought and aridity should be explicitly separated. This help to eliminate perceptions like "we are living in a permanent drought" or that "we had the drought for the last almost 60 years". Drought is a recurrent natural climatic event, which stems from the lack of precipitation over an extended period of time (e.g. a season or several years). It occurs in all the geographical zones, but its characteristics vary significantly from one region to another. Drought is a temporary anomaly and as such it differs from aridity, which is a permanent feature of climate, associated with low rainfall regions (Mutua, 2008).It is not possible to avoid drought, but drought preparedness can be developed and droughts impacts can be managed. The success of both depends amongst others on how well the droughts and drought characteristics are quantified (Smakhtin.et al 2004).Due to its complicity of occurrence, makes it difficult to define direct what is drought, but we can define it through its type as; follows (WMO, 2006).

Meteorological drought: This is defined as the precipitation deficiency threshold over a pre determined period of time in the region.

Agricultural drought: This is the drought that occurs when there is deficiency of soil moisture to support the crops growth.

Hydrological drought: Is the drought that occurs when there is deficiency of water in lakes, reservoirs, aquifers, and streams.

Social economic drought. This reflects relationship between the supply and demand for some commodity or economic goods, such as water, livestock forage, electricity power that is dependent on precipitation. When demands for an economic good exceed the supply as the result of weather related short fall in water supply.

Precipitation is the source of water in various reservoirs or direct precipitation contributes to soil moisture through various ways, also forming flow of water as rivers or streams, and then we say meteorological drought is the major source of all types of droughts. Several researchers have used precipitation as the principal indicator in drought analysis (Mohan et al,. 1991; Bogard et al,. 1994; Sharma, 1997).Thus, Meteorological droughts attempt to explain the primary causes, while agricultural, hydrological and social-economic droughts attempt to explain the secondary impacts of the meteorological droughts. The economical, social and environmental droughts, although not droughts in the strict sense, but are actually as a consequence of the secondary drought impacts are therefore attempts to explain the tertiary impacts of meteorological droughts.

1.1 Problem statement

Water resource is a major source of the life of all living organisms, and for the human developments such as Agricultural productions, mining, fishing Hydro electric power and industrializations. There is a need of frequency analysis of severity of meteorological drought in order to provide a framework for sustainable water resources management in the regions as well as agricultural sustainability. This has therefore been identified as the major challenge especially in drought prone areas like southern highland and central Tanzania.

1.2 Justification of the Problem

Most of the people in southern highland and central Tanzania are farmers. Rain fed agriculture is the main stay of their economy. This sector is a key economic sector accounting for more than a half of Tanzania economy and provides more than 50% of the total employment. Such an important sector in the economy of the country requires a favorable environment control, by controlling water resource through drought analysis.

Fresh water scarcity and land degradations are already leading to changes in human settlement pattern. A number of live stocks from Singida, Dodoma are usually moved to southern part searching for pastures. Conflict between farmers and herders arises due to scramble for the available resources, and good example is Usangu plain. Understanding drought duration and severity is important since it helps people to adjust their activities related to the drought in form of their economy. Though there is inadequate works carried out in Southern and Central Tanzania, this research will highlight and recommend guidelines useful in planning for drought monitoring and early warning in order to enhance economic growth.

1.3 Objective of the Study

1.3.1 The overall objective

The overall objective is to analyze drought severity over Southern highland and central Tanzania.

1.3.2 Specific objective

- To determine drought magnitude/severity and drought duration in the regions.
- To determine the persistence of the drought in the regions.

1.4.0 Study area

Southern highland and central Tanzania are regions that lies between longitude (30.50°E to 36.80°E) and Latitude (4.30°S to 9.80°S) as shown on figure 1 below. Based on ecological zoning of Tanzania, both South and Central Tanzania have been categorized under unimodal type of rainfall. In these areas, the rain season normally commence from December to April known as (Masika). Accordingly, these regions have been experiencing erratic rainfall both in space and time. Nyenzi et al, 1998 investigated the rainfall variation over the areas and indicated that south and central experienced significant decrease of the rainfall seasonally between 10% and 15%.

Based on this, farmers were advised to plant resistant plants to the drought to overcome the shortage of water and shortage of foods.

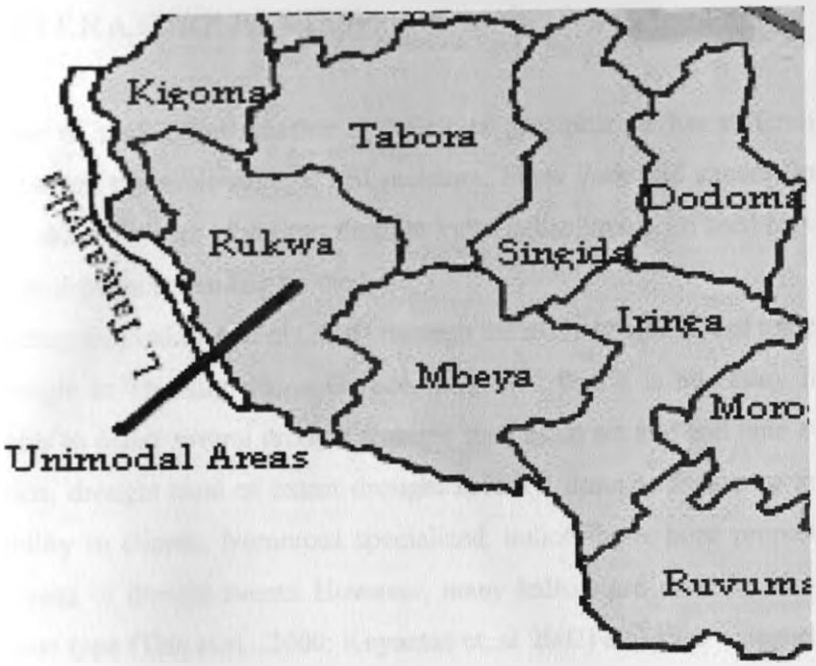

Figure 1 Position of southern highland &central Tanzania (Adopted from FSTI 2005:4, by Mwandosya, et al., 1998:19)

CHAPTER TWO

2.0 LITERATURE REVIEW

In order to understand whether a deficit of precipitation has different impacts on the groundwater, reservoir storage, soil moisture, Snow Park and stream flow. The following are the characteristics of various drought indices that have been used by various scholars to measure drought depending on the type;

According to, Loukas.A at el (2004) through the study of spatial and temporal characteristic of drought at Thessaly region Greece, suggested that it is necessary for the analysis of droughts to detect several drought features such as on set and end time of drought, drought duration, drought areal of extent drought severity, drought frequency and to link drought variability to climate. Numerous specialized, indices have been proposed to quantify the four types of drought events. However, many indices are used for identification of more than one type (Tate et.al, .2000; Keyantas et,.al 2002) and their categorization may not be appropriate, although it is widely used.

SPI was used to determine the drought using Monthly rainfall The Standardized Precipitation Index (SPI) was developed for the detection and monitoring of drought (McKee et al,. 1993). The SPI estimation for any location is based on the long-term precipitation record during a period of time. This long-term record is fitted to a probability distribution which is then transformed into a normal distribution so that the mean SPI for the location and the desired period of time is zero. Positive SPI values indicate precipitation greater than the median precipitation and negative values indicate precipitation less than the median precipitation. The SPI is normalized: therefore wet and dry climates can be represented in the same way. Wet periods can also be monitored using the SPI.

First, a time series of the precipitation value of interest is generated. Then, a frequency distribution is selected and a statistical fit to the data is determined. The cumulative distribution is formed from the fitted frequency distribution. The percentile for the particular time series element of interest, usually the latest one, is selected from the cumulative distribution. For "ties" (multiple instances of the same value), the upper value is used (probability of non-exceedance). For any other theoretical probability distribution, the analogous point on its associated cumulative frequency distribution can be determined. Here, the normal distribution is used, with mean zero and standard deviation of one, and value in standardized units of a given percentile is found can be readily determined. For the normal distribution, these are exactly the same as units of standard deviations. The Standardized Precipitation Index can be thought of as the number of standard deviations that the precipitation value of interest would be away from the mean, for an equivalent normal distribution and adequate choice of fitted theoretical distribution for the actual data. In effect, the method consists of a transformation of one frequency distribution to another frequency distribution, in this case the widely used normal, or Gaussian, distribution.

The SPI is based on the Gamma probability distributions of precipitation for any monthly time scale. The temporal and spatial characteristics of drought in Thessaly region were assessed by analyzing the gridded SPI values. For every year, the computed gridded monthly SPI values for various time scales were used. Also drought severity and frequency were assessed using curve (drought severity-Areal Frequency curves). The method revealed the frequent moderate and severity drought on monthly basis that cumulates to the prolonged and severe drought on the yearly basis. Some advantage of SPI is that it can be computed for different time scales; many drought planners appreciate the SPI's versatility and provide early warning of drought and help assess drought severity, and is less complex. And the disadvantage is that rainfall data may change over time from the baseline data which was used for calibration. Long-term precipitation record (30 years at least) is required .Misleading high values (positive or negative) in areas with low amount of seasonal rainfall for short time scales (1, 3 months) or (shorter period) data may not be necessarily gamma distributed. More so, the serial dependence in the data may contradict the use of probability distributions in this form of modeling.

Zekai et al,.(2003).Investigated drought properties using run analysis and Z-score, with application of the four stations in north-western part of Turkey. Run analysis and Z-score are used for identification of the various drought characteristics, such as drought durations, magnitudes and intensity at different truncation level. The Z-score values are similar to the standard precipitation index (SPI), which is special application of the transformation rules. Empirical calculations of drought descriptions were investigated by moving average of

3.6,12, 24, and 48 months, such as mild, moderate, severe and extreme drought cases are carried out. Then the drought characteristics were determined using the run analysis.

Drought Magnitude (M), durations (L) and the Intensity (I) were analyzed on the map. The purpose is to combine three different, but related variables and examine their common behavior in two dimensional domains as contour map. Hence in most of the studies to date have concentrated or shortages as sign of drought, because precipitation is a most significant input variable for many water-related processes such as water supply, ground water, reservoir storage, soil moisture, snow park and stream flow. Some advantages is that it is simple use and easy to visualize the parameters of drought through its analysis and its disadvantage, employs long term data from thirty years and above.

Panu et al., (2002) investigated the development of the suitable methods that can manage to monitor the onset and termination of the drought ,and the technique of time that respond to short drought monitoring such as the use of monthly data, to study drought analysis and duration as the parameters that quantify drought. The most basic elements for deriving drought parameter are truncation or the threshold level which may be constant or a function of a time. The term duration is the time points of drought initiations and terminations, while drought severity is expressed through some indices. The determinant variable for meteorological drought is precipitation/ rainfall.

Truncation level method specifies some parameters of the drought variables and serves to divide the time series of the variable in question into deficit and surplus sections. The parameters of drought such as durations and severity and intensity are based on properties of the deficit section. Dracup et al (1980). This method is based on meteorological drought and hydrological drought not suitable for agricultural drought. The regional behavior of drought is analyzed using the point behavior (rainfall or stream flow) and then mapping the relevant parameters over a region, using isolines maps of different years .The identification and prediction of drought are achieved through analysis of time series of drought variables such as rainfall. The identification and prediction a method of droughts commonly invokes on the derived or generated sets are;

In the frequency or probability based method the low flow volumes during a specific period are analyzed in manner similar to that of flood peak analysis (Joseph, 1970; Dalezios et al., 2000) Runs-based- methods. The notion of runs (Yevjevich, 1972) allows one to analyze the probabilistic structure of drought durations (runs length) and severities (run sum).In these methods, drought parameters such as longest duration and the largest severity are analyzed. The analysis is carried out on the time series.

Drought analysis in Kenya was investigated by Mutua (2008) using Precipitation drought index (PDI) using decadal rainfall data for selected stations. This method determines drought using the limited rainfall data. This method use decadal rainfall data in order to analyze drought at initial state within a month. Method employs data of any period less than thirty years. . The different values of PDI were calculated for each month (3 decadal) of three rain months of the year. Values of Precipitation drought Index (PDI)each year was plotted on the curve, PDI values against the time(year).the results showed that, the smaller the PDI the more severe the drought. Some Advantage are that PDI method is Simple to use since requires few data, easy to avoid errors from data and or in calculations, does not need continuous data, Computation data is less demanding compared to other methods and it can be used to compute other parameter such as flood in small scale of time and disadvantage is that it contains a lot of data that needs enough care during computations.

Aiguo et al,.(1995) investigated drought by studying the Global variations in droughts and wet spells using Palmer drought severity index (PDSI). The PDSI is calculated based on the monthly precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil. From the inputs, all the basic terms of the water balance equation can be determined, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. The PDSI generally ranges from -7.0 (dry) to +7.0 (wet). Temporal and spatial analysis was used to show the relation of ENSO and PDSI together with correlation method, in order to determine the wet and dry period. An empirical analysis of the PDSI revealed that PDSI correlates significantly with the ENSO event in time and space. Its disadvantage is that values may lag emerging droughts by several months; less well suited for mountainous land or areas of frequent climatic extremes; complex—has an unspecified, built-in time scale that can be misleading, often values of AWC are not always available; values may lag emerging droughts by several months, Sensitive to the AWC of a soil type;

It is calibrated for regions relatively homogeneous and is less well-suited for mountainous land or areas with frequent climatic extremes, Palmer index is not particularly suitable for droughts associated with water management systems, because they exclude water storage, snowfall, and other supplies. Human impacts on the water balance, such as irrigation, are also not considered. (Palmer 1968).

The low and unreliable rainfall is a key factor causing yield losses in Tanzania. Average maize yield loss due to drought is estimated at 50% and goes up to 100% for drier year,(Nkonya,et,al.1990).Various alternative method of overcoming drought should be made such as Irrigation, and moisture conservation so as to increase crops productions. Irrigation method from reservoirs described in term of drought indices, which are convenient and relatively simple to use. Various drought severity indices based on precipitation data have been introduced (Mbaga, 2001). Also the increase of frequency of drought is in turn likely to increase the frequency and magnitude of epidemics of water borne diseases such as typhoid, Cholera, and influence of mosquito-borne disease (Patz, 2002).

CHAPTER THREE

3.0 DATA AND METHODOLOGY

3.1 Location and stations

Southern highland and central Tanzania includes the following regions Rukwa, Iringa Mbeya, Dodoma, Tabora and Singida.

Table 1 Meteorological Stations & Reg No.

S/N	Station	Longitude	Latitude	Reg,No	Year of start
1	Rukwa	31.34°E	07.58°S	9731028	1989
2	Iringa	35.77°E	7.60°S	9735013	1959
3	Mbeya	33.47°E	8.90°S	933001	1932
4	Dodoma	35.77°E	7.60°S	9635001	1911
5	Tabora	32.80°E	5.10°S	9532012	1951
6	Singida	34.48°E	04.34°S	9434042	2000

3.2 Data coverage

Data used in this study consisted of the decadal rainfall covering a period from 1978 to 2008.

3.3 Data source

Decadal rainfall records were obtained from Tanzania Meteorological Agency (TMA). Statistical based approach used in this study was employed by many researchers to quantify various droughts characteristics. For the data to be used, they have to be subjected to the data quality control, and estimate the missing data. Droughts indices analysis has also been used in drought parameterization analysis of the temporal characteristic of drought.

3.4 Data quality control

Data quality control is the process of careful looking for the accuracy and consistence of the data in both space and time. Since source of data is through observations, most of climatic data are subjected to various errors that reduce the quality of the data. Most of error arises from instrumentations such as defective instruments, lack of proper maintenances of instruments, delay in replacing faulty components, recoding, transmissions, coding, decoding and during data processing, sickness of the observer, flood at the observatory and change in site of rain gauge. In order to avoid these errors, the data were subjected to further analysis and mass curve analysis has been used for test for consistency.

3.4.1 Temporal consistency check: mass curve analysis

Mass curve analysis is the method used to test for the homogeneity of a given data series. In this method cumulative records of rainfall data of each station were subject to time series. Within each station mass curve graphs is obtained. Based on data analysis, the shape of the graph tells the homogeneity and heterogeneity of the data. For instance, when the graph approximates a straight line, the data set was homogeneous, otherwise it was heterogeneous.

3.4.2 Estimation of missing rainfall data

Missing data were estimated using various statistical methods such as Arithmetic mean method, Isohyetal linear interpolations and Isopleths method, correlations and Regression method. Data were subjected to arithmetic mean to estimate the missing rainfall records, missing data were replaced by mean rainfall records of time series. Also the method is simple to use and not laborious.

3.5.1 Drought index

In assessing the severity of drought many indices have been used by various authors, such as Standard precipitation Index (SPI) (Mckee, et al., 1993), Palmer drought severity Index (PDSI), Palmer (1965) and Precipitation drought index(PDI), (Mutua, 2008). Rainfall amount records being a major indicator in several of these indices, since it is the major climatic parameter and usually has longest climatic records. Precipitation Drought Index (PDI) has been identify and used as an index to quantify the rainfall

3.5.2 Probability drought analysis method

Probability drought analysis (PDA) is used to compute the persistence of the drought in the particular region.

3.6.0 Data analysis

3.6.1 Precipitation drought Index

This is the method that uses the temporal analysis decadal rainfall to analyze the drought severity and drought durations. The method is straight forward since it uses only decadal rainfall as a variable. More advantage of this method is that it operates for any given amount of data of any period starting from one month not necessarily to be over thirty years. Decadal data are calculated from the collected dairy rainfall data from respective stations. Precipitation Drought Index (PDI) over year "i" for decade "m" is calculated by formula as;

$$PDI_{i,m} = \sqrt{\left(\frac{\frac{1}{15}\sum_{j=1}^{15}\left[\frac{1}{n}\sum_{k=1}^{n} R_{k,(m-j+1)}^{(P)}\right]}{\left(\underset{(j=1,2,\ldots,15)}{Max}\left[R_{i,(m-j+1)}^{(P)}\right]+1 \right)} \right)} * \frac{\frac{1}{15}\sum_{j=1}^{15} P_{i,(m-j+1)}}{\frac{1}{15}\sum_{j=1}^{15}\left[\frac{1}{n}\sum_{k=1}^{n} P_{k,(m-j+1)}\right]} \quad \text{.................. } equation\ 1$$

Where,

"R" in the equations denotes the runs and is computed on the basis of the rainfall Deficits over their respective long-term decadal means

(P) Superscript, in the equations, denotes the parameter That is being considered, decadal.

"*n*" in the summations is the number of years of available data.

"j" is the number of decadal.

By drawing the graph of time series of calculated Precipitation drought index (PDI) values drought episodes can be determined. The positive gradient on the time series determine period of excess while negative gradient determine period of deficit. The whole of the downward trend time series from the negative gradient to the positive gradient acquired is considered as the **drought durations.**

Table 2: PDI Classifications

PDI Values	
1.0	Normal rainfall
0.9 to 0.5	Mild drought
0.49 to 0.01	Moderate drought
0.0	Maximum drought

3.6.2 Persistence drought analysis method

Drought impacts are severe when is extended over a long period or several months. Then it is important to evaluate persistence of the drought over the region in order to determine the effect of the drought. Therefore probabilistic method of runs was used to assess the persistence of the drought. The probability relations between period of drought observations in a month (T), the run length (m) of wet and dry month, and drought persistence (Dp) were established.

The probability of occurrence of "m" consecutive dry months Q_m is expressed as,

$Q_m = q^2 p^m$...3.6.2.1

And probability of at least "m" consecutive dry months Q_m is expressed as,

$Q_m = q\, p^m$

Where

q= probability of wet month.

P=probability of dry month.

m= is the runs length.

And,

$$P = \frac{\text{No. of dry months}}{\text{Total No. months of observation}}$$

$q = 1 - P$ 3.6.2.2

$P \geq 0$ $q \geq 0$ $0 \leq Q_m \leq 1$

For $Q_m > 0$ decrease of drought, **$Q_m = 0$** Increase of drought

The values of Q_m indicate probability of obtaining at least m consecutive dry months and hence describe the degree of persistence.

Rainfall records were taken as the basis, where a time series records of decadal rainfall, $X_1, X_2 \ldots X_n$. is truncated at a threshold decadal rainfall value,X_0.Rainfall surplus(wet period) and rainfall deficit(dry period) are determined. The difference of decadal rainfall and threshold decadal rainfall $(x_i - x_0) > 0$ is called rainfall surplus and the difference of decadal rainfall and threshold rainfall $(x_0 - x_i) < 0$ was the rainfall deficit.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the results obtained from various analyses used to address the specific objectives of the study. This includes data quality control and Drought analysis.

4.1 Data quality control

4.1.1 Estimation of missing data

The data from the stations used in the study had about 2% of their data entries missing. Hence the missing data were estimated using Arithmetic means method discussed in sections 3.4.2

4.1.2 Data homogeneity test

The single mass curve analysis was used to test the homogeneity of data set explained in section 3.2.1. When cumulated rainfall was plotted against time, the curves showed nearly straight-line indicating that data were homogeneous as shown in figures 2-7

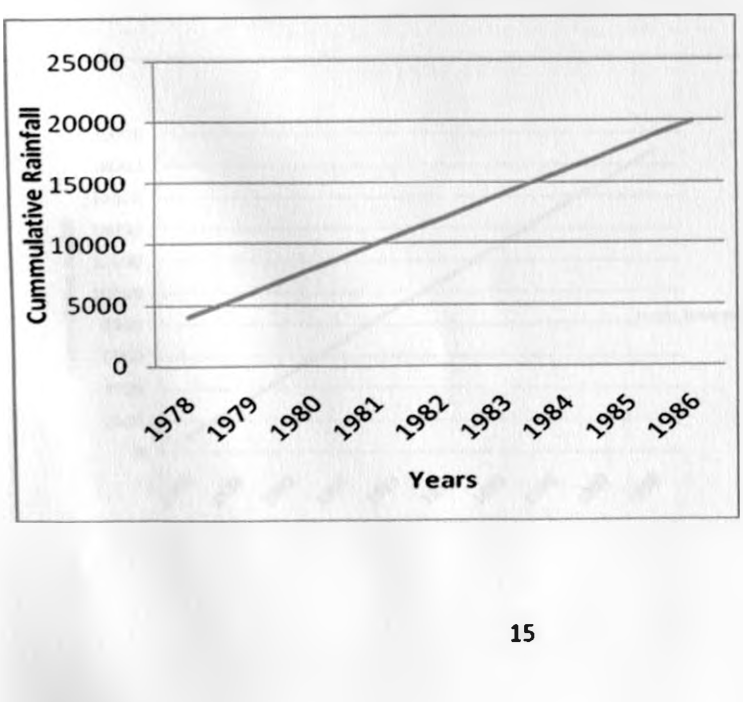

Figure 2: cumulative rainfall for Iringa

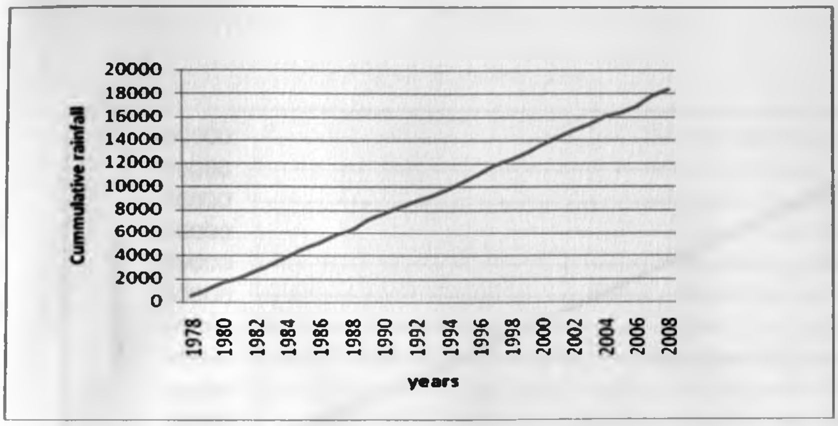

Figure 3: Cumulative rainfall for Dodoma

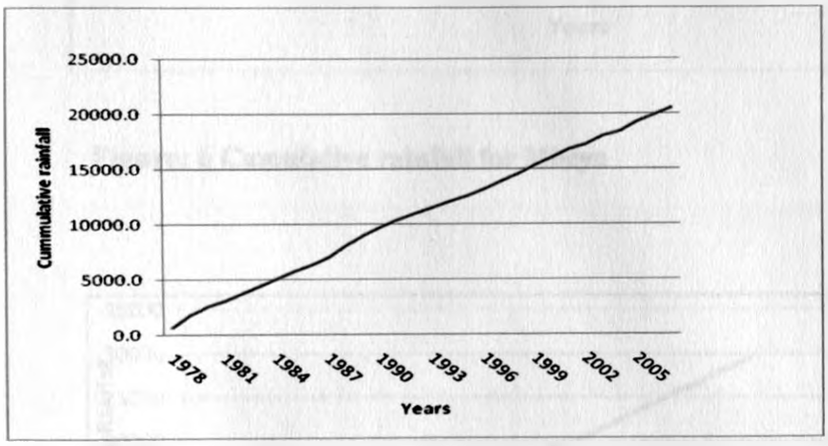

Figure 4: Cumulative rainfall For Singida

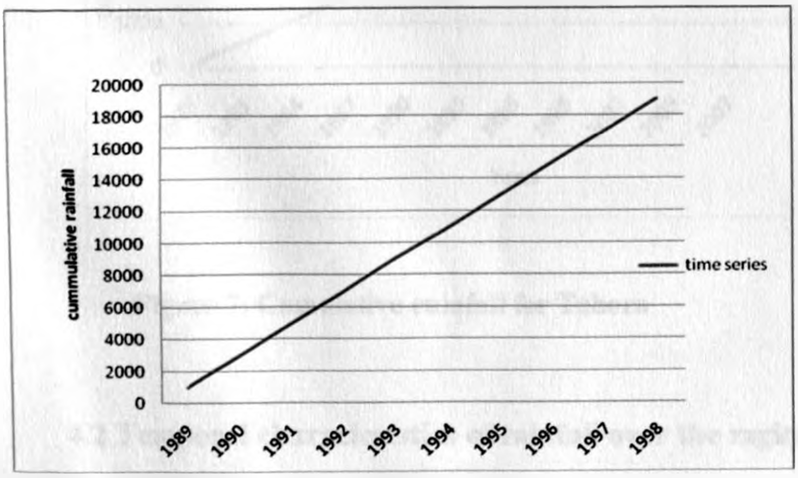

Figure 5: Cumulative rainfall for Rukwa

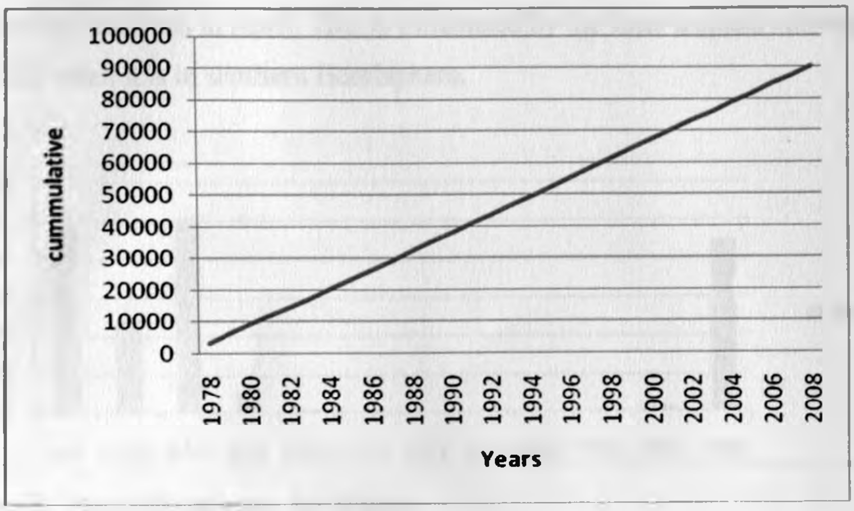

Figure: 6 Cumulative rainfall for Mbeya

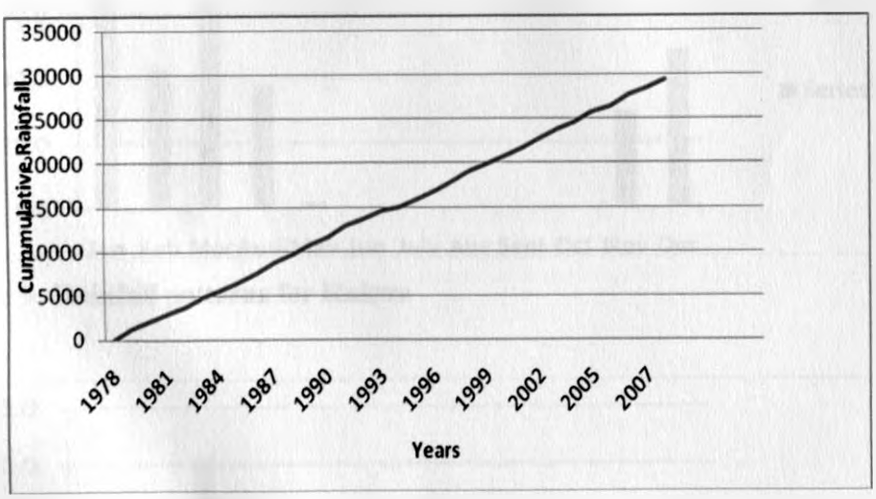

Figure 7: Cumulative rainfall for Tabora

4.2 Temporal characteristics of rainfall over the region

To identify the characteristics of the rainfall patterns in the region, annual time series and histograms were used. An annual time series rainfall characteristic was an attempt to explain the behavior of rainfall distributions over the regions. Rainfalls received over the respective stations were unimodal type of rainfall which starts from December and ends in April. This is influenced by the Inter tropical convergence zone (ITCZ) when it is in southern Hemisphere.

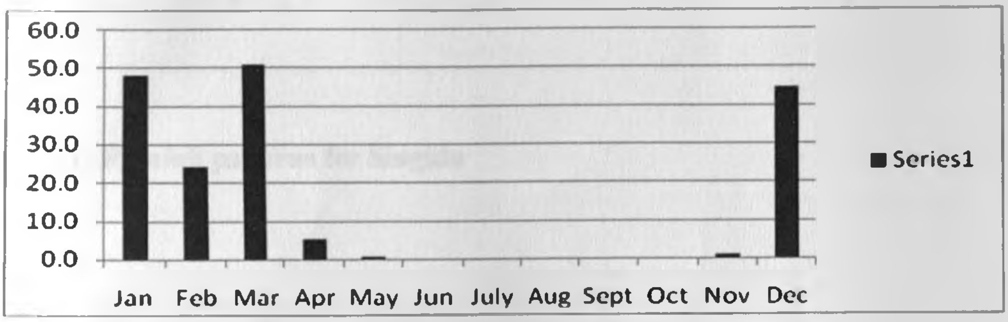

Figure 8: Rainfall patterns for Iringa

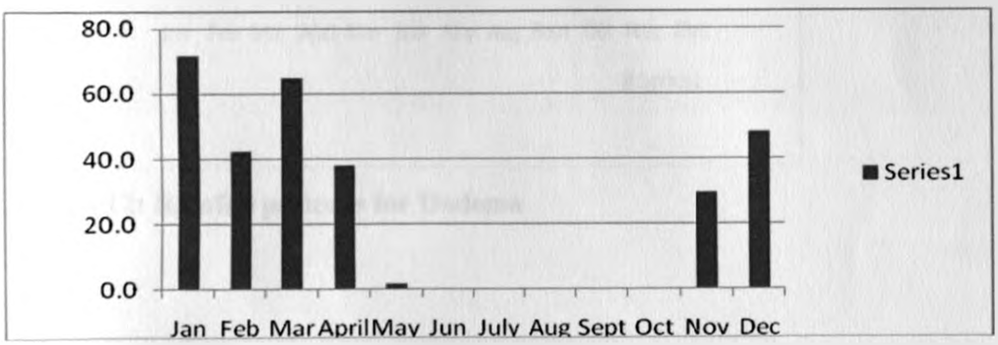

Figure 9: Rainfall patterns for Rukwa

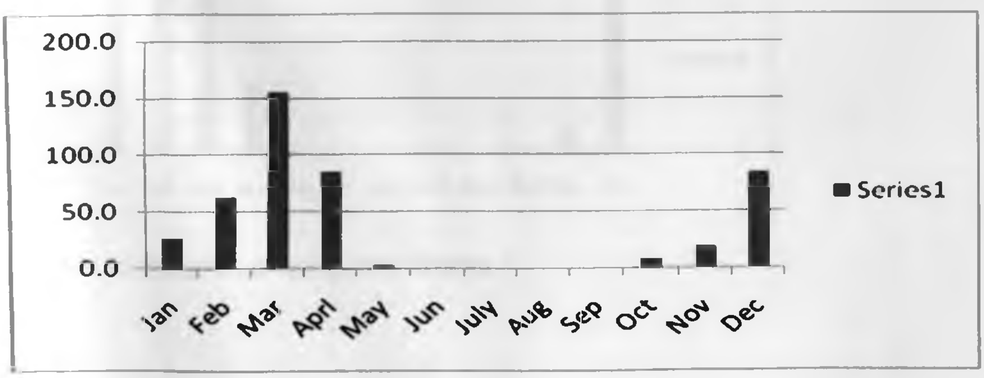

Figure 10: Rainfall pattern for Tabora

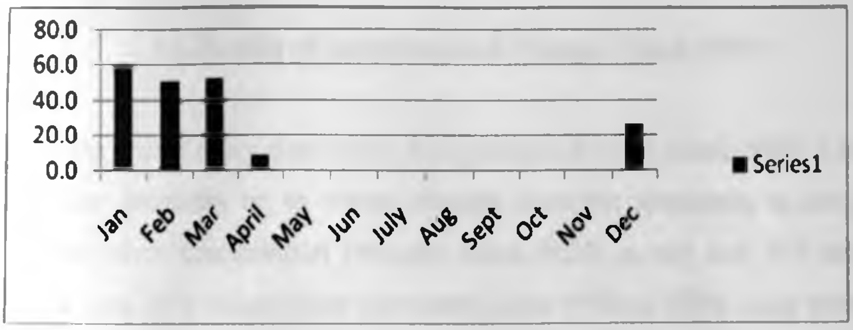

Figure 11: Rainfall patterns for Singida

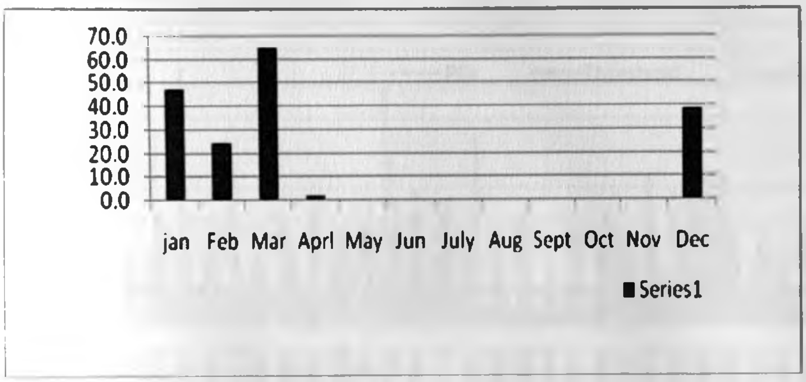

Figure 12: Rainfall patterns for Dodoma

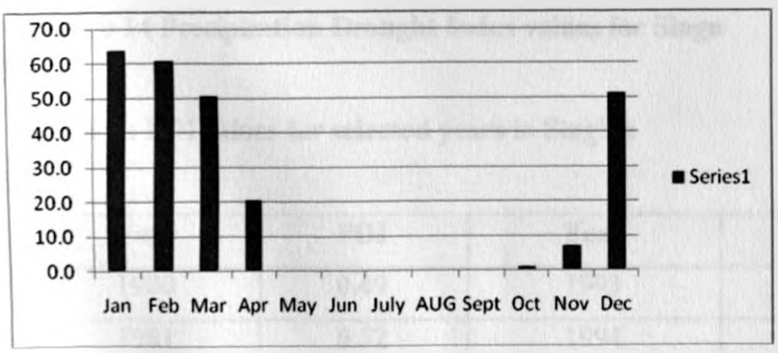

Figure 13 Rainfall patterns for Mbeya

4.3 Results of precipitations drought Index (PDI)

Drought occurs every time when Precipitation drought index (PDI) is below one and its intensity increases up to where drought becomes maximum at zero and drought is normal when Precipitation Drought Index (PDI) is one and PDI intensity decreases above one .PDI values were calculated from 1978 to 2008 using three (3) decade for each rainy month of the year.

The PDI time series analysis done gave only two type of drought category in all regions namely mild (minimum) drought and moderate drought, refer to table 2 PDI classifications

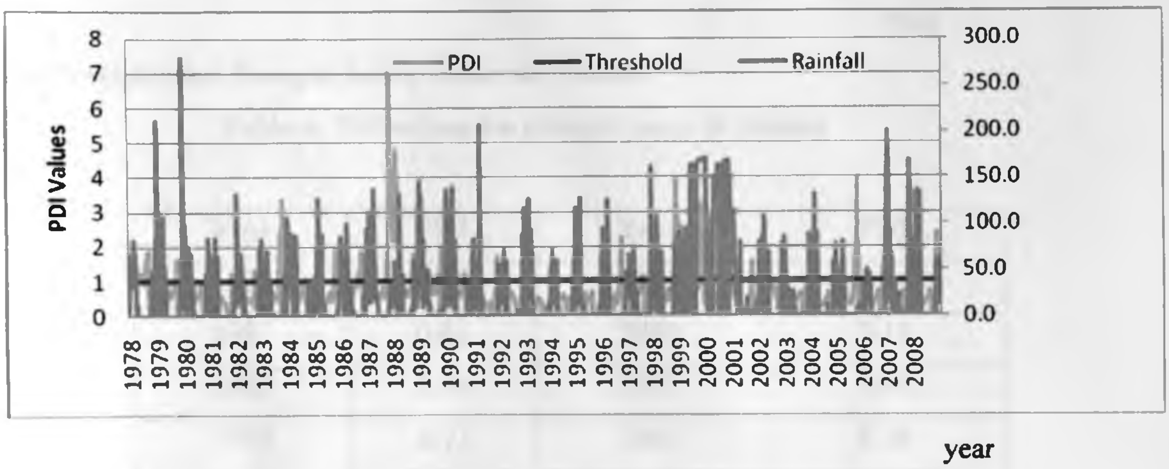

Figure 14 Precipitation Drought Index values for Singa

Table 3: PDI values for selected years in Singida

Year	PDI	Year	PDI
1980	0.49	1993	0.26
1981	0.52	1994	0.15
1983	0.78	1996	0.20
1985	0.58	2003	0.96
1991	0.32	2005	0.68

PDI analysis of Singida shows that the region had mild drought period occurred 1981, 1983, 1985, 1995,2002,2003,2004,2008, moderately drought conditions occurred in1980,1991,1993, 1994, 1996 and wet conditions occurred in 1979 and 1999-2001

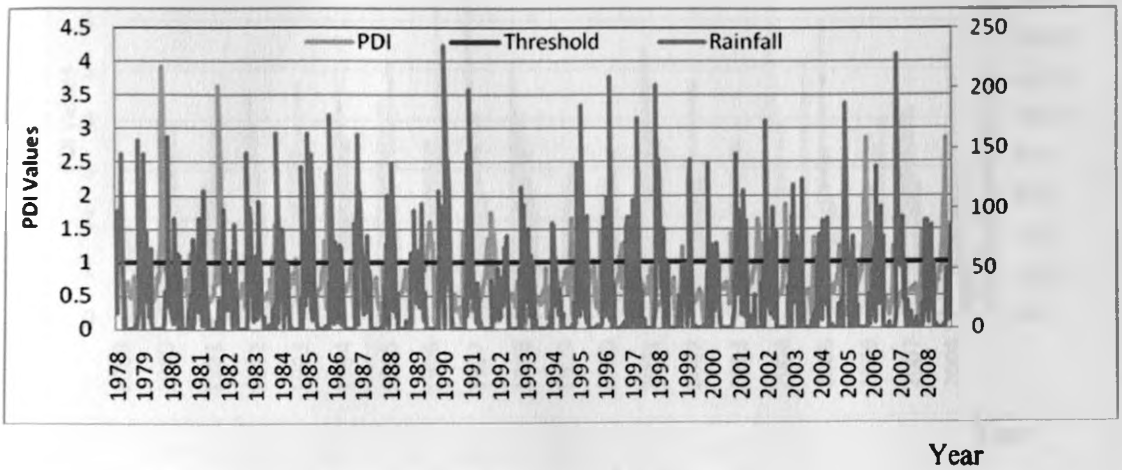

Figure Precipitation Drought Index values for Tabora

Table 4: PDI values for selected years in Tabora

Year	PDI	Year	PDI
1982	0.48	1999	0.54
1983	0.61	2000	0.18
1985	0.44	2003	0.56
1990	0.71	2005	0.29
1993	0.66	2007	0.40

In Tabora the PDI analysis shows that the region experience a mild drought conditions in 1978-1979,1981,1982-1984,1987-1989,1992,1994,2006 and moderately drought conditions occurred in 1985, 1993, 1995, 2000 and 2005 with moderately wet condition in the rest years.

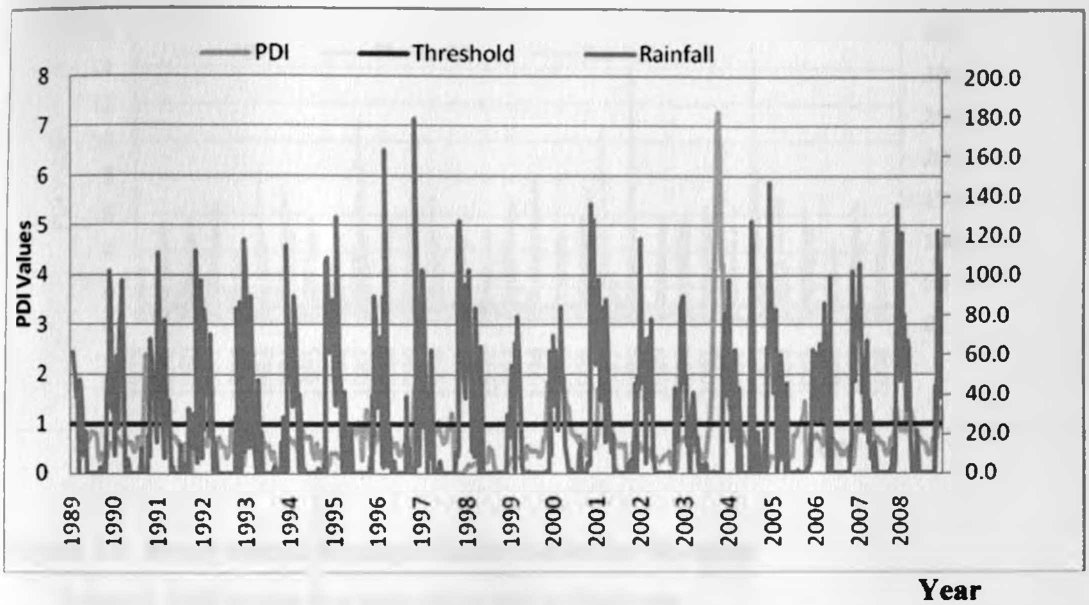

Figure 15: Precipitation Drought Index values for Rukwa

Table 5: PDI values for selected years in Rukwa

Year	PDI	Year	PDI
1990	0.42	1999	0.17
1992	0.61	2001	0.78
1993	0.30	2003	0.31
1995	0.29	2005	0.14
1998	0.11	2007	0.40

PDI analysis results in Rukwa region shows that in 1989, 2001 had mild drought conditions and 1990,1993,1994, 1995,1998-2000, 2002- 2003, 2005 had moderate drought condition, while other years experienced wet conditions

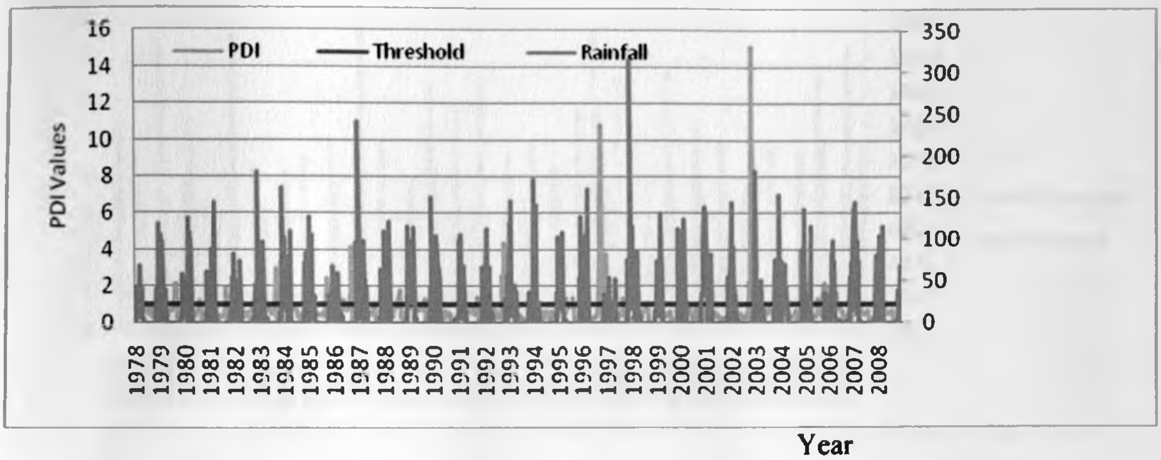

Figure 16: Precipitation Drought Index values for Dodoma

Table 6: PDI values for selected years in Dodoma

Year	PDI	Year	PDI
1979	0.56	1990	0.30
1980	0.85	1991	0.27
1981	0.45	1994	0.46
1985	0.52	2005	0.97
1988	0.10	2007	0.36

PDI analysis in Dodoma region showed that Mild drought occurred in 1979,1980, 1985 and 2005,.However moderate drought condition occurred in 1981,1983, 1989, 1990, 1991, 1996 1999-2002, 2004, 2007-2008, and high wet condition occurred in 1987, 1998.

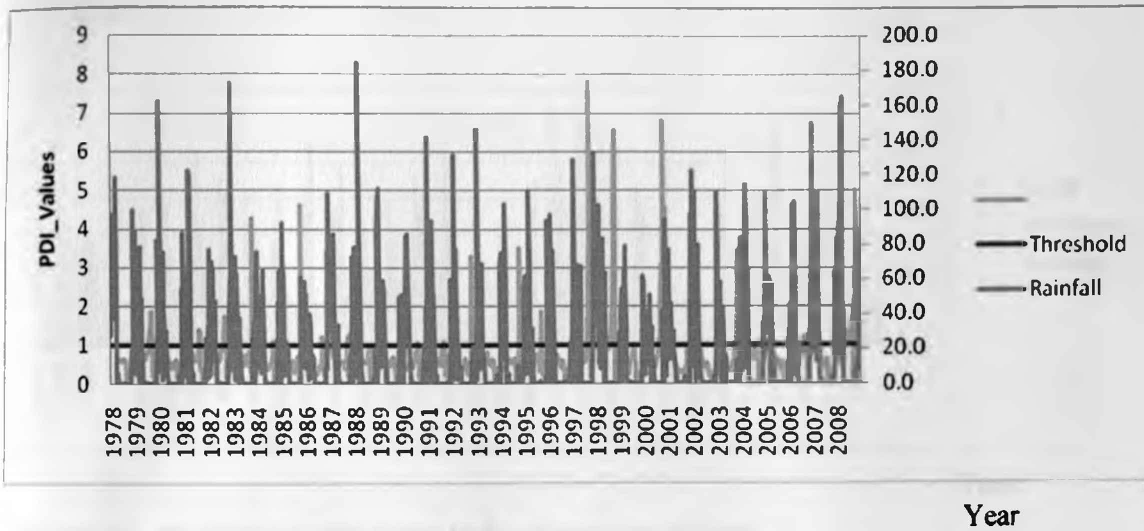

Figure 17: Precipitation Drought Index values for Iringa

Table 7:PDI values for selected year in Iringa

Year	PDI	Year	PDI
1980	0.56	1994	0.50
1981	0.47	1999	0.11
1985	0.52	2002	0.36
1990	0.80	2005	0.17
1993	0.51	2008	0.63

PDI analysis of Iringa shows that mild drought occurred in the following period of years 1980,1989,1990,1991,1993,and moderate drought condition occurred in,1999,2002,2003,2005,2007 2008, and maximum wet occurred in the years 1988.

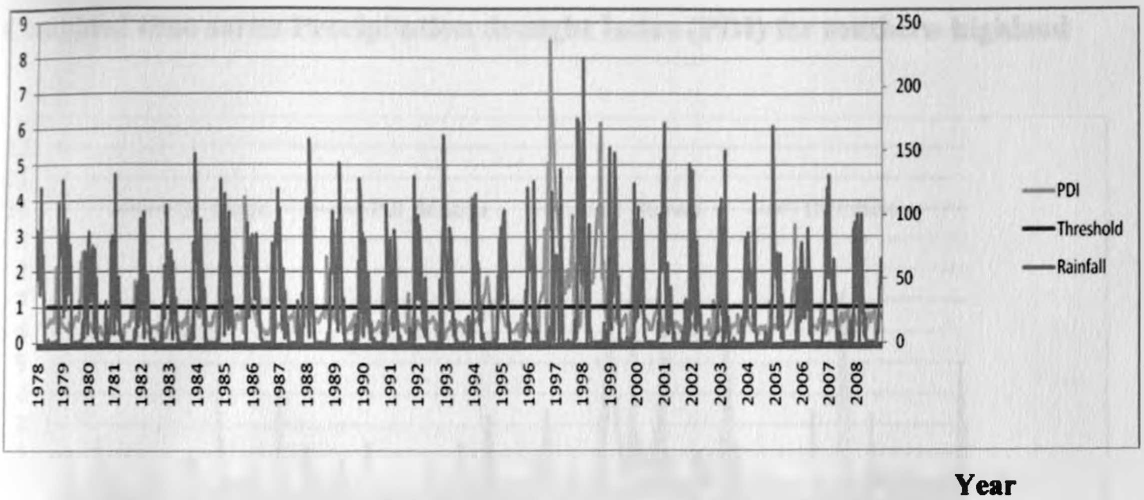

Figure 18: Precipitation Drought Index Values for Mbeya

Table 8: PDI values for selected years in Mbeya

Year	PDI	Year	PDI
1979	0.58	1993	0.38
1981	0.29	1996	0.38
1983	0.32	2000	0.12
1988	0.31	2002	0.62
1990	0.59	2005	0.57

PDI analysis of Mbeya shows that only mild drought occurred in 1979, 1980,1985,1990, 1992,1994,2005,2007-2008 and moderate drought occurred in1981, 1983,1988, 1995,1996. However extreme wet conditions occurred in 1998

Combined time series Precipitation drought Index (PDI) for southern highland

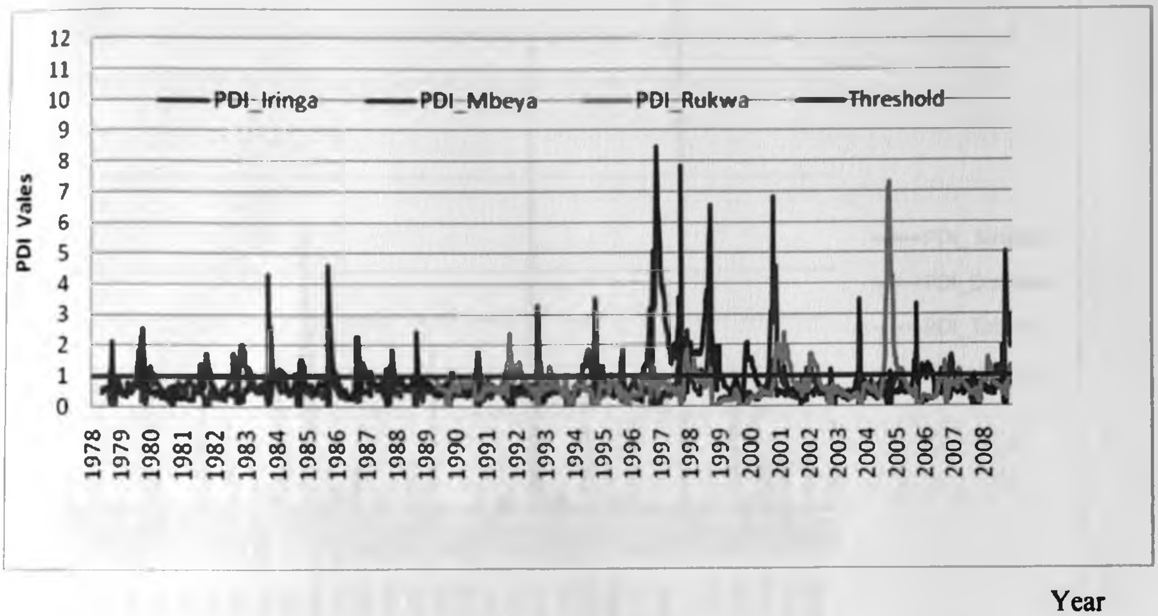

Figure 19: Precipitation Drought Index Values for southern highland

Table 9: PDI values for selected years in Southern highland

Year	PDI	Year	PDI
1980	0.62	1996	0.43
1981	0.47	1999	0.21
1990	0.82	2002	0.51
1991	0.63	2003	0.39
1993	0.10	2005	0.41

PDI shows that southern highland regions experienced similar drought episode such as in 1980-1982 both Mbeya and Iringa experienced the same mild drought, and in 1989-1996, 1999-2001, 2003-2005, 2007-2008 both three regions Mbeya, Iringa and Rukwa had mild drought for the same years

Combined time series Precipitation drought Index (PDI) for Central regions

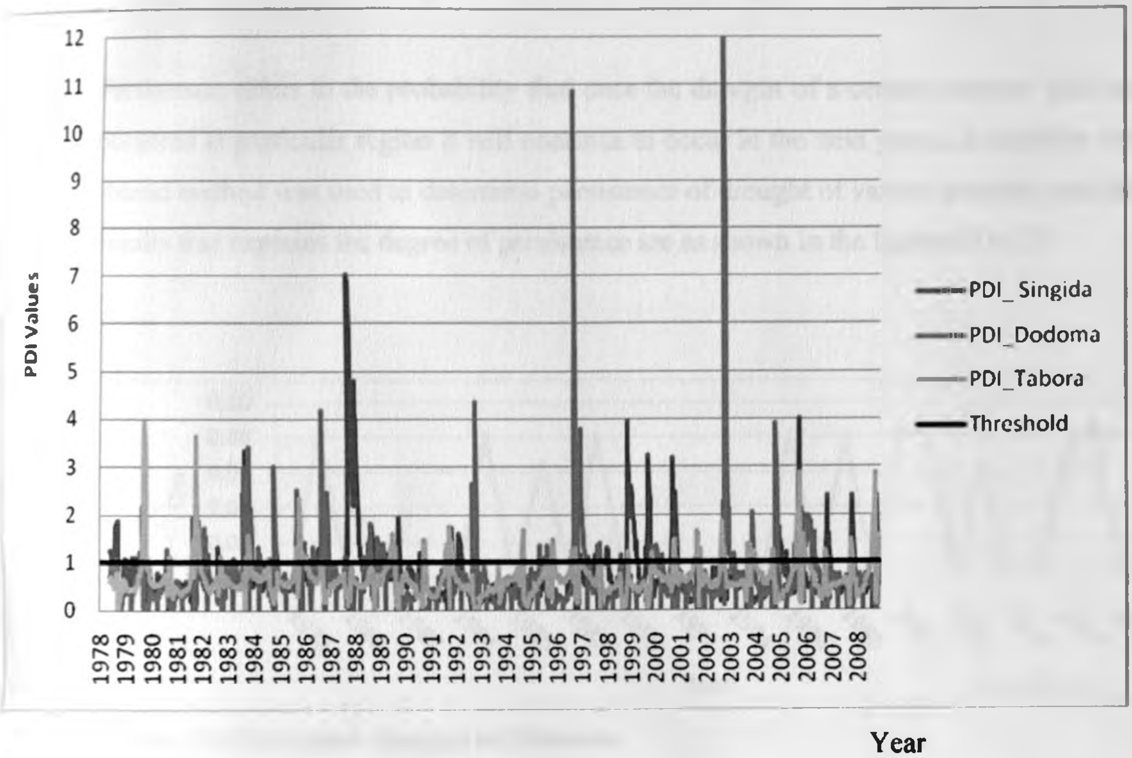

Figure 20: Precipitation Drought Index for Central regions

Table 10; PDI values for selected years in Central regions

Year	PDI	Year	PDI
1979	0.56	1995	0.53
1980	0.49	2001	0.66
1981	0.38	2002	0.66
1991	0.42	2003	0.60
1993	0.26	2005	0.35

PDI analysis shows that both regions experienced similar drought period for the following years 1980-1981,1983-1985,1990-1992,1994-1996,1998-1999,2001-2002 and 2005.

4.4 Result of persistence of drought

Persistence refers to the probability that once the drought of a certain category that has occurred at particular region it will continue to occur in the next year/s. Probability run -based method was used to determine persistence of drought of various intensity and the results that explains the degree of persistence are as shown in the figures22 to 27

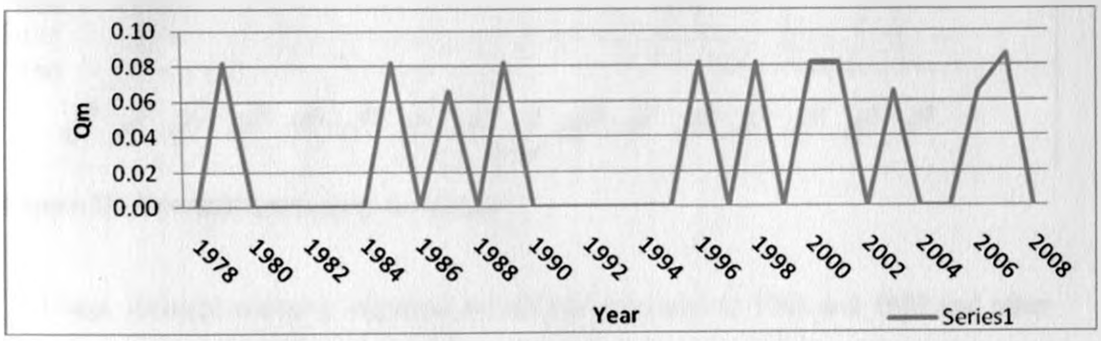

Figure 21: Persistent drought in Dodoma

In Dodoma probability of drought category occurred in 1981 and persisted for other two years 1982, 1983 also drought episode occurred in 1991 which persisted for two years 1992, 1993 followed with the other drought category 2004 that persistent for two year up 2006

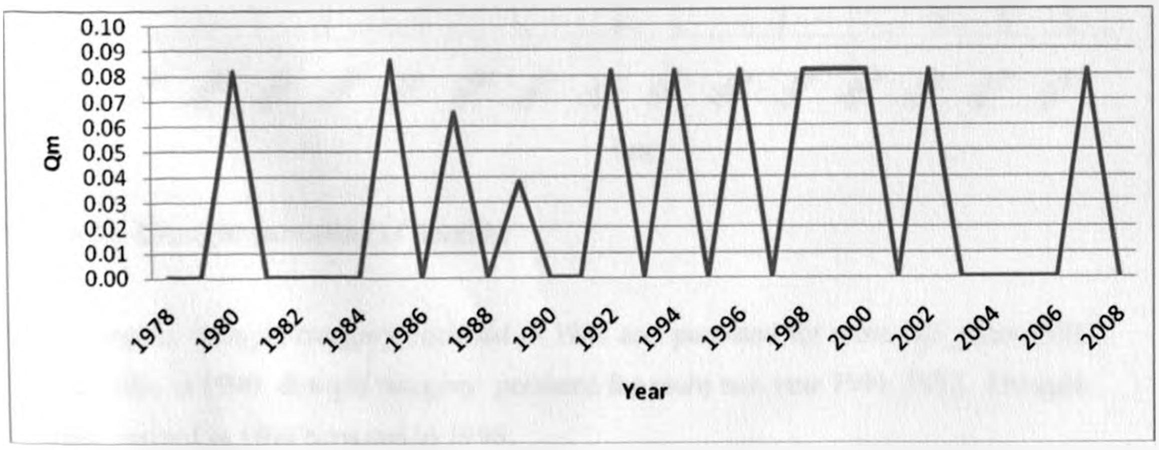

Figure 22: drought persistent in Mbeya

In Mbeya probability analysis showed that drought occurred in 1980 persisted up to year 1983, drought occurred in 1990 persisted up to 1991 and drought that occurred in 2004 persisted up to 2006.

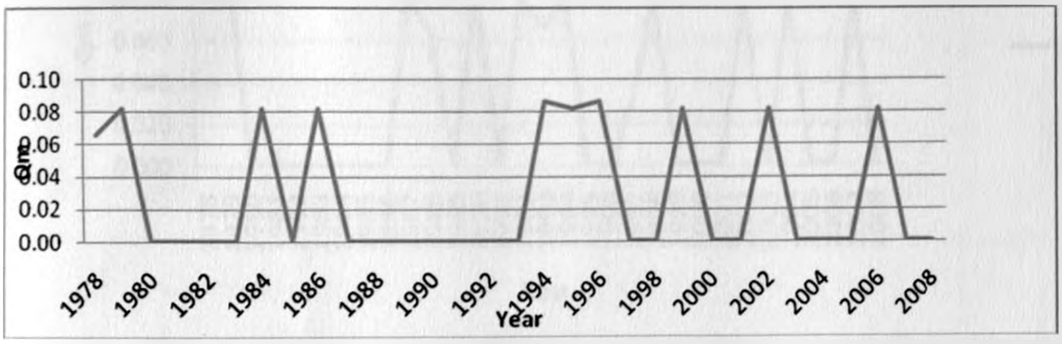

Figure 23: Drought persistent in Iringa

In Iringa drought category occurred in1980 and persisted to 1981 and 1982 and other drought occurred in 1989 which persisted for more three year 1990, 1991, 1992, and drought occurred in 2004 persisted up to 2006.

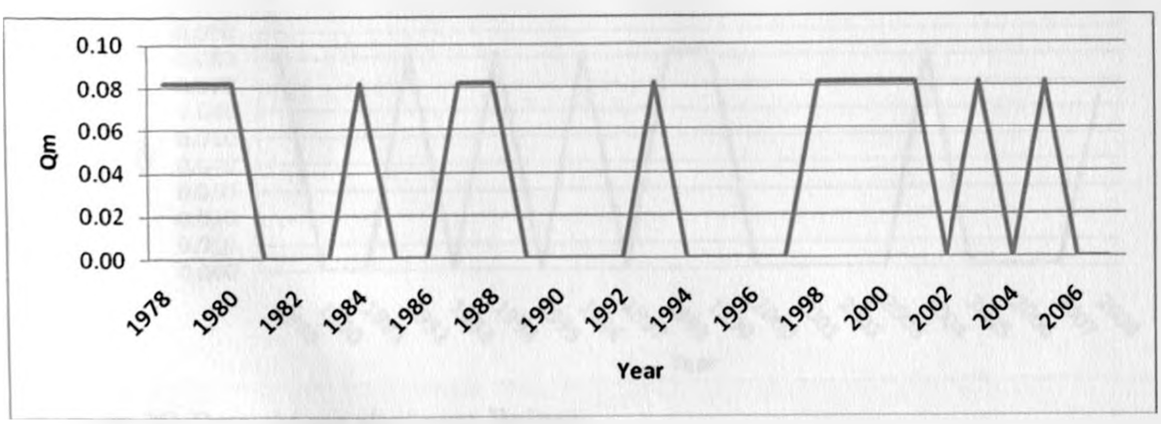

Figure 24: Drought persistent in Singida

In Singida drought category occurred in 1981 and persisted for more two years 1982 and 1983, in 1990 drought category persisted for more two year 1991, 1992. Drought that occurred in 1994 persisted to 1996.

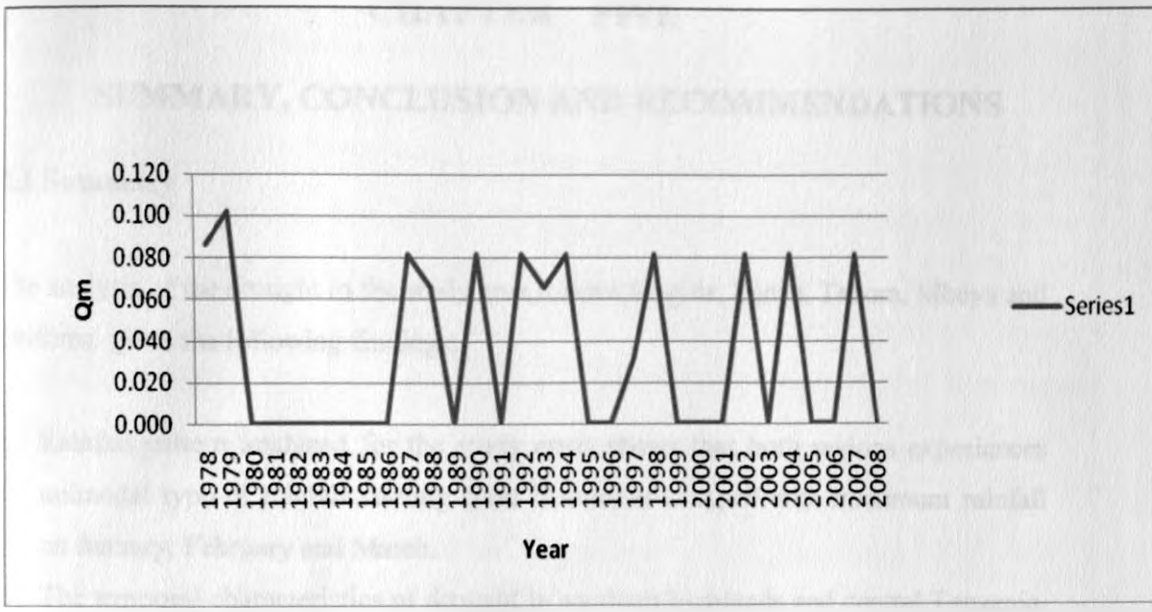

Figure 25: Drought Persistent in Tabora

In Tabora there was persistence of droughts for the following years 1980-1986, 1995-1996, 1999-2001 and 2005-2006

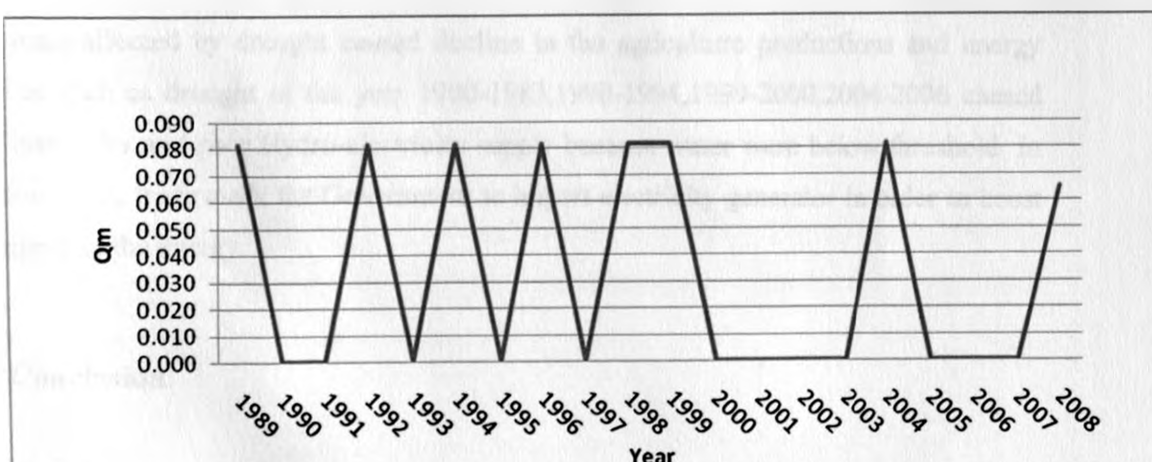

Figure 26: Drought per stent over Rukwa

In Rukwa drought that occurred in1990 persisted to the years 1991, and drought occurred in 2000 persisted to 2003 and drought that occurred in 2005 persisted for two more years 2006, and 2007.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The analysis of the drought in the study area,Rukwa,Singida, Iringa, Tabora, Mbeya and Dodoma gives the following findings;-

- Rainfall pattern analyzed for the study areas shows that both regions experiences unimodal type of rainfall starting from December to April with maximum rainfall on January, February and March.
- The temporal characteristics of drought in southern highlands and central Tanzania, PDI analyzed two types of drought namely low (mild) drought and moderate (medium) drought for whole range of the year 1978 to 2008.
- Drought that occurred was observed to persist for less than three years in both regions.

The years affected by drought caused decline in the agriculture productions and energy supplies such as drought of the year 1980-1983,1990-1994,1999-2000,2004-2006 caused food insecurity and poor Hydro-electricity supply because water were below threshold in Various dams, these made the Government to import electricity generator in order to boost the supply of the energy.

5.2 Conclusion

Central and southern highland regions are vulnerable to drought since have only one rainy season that commence on December and ends in April.

Occurrence and persistent of drought experienced in southern highland and central Tanzania may have been influenced by several factors such as the occurrence of **El Niño** which causes heavy rainfall in interior regions. El Nino episode can extent for two years with the increasing of intensity, when El Nino (wet) occurs, La Nina (Drought) might also be anticipated in the following year/s such as El Nino occurred in 1998-1999 followed with drought in 2000-2003 in most regions.

Also Change of local features which are very important in rainfall formations in particular region contributes in drought formations. Mostly local features are changed by human activities such as poor agricultural practice, increase in populations, which leads to deforestations, land degradations and depletions of natural water bodies. Central and southern highland are vulnerable to increase of populations as the result of change of local feature causing formations of droughts.

Droughts should not be perceived as extreme events in climatic system where they need to be recognized as normal occurrences. They have occurred many times already and will continue to occur yet due to growing of water demands, consequence are likely to increase in future. Unpredictable characteristics of drought including severity, initializations and terminations make drought both hazard and disaster, it is hazard because it is natural phenomena of unpredictable occurrence but recognizable persistence and disaster because it corresponds to disruptions of water supplies for natural, ecosystems as well as to human activities.

Accurate determinations of drought intensity and persistence of drought will help in drought mitigation planning for economic purposes such as in agricultural industry. Hence drought should be handled as risk-based approach rather than crisis based approach as practiced today in many countries.

5.3 Recommendations

PDI fulfill the basic requirements of the primary definition of drought by analyzing rainfall parameter in such a way that all droughts are defined from a Month to Years, Despite its limitations that it cannot account for initialization and terminations of drought.PDI should be combined with other methods so as to identify several drought characteristics.

There is need of Frequency analysis of drought using various parameters such as Evaporations, Solar radiations including sea surface Temperature (SST) that can provide accurate drought determination and accurate drought early warning system.

Finally it is recommended that there is need to make an inventory of national land resources, assessment potentials and constraints in dry land farming. Identify agricultural options to safely increase cropping intensity and yields, adopt more sustainable forms of land use, including contingency cropping in case of droughts. Encourage pastoralists to reduce their herds of stocks also encourage a forestations and land preservations.

4.4 REFERENCES;

Sardis, S. and Z. Sen, (2003): Spatial-Temporal drought analysis in the Trakya region, Turkey. Journal of Hydrological sci. 48(5), 810-813

Panu, U.S, and T. Sharma, (2002) Challenges in drought research: some perspectives and future directions. Journal of Hydrological science.47(s) 21-26

Hallack, M.and D.Watkins, (2006): Annual and season drought Intensity-duration-Frequency analysis for Sonora, Mexico. Journal of climate.20,1899-1902

Dai, A. and E. Trenberth,(1998): Global variations in drought and wet spells. Geography research Letters, Vol.25, no 17, 3367-3370.

Mutua, F.M. (2008): Analysis of General climatic conditions to support drought and Flood preparedness in Somalia. FAO-SWALIM (Gcp/som/047/EC) Nairobi Kenya

Nicholson, S. and Selato (2000): the influence of La Niña on African rainfall. International Journal of Climatology.20; 1761-1776,

Mbaga, T.and Lyamchai (2001): Drought management options in maize production in Northern Tanzania, Seventh Eastern and southern Africa region maize conference, Pg281.

Paavola, J. (2003): Vulnerability to climate change in Tanzania: Sources, Substance and Solutions. Workshop of southern Africa vulnerability Initiative (SAVI) Maputo, Mozambique, 2-16

Ehrhart.C and M. **Twena** (2006): Climate change and poverty in Tanzania. CARE international Poverty-climate change initiative. Tanzania 17-22

World Meteorological Organizations (WMO), (2006), Drought monitoring and early warning. World report No.1006.WMO, Geneva, Switzerland 4-10