# ASSESSMENT OF SEVERITY OF THE METEOROLOGICAL DROUGHT OVER DODOMA REGION

**By**

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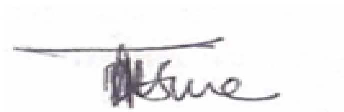
## DECLARATION

I declare that this is my original work and has not been presented for a degree in this or any other University.



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Special thanks to my lecturers, the class of 2012/2013 and my friends and colleagues who we have been cooperating together throughout this course, may God bless them abundantly.

**ABSTRACT**

Most drought studies have been dependent on limited rainfall data that is available in most parts of Tanzania. The new development in space technology, especially satellite derived products now provide new opportunities that can be used to study space- time characteristics of drought. Thus the main objective of this study is to assess meteorological drought severity using various indices over Dodoma region.

Rainfall data used in this study was obtained from the Tanzania meteorological agency and was from 1985 to 2012 for Dodoma meteorological station and Hombolo agro meteorological station.

The method used in this study includes the calculation of drought indices such as standardized precipitation index (SPI) from R- program and the drought severity index (DSI) derived from rainfall records using some standardized statistical methods. The two indices were compared for improving early warning system.

The study has shown that drought indices based on SPI and DSI can provides realistic estimates of drought conditions. There were however some challenges in using these indices because they are mostly rainfall dependent.

The study has provided a way of assessing the worse drought periods by means of SPI as well as DSI that could be used for regional drought monitoring in order to improve the early warning system.

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## LIST OF ACRONYMS

SPI: Standardized Precipitation Index

DSI: Drought Severity Index

TMA: Tanzania Meteorological Agency

UDSM; University of Dar es Salaam

UDOM: University of Dodoma

SUA: Sokoine University of Agriculture

NGO: Non-governmental Organization

NDJFMAM: month of November, December, January, February, March, April and May.

## CHAPTER ONE

## INTRODUCTION

### 1.0 Background

Mather, (1985); describe droughts are like a cancer on the land with seemingly no recognizable beginning unlike floods, earthquakes, or hurricanes, during which violent events of relatively short duration occur. Droughts covering small areas of a few hundred square kilometers do exist but these are usually of limited duration and modest severity. It is more common for drought to cover vast areas, a significant proportion of a continent or a sub-continent approaching millions of square kilometers.

According to (Schneider, 1997); Drought is defined as "an extended period – a year, season, or several years-of deficient rainfall relative to the statistical multi-year mean for a region.

Dodoma occasionally experiences severe droughts as results of failed annual rains. With crops unable to grow, many people have been left without enough food to eat, one example of such drought was in early 2002 and 2009. In the 1970's there was one major drought, in the 1980's the frequency increased to once every seven years, in the 1990's it increased to once every five years (Howden, 2008).

Most people in semi-arid areas are poor due to degrading of their environment, diseases, climate shocks, food-insecurity, and depression as a result of losing courage or hope. Dodoma region is occupied by agro-pastoralists and pastoralists, they depend on land as their natural resource and also their main physical asset as it contributes to their income. For many centuries the agro-pastoralists and pastoralists of this area have adjusted their livelihood for those seasons of resource scarcity as they survive in those droughts periods (Swiss-Report 2012).

Drought can be categorized broadly as either conceptual or operational, operational definitions attempts to identify the onset, severity and termination of drought episodes.as a result it is simply defined according to disciplinary perspective, (Wilhite and Glantz, 1985).

We can define droughts using various categories. Four of these definitions are: meteorological drought, agricultural drought, hydro meteorological and socioeconomic drought.

*Meteorological drought* is characterized by precipitation deficiency threshold over a predetermined period of time, the threshold chosen, such as 75 percent of normal precipitation, and duration period, for example, six months, will vary by location according to user needs or applications. It is a natural event and results from multiple causes, which differ from region to region.

*Agricultural drought* is defined more commonly by the availability of soil water to support crop and forage growth than by the departure of normal precipitation over some specified period of time. There is no direct relationship between precipitation and infiltration of precipitation into the soil. Infiltration rates vary, depending on antecedent moisture conditions, slope, soil type and the intensity of the precipitation event. Soil characteristics also differ: some soils have a high water-holding capacity while others do not.

*Hydrological drought* is characterized by the departure of surface and subsurface water supplies from some average condition at various points in time. Like agricultural drought, there is no direct relationship between precipitation amounts and the status of surface and subsurface water supplies in lakes, reservoirs, aquifers and streams because these hydrological system components are used for multiple and competing purposes, such as irrigation, recreation, tourism, flood control, transportation, hydroelectric power production, domestic water supply, protection of endangered species and ecosystem management and Preservation.

*Socio-economic drought* is Differs markedly from the other types of drought because it reflects the relationship between the supply and demand for some commodities or economic good, such as water, livestock forage or hydroelectric power, which is dependent on precipitation. Supply varies annually as a function of precipitation or water availability. Demand also fluctuates and is often associated with a positive trend as a result of increasing population, development or other factors (WMO report 2006).

The first essential component of drought management is an early warning system linked closely to a standby capacity to respond and manage drought. Whatever its impacts, it should be acknowledged that the poor Gogo,rangi and sandawe communities of Dodoma who are already vulnerable to a suite of already existing risks and endowed with major resources are the most adversely affected as climate change is superimposed on their already tenuous situation.

## 1.1: OBJECTIVES

The overall objective of this study is to assess the severity of meteorological drought over Dodoma using various indices.

To achieve the main objective, the following specific objectives will be undertaken;

1. To determine the trends of rainfall and temperature over Dodoma.
2. To identify drought periods using rainfall drought severity index (DSI)
3. To generate Standardized Precipitation Indices (SPI) for Dodoma

## 1.2: JUSTIFICATION OF THE STUDY

Insufficient rainfall records from ground stations calls for alternative methods for drought monitoring. For this reason, together with the creeping phenomenon of droughts makes the accurate prediction of either its onset or end a difficult task. Since, droughts are natural events whose occurrences in time and space are complex and not fully understood, rainfall measurements are always limited in spatial extent thus drought indices such as SPI and DSI allows investigation of a larger portion of the Dodoma region than previously possible through station observation.

The majority of residents of Dodoma region are pastoralists and agro-pastoralists. They depend on their cattle for survival so they are vulnerable to the risks of drought. There is a need to keep track of drought conditions or effects and environmental changes with the intension of monitoring and predicting the productivity of the marginal agricultural areas to determine whether they are the result of shifting climate, human actions or a combination of these factors.

The agro-pastoralists entirely depend on rainfall for agriculture, so improvement of the early warning system in the region will help them to overcome the situation in a way that when the rainfall is insufficient, better management of the available water resources will help ameliorate the severity of drought for that season. Conflicts between the pastoralists, agro-pastoralists and wildlife arise due to the scramble for the little available resources.

The ability to address challenges of drought monitoring is limited both by the obscurity of the changes and by uncertainty in our ability to have effective and reliable drought information from the grass root level. This emphasizes the importance of improving our understanding on various drought indices and its relationship to droughts. The use of drought indices such as DSI and SPI in Dodoma for some 27yrs, can give detailed data and the information needed to begin to model various trends of drought in the Dodoma region..

**2.3: AREA OF STUDY**

Dodoma Region lies at 4°S to 7°S and 35°E to 37°E. It is a region centrally positioned in Tanzania and is bordered by four regions namely: Manyara in the North, Morogoro in the East, Iringa in the South and Singida in the West. Much of the region is a plateau rising gradually from some 830 meters in Bahi Swamps to 2000 meters above sea level in the highlands north of Kondoa.

Dodoma region has four rural districts and one urban District namely: Dodoma-Rural, Kondoa, Mpwapwa, Kongwa and Dodoma Urban. The region is the 12$^{th}$ largest in the country and covers an area of 41,310 sq. km equivalent to 5% of the total area of Mainland Tanzania and has a population of 2,083,588 with a density of 125.9 persons per square kilometers (326/sq mi) (Census report 2012).

Dodoma region has a savanna type of climate, which is characterized by a long dry season lasting between late April and early December, and a short single wet season occurring during the remaining months. In the long dry season, persistent desiccating winds and low humidity contribute to high evapo-transpiration and high soil erosion.

The average rainfall for Dodoma region is 570 millimeters, and about 85 percent of this falls in the months between December and April. Rainfall figures are higher in the more agriculturally productive parts of Mpwapwa and Kondoa Districts. Apart from the rainfall being relatively low, it is rather unpredictable in frequency and amount. It is this unreliable rainfall, which has imposed a pattern of risk aversion in traditional agriculture and is a serious constraint on present efforts to improve crop yields.

Temperature in the region varies according to altitude but generally the average maximum and minimum is 31°C and 18°C respectively. In June – August, temperatures are at times very high with hot afternoons up to 35°C and chilly nights on hilly areas down to 10°C.

The characteristic vegetation of the region is of "bush" or thicket type, which is widespread throughout the area wherever the natural plant cover has been altered by biotic factors. Depressions and seasonally wet areas with impeded drainage support grasses and sometimes a mixture of grasses mixed with woody plants. Wherever the natural vegetation has been altered by agricultural activities, regenerating bushes mixed with annual herbs and grasses forming a type of induced vegetation. Most of the hill ranges, steep slopes and protected forest reserves are covered with large woody plants, which form good watershed protective covers (*Regional Commissioner's Office – Dodoma, 2012*).

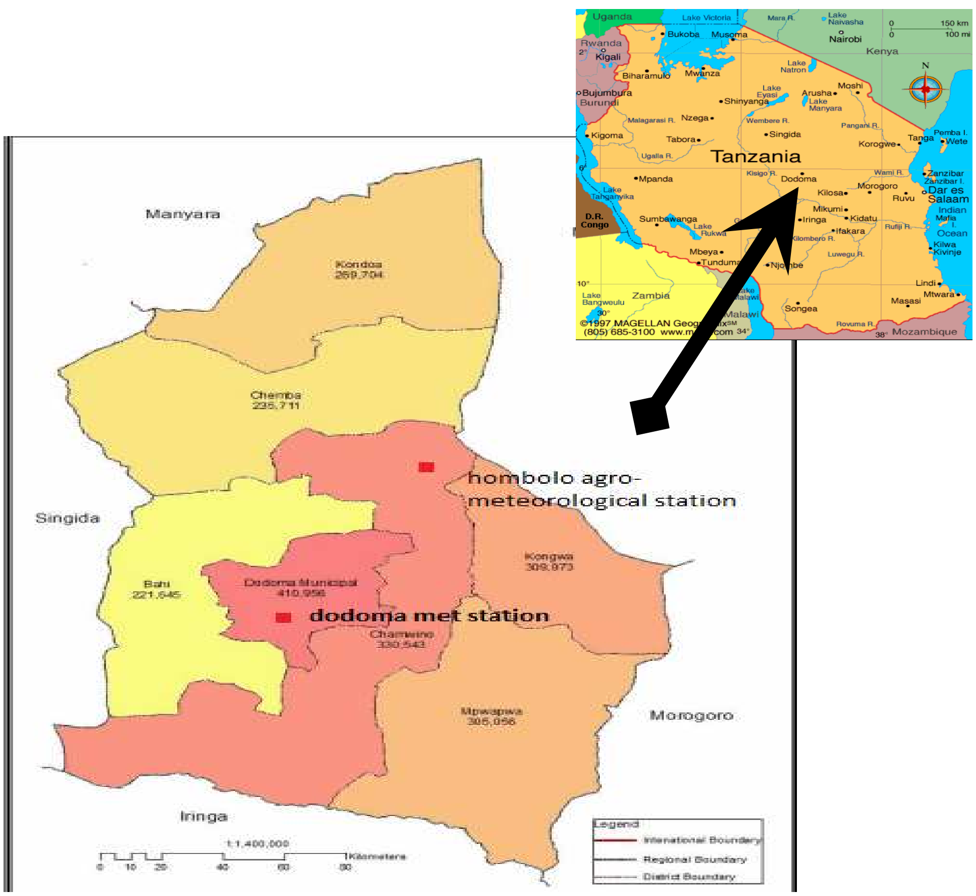


**Figure 1: Domain of study showing administrative districts of Dodoma and the location of the stations used in this study. (The map of Tanzania is provided for orientation)**

# CHAPTER TWO

# LITERATURE REVIEW

## 2.0 Introduction

In this chapter discusses the studies that have been done previously.

## 2.1 literature Review

Extreme drought is a natural disaster as recently illustrated in the United States by economic and environmental damage (Mayer et al., 1988, and Kennedy et al., 1991) and in parts of Africa by severe famine (Glantz, 1987). Such extreme droughts can influence transportation, water-resource systems, and agriculture as well as intensify anthropogenic impacts on ecosystems potentially causing desertification.

Ininda (1987) studied the spatial and temporal characteristics of drought in Eastern and Southern Africa. The study used indices; like decile range, standard anomaly and weighted anomaly to group drought into various drought episodes. The components of drought investigated included: the intensity, onset, withdrawal, and persistence, and frequency, probability of various occurrences and recurrence patterns of droughts. The indices gave good results as expected but did not account for the other parameters as it dwelled more on precipitation.

At the global level, between 1967 and 1991 droughts affected 80% of the 2.8 billion people who suffered from all natural disasters and killed 35% of the 3.5 million people who lost their lives according to (Jeyaseelan, 2009). Furthermore, droughts leads to reduced crop production, rangeland, forest productivity, increased fire hazards, reduced water levels, increased livestock and wildlife mortality rates, damage to wildlife.

Drought would exist if the criteria defining the drought was met, and the index would then be a measure of the drought’s duration and/or intensity. During the first decade of the twentieth century, the U.S. Weather Bureau identified drought as occurring during any periods of 21 or more days with rainfall 30% r more below normal normal for the period (Steila 1987). During this time, a drought measure frequently used was accumulated precipitation deficit, or the the accumulation departure from normal. Most of these definitions were valid only for their specific application in their specific region. Indices developed for one region may not be applicable in other regions because the meteorological conditions that result in drought are highly variable around the world.

The historical and contemporary case studies that often offer the most plausible analogies with global climate change come from multidisciplinary areas of environmental hazards, climate impacts assessment and climate history. Among geophysical agents, weather and climate are the most lethal to humankind worldwide. When atmosphere related hazard are classified by duration, speed of onset, area affected and other physical characteristics, drought appears the one most akin to the longer term challenges of climate change (Burton *et al*. 1993)

Human activities are sensitive to climate to the degree that they can be affected by it, and vulnerable to the degree that they can be harmed, with the latter incorporating a human judgment of value. “Sensitivity” refers to the elasticity between different processes or state, “vulnerability” to the potential for negative outcomes or consequences (Rayner *et al.* 1995). A resilient system, activity or population is one with low vulnerability, being either resilient to hazard effects or readily capable of coping with and recovering from them.

The vulnerability of populations and activities is the most widely used umbrella concept for those factors that mediate between geophysical events and human losses. Because vulnerability and its causes play an essential role in determining impacts, hence understanding the dynamics of vulnerability is as essential as monitoring and predicting climate change and variation. Therefore vulnerability is a composite concept incorporating environmental, social, economic, political, cultural and psychological factors described in integrated terms (Kates *et al.* 1995)

Ominde and Juma Vulnerability varies from group to group and changes over time. During the Kenya drought, impacts varied substantially among regions, communities, households and individuals with results ranging from death and disability of family members to wind fall profits from livestock and food trading (Rocheleau *et al*. 1994)

Droughts differ from one another in three essential characteristic; intensity, duration and spatial coverage. Intensity refers to the degree of precipitation shortfall and/or the severity of impacts associated with the shortfall. It is usually measured by the departure of some climatic index from the normal and is closely linked to the duration in the determination of impacts.

Many indices are in wide spread use today such as the decile approach (Gibbs and Maher, 1967; Lee 1979, Coughlan 1987) mostly used in Australia. The Palmer drought severity index and crop moisture index (Palmer 1965, 1968; Alley 1984) are used in United States. A relatively new index that is gaining increasing popularity in the United States and worldwide is the Standardized precipitation index developed by Mckee *et al*. 1993, 1995.

Another distinguishing feature of drought is its duration. Drought usually requires a minimum of two to three months to become established but can then continue for months or years. The magnitude of drought impacts is closely related to the timing of the onset of the precipitation shortage, its intensity and the duration of the event. Droughts also differ in terms of their spatial characteristics. During the drought of 1934 in the United States, the area affected was approximately 65% of the country. In the United States and many African countries it is unusual for drought not to exist in a portion of the country in each year (Jeyaseelan, 2003).

Shongwe, Van Oldenborgh and Aalst (2009) in their report showed that there had been an increase in the number of reported hydro-meteorological disasters in the region, from an average of less than 3 events per year in the 1980’s to over 7 events per year in the 1990’s and 10 events per year from 2000 to 2006, with a particular increase in floods and droughts.

Indices developed to measure the intensity of meteorological drought, for instance were inadequate for agricultural, hydrological, or other applications. These deficiencies were recognized early (Henry 1906). The problem with developing an agricultural index, for example, include consideration of vegetation, soil type, soil moisture and evapotranspiration as influenced by wind speed  and the temperature and humidity of the air. Many of those climatic elements were not widely measured, or could not be incorporated into a drought index. But over time other indices were brought into picture (Johnson, *et al*., 1993).

# CHAPTER THREE

# DATA AND METHODOLOGY

## 3.0 Introduction

This chapter outlines the datasets which were used and the methods of analysis adopted to achieve the objectives of the study.

## 3.1 DATA

The data used here includes monthly temperature and rainfall records from the Dodoma Meteorological Station and Hombolo Agro meteorological Station for the period 1985 to 2012. Drought Severity Index (SDI) and Standardized Precipitation Index (SPI) were utilizing these data in order to achieve objectives of the study.

### 3.1.1 Data Quality Control

In order for the results from the data analysis to have proper interpretation, the data was subjected to quality control and the methods used to ensure data quality are arithmetic mean method for estimation of missing data and single mass curve for homogeneity of the data.

### 3.1.2 Estimation of Missing Data

There are several methods of estimating missing climatic data record. Types of method depends on whether the missing data are temporal or spatial data. Temporal resolution is good for annual, monthly, daily and hourly depends on the length or amount of missing records. In some cases, certain methods (e.g. methods based on time series analysis) can only be applied on the available record length (Salas, 2006). Apart from normal ratio, inverse distance method, correlation and regression, this research employed arithmetic mean method which is the simplest and most objective method of estimating missing data. It involves replacing the missing data with the average or the mean for a given station and it is given by the Equation 1;

$$X_m = \left(\frac{\bar{X}}{\bar{Y}}\right) Y_m \quad \text{.........................} \quad (1)$$

In equation 1, Xm is the missing records at station, $\bar{X}$ is the long term mean for the station with missing data in certainyear and month, Y is the long term mean for the station with complete data and Ym is the corresponding records at station having complete data.

### 3.1.3 Consistency/Homogeneity test

The methods that are commonly used to detect and correct heterogeneity in the datasets are single and double mass curves. Mass curve analysis is the method used to test for the homogeneity of a given datasets. In this method cumulative rainfall, temperature was being plotted against time. The graph so obtained is a single mass curve. From the shape of the graph, i.e. If the graph approximates a straight line, then the data sets are said to be homogeneous, otherwise they are heterogeneous. If the data is heterogeneous then cumulative plot of stations rainfall data against corresponding cumulative rainfall data from two or more neighboring homogeneous stations is plotted. The graph so obtained is a double mass curve and would be used to adjust the heterogeneous records accordingly.

## 3.2 METHODOLOGY

This section discusses the various methods that were employed to address the overall and specific objectives of the study.

## 3.3 Time Series

A time series of the rainfall data will be plotted to show the distribution of rainfall over the time period of interest for the study. This is important in analyzing the temporal variability of rainfall and hence identifying the dry and wet seasons. The time series would be achieved through the accumulated rainfall values and normalized using Equation

$$Z = \frac{X - \bar{X}}{\partial} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In the equation 2; Z is the Standard Anomaly, $\bar{X}$ is the Mean value of the variable, X is the Variable in consideration and $\partial$ is the Standard deviation.

## 3.4 Drought Indices

This study utilized the Standardized Precipitation Index (SPI) and Drought Severity Index (DSI) in assessing meteorological drought severity over Dodoma.

### 3.4.1 Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is calculated in the following sequence. A monthly precipitation data set is prepared for a period of months, ideally a continuous period of at least 30years. A set of averaging periods are selected to determine a set of time scales of period j months where j is 3, 6, 12, 24, or 48 months. These represent arbitrary but typical time scales for precipitation deficits to affect the five types of usable water sources. The data set is moving in the sense that each month a new value is determined from the previous i months. Each of the data sets is fitted to the Gamma function to define the relationship of probability to precipitation. Once the relationship of probability to precipitation is established from the historic records, the probability of any observed precipitation data point is calculated and used along with an estimate of the inverse normal to calculate the precipitation deviation for a normally distributed probability density with a mean of zero and standard deviation of unity. This value is the SPI for the particular precipitation data. .

It involves probability of precipitation for a given period and is negative for drought while it is positive for wet conditions. SPI is a probability index that considers only precipitation while at the same time flexible to measure drought at different time scales.

Table 1**: Drought defined by the SPI in various categories**

| **SPI values** | **Drought category** |
|---|---|
| 0 to -0.99 | Mild drought |
| -1.00 to -1.49 | Moderate drought |
| -1.50 to -1.99 | Severe drought |
| ≤ -2.00 | Extreme drought |

### 3.4.2: Drought Severity Index

Drought severity index is used to determine the drought. This meteorological drought index responds to weather conditions that have been abnormally dry or abnormally wet.

Various drought indices have been developed and used in many parts of the world (including Africa) to monitor the spatial extent and severity of drought conditions. Generally drought indices are developed based on cumulative precipitation deficit. It provides guidance for the use of mitigation measures during a drought. In this study, rainfall data was used to calculate drought severity index which responds well with the increase and decrease of vegetation and as results drought detection through periods associated with drought and its effects are going to be assesed using the drought severity index.

The drought index measures how much precipitation for the Dodoma region has been deviated from established averaged condition. The DSI is calculated using the actual precipitation and the long term average precipitation and expressed as a percentage according to equation 3. In this study, the precipitation was averaged over 27 years,

$$DSI = \frac{P_i}{P_a} \times 100\% \qquad \text{………………….} (3)$$

In equation 3, P **(i)** is the actual precipitation (observed), P**(a)** is the Long term precipitation averaged over 27yrs. This was calculated for month with rainfall putting in mind that normal precipitation for a specific location is considered to be 100%.

Table 2**: Drought defined by the DSI in various categories.**

| class | percentage | Drought categories |
|---|---|---|
| 5 | >175% | very wet (wettest on records) |
| 4 | 125 -175% | wet |
| 3 | 125 -175% | near normal |
| 2 | 25 -75% | Dry |
| 1 | 10 – 25% | generally dry |
| -1 | <10% | extremely dry (driest on record) |

## CHAPTER FOUR

## RESULTS AND DISCUSSION

### 4.0 Introduction

This chapter presents and discusses the results that were obtained from the various methods that were used to address the objectives of this study.

### 4.1 Results for Estimation of Missing Data Using Interpolation Methods

Missing data were estimated by calculating the long term mean for each month and replace the missing value by its corresponding long term mean.

### 4.2 Homogeneity Assessment Results

Homogeneity test was necessary for detection of errors in data and ensured that the datasets were free from errors. The cumulative mass curve technique was used in this study. It is a technique that involves accumulating monthly records for each station and plotting these values against time. A single straight line indicates a homogeneous record whereas homogeneity tendency is indicated by existence of one line fitted to the graphical plots of the cumulative data, MO (1970, 1986), Siegel (1956) and Basalirwa (1991). Examples of the derived mass curves are shown in figure 2(a) to 2(f), the results were indicative of good quality of rainfall and temperature records.

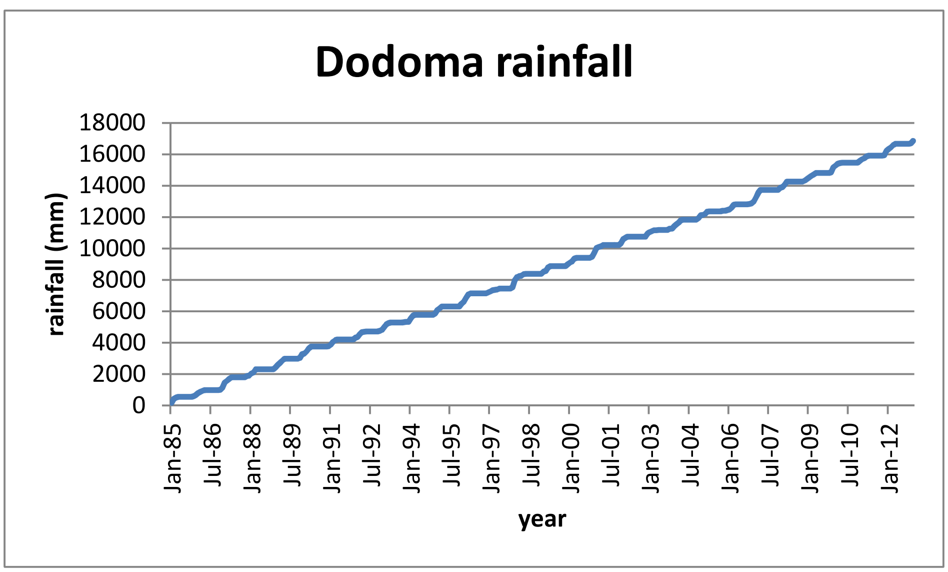


Figure 2(a): **single mass curve of monthly mean rainfall over Dodoma from 1985 to 2012.**

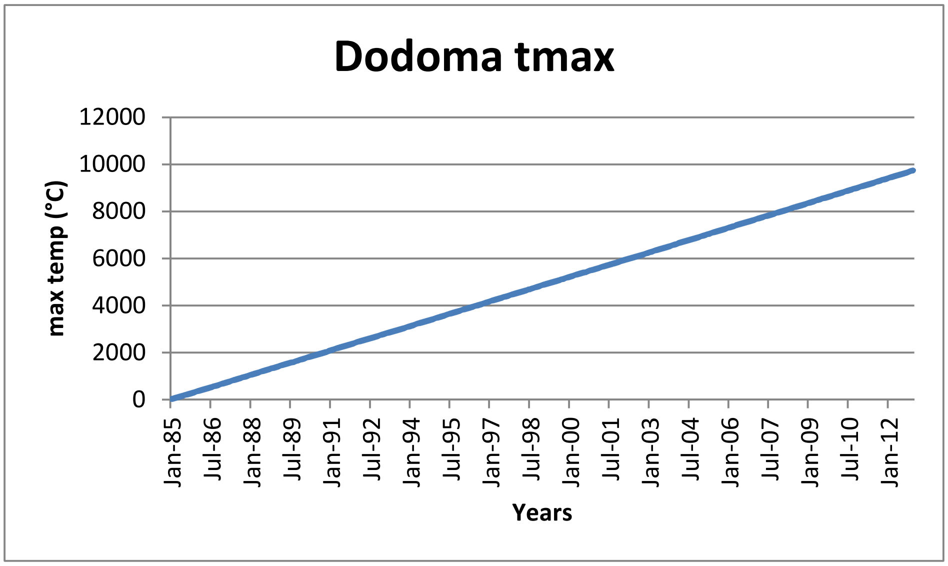


Figure 2(b): **single mass curve of monthly mean max temperature over Dodoma from 1985 to 2012.**

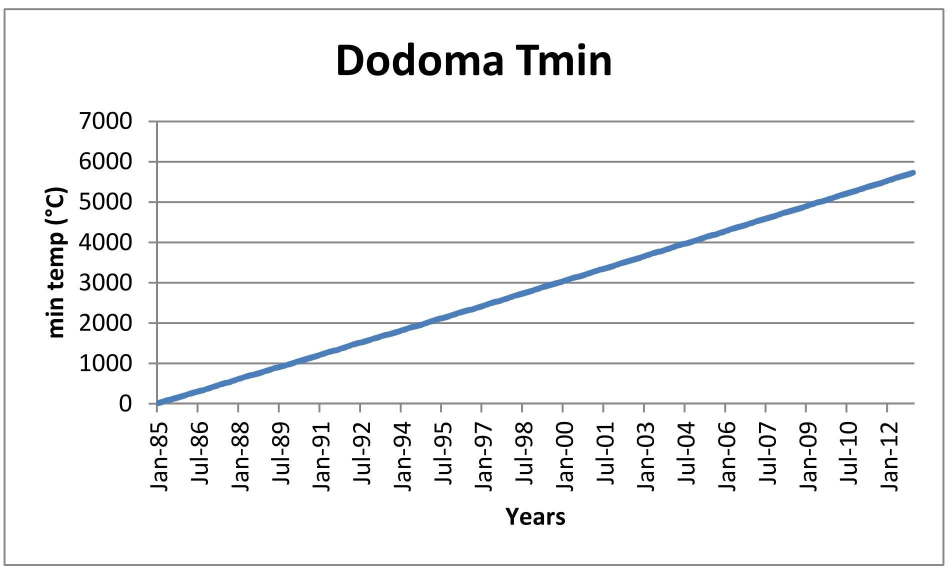


Figure 2(c): **single mass curve of monthly mean min temperature over Dodoma from 1985 to 2012.**

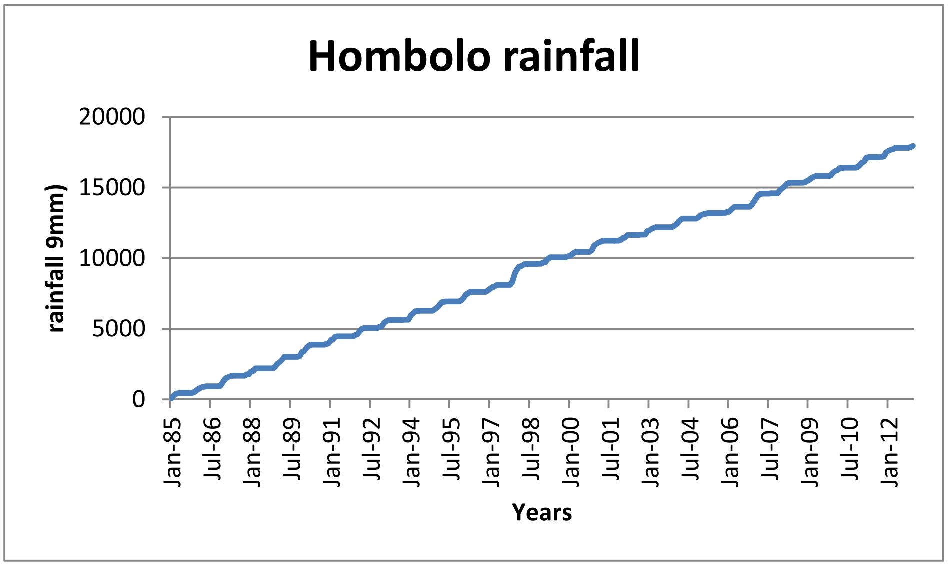


**Figure 2(d): single mass curve of monthly mean rainfall over Hombolo from 1985 to 2012.**

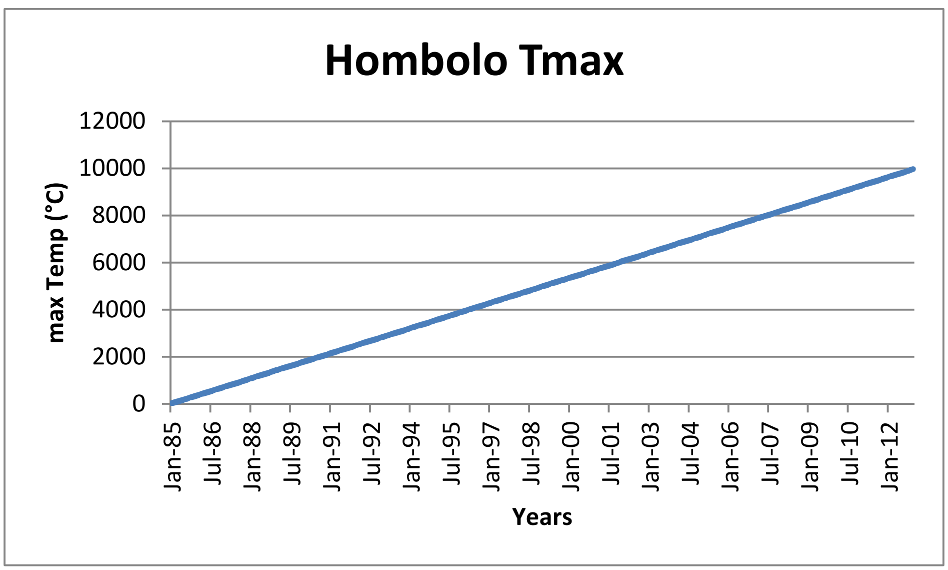


Figure 2(e**): single mass curve of monthly mean max temperature over Hombolo from 1985 to 2012.**

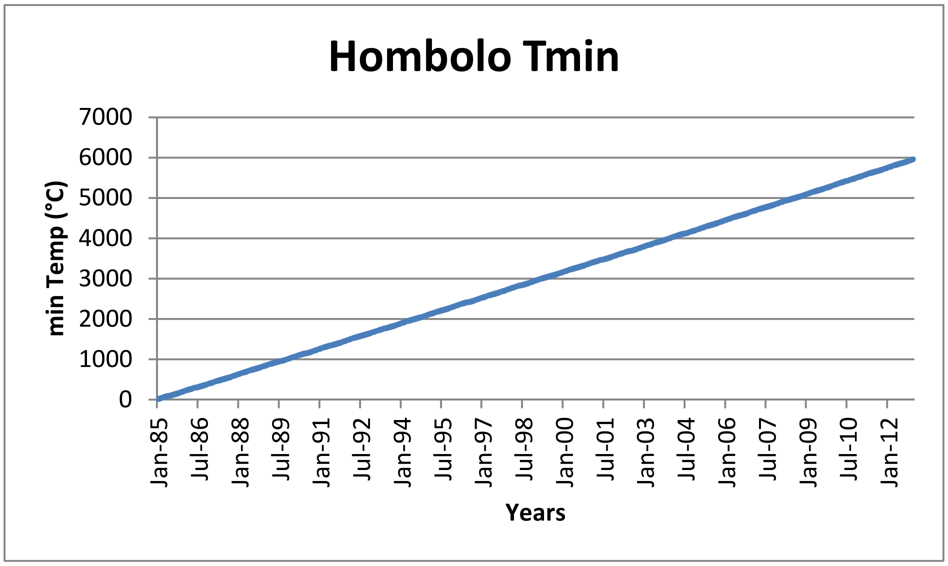


Figure 2(f): **single mass curve of monthly mean min temperature over Hombolo from 1985 to 2012.**

## 4.3 RESULTS FOR TIME SERIES ANALYSIS

Various techniques were used to identify the patterns in the time series data. One of these techniques is the trend analysis as discussed below.

In this study, the graphical approach was used to assess the trend of rainfall and temperature over Dodoma for the stations used. A time series for each data set of this study was plotted and the emerging patterns noted. Figure 3(a) to 3(f) below shows the time series plots for rainfall and temperature data of Dodoma and Hombolo stations.

Figure 3(a) shows the rainfall trend for Dodoma station the figure shows that the trend of rainfall was decreasing over this period. It can be noted from the figure that in 1989 there was a peak in the rainfall pattern, but it decreased since then up to another peak in 2007, before decreasing in the recent years. This situation is attributed to drought severity over the region.

Figure 3(b) and 3(c) shows the increasing trends of maximum and minimum temperatures in Dodoma station this could be one of the factors that contribute to the severity off drought in Dodoma.

Figure 3(d) shows the decreasing trend of rainfall in hombolo agro meteorological station over Dodoma region, except in years 1989 and 1997 and a bit of 2011 shows the increasing trend, but the rest of the years rainfall was decreasing which could be one of the factors contributing to severity of drought on the region. Also figure 3(e) and 3(f) indicates an increasing trend of maximum and minimum temperatures, and that increase may contribute to drought episodes in the region.

On average there was a decreasing trend of rainfall over the region, as it is known that rainfall deficiency contribute largely on drought severity in any area, this study has shown that if rainfall continued decreasing in years to come drought will be more severe in Dodoma region.so the government and policy makers need to address an effective tool to bring awareness to the people.so as to help improving people's standard of lives, because drought has a serious consequences on any country's economy..

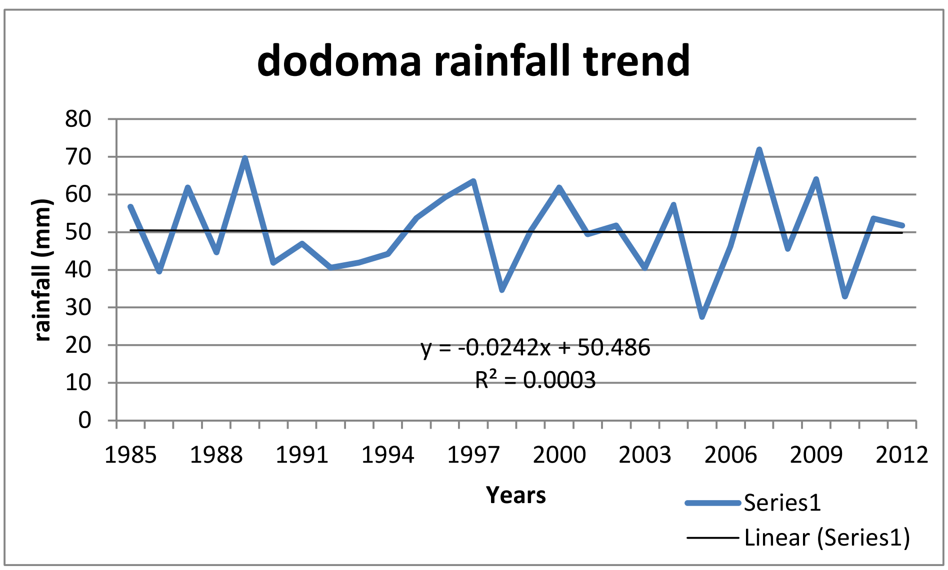


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Figure 3(a): **Trend of rainfall over Dodoma from 1985 -2012.**

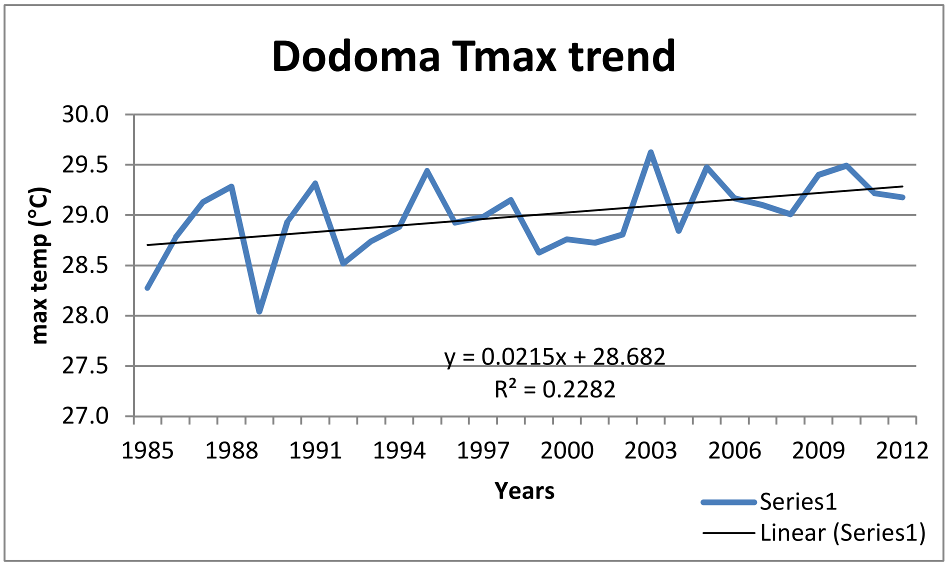


Figure 3(b): **Trend of maximum temperature over Dodoma from 1985-2012.**

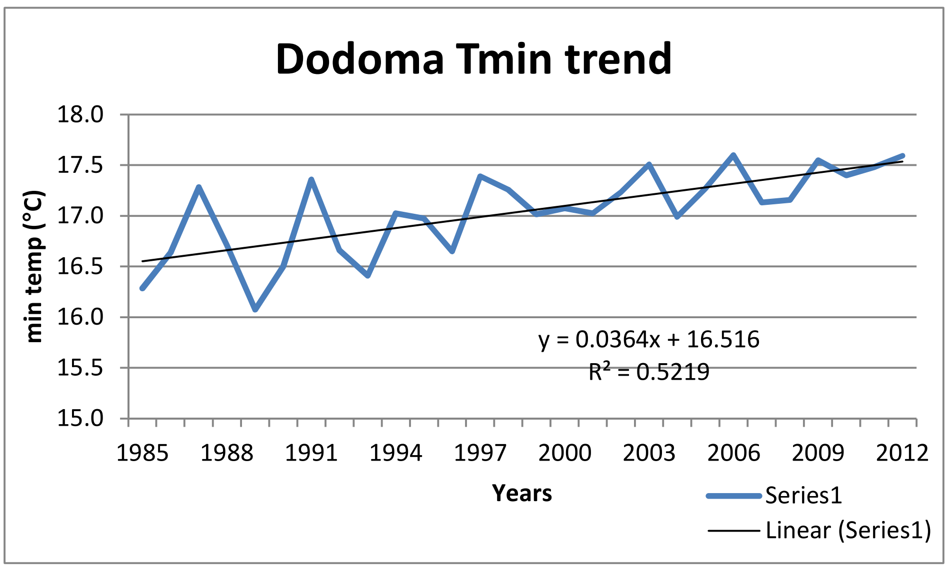


Figure 3(c): **Trend of minimum temperature over Dodoma from 1985-2012.**

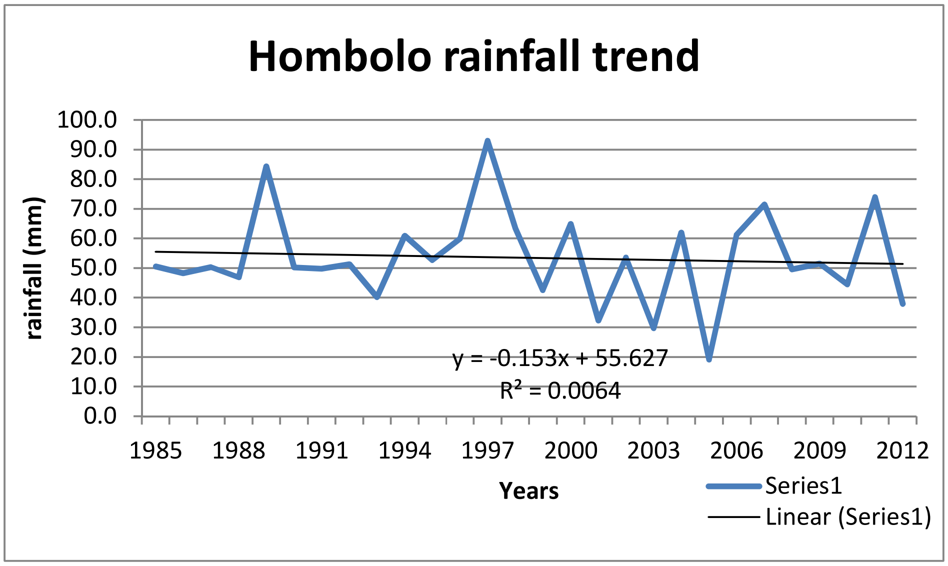


Figure 3(d): **Rainfall trend over Hombolo from 1985 to 2012.**

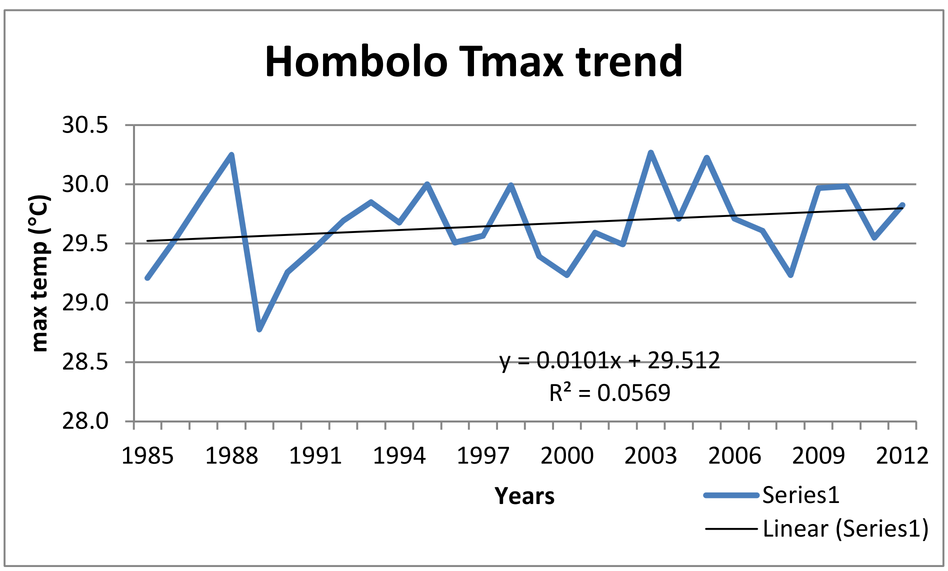


Figure 3(e):**Trend of maximum temperature over Hombolo from 1985-2012.**

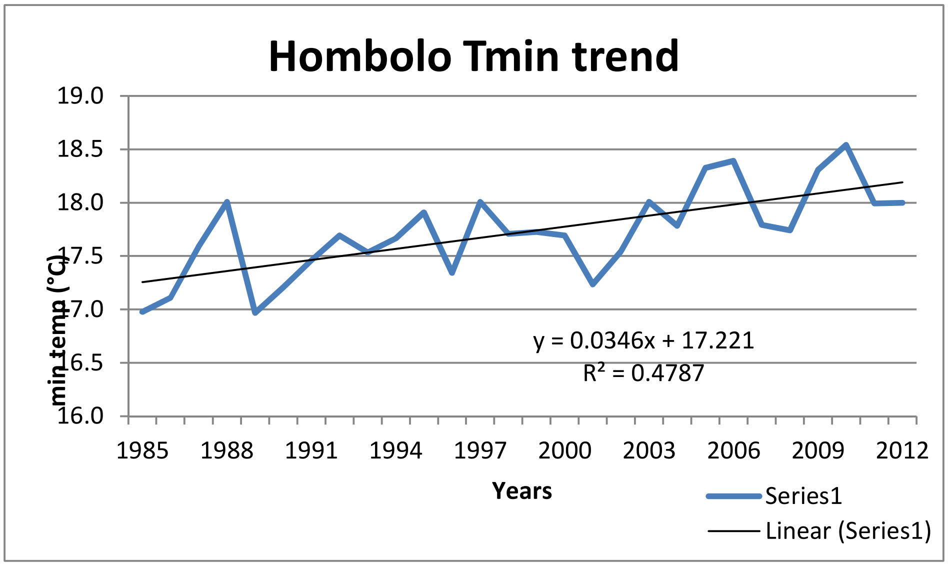


Figure 3(f): **Trend of minimum temperature over Hombolo from 1985-2012.**

### 4.4 DROUGHT INDICES

The Drought Severity Index (DSI) is used as an indicator of drought severity, and a particular index value is often the signal to begin or discontinue elements of a drought contingency plan. The Standardized Precipitation Index (SPI) was developed to quantify a precipitation deficit for different time scales. It was designed to be an indicator of drought that recognizes the importance of time scales in the analysis of water availability and water use.

#### 4.4.1 Results for Identifying Drought Periods using Drought Severity Index

Dodoma has near normal conditions but having dry years in 2003 2005, 2010 and 2012 NDJFMAM season of the decade. The rest of the years showing near normal tendency except 2007 which was the wettest year of the decade? Fairly near normal conditions in the past ten years have been noted in year 2002, 2004, 2006, and 2008 but with a tendency of below average expectancy as you go towards the end of the decade.

Also noted that for the most part of the decade, Dodoma has recorded small variations in all stations and this might be due to human influence on drought. So the driest and the near normal conditions over Dodoma may be one of the factors for the severe drought for some years to come, it is very important to take some measures before the situations became worse, the early warning sytem improvement will help improve the situation.

Table 3: **DSI results defined by percentage and classes of drought category**

| Years | | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DODOMA | % | 104 | 67 | 116 | 84 | 92 | 145 | 92 | 129 | 66 | 108 | 102 |
| | class | 3 | 2 | 3 | 3 | 3 | 4 | 3 | 4 | 2 | 3 | 3 |
| HOMBOLO | % | 104 | 55 | 116 | 33 | 114 | 133 | 93 | 97 | 84 | 139 | 71 |
| | class | 3 | 2 | 3 | 2 | 3 | 4 | 3 | 3 | 3 | 4 | 2 |

**4.4.2 Results from Standardized Precipitation Index**

From the SPI graphs below, figure 4(a) and 4(b) stations shows drought tendency in recent years compared to some years back, the wettest periods are shown by blue and green colors that contain positive numbers on the legend (+2 and +1) for Dodoma it was in the mid 1980's, late 1990's and .in 2007.but the rest of the years on this study shows mild drought, moderate drought and severe drought categories according to SPI, and it can get even more severe in some years to come if no measures are taken to address this situation. The situation is more or less the same in hombolo as it is shown in the figure 4(b), since 2000 to date dry periods persist, the red and deed red colors containing the negative numbers(-2 and -1) on the legend shows severe drought periods in recent years, this alert for the early warning system for the region.

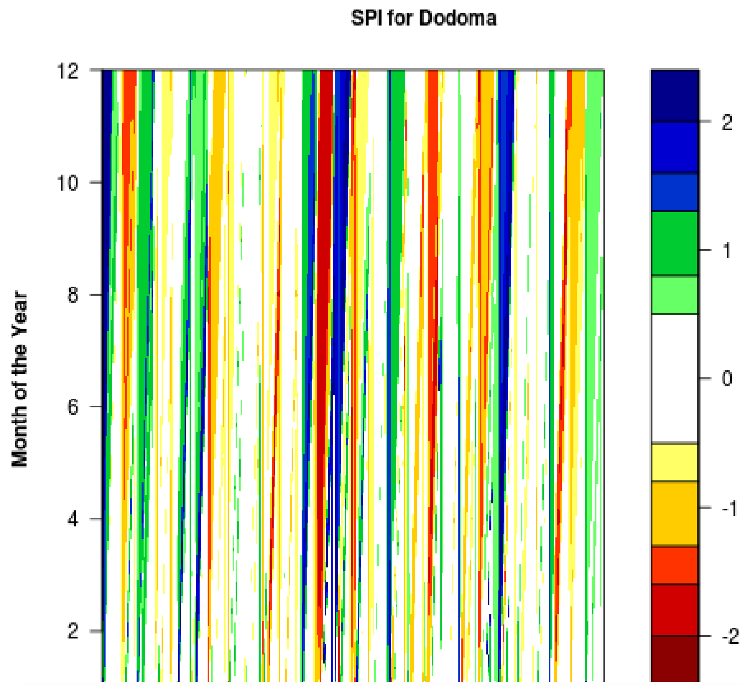


Figure 4(a) **Results from Standardized Precipitation Index (SPI) analysis for Dodoma.**

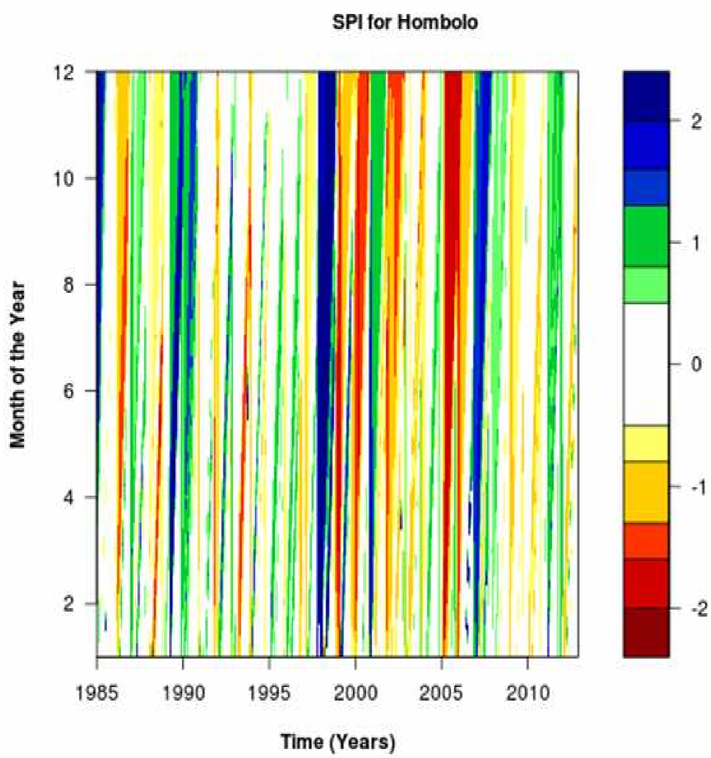


Figure 4(b) **Results from Standardized Precipitation Index (SPI) analysis for Hombolo.**

**CHAPTER FIVE**

**SUMMARY, CONCLUSSIONS AND RECOMMENDATIONS**

## 5.0 SUMMARY

Meteorological drought in Dodoma region shows equal chances of occurrence in all station used. This is shown by the average SPI images and SDI table for NDJFMAM season, the whole region of Dodoma have 50% chances of improving drought severity and same chances of performing poorly.

The best condition in Dodoma was recorded in mid-1980's, 1990's and 2000's years where majority of the region recorded a 60 -80% and even 80 -100% in some places, meaning that no more improvement could be got at that time.in recent years 2003, 2005,2010,and 2012 it shows bad condition of drought.

Drought-related impacts are also becoming more complex, as illustrated by the rapidly rising impacts in sectors such as recreation and tourism, energy, and transportation. Environmental and social consequences are also of increasing importance. Conflicts between water users and disputes between political entities on transboundary water issues are a reflection of the need for improved documentation of the consequences of extended periods of water shortage. Unfortunately, no national drought impact database exists and drought impact statistics are not routinely compiled at the state, regional, or national level. Without this information, it is an arduous task to convince policy and other decision makers of the need for additional investments in drought monitoring and prediction, mitigation, and preparedness.

## 5.1 Conclusion

In conclusion, from the study it is found that drought severity can basically be assessed by means of drought indices products which are associated with a period of abnormally dry weather as it is seen on the SPI images. Drought indices showed that meteorological drought can be monitored by using SDI and SPI indices and it can be concluded that SPI index is more sensitive and perform well with any rainfall records available, this shows that meteorological drought affects the area in the stations used and thus monitoring of this effects are very crucial for the people of Dodoma who highly depends on agriculture and pastoralism for their income as well as their economic development.

Drought occurs nearly in every part of the region and adversely affects the lives of a large number of people, causing considerable damage to economy, the environment, and property of the region, it also affects the agriculture productivity since it is mostly depending on rainfall.

From the results noted in the study, it is possible to state that meteorological drought severity assessment by means of drought indices is realistic and can be used in improving early warning system. This has been proven by results of the objective of this study.

**5.2 Recommendations**

The recommendations of this study are directed towards climate research scientists, higher learning institutions, Government policy makers, and various professionals in all sectors that are affected by the adverse impacts of droughts.

Data for this study was carried out for the Dodoma region and further study can be done for a specific region for verification i.e. an individual country.

For the scientists: Further enhancement of the drought indices used in assessing drought in the study should be encouraged such that scenario development and modelling at regional and even local levels are explored aiming to have a good early warning mechanisms.

Different research institutions within Tanzania such as UDSM, SUA, UDOM, MIPANGO, ST JOHN and others should encourage collaborating together to determine what is needed to promote the awareness on drought and its impacts.

It is also recommended that research institution within the region work together to develop a regional data base or data assimilation capability that highlights drought severity using drought indices as well as satellite products for research colleges so as to create awareness of dough for intellectuals for further studies to be done in the region for improving early warning system.

Institution like TMA should participate fully in co-operation with the Government and non-governmental organization (NGO’s) in providing educational programmes on media to the community for them to be aware of the meteorological drought severity and how to deal with for the betterment of all regions which experience drought that hinder their economic development.

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## Appendix

R- Script for SPI

*setwd("/media/tunsume/")*

```
filenames<-list.files("/media/tunsume/","txt")
names<-unlist(lapply(filenames,function(tunsume)
strsplit(tunsume[[1]],"\\.")[[1]][1]))
vari<-vector(mode="list",length=length(filenames))
precip<-vari
tmin<-vari
tmax<-vari
for(file in 1:length(filenames)){
vari[[file]]<-read.delim(filenames[file],sep="",header=TRUE)
precip[[file]]<-matrix(vari[[file]][,1],ncol=12,byrow=TRUE)
Year<-1985:2012
precip[[file]]<-as.data.frame(cbind(Year,precip[[file]]))
colnames(precip[[file]])<-c("Year",month.abb)
tmin[[file]]<-matrix(vari[[file]][,2],ncol=12,byrow=TRUE)
tmin[[file]]<-as.data.frame(cbind(Year,tmin[[file]]))
colnames(tmin[[file]])<-c("Year",month.abb)
tmax[[file]]<-matrix(vari[[file]][,3],ncol=12,byrow=TRUE)
tmax[[file]]<-as.data.frame(cbind(Year,tmax[[file]]))
colnames(tmax[[file]])<-c("Year",month.abb)
}
```