# APPLICATION OF REMOTE SENSING IN DROUGHT MONITORING:
## The Case of Thyolo, Malawi.


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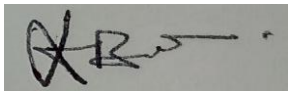
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## ABSTRACT

Remote sensing stands to be the most vibrant method that provides real time and large area data. It is more advantageous in drought monitoring than traditional methods. In instances, meteorological observations become unreliable in particular regions where scarcity of weather monitoring tools is problem. The study involved the extraction of advanced drought indicators from remotely sensed data to assess the drought occurrence in Thyolo. Such indicators include, Land Surface Temperature (LST), Normalised Difference Vegetation index (NDVI) and Vegetation Water Supply Index (VWSI). The study shows that many locations in the district experienced high temperatures for a prolonged period. There was also poor vegetation which predominated during the 2015/16 growing season. Most importantly, the study finds that the district was hit by drought during that season. The north, northeast, east and southeast locations were mostly hit by extreme drought. Such areas were the ones which were mostly hit by high temperatures for a prolonged period which led to vegetation failure. Furthermore, the study indicates that 40 %, 35 %, 10 % and 5 % of the areas were affected by severe, extreme, moderate and slight droughts respectively. Only 10 % of the area had normal conditions for health vegetation growth. Such being the case, I recommend the GoM to develop drought monitoring systems so that future drought cases are detected and initiatives must be put in place to minimize their likely adverse impacts to communities in the country as a whole.

**Key words;** Drought, monitoring, NDVI, LST, VWSI and Remote Sensing

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# I ABREVIATIONS

**GIS** : Geographical Information System

**IK** : Indigenous Knowledge

**GoM** : Government of Malawi

**LST** : Land Surface Temperature

**MVAC** : Malawi Vulnerability Assessment Committee

**NDVI** : Normalised Difference Vegetation Index

**OLI** : Operational Land Imager

**QGIS** : Quantum Geographical Information System

**USGS** : United States Geological Survey

**VWSI** : Vegetation Water Supply Index

# 1. CHAPTER 1. INTRODUCTION

## 1.1 BACKGROUND

Several scholars have provided different definitions for drought. Drought is a prolonged period of abnormally dry weather condition leading to severe shortage of water (Creswell & Creswell, 2018). Drought refers to the abnormal water shortage resulted from the imbalance of water budget (Benin et. al., 2008). Generally, most definitions entail that there is an imbalance in hydrological system that exists that leads to drying up of reservoirs, thus including the wells (Harikishan, 2013). When this situation changes to threaten human's daily life and living conditions, drought becomes drought disaster. Lack or deficit of precipitation is the major driving force and feature of drought and constitutes a serious threat for the protection of certain environments (MVAC, 2015). Specifically, drought periods extending in areal coverage and extensive in duration and severity result, among others, in disastrous heat waves and/ or extensive forest fires. It is recognized that droughts result in several significant impacts, which can be defined as direct and indirect (Engdaw, 2014).

Drought has become a recurrent phenomenon in several countries across the globe (Katharine, 2014). This has been so due to continuous climate change processes that are escalating the severity of such disasters. In instances, frequent and severe drought has become one of the most important natural disasters in sub-Saharan Africa and often results in serious economic, social, and environmental crises (MVAC, 2015). In America, recent assessments, show that drought has impacted different regions. Similarly to what has been said in the above paragraph, there exists prolonged abnormal dryness which leads to extensive losses in agricultural productions (Harikishan, 2013). The Northeast, Southeast, South, Mideast, High plains and the West regions are some of the regions that the drought has brought extensive destructions in different development sectors including the agricultural sector (Harikishan, 2013). In general, drought affects each and every continent across the world of which scarcity of precipitation stands to be common features that drives drought occurrence. Drought is a global disaster event that impacts 40% of the world's population (Creswell & Creswell, 2018). Over 55 million people

globally are affected by droughts every year and they are most serious hazard to livestock and crops in nearly every part of the world (Creswell & Creswell, 2018).

Now, in Africa as a whole, drought has been one of the most devastating events which has had several impacts to the continent's communities (Mukherjee & Samuel, 2016). Water shortages are the major threat and their impacts on Africa has been most devastating as compared with any other continents. SADIC (2016) identified that many countries in Africa suffer such events due to limited capacities. For example, people in Africa lack knowledge on how best they can handle such events to minimize their impacts. In most cases poor people are the ones that become most likely to suffer drought impacts (SADIC, 2016). Such people mostly lack financial capital for buying insurances that can help them to be shielded from losses that drought associates with. Some of such countries include, Malawi, Mozambique, Zambia, and Tanzania. Some of these countries in southern region report the occurrence of drought events almost every year (Creswell & Creswell, 2018). The impacts that these countries experience due to such disasters are mapped at all scales, thus the global, national and local scales.

Malawi is highly exposed to natural disasters of which drought has been the most devastating disaster. Available records indicate that in the last 100 plus years, the country has experienced over 20 droughts (Botolo, 2019). In the last 36 years alone, the country has experienced eight major droughts, affecting over 24 million people in total (MVAC, 2015). The impact, frequency and spread of drought in Malawi have intensified due to continual climate changes (Yared, 2018). Poverty stands to be the most common factor that leads to an increase in the impact that drought cause to many communities in the country (MVAC, 2015). Southern region suffers a lot among all regions in the country. Most drought episodes have occurred in El Nino years, during which the country experiences rainfall deficits (Katharine, 2014). During 2015/16 season there was extremely shortage of water for agriculture, forestry, human beings and living stocks, and a huge loss in local and national economy. Over 6.4 million people were left food insecure due to such drought (Botolo, 2019).

Drought monitoring is very important for the local government through its stakeholders to make some measurements to reduce losses and water supplying problems. Classic drought monitoring approaches are mostly based on the point-based data predominantly using meteorological observations and regional drought records (Guoyin, 2011). Such meteorological observations are centrally based in locations where for example that have weather stations (Benin et. al., 2008). Poverty being limiting factor for most countries, such stations are not evenly distributed and this increases the scarcity of real time data in areas that are subject to drought. Because of the characteristics that drought exhibit, remote sensing technology has become the most promising tool for large scale monitoring of drought. Remote sensing provides real time data and cover large areas thus increasing advantage over the meteorological observations (Abdullah, 2015). Furthermore, remote sensing data are continuous datasets consistently available and can be used to detect the onset of drought, its duration and magnitude. Generally speaking, there are different methods for drought monitoring using remote sensing (Yared, 2018). And among such different methods the analysis of vegetation and temperatures using vegetation and temperature indices is the method that the study employed.

In this study, VWSI, LST and NDVI were applied to monitor the drought events in Thyolo district. The aim of the study was to assess the occurrence of drought using advanced drought indicators derived from remotely sensed data. In what follows, the study area and data source are given, as are the methodology employed in the research. The results and analysis are then presented in form of index maps. The paper closes with preliminary conclusion and recommendations.

## 1.2 PROBLEM STATEMENT

Malawi had about 6.5 million people who were found food insecure during 2016/17 season (MVAC, 2015). This was due to bad weather conditions that were experienced during the 2015/16 growing season (Botolo, 2019). The southern region was affected most amongst all other regions during that period. Thyolo district among other districts in the southern region received less than average rainfall from November to December (Botolo, 2019). The situation worsened from January to March 2016, the most critical months for rainfed agricultural production (MVAC, 2015). The region had to receive 36.5 percent less than average rainfall, with Thyolo district having extremely below average rainfall at this period (MVAC, 2015). Furthermore, the event also affected some other districts in the southern region which include Nsanje, Chikwawa, Blantyre and Mwanza. Phalombe and some parts of Chiradzulu were also affected by such phenomena. The 2015/16 agricultural season was greatly affected by strong El Nino conditions (Botolo, 2019). In particular, Thyolo experienced a delayed start of the 2015/16 agricultural season by two to four weeks followed by erratic and below average rains in November and December 2015 (MVAC, 2015). Prolonged severe weather resulted in severe crop failure in the district. The drought was characterized as an agricultural drought (MVAC, 2015), as in large parts of the district precipitation commenced too late and was too erratic or occurred over a short period of time. In response to the situation, the GoM just declared a state of disaster in April 2016 in order to seek help from local and international assistant stakeholders.

## 1.3 OBJECTIVES OF THE STUDY

The main objective is to assess the occurrence of (2015/16 growing season) drought using advanced drought indicators derived from remote sensing data in Thyolo district.

Specifically the study wanted;

- To analyse the vegetation health as a proxy to drought throughout the growing season.
- To analyse the land surface temperature distribution as a proxy to drought throughout the growing season.

- To classify the level of the drought distributed in different locations throughout the season.

## 1.4 RESEARCH QUESTIONS

The research answered the questions on;

- The distribution of trending vegetation of the study area.
- The distribution of trending temperatures in the area.
- The drought level distribution, particularly during the growing season.

## 1.5 SIGNIFICANCE OF THE RESEARCH

This scientific approach to drought monitoring provides a way out to issue warnings of drought cases in timely manner despite the scarcity of monitoring tools in terms of restricted data availability for specific locations in the area (Thenkabail, 2015). In so doing, decision makers will be taking appropriate actions in a timely manner, reduce the impact of drought conditions, and mitigate drought's adverse effects on the environment (Guoyin, 2011). This effort is indicated to be one of the climatic change mitigation efforts for countries that have been affected by recurrent droughts in the past. So, if these events are being monitored and people are being communicated on the pending droughts and their consequences, they will try as much as possible so that they find means to reduce the risks that the events may associate (Yared, 2018). This helps in the building of resilient community by the end of the day. Thus the communities that are subject to drought cases within the area shall now be able to absorb the stresses that drought puts on their lives. Thus the communities will be able to practice agricultural or whatever activities done to be food secured.

# 2. CHAPTER 2. LITERATURE REVIEW

## 2.1 DROUGHT

Drought is the second from floods, the most widely distributed disaster on the earth's land. Global damage of the drought per annum is estimated to be $6-$8 billion (Mukherjee & Samuel, 2016). The frequency and intensity of the drought is increasing in different parts of the world. Drought is categorized into two main classes when the amount of precipitation is smaller than the normal or the average amount over the region and identifying the severity, when it starts and ends (Engdaw, 2014). Drought occurs when rainfall amount is below the average or when the amount of water that evaporates from the soil and water bodies and transpiration from plants is high. Rainfall records, compared to climatology are the first evidences either drought is occurring or not, and consequently the soil moisture starts to drop if the amount of rain falling is decreasing. Drought exists in four categories which include; meteorological, hydrological, agricultural, and socio-economical droughts. Yihdego (2017) says these types of drought occur because of the following reasons;

- When precipitation for a period of the time (monthly or seasonal) falls below the average, the meteorological starts.
- When the shortage of precipitation leads to shortage of ground and surface water, the hydrological drought starts.
- When the available moisture for the successful growth of crops is not sufficient and consequently their yield reduces, the agricultural drought starts.
- When shortage of precipitation starts to affect the economy and socio-political growth in an area, socio-economic drought starts.

## 2.2 DROUGHT MONITORING

Mukherjee and Samuel (2016) presented interests to gather the information about drought through the process of monitoring which is said to be a most sure way through which decision makers can rely on during the management of such event to reduce its adverse impacts to communities. Severally, the activity is performed either using the scientific approaches done either through application of remote sensing or in situ data analysis processes (Mukherjee & Samuel, 2016). The indigenous techniques are mostly

applied by local people. Remote sensing is one of the scientific approaches that most people take to monitor drought. Generally, there are three different ways for drought monitoring using remote sensing (Botolo, 2019). 1), detecting soil moisture using remote sensing, and then the drought condition is derived using relationship between soil moisture and drought; 2) Since vegetation developing status was found to be sensitive to water stress, vegetation index is regarded as the indicator of the drought condition, such as NDVI and other vegetation indices including, Atmospherically Resistant Vegetation Index (ARVI) and Soil Adjusted Vegetation Index (SAVI). If vegetation index is calculated from satellite images, drought condition is acquired based on the empirical relationship between vegetation index and drought, 3), like vegetation index, land surface temperature (LST) is also sensitive to drought phenomenon (Mukherjee & Samuel, 2016). LST is a good indicator of the energy balance at the earth's surface processes on regional and global scales (Botolo, 2019). On the indigenous part, drought is monitored based on the knowledge of local people about the system (earth) and its elements behaviors (Dube & Sekhwela, 2008). This chapter reviews both the scientific and indigenous approaches that different researchers have used to monitor drought events.

### 2.2.1 REMOTE SENSING TECHNIQUES OR SCIENTIFIC APPROACH

Most of the quantification of drought is accomplished through drought indicators, which are variables describing drought features, such as magnitude, duration, severity, periodicity, areal extent, onset, and end time (Mukherjee & Samuel, 2016). Primary data for meteorological, agricultural, or hydrological drought indicators are climate variables, such as temperature and precipitation, stream flows, soil moisture, reservoir storage, groundwater levels, snow pack, and vegetation (Mukherjee & Samuel, 2016). It is on these variables where all indicators are built on to detect whether an area is experiencing or experienced a drought.

The NDVI is the most drought indicator that most individuals or organisations use when monitoring drought. To come up with desirable goals, different methods are used. The NDVI in remote sensing are applied by comparing the deviation of the current satellite

observation from the historical average within a certain time period, or window, of interest (Mustafa & Mustafa, 2017). In the analysis of droughts, the onset, duration, and severity is somehow a tough work, thus it is difficult to determine and characterize the varying impact that the event had from one region to another using the index. So, this index has to be combined with other indices in either way to have valid results during various assessments.

Another index that is mostly used is the LST. In order to calculate emissivities and LSTs, the study area is classified as several land cover types (Mukherjee& Samuel, 2016). Nevertheless, drought indices are easy to implement and extensively used in drought quantification and assessment. In evaluating the overall utility of indices, a set of weighted decision criteria is usually assigned to each index that are based on desirable properties of each index, namely, robustness, tractability, transparency, sophistication, expendability, and dimensionality (Mukherjee& Samuel, 2016). The criteria taken to monitor drought provide a reasonable framework for the evaluation of drought indices without excessive complication.

It is clear that the criteria weights, which reflect the relative importance of the evaluation criteria, are difficult to be precisely justified. Some vegetation indices exhibit drawbacks when it comes to drought monitoring. For instance, the main drawback using LST to detect drought is that it is quite difficult to normalize the variation of daily meteorological conditions such as net radiation, air temperature, wind speed, humidity, which affect daytime thermal measurements. So the vegetation index and LST are combined to evaluate drought status in most cases. Guoyin (2011) identified a combined method (Vegetation Water Supply Index) to monitor drought. This method combines the Normalised Difference Vegetation Index and Land Surface Temperature to avoid problems that are met when validating the results when each indices is applied independently.

### 2.2.2 INDIGENOUS KNOWLEDGE (IK)

The terms IK, also called traditional ecological knowledge or local knowledge and local ecological knowledge (Gilchrist et al. 2005) are used to refer to knowledge that are location specific, acquired through long-term observation of (and interaction with) the environment, and transferred through oral traditions from generation to generation. This involves the methods and practices developed by a group of people from an advanced understanding of the local environment, which was formed over numerous generations of habitation. Dekens (2007) proposed a framework of IK on disaster risk reduction and argues that IK is based on; 1), Observation, thus people's experience of the local surroundings (history of natural hazards, nature of natural hazards, evolution of social and physical vulnerabilities to natural hazards).2), Anticipation, thus people's ability to identify and monitor the environmental indicators (early warning signals, time thresholds, escape route and safe places for humans and animals, key actors and skills). 3), Adaptation, based on people's access to assets and their ability to learn, self-organise and innovate (human, sociocultural, institutional, financial, natural and physical assets) 4), Communication, thus people's ability to transfer knowledge among themselves and between generations (oral and written communication, early warning systems, other practices). It is through these four aspects highlighted in the framework people monitor the drought events. The following are the reasons why people use indigenous knowledge and practices (Gilchrist et al. 2005);

- Source of "knowledge, innovation and education to build a culture of safety and resilience at all levels.

- The resilience of communities facing disasters can increase when new and old techniques and knowledge are combined.

- Indigenous people's knowledge provides information and insight that complement conventional science and environmental observations.

- Important in planning for community development thus indigenous local communities can use knowledge as a planning tool.

Lesnoff, Corniaux and Hiernaux (2012) identified that though the contribution of IK to climate change (direct phenomenon related to drought) research are still few, the contributions of IK to understanding and interpreting ecological processes, and for use in environmental and social impact assessments is widely acknowledged. These contributions can be related to climate change mitigation and adaptation activities as human activities in the ecological sphere like reforestation can reduce green-house gas (GHG) emissions while the adoption of drought tolerant seeds for example may improve adaptation.

The few existing studies on the contributions of IK to climate change research show that IK and science can complement each other (Luseno et al. 2012) through the different types of data collected, the different scales of analysis and the temporal scales at which both forms of knowledge are generated. Studies show that IK can contribute to fill gaps in formal seasonal forecasts, which are largely at broader spatial and temporal scales (Luseno et al. 2012). Luseno et al. (2012) suggest that indigenous climate forecasting methods can offer insights to improving the value of modern seasonal forecasts for pastoralists in East Africa as indigenous forecasting methods are need driven, focus on the locality, on the timing of rains, and indigenous forecasts are 'communicated in local languages and typically by "experts" known and trusted by pastoralists' (Luseno et al. 2012).

Yet no generalisations can be made about the spread in the use of IK in climate related issues (for instance drought monitoring). The local people interpret the surrounding environment based on the observations at particular time and place (Dube & Sekhwela, 2008). In instances, the pastoralists in southern Ethiopia and northern Kenya still widely employ an extraordinary variety of indigenous forecasting methods like observing clouds, stars, wind, lightening and the behaviour of animals and (Roncoli et al. 2000) says that local forecasting knowledge seems to be less widely used than in the past. Luseno et al., (2012) attributed the high confidence to the wide variety of indigenous forecasting methods that the pastoralists use: the focus on climatic features of interest to the

pastoralists like the onset of rains, the small spatial resolution of the indigenous forecasts, their communication in local languages by recognised 'local experts' in the community and the accessibility of the indigenous forecasts compared to the forecasts by the meteorological agencies.

Despite the fact that indigenous knowledge helps local communities to be self-reliant when it comes to the management of drought hazards, it has a number of draw backs that lessen the weight in their contributions to the modern world (Dube & Sekhwela, 2008). The IK lacks documentation among other disadvantages which put many communities at failure to sustain it.

To sum up, both indigenous and scientific techniques (remote sensing technologies) need to be acknowledged when monitoring drought events. As for the indigenous knowledge it complements the scientific approaches taken to monitor or carryout any other assessments which involve community members especially the vulnerable or those affected by the disaster negative impacts.

# 3. CHAPTER 3. METHODOLOGY

To meet the desired objectives, the study involved the extraction of NDVI, LST and VWSI from remotely sensed data. Drought is a virtual geographic entity (Guoyin, 2011), such that it requires passive sensors to monitor it. In this study, the VWSI was used to monitor the drought. This method combines the NDVI and the LST (Showalter, 2001). The values of satellite image indices were used to describe the conditions that increase the likelihood of drought occurrence. The notion of virtual GIS techniques is applied in the real identification and analysis of situations in this research. For automatic interpretation of remotely sensed pictures, the GIS employs the knowledge base that is built in the system (Zlatanova & Li, 2008).

## 3.1. STUDY AREA

The study was conducted in Thyolo district as it is the one of the districts that suffered food insecurity during 2016-2017 season in the southern region. The district is located in the southern region of Malawi at 13°30′ South latitude and 34° East and covers an area of 1,715 km² (Katherine, 2014). According to Katharine (2014), the wet season is muggy and mostly cloudy, the dry season is mostly clear and its warm year around and over the course of the year. The temperature typically varies from 14$^0$C to 30$^0$C and is rarely below 13$^0$C or above 35$^0$C (Katharine, 2014). The hot season lasts for 2.4 months from September 23 to December 2, with an average high temperature above 28$^0$ C (Katharine, 2014). The cool season lasts for 2.2 months, from June 2 to August 9, with an average daily high temperature below 24$^0$ C (Creswell & Creswell, 2018). The average percentage of the sky covered by clouds experiences extreme seasonal variation over the course of the year (Katharine, 2014). The cloudier part of the year begins around November 15 and lasts for 4.4 months, ending around March 28 (Katharine, 2014). A wet day is one with at least 0.04 inches of liquid or liquid-equivalent precipitation (Creswell & Creswell, 2018). The chance of wet days in Thyolo varies very significantly throughout the year (Katharine, 2014). The wetter season lasts for 4.2 months, from November 23 to March 28, with a greater chance of a given day being a wet day

(Creswell & Creswell, 2018). The chance of wet day peaks as 72% on January 18 and drier season lasts 7.8 months, from March 28 to November 23 (Katharine, 2014).

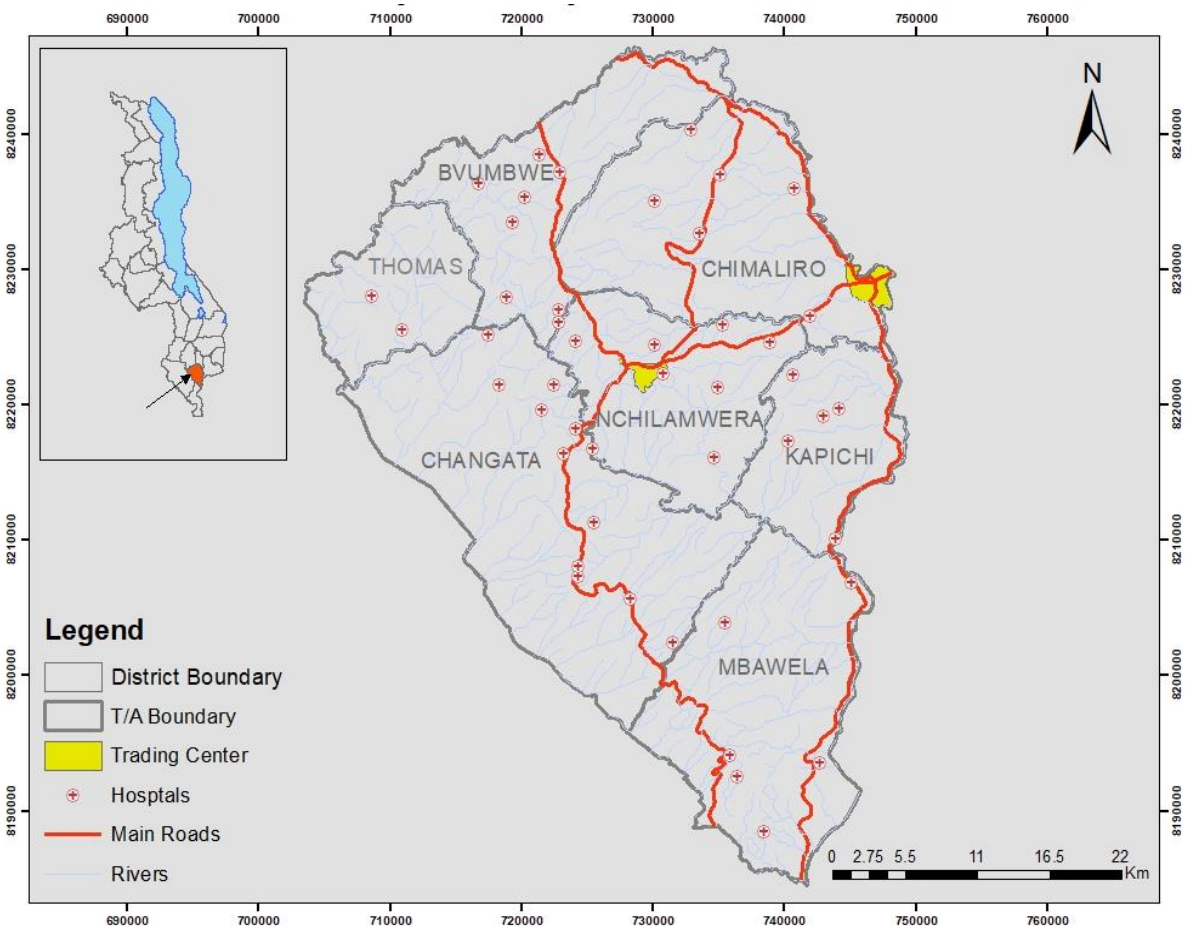



**Figure 1.** Map of Malawi and polygon map for Thyolo district illustrating district and T/A boundaries, trading centers, hospitals, main roads and rivers.

## 3.2. DATASETS AND DATA COLLECTION

The data (Landsat 8 images) was downloaded from the USGS website. USGS website provides free datasets. To access the data, a person requires an account that you create for free to get registered. The Landsat 8 type of images were selected because the images provide the most vibrant datasets nowadays due to technological evolution that has taken place (Harikishan, 2013). Gao (2008) identified that images selected for NDVI, LST and VWSI parameter calculations should not be containing large surface cloud coverage percentages. This helps to reduce the risk of compromising the results (Gao, 2008). And

no wonder in this study, only images that had minimal percent land surface cloud coverage were selected.

**Table 1.** Illustrates a summary of the dataset used and it characteristics.

| Image no. | Satellite Data | Path/row (Km) | Spatial resolution (m) | Temporal resolution (Days) | Date of acquisition | Cloud cover (%) | Source |
|---|---|---|---|---|---|---|---|
| 1 | Landsat $^{OLI}$2018 | North to South, at altitude of 705Km | 30 | 16 | 5 December, 2015 | 0.01 | USGS |
| 2 | Landsat $^{OLI}$2018 | North to South, at altitude of 705Km | 30 | 16 | 7 January, 2016 | 1 | USGS |
| 3 | Landsat $^{OLI}$2018 | North to South, at altitude of 705Km | 30 | 16 | 9 February, 2016 | 0.1 | USGS |
| 4 | Landsat $^{OLI}$2018 | North to South, at altitude of 705Km | 30 | 16 | 21 March, 2016 | 1.5 | USGS |
| 5 | Landsat $^{OLI}$2018 | North to South, at altitude of 705Km | 30 | 16 | 6 April, 2016 | 1 | USGS |

The five images were selected to focuses the target growing season that prevails in the district most of the times. The OLI sensors were the preferred sensors as they measure in near infrared and short wave infrared portions of the spectrum (Gao et. al., 2008). Such

being the case, they provide data suitable for calculation of the NDVI, LST and VWSI parameters. Before using the data to calculate the NDVI, LST and VWSI, two pre-processing steps were undertaken. (1) Cloud screen: to remove the cloud influences, cloud screening was performed in the study area. The near infrared reflection method was used in this paper. (2) Water body removing: because I was focusing on the land surface, so the water bodies were removed before calculating NDVI and VWSI.

## 3.3. MATERIALS AND METHODS

After the execution of the steps to preprocess the data, the calculation of the NDVI, LST and VWSI was done using the ArcGIS, QGIS and ArcMap software using the following formulas in the following sections.

### 3.3.1. Normalised Difference Vegetation Index Calculation

$$NDVI = (NIR - RED) / (NIR + RED) \quad \text{..... (I)}$$

Where NIR and Red are reflectance in near infrared and red bands of the satellite imageries, respectively. It is a non-linear function that varies between -1 and +1 and it's undefined when both NIR and Red are zero. NDVI values for vegetated land areas generally range from approximately 0.1 to 0.7. Values greater than 0.5 indicate dense vegetation, whereas values lower than 0.1 indicate near zero vegetation such as barren area, rock, sand, or snow.

### 3.3.2. Land Surface Temperature Calculation

Drought is associated with high temperatures that in most cases generate heat waves in areas of impact (Gao et. al., 2008). As this situation persists, the area suffer a lot of problems which include, water supply problems, severe crop failure and other primary and secondary effects. The areas with a continuous trends pf high temperatures are the ones that mostly suffer severe crop failure among other problems during the growing season.

### 3.3.2.1. Data preprocessing stage for temperature calculation

To calculate the LST with Landsat 8 satellite images, the following operations are done to preprocess the data (Bao, 2011).

Firstly, the TOA (Top of Atmospheric) spectral radius is calculated as follows;

$$TOA\ (L) = M_L * Q_{cal} + A_L \quad \text{(II)}$$

Where;

$M_L$ = Band specific multiplicative rescaling factor from metadata (RADIANCE_BAND_X, where X is a band number)

$Q_{cal}$ = corresponds to band 10

$A_L$ = Band-specific additive rescaling factor from the metadata

$$TOA = 0.0003342 * \text{“Band 10”} + 0.1 \quad \text{(III)}$$

Secondly, the TOA is converted to Brightness Temperature.

$$BT = (K_2/ (\ln (K_1/L) +1))-273.15 \quad \text{(IV)}$$

Where;

$K_1$ = Band specific thermal conversion constant from metadata (K1_CONSTANT_BAND_X, where x is the thermal band number)

$K_2$ = Band-specific thermal conversion from metadata (K2_CONSTANT_BAND_X, where x is the thermal band number)

L = TOA

Therefore, to obtain the result in Celsius, the radiant temperature is adjusted by adding the absolute zero, which approximately is -273.15$^0$C.

$$BT = (1321.0789 / \text{Ln} ((774.8853/ \text{“\%TOA\%”}) + 1))- 273.15 \quad \text{(V)}$$

Thirdly, you calculate the NDVI using equation (I).

Furthermore, the proportion of vegetation $P_v$ is calculated as follows;

$$P_v = \text{Square}((NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min})) \quad \text{.....(VI)}$$

Where; $NDVI_{min}$ and $NDVI_{max}$ are the minimum NDVI and maximum NDVI values respectively.

Then the Emissivity is calculated as follows;

$$è = 0.004*P_v + 0.986 \quad \text{..... (VII)}$$

### 3.3.2.2. Land Surface Temperature calculation stage

Finally, the LST is calculated using the equation below;

$$LST = (BT/(1+(0.00115*BT/1.4388)*Ln(è)) \quad \text{.....(VIII)}$$

Therefore, the LST equation is then applied to obtain the Surface Temperature Map.

### 3.3.3. Vegetation Water Supply Index Calculation

According to Bao (2011), the principle of VWSI states that when the water supply is sufficient, the vegetation grows normally while the vegetation index observed by satellite remote sensing will remain within a certain reasonable range during the stated growing period, so will the canopy temperature of the crop. In case of drought, the growing of the vegetation is affected due to insufficient water supply, hence a reduced vegetation index detected by the satellite (Benin et. al., 2008). With insufficient water absorption, leaf surface transpiration will be decreased as a result of the self-protective closing of the leaf stomata, which, in turn, increases the leaf and canopy temperatures. According to Zhu (2010), the ratio of vegetation index and canopy temperature can show the state of water supply for vegetation: the greater the ratio is, the sufficient the water supply is, and vice versa. Zhu (2010) defined the ratio as vegetation water supply index, and the expression is:

$$VWSI = (NDVI) / (LST) \quad \text{(IX)}$$

Where, NDVI, Normalized Difference Vegetation Index; LST, Land Surface Temperature. The highest temperature of the year is usually between 14 $^0$C and 30 $^0$C and between 7 $^0$C and 28 $^0$C in the growing season (Katharine, 2014).

Currently Malawi, through its drought early warning systems has not yet developed indicator (including the VWSI) thresholds for drought classification (Botolo, 2019). Instead, the study used the thresholds below ratified by China (Bao et. al., 2011).

**Table 2**. Illustrating VWSI thresholds and drought classes.

| VWSI Threshold | Drought class |
|---|---|
| ≤ 0.008 | Extreme drought |
| ≥ 0.008 ≤ 0.0098 | Severe drought |
| ≥ 0.0098 ≤ 0.012 | Moderate drought |
| ≥ 0.012 ≤ 0.025 | Slight drought |
| ≥ 0.025 | Normal |

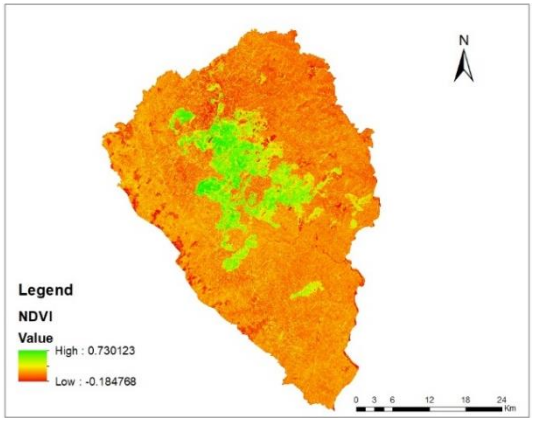
# 4. CHAPTER 4. RESULTS AND DISCUSION

## 4.1. RESULTS

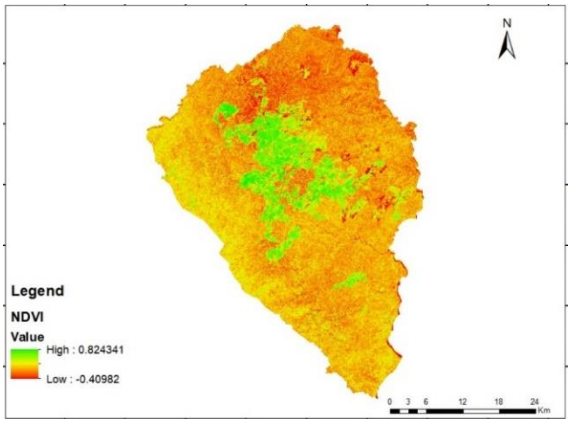
### 4.1.1. Vegetation Health of the area

The NDVI result for figure 2 (a) shows that most locations experienced poor vegetation health. With an exception of most central locations that show that there was normal vegetation, the inner northeastern and northwestern marginal areas had poor vegetation. The figure 2 (a) also indicates that there was relatively less vegetation failure in the south compared to the inner northeastern and northwestern marginal areas.

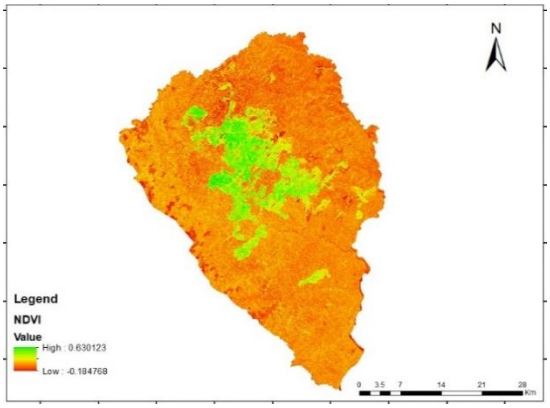
2015-2016 GROWING SEASON NDVI MAPS



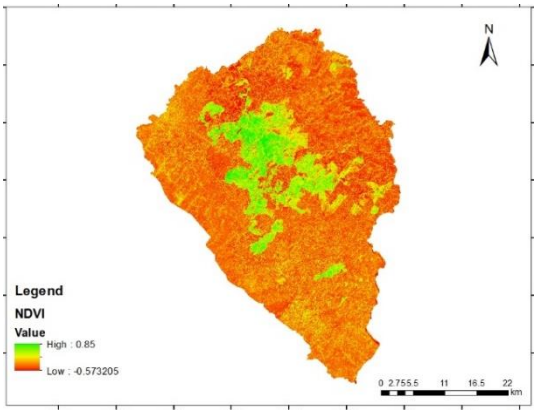

(a)



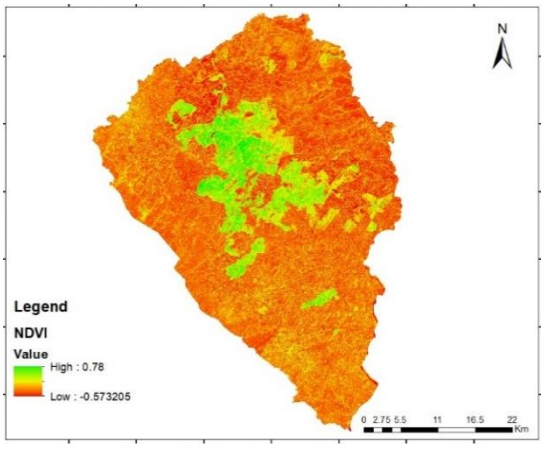

(b)




(c)




(d)




(e)

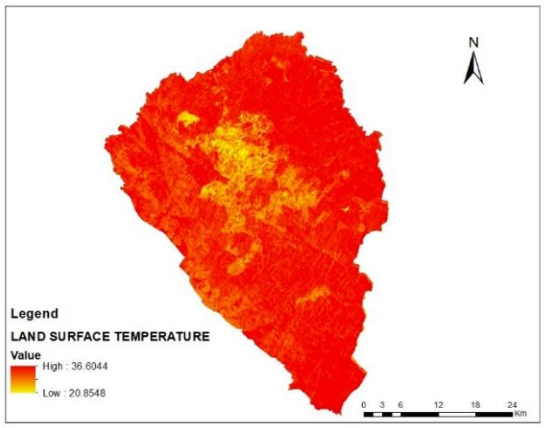
**Figure 2.** (a) NDVI for 5 December, 2015, (2) NDVI for 7 January, 2016, (c) NDVI for 9 February, 2016, (d) NDVI for 21 March, 2016 and (e) NDVI for 6 April, 2016.

The NDVI result for figure 2 (b) shows that the north and inner northeast locations were the ones that had the highest vegetation failure as compared to all other locations in the district. It is the central part that had good vegetation. The northwest, west and southern parts show that there was relatively considerable vegetation as compared to the north and inner northeast locations. The figure 2 (c) shows that the marginal locations in the west as well as northwest and, southwest had poor vegetation. The central part shows good vegetation while the northeast had poor vegetation. And all other locations show considerable vegetation as compared to other locations that had poor vegetation.
The figure 2 (d) shows that the north and northeast locations are the ones that mostly suffered vegetation failure. It is at the central part that shows that the area had good vegetation. All other locations show that the vegetation failure was not that much as compared to the north and northeast areas. And figure 2 (e) for the NDVI shows that there was slight difference in many locations as compared to results shown in figure 2 (d).

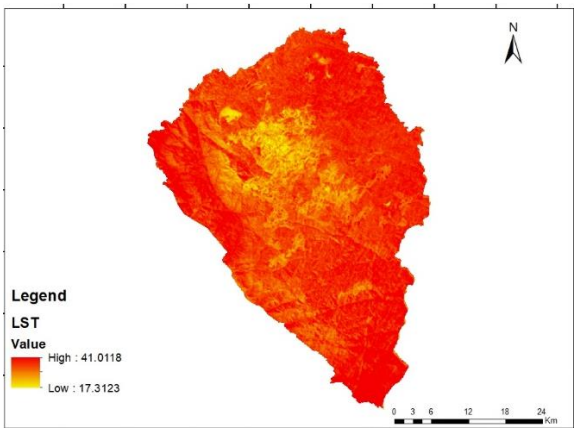
4.1.2 Land Surface Temperatures of the area

The figure 3 (a) shows that the north, northeast, southeast and south locations experienced higher temperatures than any other locations in the district. It is only the southwest, west and mostly the central part that show relatively lower temperatures.

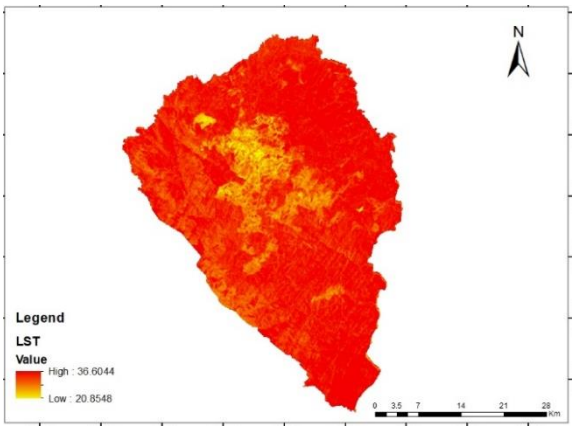
## 2015-2016 GROWING SEASON LST MAPS



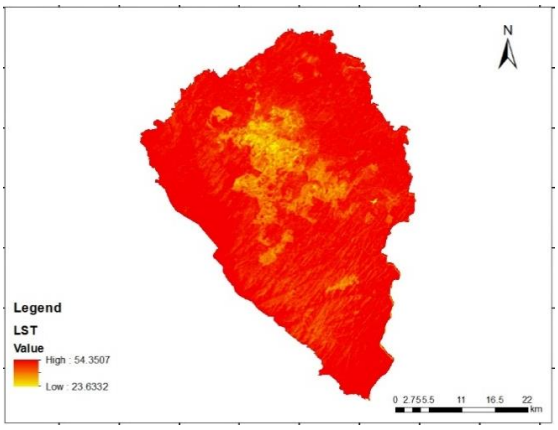

(a)



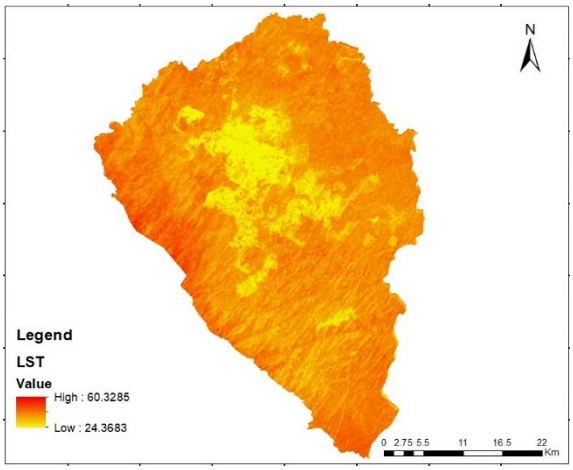

(b)




(c)




(d)




(e)

**Figure 3.** (a) LST for 5 December, 2015, (2) LST for 7 January, 2016, (c) LST for 9 February, 2016, (d) LST for 21 March, 2016 and (e) LST for 6 April, 2016.

The figure 3 (b) shows that the central and southwest locations experienced relatively lower temperatures as compared to all other locations. The result shows that most locations (thus including west, northwest, north and south locations) were in high temperatures. The figure 3 (c) shows that there was a slight difference from the figure 3 (b) output. The central and many locations other in the northwest, west, southeast and southern had considerable lower temperatures as compared to all other locations in the district. The figure 3 (d) shows that many locations except the central and southwest locations were in high temperatures. The figure 3 (e) shows that there were high temperatures in the marginal west, southwest and south locations. At this time many other location's (including the central part) temperatures were low.

4.1.3. Drought Class Characterising Conditions

**Table 3.** Indicates the VWSI ranges.

| COLOUR | RANGE | CONDITION |
|---|---|---|
| Purple | -0.0116-0.0074 | Extreme |
| Red | 0.0074-0.0096 | Severe |
| Orange | 0.0095-0.0132 | Moderate |
| Yellow | 0.0132-0.0186 | Slight |
| Green | 0.0186-0.0305 | Normal |

2015-2016 GROWING SEASON DROUGHT CLASSIFICATION VWSI MAP

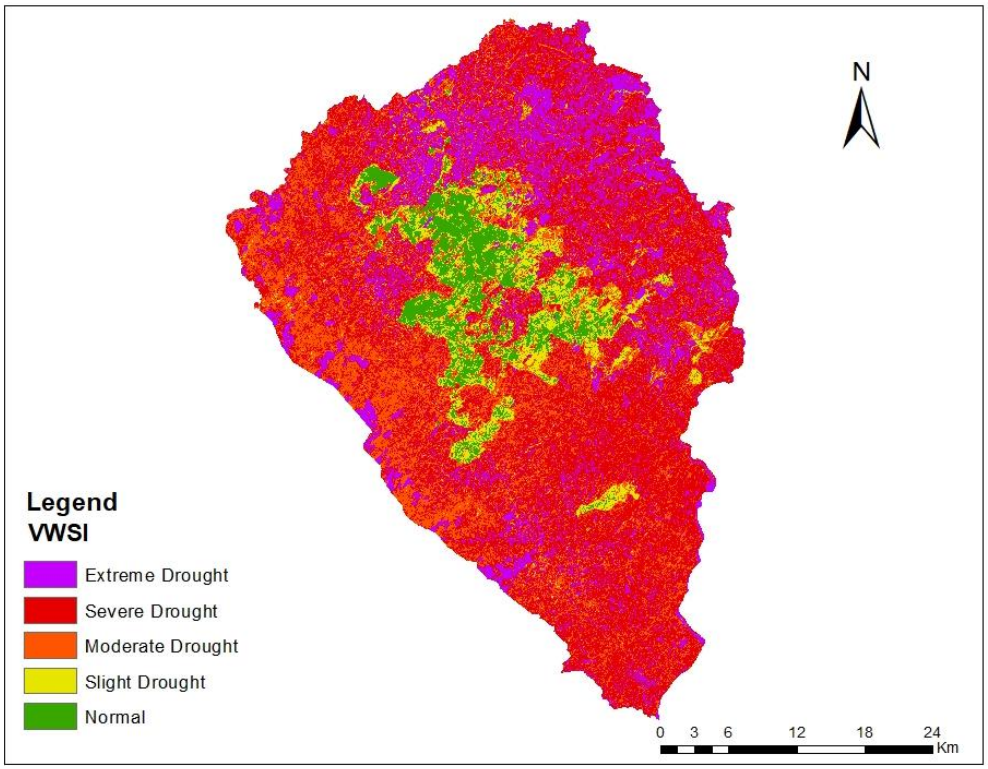



**Figure 4.** VWSI output.

The figure 4 shows that most parts were subject to severe conditions, thus including the northern, southern, eastern and western locations. Among all these locations there existed other locations that were in moderate slight and worst (extreme) conditions

during the season. The north, northeast, east and southeast locations were the locations that were mostly hit by extreme conditions.

## 4.2. DISCUSSION

The lower surface cloud cover percentages that prevailed during the season reflect the NDVI, LST and VWSI results got in this study. It shows that the season was dominated with almost clear skies which made the surface temperatures increase resulting into poor vegetation. Refer to dataset summary in table (1) above for surface cloud cover percentages of the data that was used in the study. Lack or deficit of precipitation was the major conditioning force for poor vegetation that was experienced in the district. The high temperatures and less cloud coverage that the season mostly experienced had an impact on the district. The district was subject to receive insufficient rainfall resulting into poor vegetation. Basu (2005) identifies increasing temperatures as conditioning factors for drought occurrence. Increased surface temperatures interfere with the hydrological cycle. Such temperatures create the imbalance in the cycle in such a way that they lead to drying up of reservoirs. The hydrological imbalance also leads to reduction in the ground water, thus increasing the threat of crop failure that the district suffered. Increased temperatures result into increased amount of surface and ground water that escape into the atmosphere. Evapotranspiration is the process that feeds the atmosphere with water inform of vapor that condense to form clouds (McIlveen, 2010). Clouds are defined as a collection of water droplets (McIlveen, 2010). When such a collection increases in amount it results into rainfalls. So, when the water that falls onto the ground in any forms of precipitation is less than the water that escapes into the atmosphere, there becomes an increased risk of drought occurrence. Such cases increase due to persistent or long duration high surface temperatures (Basu, 2005).

The VWSI results simply complements the results that the study revealed about the temperatures and vegetation growth in the district. The VWSI only indicates that there had been variations from location to location interms of how the temperatures and poor vegetation growth escalated the drought risks in the district. Based on the principle of VWSI, it shows that many parts of the district had to undergo a water deficit. Such being

the case, there was increased chances for drought occurrence because many parts had no enough ground water supply for health vegetation.

# CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

## 5.1. CONCLUSION

The study shows that the maximum average NDVI was 0.7634 and minimum average NDVI was -0.3852. The maximum average LST of the district was 45.7800$^0$C whereas the minimum average temperature was 21.4047$^0$C. The vegetation and temperature distributions that predominated in the district entail that there was water deficit in the district during the 2015-2016 season. And the VWSI takes us to a conclusion that there was indeed a drought during the 2015-2016 season. Such an event reflects the food insecurity that most people in the district suffered during the 2016/17 season. The figure (5) below summarises the drought classes that the district experienced during the 2015-2016 season.

### 2015-2016 GROWING SEASON DROUGHT CLASSIFICATION CHART

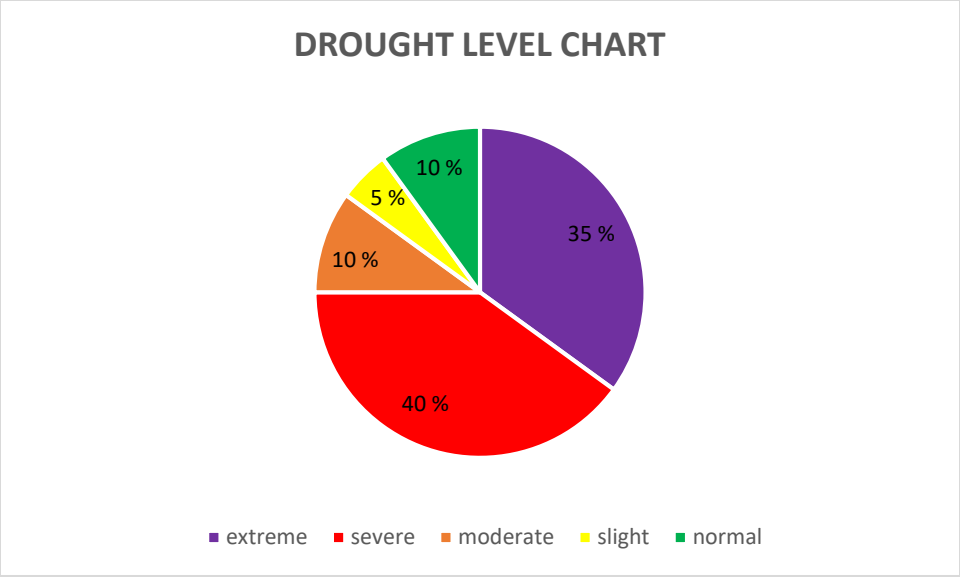



**Figure 5.** Pie chart illustrating the percentage of the land in which each drought level covered in the district.

Using the chart, it indicates that 40% of the land in the district was hit by severe drought whereas 35%, 10% and 5% of the land was hit by extreme, moderate and slight

droughts respectively. And only 10% of the land experienced normal conditions with good vegetation health.

## 5.2. RECOMMENDATIONS

It is recommended that the GoM together with other co-stakeholders works in hand so that it takes proper initiatives for minimising the adverse impacts that the event caused in the district. Furthermore, a drought monitoring system should be developed to detect the drought status and give some prediction for the future possible drought. This might be helpful for the local government and farmers to make some measurements to decreasing losses. The government can be subsidizing the farm inputs so that people, mostly the most vulnerable ones to prevent themselves from food insecurity. For further studies, the fellow researchers can add any other two or more indices as it also helps to validate the conclusions that their studies can draw.

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