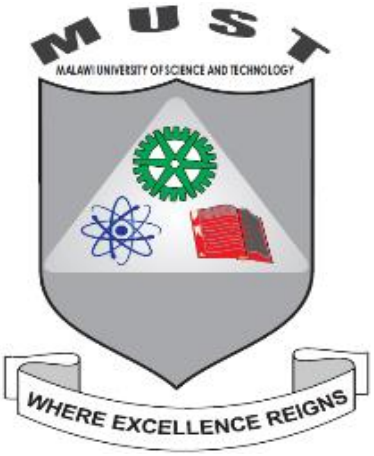


[INVESTIGATING THE RELATIONSHIP BETWEEN RAINFALL AND MAIZE CROP PRODUCTION IN MUBANGWE]

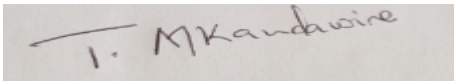
MKANDAWIRE TOWERA
Thyolo, Malawi

Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfilment of the requirements for the Bachelor of Science degree in Geo-information and Earth Observation Sciences

JULY, 2021

DECLARATION

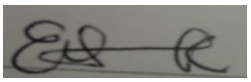
I TOWERA MKANDAWIRE declare that this research project represents my own work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

Signature ___  _____

Date 16TH JULY 2021

DISSERTATION APPROVED BY:

SUPERVISOR:

Mrs. Enelles Nsamila Signature: 

ASSESSOR:
Title, Initials, Name Signature: _____

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ABSTRACT

Most countries in South-Eastern Africa are described by large variability in rainfall in addition to the occurrence of prolonged and severe drought, starvation, and building destruction. The scientific evidence on rainfall variability with its significant impacts on crop yield is stronger than ever (FAO, 2015). The research analyzed the relationship of rainfall variability and Maize crop production in Mubangwe- Mzimba district, Malawi for the period 2015-2020. Maize serves as a staple food in Malawi including the Mzimba district. The specific objectives of this study were; to identify rainfall trends for Mubangwe, to analyze the Normalized Difference Vegetation Index for Mubangwe using Landsat 8 imagery, and to examine the impacts of rainfall on Maize crop production. The climatic parameters used include annual rainfall for the growing season that is from Nov to April. The descriptive method was used relying on secondary data. Rainfall data for the past 5 years (2015-2020) was collected from the department of climate change and meteorological service of Malawi (Blantyre). Maize crop data were collected from the Agricultural office for the same period. The rainfall data collected were analyzed using Microsoft Office Excel 2010, SPSS, and R studio (version 3.60). Correlation and regression analysis were used on the data sets. The study found out that rainfall varies (678.3mm-1372.0mm) from one year to other and from place to place over a while. The results show that there is a strong significant between rainfall and Maize crop production where the value of $r = 0.92975$, at $p = 0.02211$ for maize crop yield. Therefore, this research concluded that geographical information systems are sufficient tools that should be explored further for a realistic assessment of the effects on the climate of farming activities.

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If it were not for the almighty God to give me power and blessings, this work would not have been completed, May the Lord be Magnified, Psalm 32:8-9.

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ACRONYMS/ABBREVIATIONS

NDVI : Normalized Difference Vegetation Index

ENVI : Environmental for Visualizing images (image processing software)

GIS : Geographic Information Systems

GoM : Government of Malawi

ESRI : Environmental Systems Research Institute

TM : Thematic mapper

MSS : Multispectral Scanner

QGIS : Quantum GIS

USGS : United State Geological Survey

SPSS : Statistical Package for Social Science

STD : Standard

JAN : January

FEB : February

MAR : March

APR : April

NOV : November

DEC : December

T/A : Traditional Authority

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1. INTRODUCTION

1.1. Background of the study

Rainwater variability impacts assessment is the way of looking at the range of consequences of a given rainfall event or change (Adejuwon, 2004). According to Asejuwon and Odenkunle states that the scientific evidence on rainfall variability with its significant impacts on crop yields is now stronger than ever. There is increasing evidence that climate change is affecting rainfall variability and the frequency of extreme events such as drought, floods, and hurricanes (IPCC, 2007).

Rainfall is one of the meteorological parameters that affect virtually all human activities (Obot; Chendo; Udo and Ewona, 2010). Crop production is affected by rainfall which is a country or an area receive. According to (Olatunde,2012), the availability or non-availability of rainfall is normally employed to determine the level of wetness or dryness during the growing season which makes rainfall the single most important element of the climate system affecting the agricultural and water resource management of any region.

A lot of studies on the relationship between rainfall variability and crop production are called using a different model for instance model-based simulation. To relate rainfall variability and crop production using model-based simulation is not enough. Other studies on the impacts of climate variability on crop yield have been carried out in different parts of the world by Intergovernmental Panel on Climate Change (IPCC) and other scholars. Some of these studies show a significant relationship between these two parameters.

Generally, rainfall is the most important factor that influences agricultural activities, particularly in tropical regions. Rainfall can vary within a few kilometers distance and at different time scales. This implies that crop yield is exceedingly variable over space and time. And this brings effect in determining the crops that can be grown, the farming system, and the sequence and timing of farming pertain (Adejuwon, 2005). This helps to describe that the water that crops use during the season depends on

rainfall and in many areas the amount of rainfall is less than the amount of water that crop could transpire.

This study will model with GIS since GIS has become an efficient tool nowadays which is used in many fields and agriculture is not optional. Many types of research focused on the distributional patterns of the impacts of rainfall variability in terms of the Spatio-temporal impact of this modern GIS equipment. Landsat 8 imagery in this scenario is the one that will be used to describe the relationship between crop production and rainfall through the analysis of NDVI and NDWI. This study is important since there is no data for Mubangwe for the relationship of rainfall and crop production, this will help farmers, the agricultural sector including the government to have the data if they want to use it or referencing. To fulfill the sustainable development goal number 1, 2, and 8 which state about no poverty, no hunger, and decent work and economic growth respectively. The rainfall trends, Analysis of Landsat 8 imagery for the area through NDVI and NDWI analysis, and examining the relationship between crop production and rainfall will help to investigate the relationship between rainfall and crop production.

1.2 problem statement

Rainfall is one of the important factors that influence agriculture in most parts of the world including Malawi. According to (Osagie,2002), states that the zonal variability of rainfall is observed to bring about not only the difference in the type of crops cultivated but also the rate of yield of such crops. Rainfall variability leads to some areas receiving heavy or no rainfall resulting reduction of the crop yield to the farmer's hence increasing poverty. Rainfall impacts can result in the area having low or heavy rainfall to have low nutrients concentration as they are washed can be washed away, low water contents, floods and pest and diseases hence many parts of Malawi, agricultural production is affected by rainfall variability. In Mubangwe farmers lack information about how they handle these climates change challenges for them to increase crop production. Hence the impact of rainfall variability on crop production needs to be addressed with care to ways of adapting and mitigation measures. The use of GIS can help in investigating the relationship between rainfall

variability and crop production resulting in an area having information about rainfall and the production of crops since the department of meteorological services does not provide enough information about the climate of the area.

1.3 Research Questions

The study addresses the following questions:

- Is there any rainfall trend that exist in Mubangwe?
- Can NDVI be used to predict crop yields?
- Can rainfall have impacts on Maize crop production?

1.4 Research Objectives

To investigate the relationship between rainfall variability and crop production.

1.4.1 Specific Objectives

Specifically, the study attempts to

- To determine rainfall trend that affect Maize crop in Mubangwe.
- To predict crop yields using NDVI.
- To examine the impact of rainfall and Maize crop production in Mubangwe.

1.5 Research Hypothesis

The study hypothesizes that Rainfall plays a significant role in crop production and rainfall recorded annually in Mubangwe-Mzimba.

1.6 Significance of the Study

This will help farmers, the agriculture sector, and the government to have the data that will be used when it is needed and for referencing since there is data for Mubangwe. It will also help to fulfil some sustainable goals, for instance; no poverty, no hunger, and decent works, and economic growth after investigating the relationship between rainfall and crop production. The research will help to increase knowledge to farmers, agriculture sectors, and the climate and meteorology department. This research is intended to publish the findings of this study in an open-source journal which will add literature on the existing knowledge. Whereby satellite imagery data will be used to analyse the relationship between rainfall variability and crop production.

2. LITERATURE REVIEW LITERATURE REVIEW

2.1 Rainfall Trends

Malawi, in Southern Africa, is among the world's twelve most vulnerable countries to the adverse effects of climate change (The World Bank 2010), and farmers are affected directly by climate-related stressors such as floods, droughts, and dry spells (Chinsinga 2011). Because agricultural production is the main source of income for most rural communities, increased frequency of extreme events will increase the risk of production failure. Any changes in rainfall amounts, intensity, or temporal or spatial distribution would further threaten food security.

Assessment of rainfall variability plays a crucial role in various decision-making processes related to agriculture (Mathungama and Paris, 2011). The consideration of rainfall trends is very important because it helps to consider the amount of rainfall distributed seasonally at different spatial and temporal across Malawi. Most of the studies on inter-annual rainfall variability impacts on crop yield used model base simulations in their analysis (Tim, 2000). Nonetheless, to relate rainfall variability with actual crop yield, model-based simulations are not sufficient. So, modeling with GIS offers a mechanism to integrate many scales of data developed for agricultural research.

In addition, little systematic research has focused on the distribution patterns of the impacts of rainfall variability in terms of mapping the Spatio-temporal impact using modern GIS equipment. In agriculture, GIS maps are important since they provide means of a Spatial Decision Support System (SDSS) to plan crop planting schemes and to monitor yield rates.

2.2 Predicting Crop yields using NDVI

Several studies have explored drivers of changes in Malawi's climate seasonality. (Vrieling, 2013) reported a reduction in the length of growing period for Malawi over 1981–2011 using NDVI (Normalized Difference Vegetation). This suggests that

characterizing the effects of climate change on rainfall for much of Africa may not be evident in a single variable (e.g., average annual rainfall) and may not be captured due to low station density.

In southern Africa, strong correlations occurred between monthly NDVI (1983–1988) and bimonthly preceding rainfall amounts, attesting a time response of one to two months (Richard and Poccard 1998). The sensitivity to inter-annual rainfall anomalies was observed only for relative dry areas (mean annual rainfall 300–500mm) with good correlation regardless of soil type or vegetation formation. Many of the above studies indicated that rainfall, crop production, and NDVI were strongly correlated. The relationship between crop production, rainfall, and NDVI, however, depends on the NDVI time series and the ecological zone. The study will provide empirical results of the relationship between rainfall and NDVI in Mubangwe to facilitate the use of Landsat-NDVI data related to climate studies.

The normalized difference water index (NDWI), according to Gao,1996 is an index that can be obtained from band 8A (B8A; 865 nm) and band 11 (B11; 1610 nm) of Sentinel-2 spectral data and which can be of great interest as a support to decision making in terms of pasture and grazing management. It was initially proposed for describing the status of the vegetation water content over large areas from space: the NDWI values over areas with dead grass are negative, while those over green vegetation are positive (GAO, 1996).

The NDWI is a measure of liquid water molecules in vegetation canopies that interact with the incoming solar radiation [GAO, 1996], specially conceived for the estimate of soil moisture and canopy water content (Jackson et all, 2004). The NDWI is often a function of local climate and soil properties controlling water availability (Jackson et all, 2004), and sensitive to changes in liquid water because it incorporates a short-wave infrared (SWIR) band (B8A ;). This green vegetation spectra region is dominated by water absorption effects that capture important information on seasonally variable water status (Wang et all, 2011). The NDWI responds to changes in both the water content (absorption of B8A radiation) and spongy mesophyll (reflectance of B11 radiation) in vegetation canopies, respectively (GAO, 1996).

2.3 Impacts of Rainfall Variability on Maize crop yields

Since the variation of agricultural crop output to a large extent depends on rainfall amounts and seasonality, investigating the variability and the trend since the late 1980s most agricultural fields are lying fallow and the total output is declining at a remarkable rate (ICRA 2003). Since the variation of agricultural crop output to a large extent depends on rainfall amounts and seasonality, investigating the variability and the trend of these phenomena at a local scale is highly imperative.

As the major element of climatic change, rainfall variability can adversely affect the social, economic, political, cultural, and other functions of a region during extreme climatic regimes. These phenomena at a local scale are highly imperative. As the major element of climatic change, rainfall variability can adversely affect the social, economic, political, cultural, and other functions of a region during extreme climatic regimes. Rainfall variability is a complex phenomenon that mostly depends on various interactions of meteorological elements. The extent and variability of rainfall remain the most difficult to quantify, delineate, visualize and quickly interpret in maps (icra 2003).

The variability of rainfall emerges evolves and migrates most of the time without considering major physical barriers in the landscape and most cases farmers many hundreds of kilometers away from the actual phenomena can be impacted (Wilhite and Glantz 1987). This study presents a systematic analysis of how rainfall variability can affect changes in crop production in the study area (Mubangwe).

Agriculture production is largely undertaken by smallholder subsistence farmers who rely solely on high unpredictable and sporadic seasonal rainfall (Ndamani 2008). The majority of people in the area rely on crop and livestock production for their livelihood. Therefore, extreme variations to agro-climatic conditions (e.g., rainfall) in the area could directly affect the survival of people. In east Africa, a distributed lag model showed that only 10% of the variation in 10-day NDVI and 36% of the variation in the monthly NDVI were explained by concurrent and preceding rainfall (Eklundh 1998)

2.4 USGS Earth Explorer

The United States Geological Survey (USGS) is a data portal for obtaining geospatial datasets from extensive collections. The users can navigate via the interactive map or text to obtain Landsat satellite imagery, Digital line, UAS data, and Radar data among other datasets. Users can search by exact location via the interactive map or input specific coordinates to view what data types are available. This is a similar tool to the USGS Global Visualization Viewer (GloVis) in that users search catalogs of satellites and aerial imagery. USGS is an earth explorer which will be used for downloading the satellite image (USGS Data Sites).

2.5 Arc Map and ENVI

Arc Map and ENVI are GIS software that was used for the analysis of the data used in this study. Arc Map was used to come up with the map of the study area. ENVI was used to process Landsat 8 imagery that was used in this project as it simplifies comprehensive interactive processing of large multiband datasets, screen-sized images, spectral plots and libraries, and image regions of interest (ROIs) while providing flexible display capabilities and geographic-based image browsing.

3. METHODOLOGY

3.1 Study Area

Malawi lies in south-eastern Africa, extending between 9°21°51°S and 17°34°S, and 32°41°53°E and 35°53°11°E. It shares borders with Tanzania to the north, and Zambia to the West, and Mozambique to the south and east. The total geographical area is about 11.8Mha, it has approximately 7.2 Mha of agricultural land including plantations and 28 administrative districts. It has an estimated population of 18 million (Anhuf, 2006). The economy of Malawi is predominantly agro-based with over 80% of the population depending on agriculture (World Bank, 1995).

Malawi experiences a subtropical climate with relatively predictable weather. It has three growing seasons, hot wet (>95% rainfall) from December to April; cold dry season from May to August, and hot dry season from September to November. Rainfall is strongly seasonal and varies from 725 mm to 2500 mm, and is mostly derived from the Inter-Tropical Convergence Zone (ITCZ), the Zaire Air Boundary (Congo Air Mass), and Tropical Cyclones as they veer away from the east to the west path in the Mozambique Channel (Kamanga,2009).

The study area is situated in the Mzimba district, the northern part of Malawi. The geographical coordinates in degree minutes' seconds (WGS84) show that the area is located at -11025' 0" south and 33049'13.3" East with an elevation of 1225 meters. Mubangwe is in Tradition Authority Mtwalo. Mubangwe is in Mzimba north just 25kilometers from Ekwendeni Township as you take the M1 road from Mzuzu. In Mubangwe most people depend on agriculture for their daily life and the crop that they do cultivate are; Maize, Tobacco, and groundnuts.

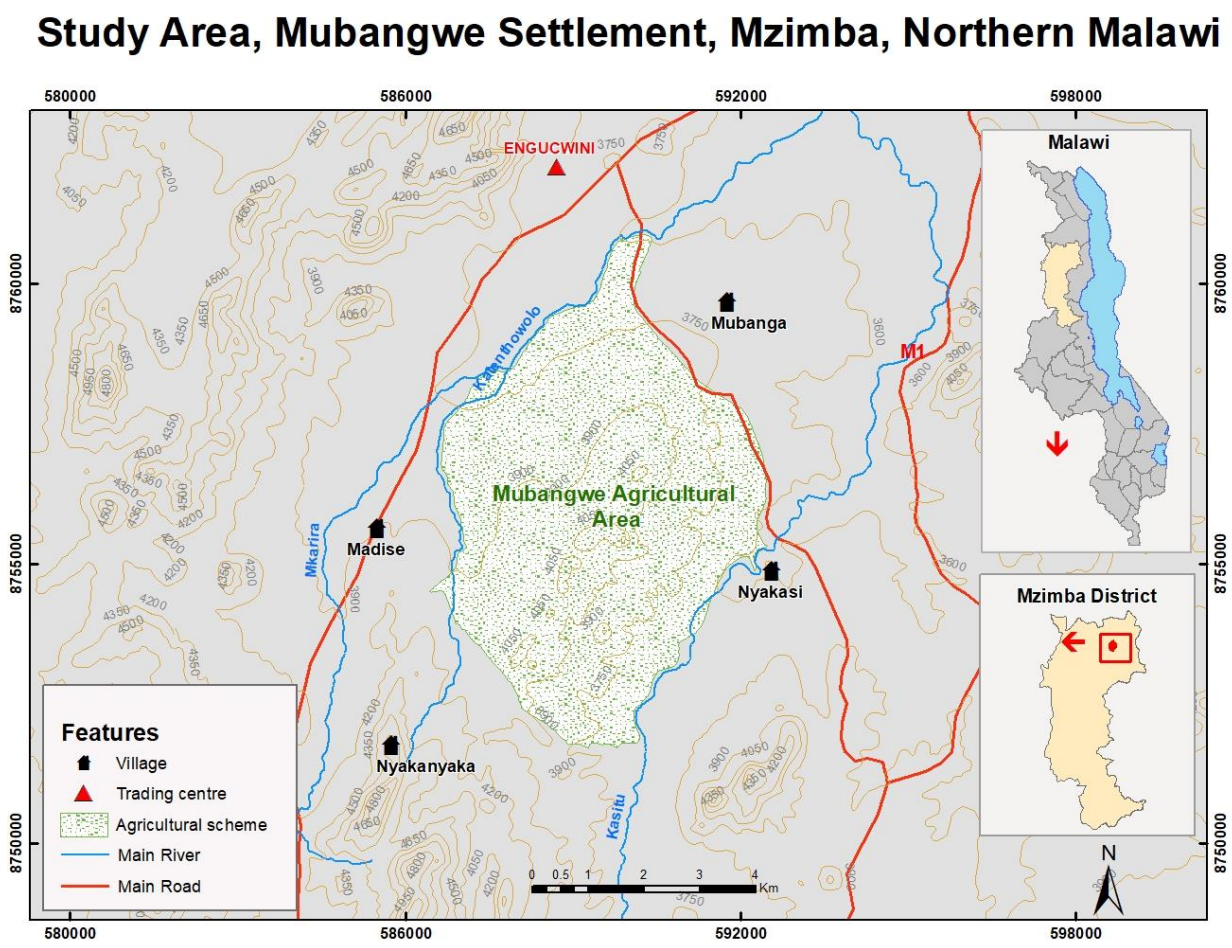


Figure 1: Study Area

3.2 Research Design

Both qualitative and quantitative research methods were used in this study.

The formula for the coefficient of variation

3.3 Static Design

The study used parametric and non-parametric statistical approaches. Parametric measurements statistical technique used to answer questions that demand the establishment of the relationship between a dependent variable (Crop yields) and explanatory variables (rainfall) techniques to carry out the relationship and strength between rainfall and Maize crop yield.

$$r_{xy} = \frac{\left[\sum xy - \frac{\sum x \sum y}{n}\right]}{\sqrt{(\sum x^2 - \frac{(\sum x)^2}{n})(\sum y^2 - \frac{(\sum y)^2}{n})}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

X = Rainfall

Y = Maize crop yield

n = Number of season

3.3.1 Data Collection

The first phase of data collection involved downloading satellite images from the United States Geological Survey (USGS) which were manipulated using Arc GIS. Four images were downloaded for 2015, 2016, 2017, 2018, and 2019. The second phase includes; the collection of rainfall data from the department of meteorological and climate change in Blantyre for Mubangwe. Finally, the Maize yield data was collected from Mzimba North Agricultural office. Maize yield data collected from 2015/2016 to 2019/2020.

3.3.2 Desk Work Data Analysis

Rainfall variability or changes from the year 2015 to 2012 were analyzed and its possible relationship with crop production (Maize) was determined through NDVI analysis. The analysis of the first phase involved classifying the downloaded images to detect the changes in crops. Five classified maps were produced and five NDVI maps were produced to show the changes detected on the vegetation index from 2015-2020 due to different amounts of rainfall received during the specified years. The rainfall data were obtained from the department of meteorological and climate change in Blantyre from 2015 to 2020 and it was used to produce graphs showing total inter-annual rainfall from 2015/2016 to 2019/2020 rainy season. Both satellite data, Maize yield data, and rainfall data were used to evaluate the three specific objectives so that the main objective is reached.

3.4 Materials and Methods

The materials that were used in this study include; GIS software (Arc GIS and ENVI), Satellite data (Landsat 8 images) and Rainfall data, Excel sheet, and Google earth explorer. This analysis utilizes two kinds of datasets which involve; the tabular data for Rainfall from the department of meteorological and climate change and satellite data (Landsat 8 imagery). The data was in a table in a hardcopy format. The data was encoded in an Excel sheet where different kinds of graphs were plotted by firstly determining what the graph should be emphasized. The required data is selected and then it involved clicking on insert where a graph suiting to represent the data was chosen and then the graphs pop up. Thereafter, the chart is edited to add some features to the chart and make it more self-explanatory e.g., a heading, axis titles, and a legend.

The satellite images that were used were from Landsat 8 imagery, from 2015 to 2020 were examples of Landsat 8 Operational Land Imager (OLI) and Thermal Infrared sensor. The Landsat has 30 meters resolution which makes changes within the 30 meters distance undetectable. Jensen (2005) defines image classification as the process of categorizing an image into a smaller number of individual classes based on reflectance values. The images were classified based on physiographical knowledge of the study area, ancillary information, the researcher's local knowledge, and visual interpretation of each LULC class supported with the use of the historical function of Google Earth. To determine the impact of rainfall change patterns on maize crop production between 2015 and 2020, the satellite images for 2015, 2016, 2017, 2018, and 2019 were uploaded and composite images were created. Then the area of interest which is Mubangwe in the Mzimba district was extracted and by a merged shapefile of the lake area and the district. Training samples were created followed by supervised classification using minimum and it was followed by post-classification analysis through minimum majority analysis. After that, it was converted from raster to vectors then lastly it was converted to vector shapefile so that the classified features are named and the area for every feature was calculated, and additional map element in Arc Map. The same satellite images were used to calculate NDVI (Normalized Difference Vegetation Index). Firstly, an area extent of about 1463 square kilometers

of Mubangwe was extracted from the Landsat images and used for calculating NDVI and making land use cover maps. The bands for calculating NDVI for Landsat 8 Operational Land Imager (OLI) and Thermal Infrared sensor image uses bands 5 and 4. The required bands for an image for Mubangwe were loaded. The shapefile was then used to extract Mubangwe only from the image using an extraction by the mask. To calculate NDVI the process involved is as follows clicked on Arc Toolbox>Spatial analysis tools>Map algebra>Raster Calculator. In the raster, the calculator entered the formula as below using the bands the float in the pop-ups.

Float (band 5 - band 4)/float (band 5 + band 4) and substituted the number of bands for the Landsat 8 image the ok. The calculated NDVI is classified and each class is assigned a color as green representing high values and red representing low values using the color lamp. Thereafter a map and a bar graph of the map were created and it is as shown in the results below.

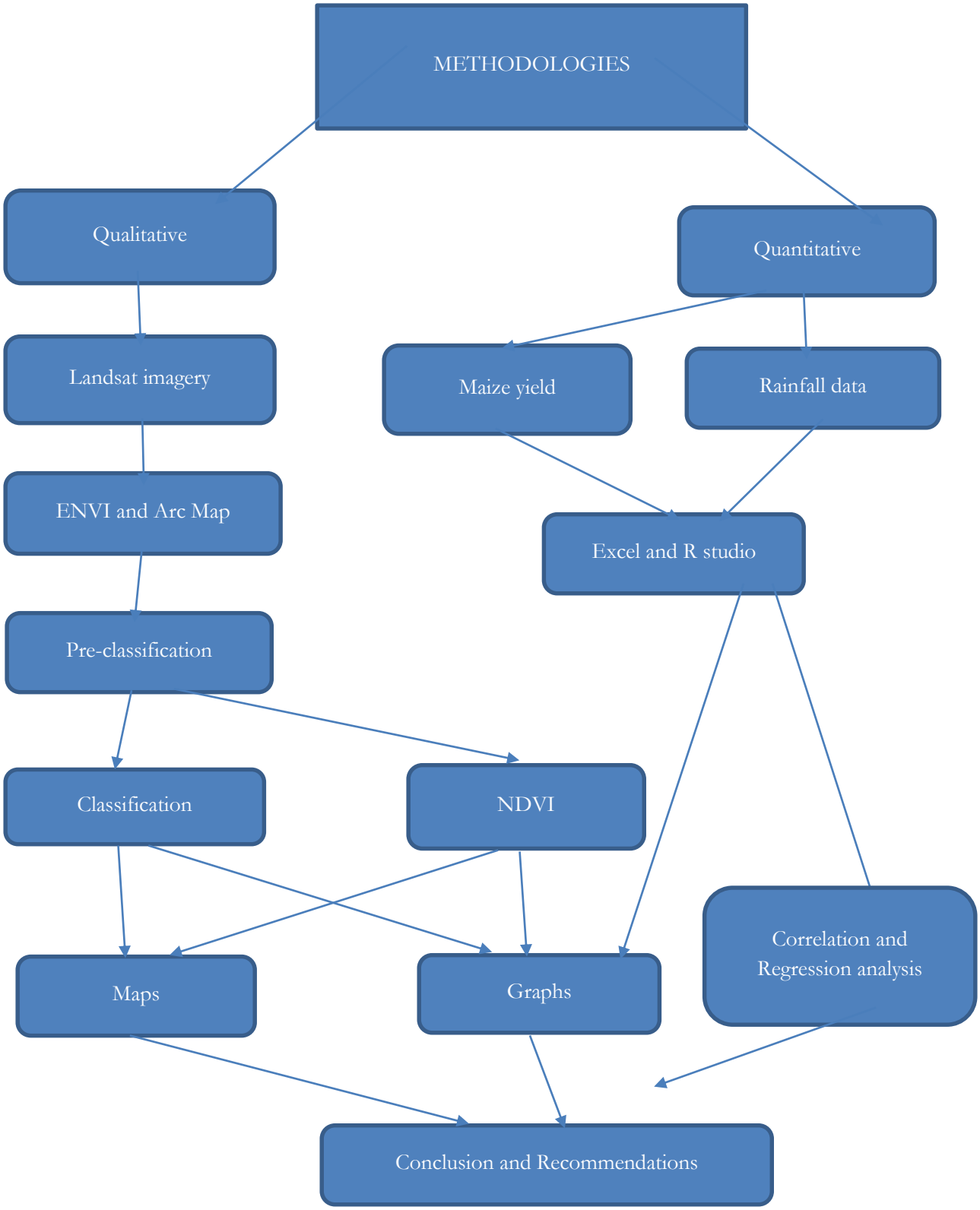


Figure 2: Methodology in General

3.5 Study Limitations

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared sensor satellite missions were the ones that were used in this analysis and have a spatial resolution of 30 meters which means that all objects that are less than 30 meters are generalized into a single object. This limits the amount of data shown on the image such that the number of settlements shown on the map may be lesser than the settlements that exist on the ground. Availability of clouds on the image Despite this more care was emphasized when classifying the images to reduce the risks of misinterpretation. Unavailability of long-term data for rainfall and Maize crop yield for Mubangwe.

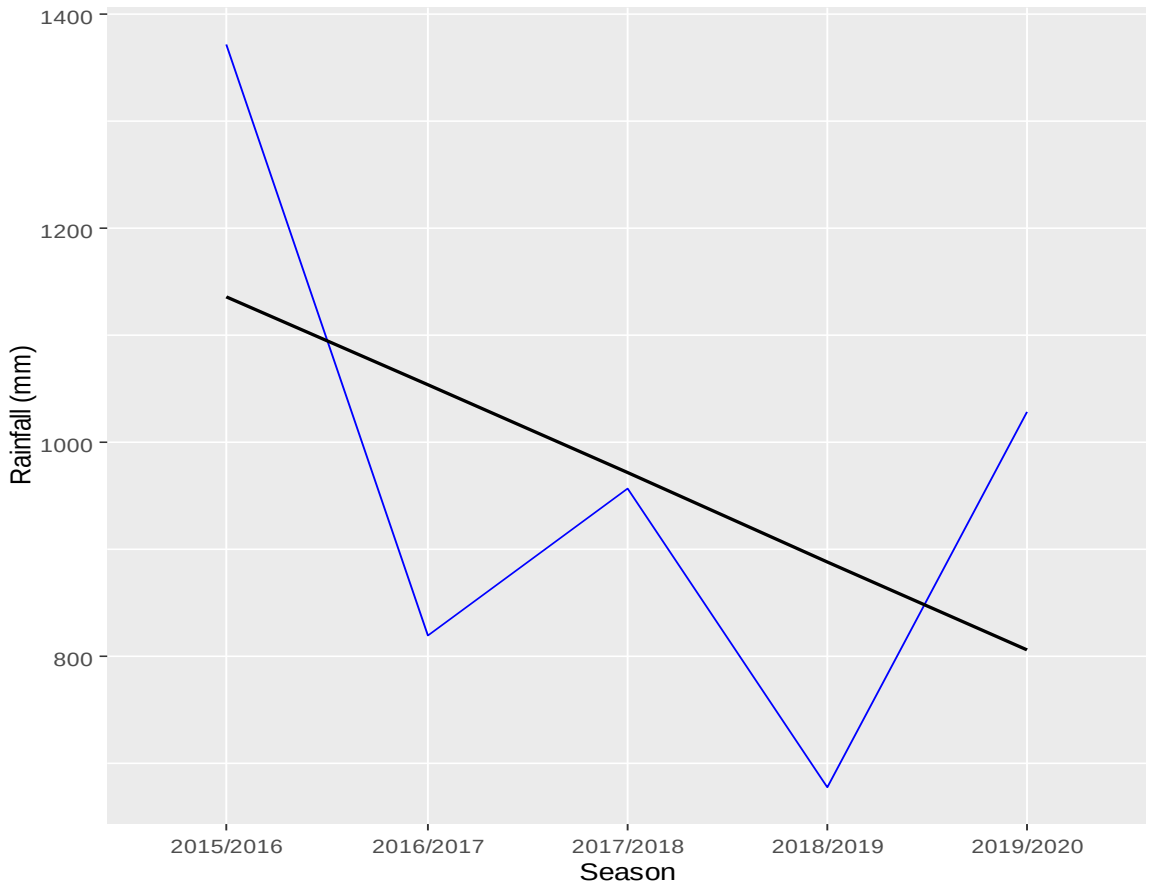
4. RESULTS AND DISCUSSIONS

The results for this analysis are in three categories depending on the specific objectives because each specific objective involves the use of a different way of analysing the data.

4.1 Rainfall Trends

The data was collected from the department of meteorological services in Blantyre which was analysed using an excel sheet. The graph below shows the yearly total rainfall for different years from 2015-2020

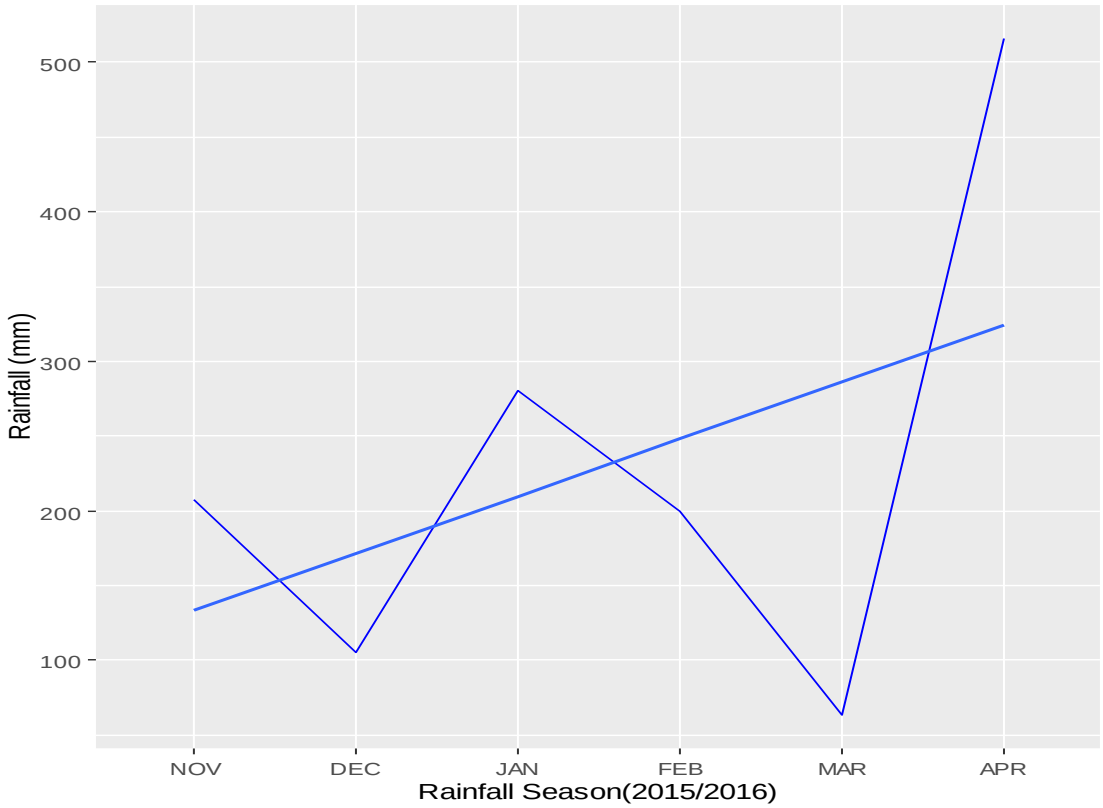
Figure 3: Shows the total annual Rainfall trends from 2015-2020



The time frame of the analysis ranges from 2015-2020 hence the rainfall data provided by the department of climate and meteorological services were from 2015-

2020. The time ranges on the graphs show only the rainy season since it focuses on rainfall variability and crop production.). Generally, the scientific evidence on rainfall variability with its significant impacts on crop yields is now stronger than ever (Adejuwon and Odenkule), 2004, 2005). According to the graph above, Mubangwe agricultural area has gone through a logical trend of decrease in rainfall.

Figure 4: Shows the Annual Rainfall season for 2015/2016



For the 2015/2016 rainy season, the graphs show an increase in the amount of rainfall from November to April hence rainfall variability affects the availability of water and crop production.

Figure 5: Shows the Rainfall trend for 2016/2017

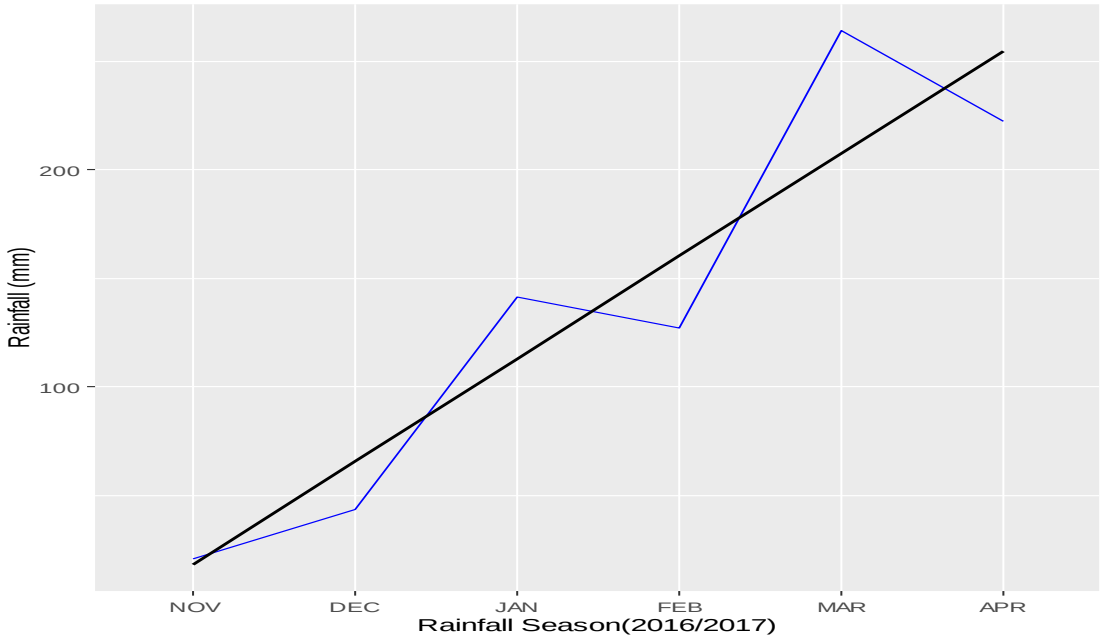
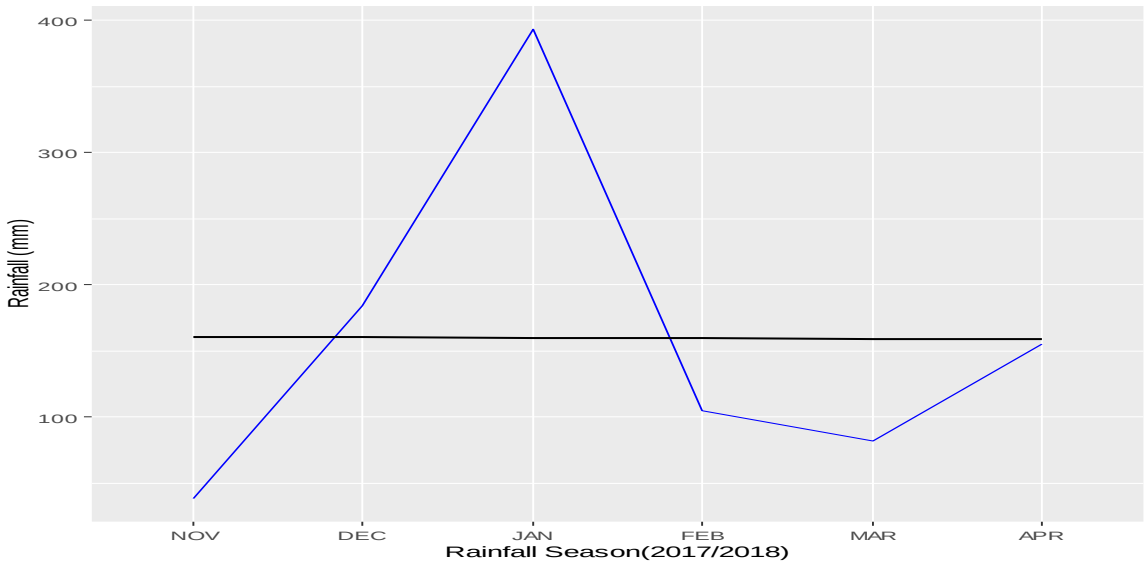


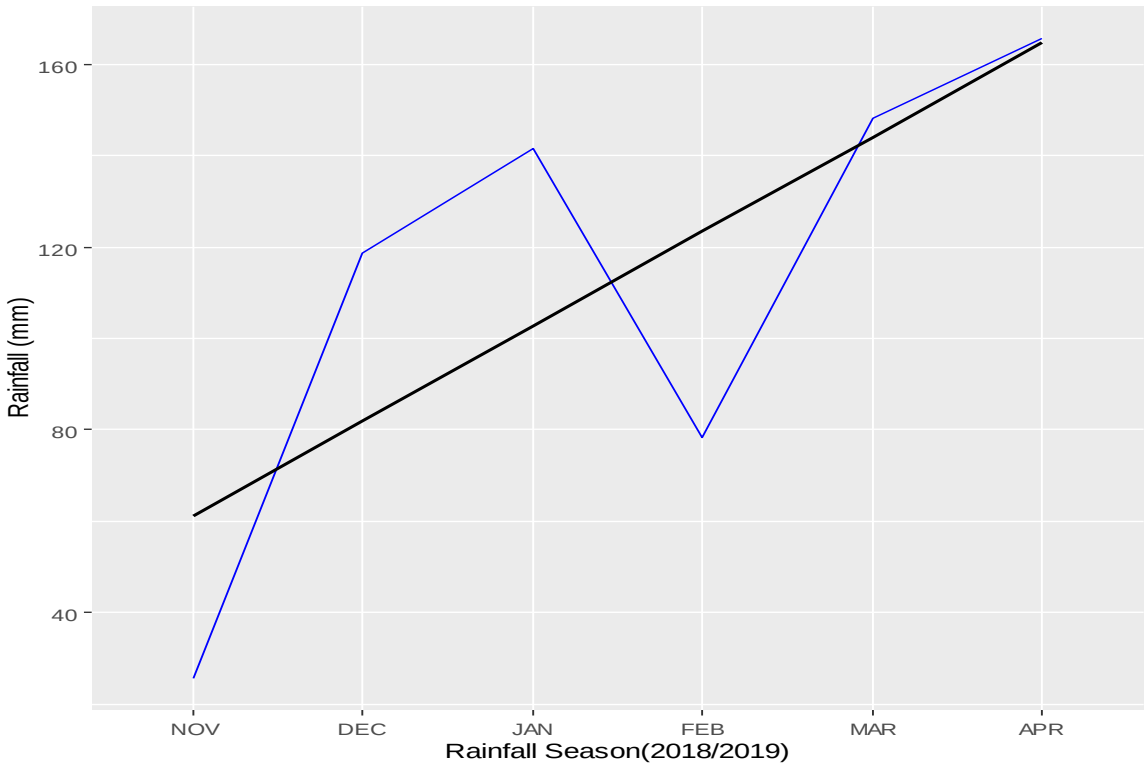
Figure 5 above shows the rainfall trend which shows a perfect increase in rainfall from the starting month of November to April.

Figure 6: Shows the Rainfall trend for the 2017/2018 rainy season



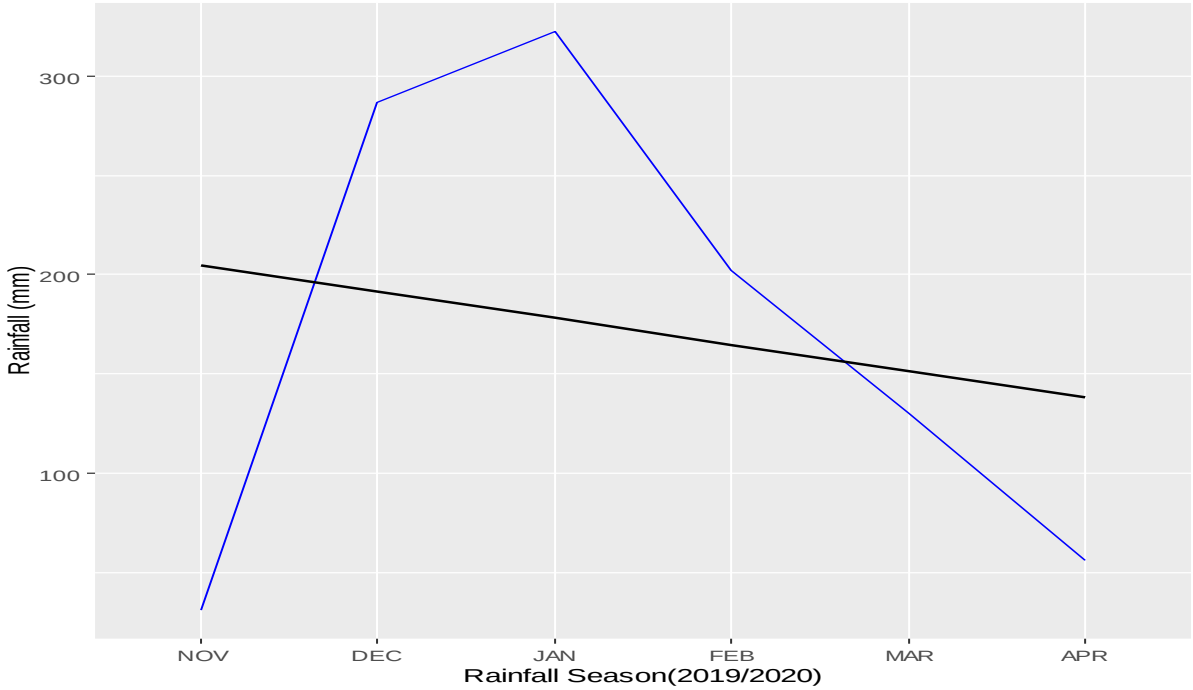
The rainfall trend for 2017/2018 for the area shows that the rainfall was constant throughout the rainy season.

Figure 7: Shows the Rainfall trend for the 2018/2019 rainy season



For the 2018/2019 rainy season, the graphs show an increase in the amount of rainfall from November to April hence the rainfall variability affects the availability of water and crop production.

Figure 8: Shows the Rainfall trend for the 2019/2020 rainy season



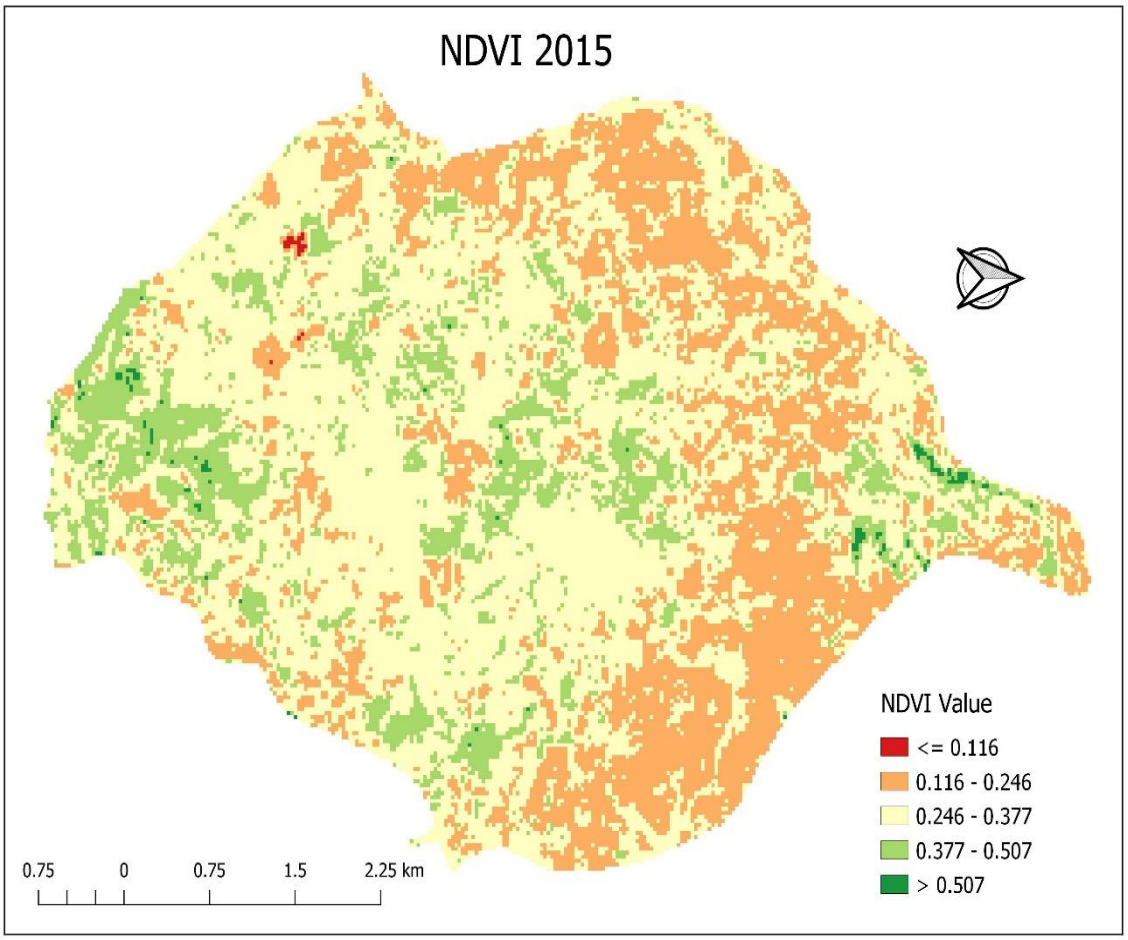
The graph for the 2019/2020 rainy season shows the decrease in rainfall from November to April. A decrease in rainfall results in a decrease in water availability in crop fields hence crops stress.

Rainfall is an important factor that crops depend on during the rainy season to grow. Both large and small scale farmers contribute to food security and the poverty reduction goal of the Government of Malawi (GoM) as highlighted in Malawi

Growth and Development Strategy Framework (MGDS) (GoM, 2006).

4.2 Normalized Difference Vegetation Index and Crop Production

The rainfall variability has affected crop production in several ways thereby putting the surrounding communities' livelihoods in different conditions. Both the analysis of satellite images and crop production data were used to evaluate the effects.



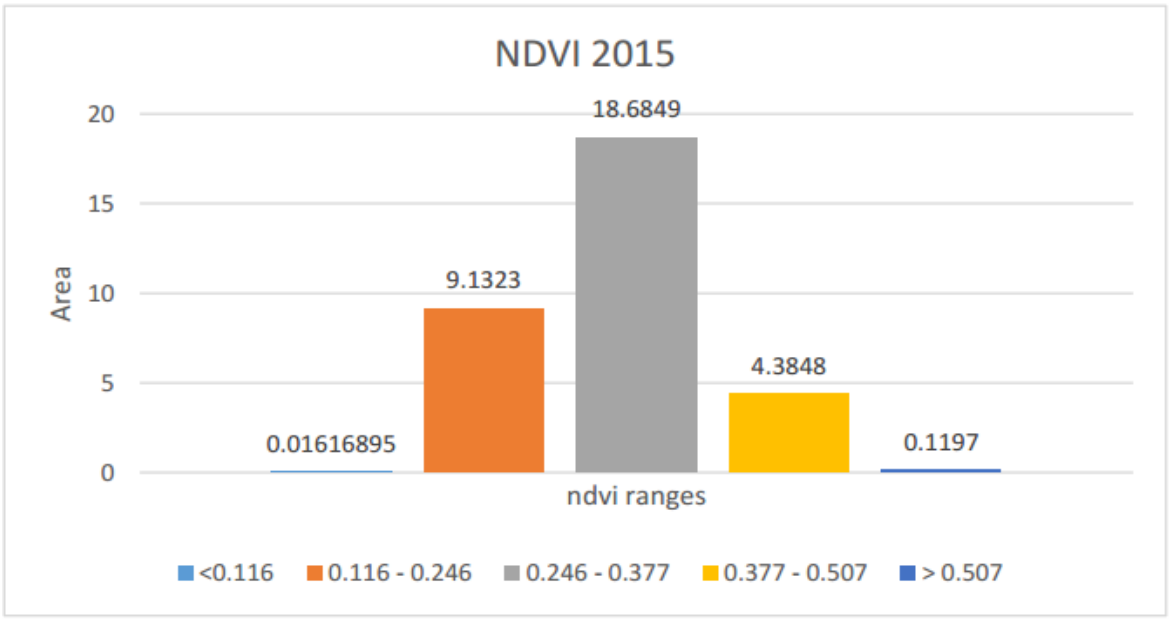


Figure 9: NDVI 2015

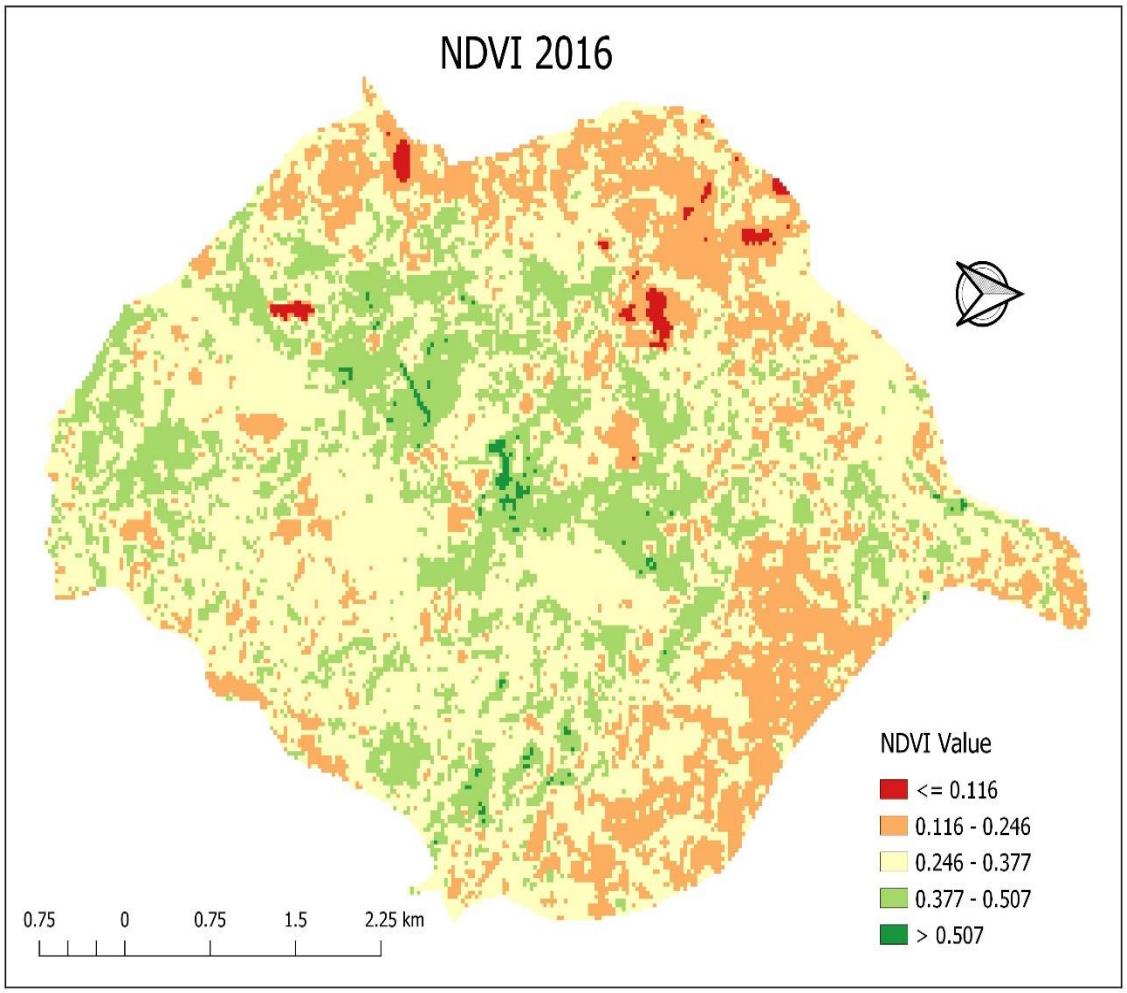
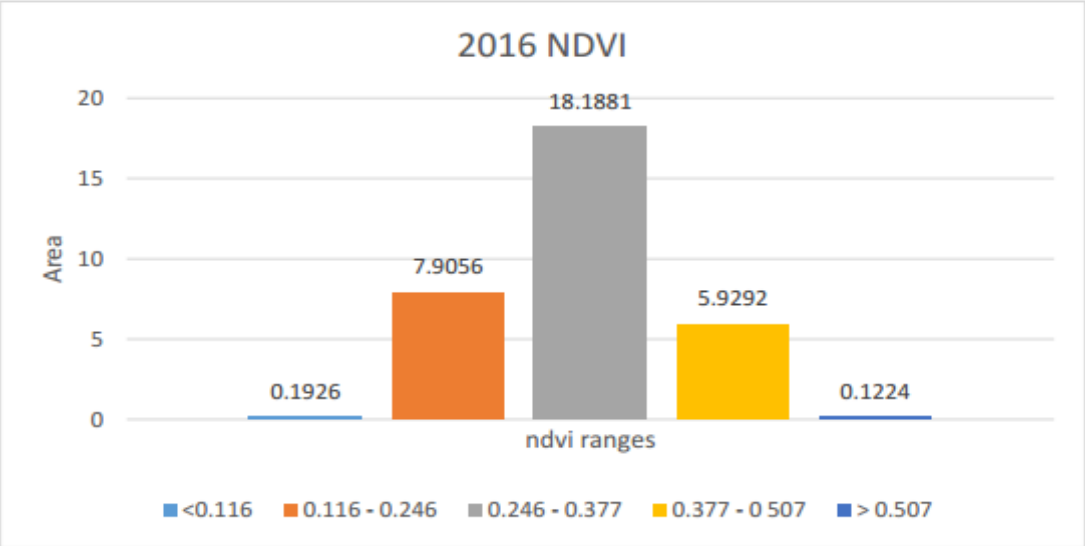


Figure 10: NDVI 2016



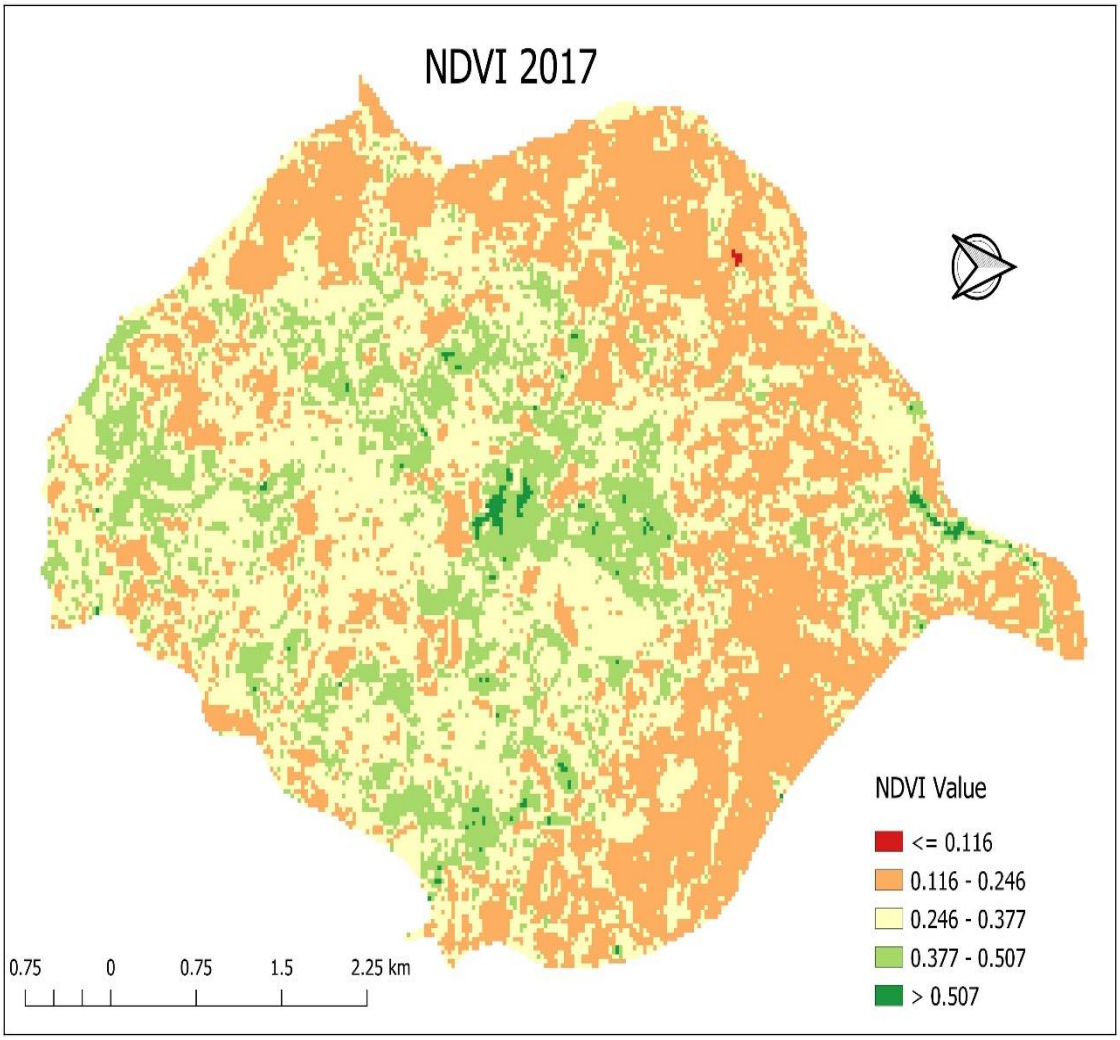
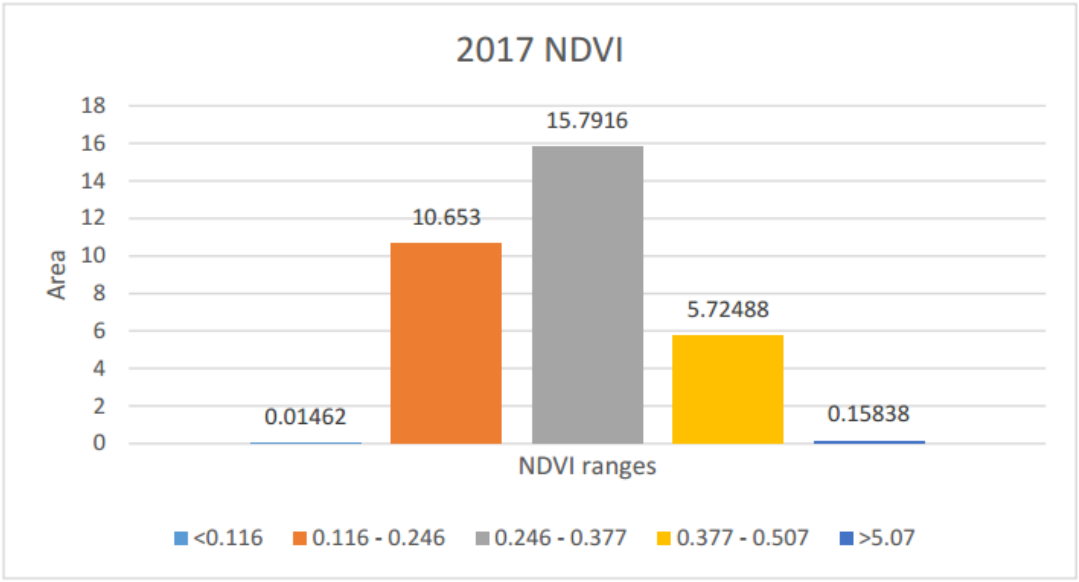


Figure 11: NDVI 2017



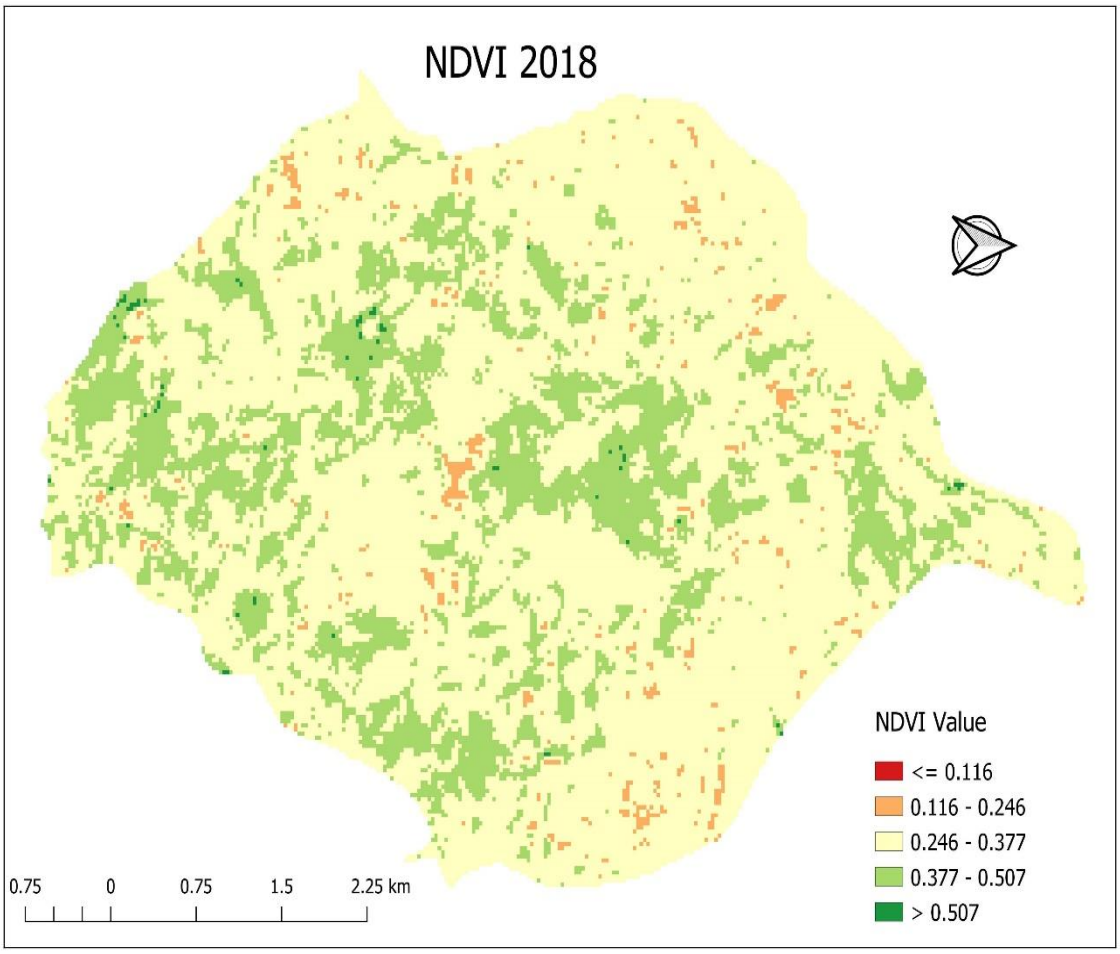
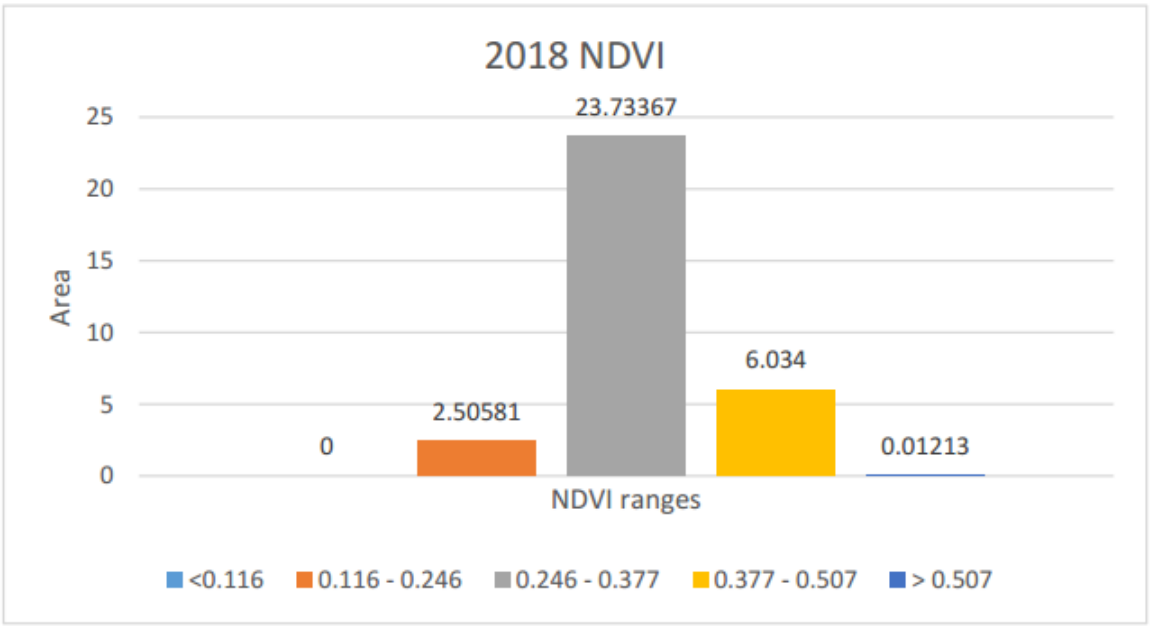


Figure 12: NDVI 2018



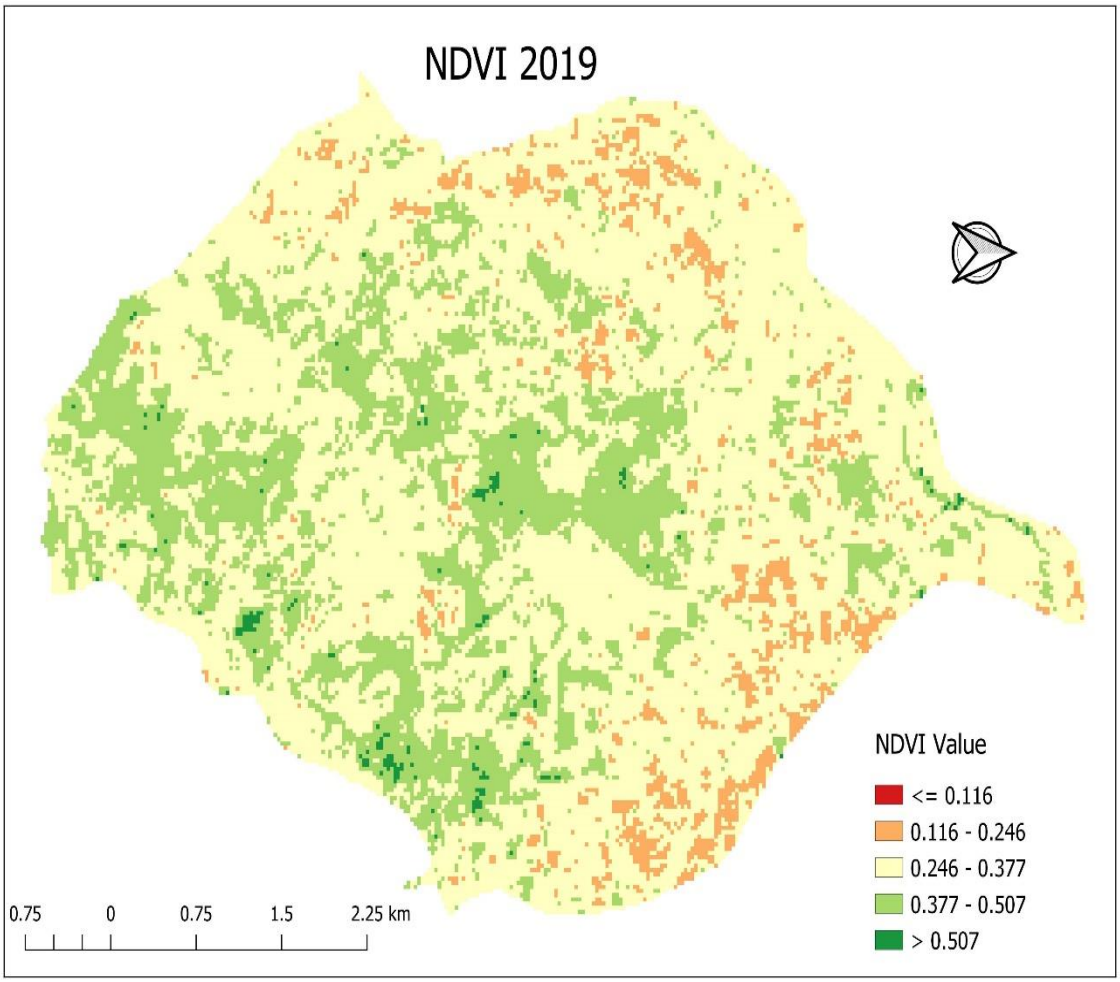
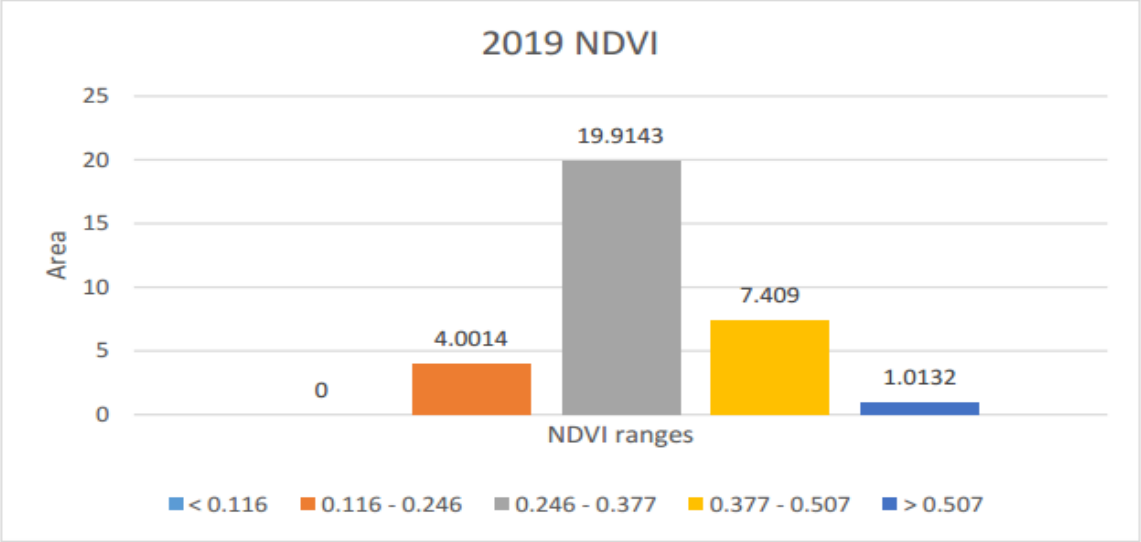


Figure 13: NDVI 2019



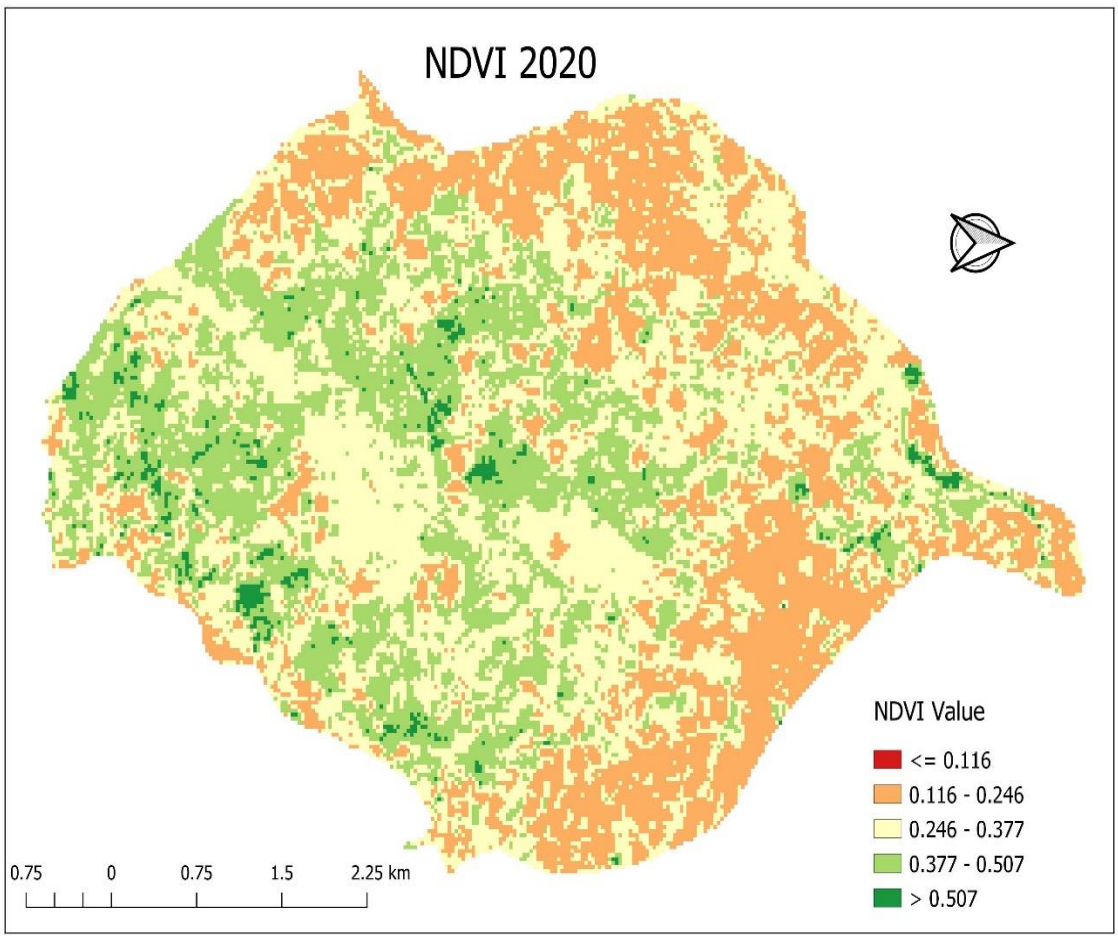
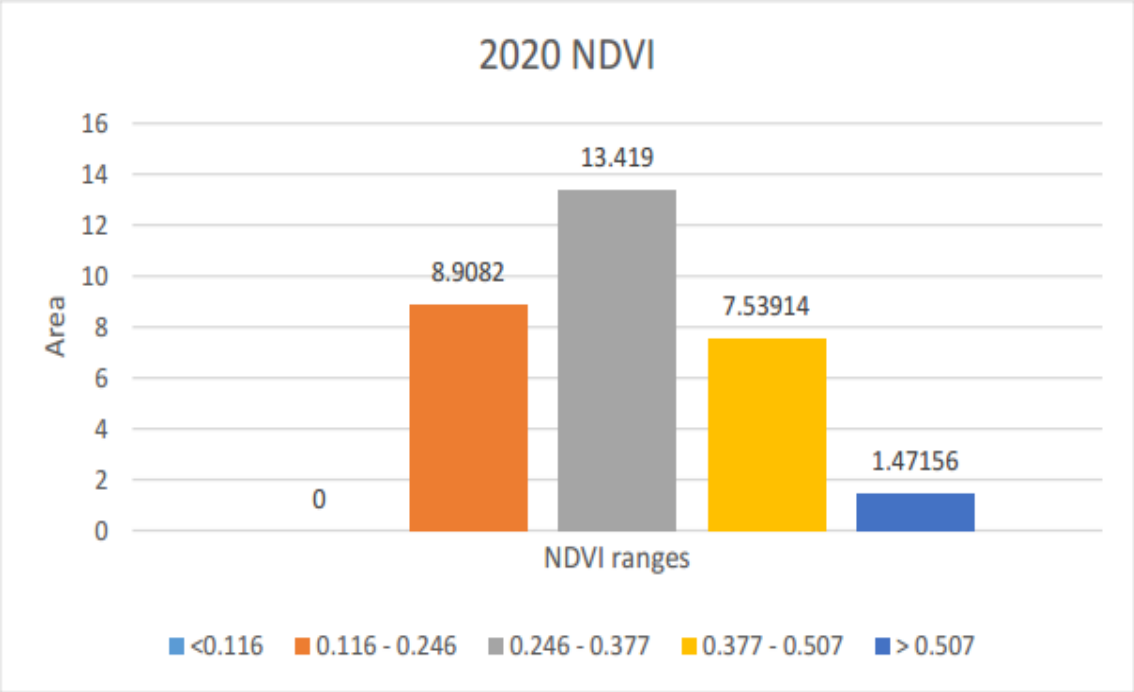


Figure 14: NDVI 2020



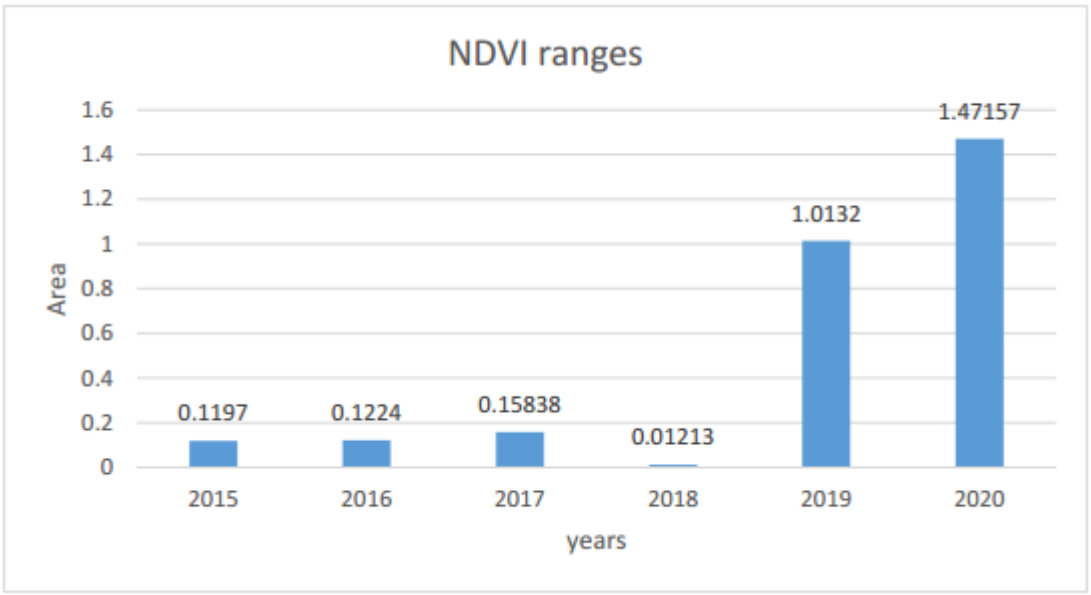
A vegetation index is a combination of surface reflectance at two or more wavelengths designed to highlight a particular property of vegetation. They are derived using the reflectance properties of vegetation (L3Harris Geospatial, 2020). NDVI measures the state and health of crops or plant's vigor. This vegetation index is an indicator of greenness and has a strong correlation with green biomass which indicates the strength and growth of plants (eos.com, 2020). This study analyzed how crop production has been affected by rainfall variability about NDVI. Satellite images show that Mubangwe is an agricultural area surrounded by farms. NDVI range between 1 and -1 whereby 1 represents vegetation and -1 represents water. Values lower than 0.15 mean that there is no vegetation and the values correspond to the plowed soil without any vegetation or dead plants. The NDVI values from 0.2 to 0.3 represent stressed vegetation while 0.3 to 0.7 represent healthy vegetation (Brown, 2018).

Since the NDVI classes for different years have different ranges, the classes on the maps were reclassified whereby the class represented by red in all the maps corresponds to class 1, the class in faded red as class 2, the class in yellow as class 3, the class in light green as class 4 and the class in dark green as class 5. This was to group the NDVI values percentages depending on classes to show the trend the vegetation index went through in the four the six years.

Based on the output images, maize crop yield can be predicted through the NDVI ranges. For instance; 2015 and 2016 images, 2015 season can be predicted to yield higher yield compared to 2016 due to the ranges of healthy vegetation which in our case shows heathy crop that is higher than 2016. And in addition comparing amount of ranges of stressed crops in the same area.

For the output images of 2017 and 2018, maize crop yield can be predicted through the NDVI ranges as 2017 shows less ranges of healthy crop compared to 2018. Hence 2018 can be predicted to yield more Maize crop yield compared to 2017.

2019 image shows less area that is covered with healthy vegetation compared to 2020. And 2020 cover small area which contain stressed crop than 2019. Therefore, 2020 can be predicted as high Maize yield production compared to 2019.



Mubangwe covers a total area of 32.337900Km squares.

All in all, NDVI can be used as important tool for predicting crop yields. Based on Maize yield data collected from Mzimba north agricultural office which shows that

in 2015/2016 they yield 3878 Kilograms of Maize per hectare compared to 2016/2017 rainy season, where they yield 3372 Kilograms of Maize per hectare.
In 2017/2018 they yield 3560 Kilograms of Maize per hectare, In 2018/2019 they yield 3111 Kilograms of Maize per hectare, In 2019/2020 they yield 3364 Kilograms of Maize per hectare which shows the same as what is shown by the NDVI images for Mubangwe.

LAND USE COVER

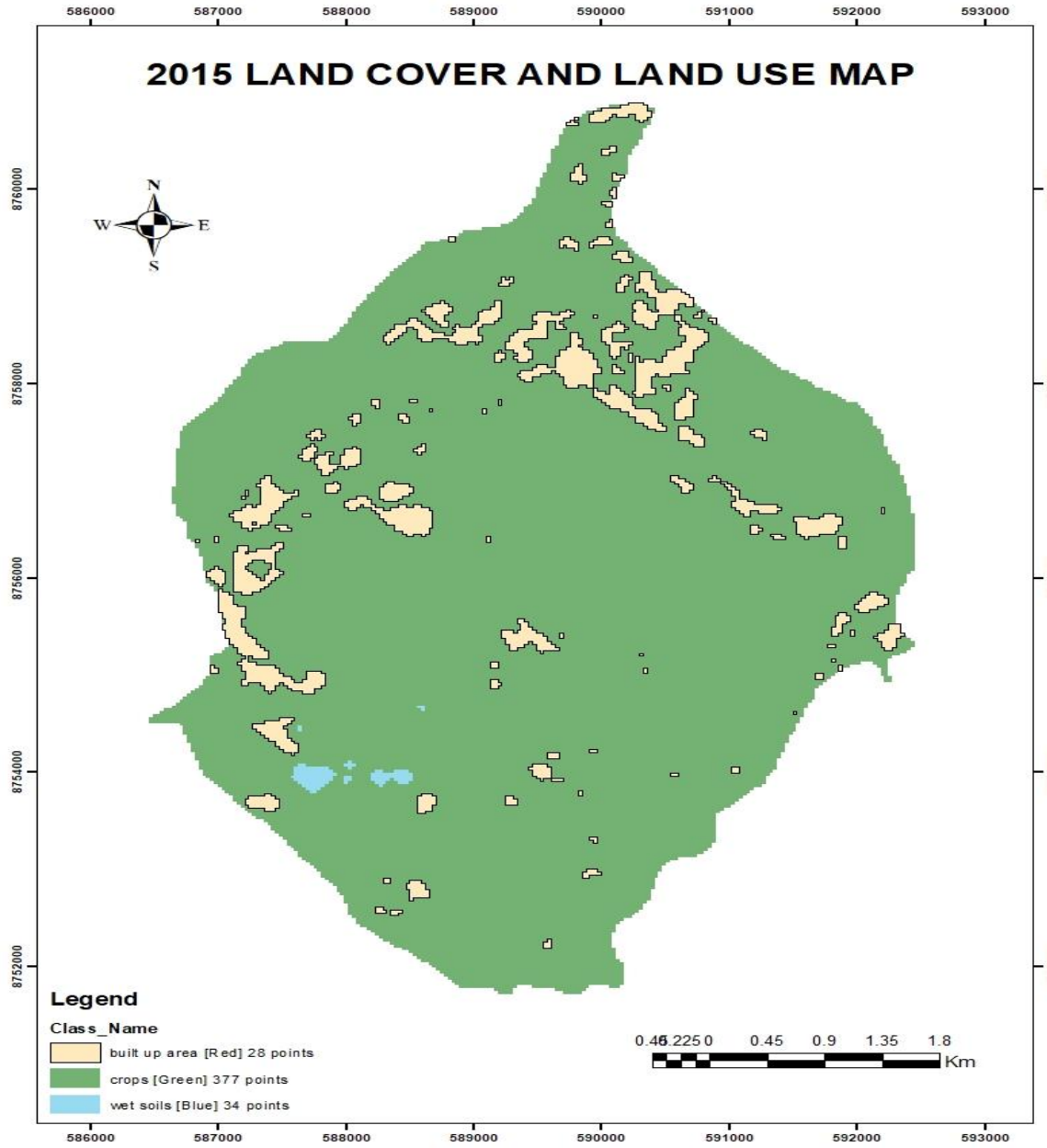
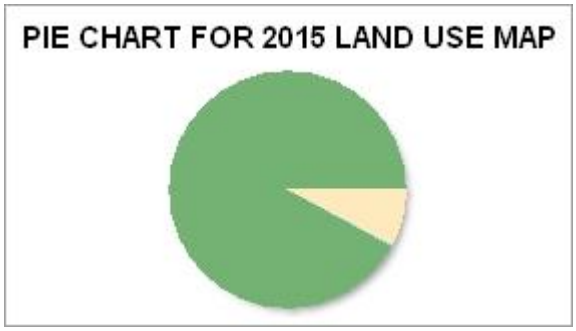


Figure 15: 2015 LAND USE MAP



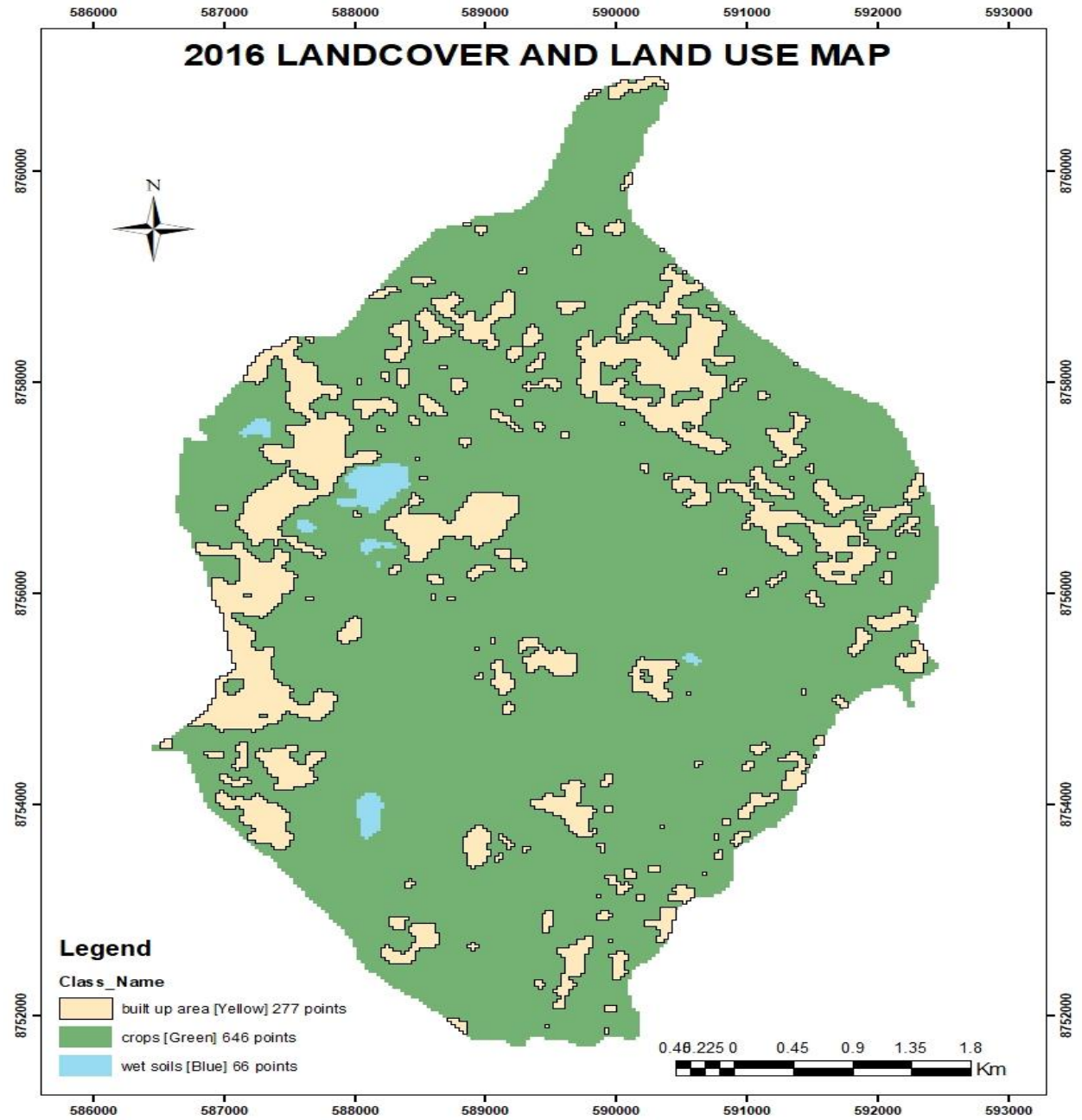
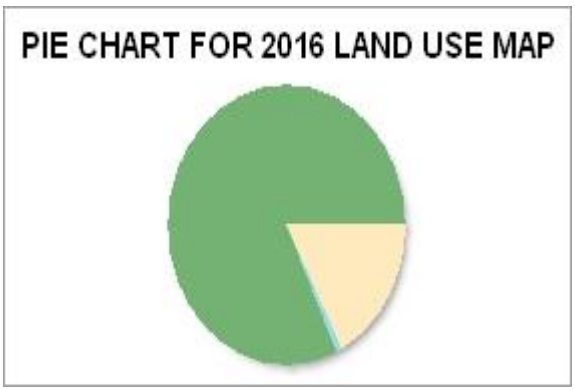


Figure 16: 2016 LAND USE MAP



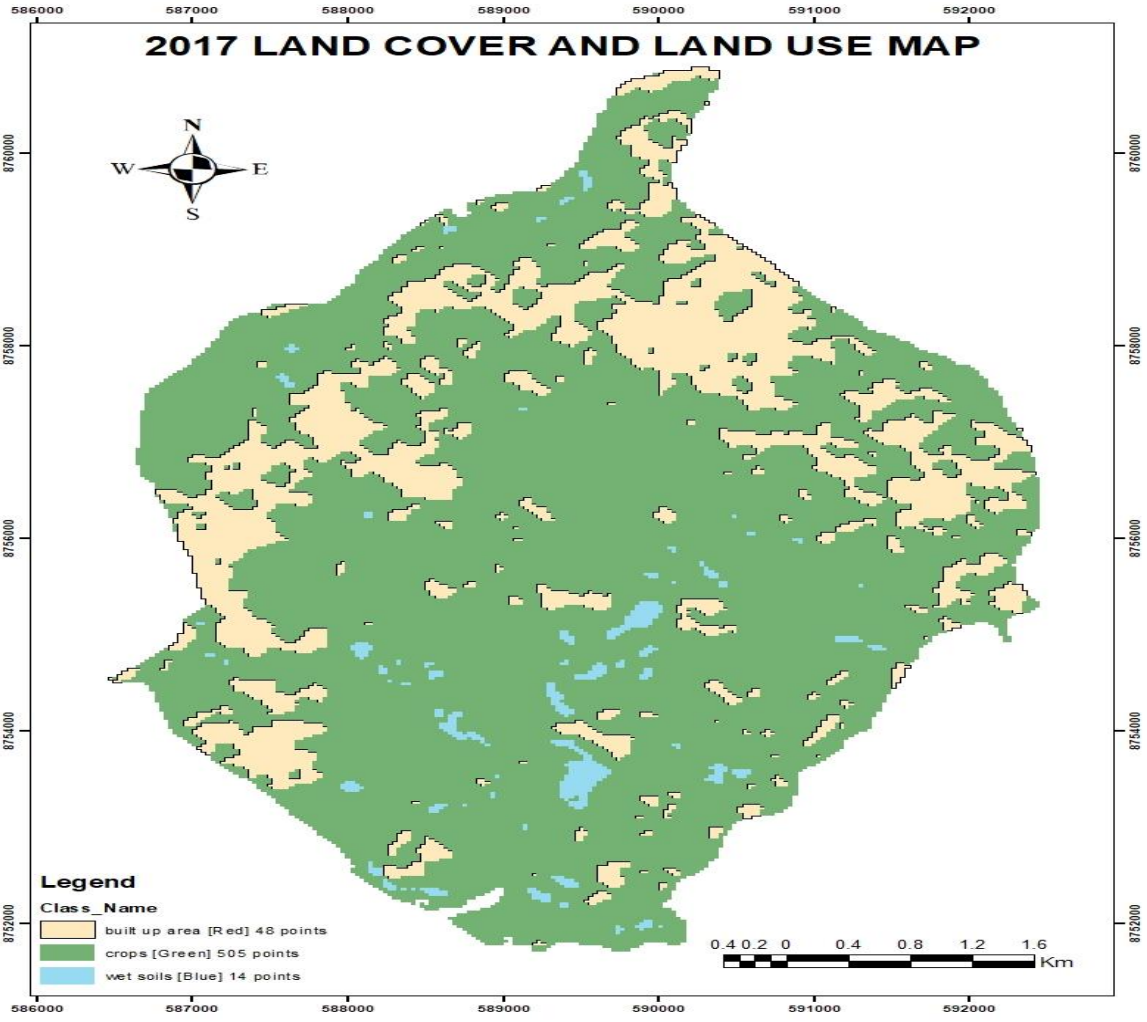
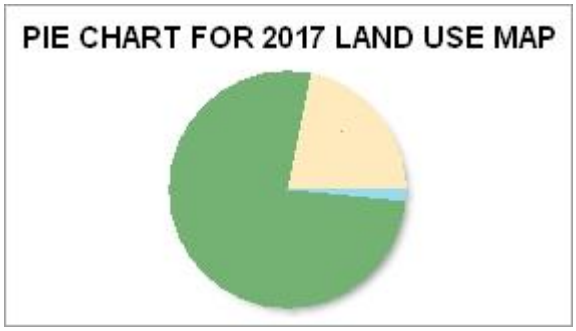


Figure 17: LAND USE MAP



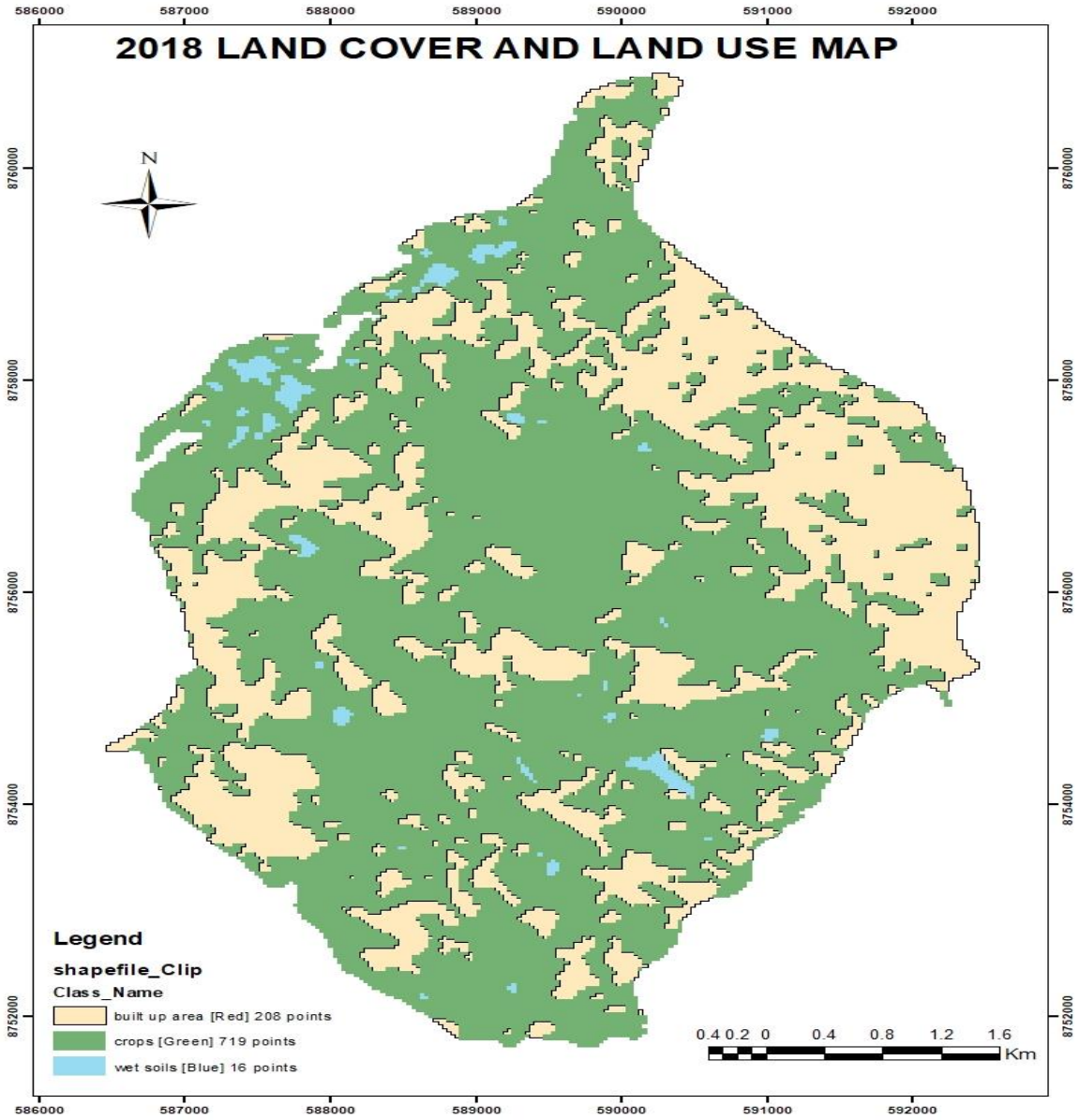
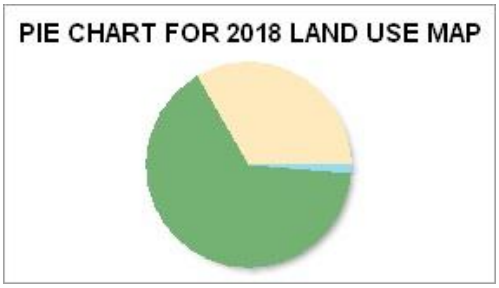


Figure 18: 2018 LAND USE MAP



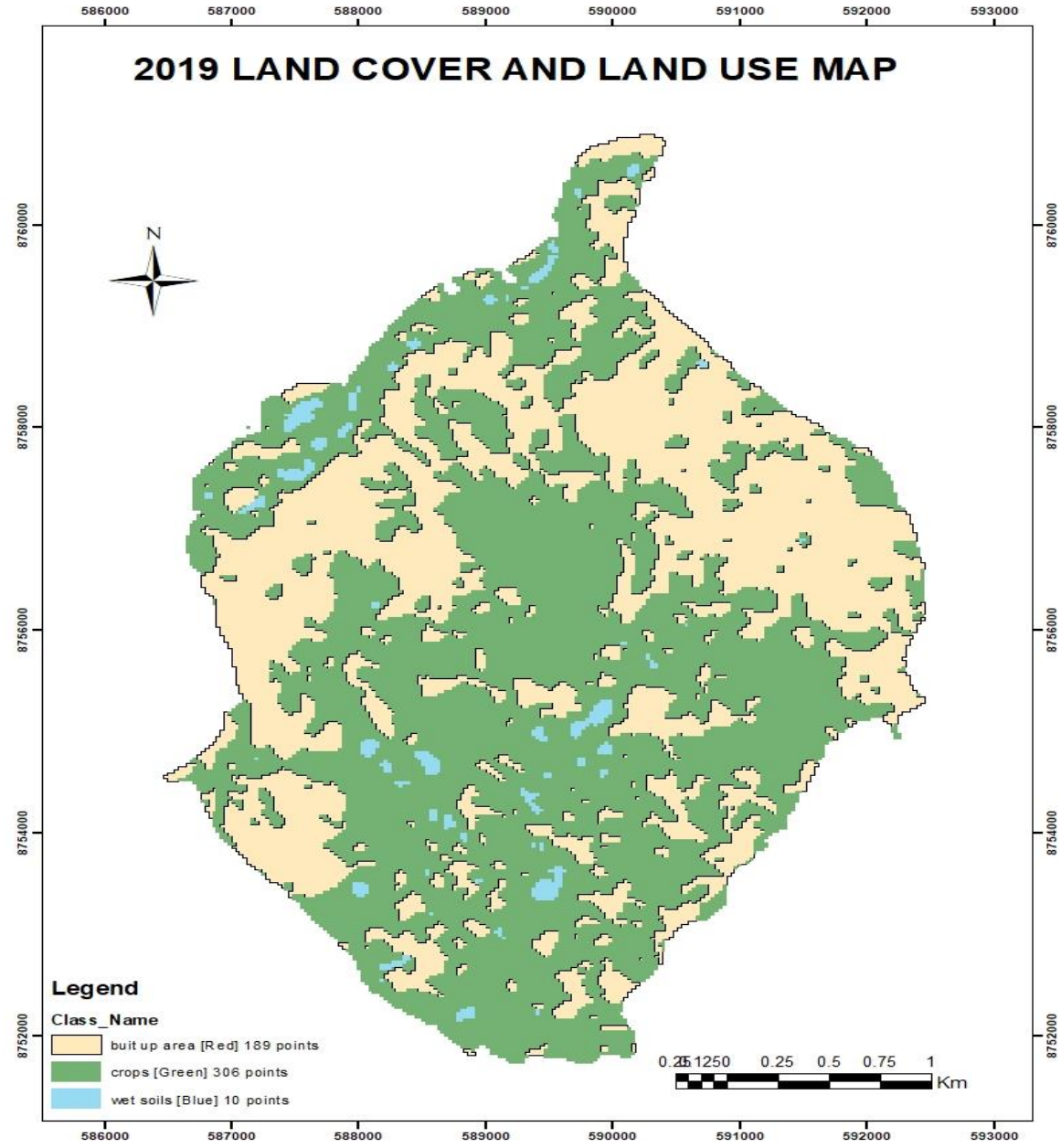
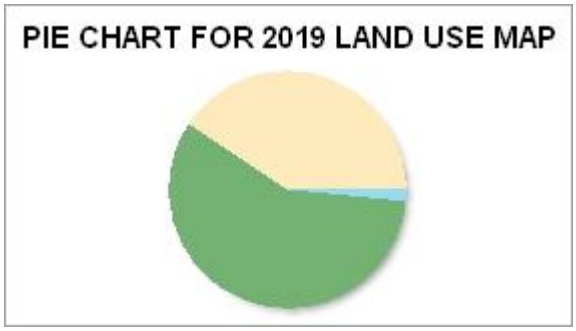


Figure 19: 2019 LAND USE MAP


PIE CHART FOR 2019 LAND USE MAP

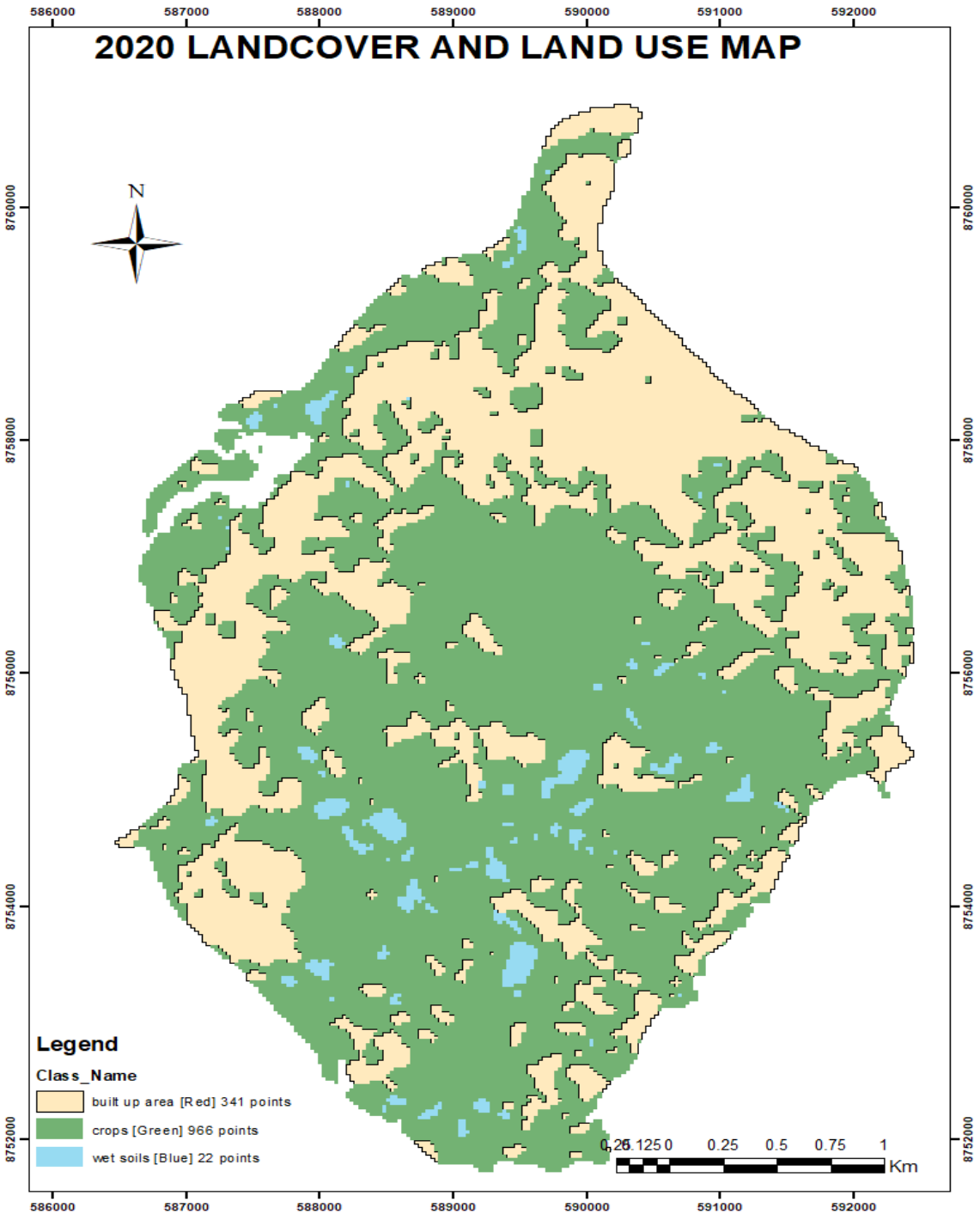
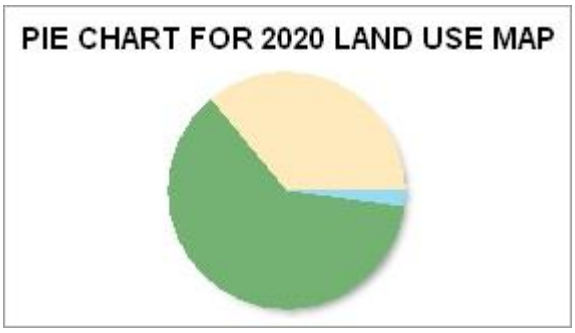

2020 LANDCOVER AND LAND USE MAP
586000
587000
588000
589000
590000
591000
592000
8760000
8758000
8756000
8754000
8752000
N
Legend
Class_Name
built up area [Red] 341 points
crops [Green] 966 points
wet soils [Blue] 22 points
0.25 0.125 0 0.25 0.5 0.75 1
Km

Figure 20: LAND USE MAP



From the land cover and land use maps shown in the years 2015, 2016, 2017, 2018, 2019, and 2020. The built-up area was used to assess how rainfall affected crop production. The built-up area show an increasing trend from 2015 to 2020 as shown in the pie charts

The classification maps show that there was a logical increase in the percentage or amount of built-up areas hence decreasing the land that was used for cultivating crops in the area (Mubangwe). These may include thatched houses that tenants used to stay in during the rainy season. These houses have low digital number values such that they get mixed with other pixels hence only iron sheets houses are the only ones that can be shown on a satellite image and this reduces of settlement classified on a satellite image. The availability of wet soils increases from 2015 to 2020 during the rainy season which indicates that there was enough amount of water for plant's growth hence increasing crop production.

4.3 Impacts of Rainfall on Maize Crop Production

4.31 Correlation analysis

Correlation analysis was done to determine the relationship that prevails between the dependent variable (Y) (Crop yield) and explanatory variable (X) (Rainfall). Correlation analysis in research helps in explaining or understanding the contribution of each climate variable as rainfall is involved have on maize crop yield production.

The impact of rainfall on Maize crop production was discovered using the correlation analysis.

Table 1. CORRELATION

Climate parameter	Maize Yield	Std. error	t- value	Remarks
Rainfall	r =0.92975 p =0.02211	0.2315	4.374	Strong significant

Residual standard error= 120.9 on 3 degrees of freedom

Adjusted R – squared = 0.8193

Multiple R – squared = 0.8644

The correlation shows that there is a strong relationship between rainfall and Maize yield which is shown by the r value which is 0.92975 since it is close to 1. The regression analysis also shows that there is a relationship since the P-value is in the range of 0.05-0.01.

4.32 Regression analysis

To describe the nature of the relationship between climate parameter (rainfall) and maize yield crop production, regression analysis statistical method was used to find out whether the relationship is positive/negative or linear, or nonlinear. Below is the model equation that can be used to predict crop yield production with the amount of rainfall.

Model equation

Maize yield= 2473.7510 + 1.0124 Rainfall

Y = 2473.7510 + 1.0124X

KEY

Correlation is significant at $\alpha \leq 0.01$

Correlation is significant at $\alpha \leq 0.05$

Dependent variable Y is maize yield while explanatory variable X is rainfall

In this case P value = 0.02211 which shows that there is a relationship as it is within the range between 0.01 and 0.05. The equation above shows that Maize yield in Mubangwe can be estimated up to 80% which is shown by Adjusted R-Squared = 0.8193.

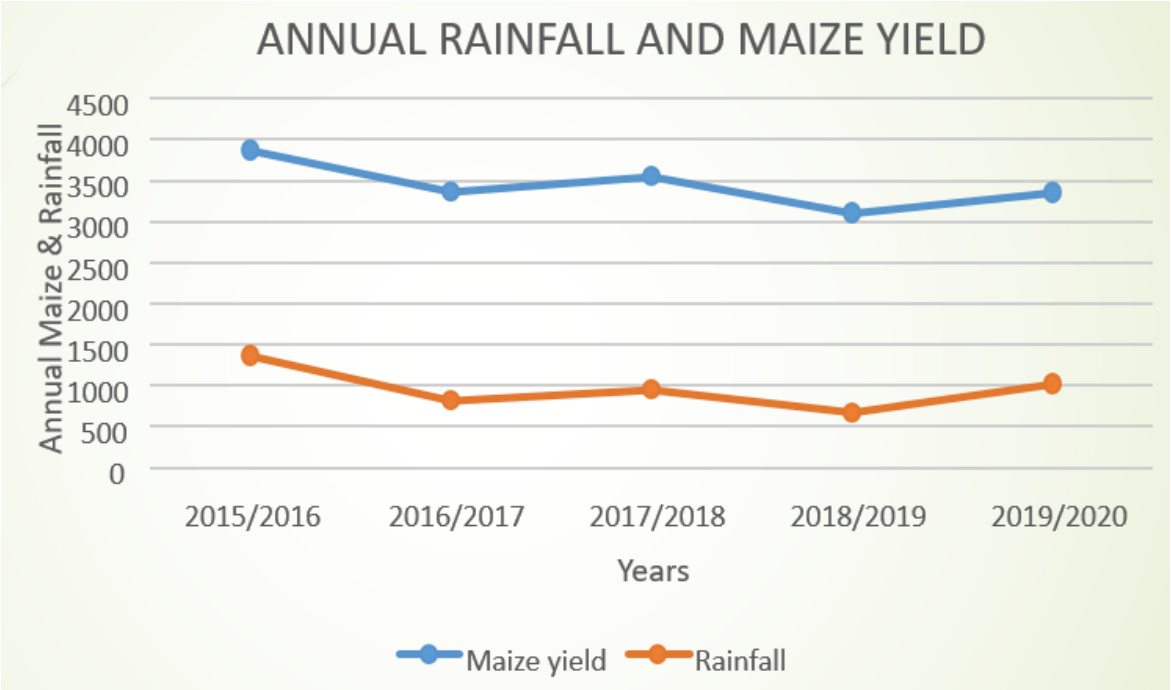


Figure 21: Rainfall and maize crop yields

The graph above shows the relationship between rainfall and maize yield according to the data collected from Meteorological department and Mzimba North Agricultural office to be specific Mubangwe EPA. The results shows that when rainfall increases, the Maize yield also increases and the vice versa is true.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The main objective of the study was to investigate the relationship between rainfall and crop production in Mubangwe - Mzimba district, Malawi for the period 2015-2020. The study found out that the annual rainfall amount had decreased over years. The NDVI for Mubangwe shows that, NDVI is an important tool for predicting crop yields based on the healthy status of the crops in the fields since the output images described the same thing referring to the data collected from Agricultural office for Mzimba North.

The annual rainfall and crop production (maize) shown a significant and strong relationship exist between them with indirect related through its negative r-coefficient value. As such maize yield increases with increase in rainfall and decreases with decrease in rainfall.

Challenges were identified that are faced by farmers in Mubangwe and this includes; soil erosion, inadequate agricultural officers, crop diseases, inadequate capital, and climate variability. The study also shows that farmers are not advanced in the adaptation measures to climate variability.

5.2 Recommendations

The study recommends that more adaptation and coping strategies to climate variability should be introduced to the farmers to mitigate them from the impacts of climate variability, thus ensuring Mubangwe food security. Irrigation practices should be promoted to reduce the large community dependence on rainfall to grow their crops hence this will in return help supplement the crop water requirement.

The advisory officers should be deployed to the area to educate the farmers on the impacts of climate variability and on the importance of monitoring the crop-climate

relationship hence improving crop yields. The farmers should also be encouraged to enhance crop diversification to help mitigate them from climate variability.

In addition, the stakeholders and policymakers should ensure that they provide climate-related information to the farmers that are timely, proven, and reliable to ensure that farmers are in a better position to cope with climate variability. This will ensure that the area is food secure. Because of the high correlation between rainfall and crop production, the adoption of maize varieties that are resistant to heat, drought, and stress should be bred for farmers in Mubangwe.

5.3 Area of further Research

Other climatic variables like temperature, pressure, wind, humidity, water vapor, and sunshine need to be looked at in comparison with maize crop production to have precise weather parameters that affect crop production.

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