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Remote sensing based fire frequency mapping in Mazowe district of Zimbabwe

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Remote sensing based fire frequency mapping in Mazowe District of Zimbabwe

by

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A research report submitted to the Faculty of Science, University of the Witwatersrand, and Johannesburg in partial fulfilment of the requirements for the degree Master of Science (Geographical Information System and Remote Sensing)

Supervisor Professor Fethi Ahmed

Johannesburg, 2017

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted for the Master of Science in Geographical Information Systems and Remote Sensing at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University

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Signature of candidate

……..day of ……20…….in……

ABSTRACT

The purpose of this analysis was to map the frequency of veld fires using remote sensing data from 2012 to 2016. The analysis successfully answered three objectives which are mapping the spatio-temporal pattern of veld fires in Mazowe district from 2012 to 2016, assessing the strength of association between burnt area and land cover classes and to determine the degree of veld fires in Mazowe district.

The analysis of the veld fire frequency was undertaken in ENVI 5.3 and Arc Map software. Landsat imagery and MODIS fire products were collected and processed. For each year two Landsat images were used, one image before the season of fire starts which was used to classify the land cover classes and one image after fire season which was used to classify the burnt and unburnt classes. The MODIS fire products data were used to validate the burnt and the unburnt classification. The evaluations of the classifiers were done through accuracy assessment using confusion matrix and the results ranged from 85 to 95%.The study quantified the relationship between burnt areas land cover classes. The study also calculated the fire frequency.

The results revealed that the veld fire frequency was high in A1 farms which measures 5 hectares, A2 farms which measures average of 318 hectares and grasslands compared to other land tenure and land cover classes. Areas with high frequency were observed in south, south west and some central parts of Mazowe district. There was high fire occurrence in 2012 and 2014. The study also noted that the fire occurrence was gradually decreasing, however the levels of fire occurrence remains high.

The study concluded that A1, A2 farms and grasslands are prone to veld fires. The study recommends adaption of remote sensing techniques in eradicating veld fires.

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ABBREVATIONS AND ACRONYMS

ARCGIS	Aeronautical Reconnaissance Coverage Geographical Information System EMA Environment Management Agency
ENVI	Environment for Visualizing Images
ERDAS	Earth Resource Development Assessment System
ESRI	Environmental Systems Research institute
ETM+	Enhanced Thematic Mapper Plus
KM	Kilometers
LC	Land covers
GIS	Geographic Information System
LT	Land tenure
ML	Maximum Likelihood
MODIS	Moderate resolution imaging Spectroradiometer
ROI	Region of Interest
RS	Remote Sensing
SV	Support Vector Mapper
SLC	Scan Line Corrector

CHAPTER ONE: INTRODUCTION

1.1. Background

Veld fires causes huge destruction and damage of ecosystem such as waste assimilation, ecosystem functions as well as economic assets (Stephenson *et al.,* 2013). Fires cause instability of soil nutrients and destruction of soil structure which can contribute to a global climate change (Sowmya *et al.,* 2010). Of late uncontrolled fires have been increasing, affecting agriculture land, wild life and human lives. Most of these damages have been caused to newly resettled small holder farmers (EMA, 2011; Phiri *et al.,* 2011).

On the other side, veld fires perform important part in the ecosystem operations such as offsetting plants and grass regrowth through providing suitable conditions for germination and growth conditions (Masocha *et al.,* 2011; Kusangaya *et al.,* 2015). Thus in Southern Africa, veld fires are perceived ambiguously because there is a conflict between fire as a crucial process in certain ecosystems and fire events as a threat to property and human life (Chirugah *et al.,* 2010).

Mazowe district was selected for the analysis study due to its agricultural activities which are important to the economy of the country. Mazowe was the most affected district in Mashonaland Central province recording high fire frequency and damage of property. In 2010 Mazowe Rural District Council launched a fire management committee which composes the Environmental Management Agency (EMA) and the Zimbabwe Republic of Zimbabwe Police to deal with the perennial problem of uncontrolled veld fires.

Causes of veld fires are grouped into two groups which are natural and human (Kusangaya *et al.,* 2015). Natural fires are mainly as a result of lightning and human induced are those fires that are caused directly or indirectly by humans. In Mazowe district farmers' exercises commercial farming mainly maize, soya bean and grass for pastures (Junior *et al.,* 2014).

As observed by (Swotwa *et al.,* 2017) newly resettled farmers use fire to clear bush and crop residue, preparing for the new planting season. In most cases the veld fires run wild and becomes uncontrolled fires due to lack of proper management. On the other hand hunting escapades which normally take place in the summer season when the fuel load is abundant and dry also facilitate ignition spread of veld fires since fire is continuously being used for hunting in Zimbabwe (Nyamadzawo *et al.,* 2013).

Environment Management Agency (EMA) of Zimbabwe is responsible for environmental management and has created fire occurrences database in each province in Zimbabwe. EMA (2011) notes that the official fire season in Zimbabwe starts in May and ends towards the end of October.

The Government of Zimbabwe in 2000 initiated a fast tract land redistribution program acquiring 12.4 million hectares of the 16 million hectares dividing it into A1 and A2 farms. A1 farms measures 5 hectares and A2 measures average of 318 hectares per farmer. As investigations on veld fires keep going Phiri *et al.,* (2011) observed that an increase in veld fires was fueled by the use of fires to clear land in resettled small holder farmers in Zimbabwe. Thus there is an urgent need to map and monitor veld fires to be able to track, identify unanticipated impacts and propose informed fire management strategies

Taking into account all of these issues, it then becomes vital to understand the spatio and temporal patterns of veld fires so as to promote sustainable use and management of ecosystem goods and services especially in Zimbabwean ecosystems. This study seeks to implement the use of available imagery (MODIS burnt areas products and Landsat imagery) in the mapping of fire frequency in Zimbabwe with particular reference to high farming and high fuel load zone of Mazowe District of Mashonaland Central Province. Veldfire mapping through image classification would form the backbone of the methods to be used.

1.2. Problem Statement

The ecological and socioeconomic impacts of fire have a potential to constrain sustainable development. In Zimbabwe, however, the current fire monitoring methods are limited. The fire frequency in the Mazowe districts are poorly documented which makes it very difficult to analyze the changes in fire extent over time. There is paucity of data on the spatial distribution or trends in burned areas annually to meet the needs of the responsible authorities. In Mazowe district the veld fires are impacting negatively to the people's livelihoods who are mostly commercial farmers who specialize in crop production and animal husbandry. Frequently burning has implication in animal habitant and human life. In the district animal production is decreasing due to the continuous burning of pastures. In Zimbabwe veld fires are a single threat of to the economic recovery. Food security is now compromised as recorded in some years back where maize fields and wheat fields were destroyed. Mapping fire frequency is useful to identify areas that frequently burn. Satellite remote sensing provides practical ways to map biomass in extensive areas such as Zimbabwe (Roy *et al.*, 2005) hence there is need for this empirical study in fire prone district.

The Zimbabwe National Fire Protection Strategy and Implementation Plan (2006) require that responsible authorities audit and document the extent of damages done by fire. However, studies to generate knowledge on the burned areas on spatial distribution remain largely scanty. The measurements of burned areas in Zimbabwe have been based on estimates. Literature on the mapping of veld fire frequency in Zimbabwe using remote sensing techniques is limited. Therefore, this study seeks to improve the implementation of the National Fire Protection Strategy and Implementation Plan in Zimbabwe by using of remote sensing applications. Mapping of veld fire based on ground surveillance is both tedious and time consuming. Remote sensing techniques have proved successful in providing wide spectral in terms of coverage and both spatial and temporal resolution.

A few studies done in Southern Africa on the spatial patterns of burnt area using remote sensing have covered only parts of Zimbabwe. It is therefore vital to analyze the spatio-patterns of burnt areas and temporal variation. Limited studies have been done in Zimbabwe

on fire mapping. Veld fire mapping in Zimbabwe is currently based on traditional methods. This can represent a pro-active approach to fire management that can be utilized by land use planners and policy makers in Zimbabwe.

Also fire outbreaks have been reported to cause significant damage of property and loss of human live. For example in Zimbabwe in 2005, seven people lost their lives and also timber worth over $1.5 billion was lost due to uncontrolled veld fires (Ministry of Environment and Tourism 2006). As a result there was reduction in timber production that same year hence a decline in exports and foreign currency earnings thereby negatively impacting on the economy of the country. Thus, it is invaluable to analyze spatio-temporal patterns of fire incidences as a way of identifying areas that frequently burn, likely origins of such fires to be able to propose management strategies for effective control of fires in Zimbabwe.

1.3. Aim of the study

The aim of the analysis is to map veld fires frequency in Mazowe district of Zimbabwe, in order to determine the areas that are frequently affected by the veld fires from 2012 to 2016

1.4. Research questions

This study seek to answer the questions below

- What are the spatial temporal patterns of veld fires in Mazowe district from 2012 to 2016?
- How do land cover classes relate to burnt area?
- How do land tenure system relate to burnt area?
- What are the trends of fire frequency in Mazowe district

1.5.Objectives of the research

The main objective of this analysis is to map the spatial distribution of burnt areas in Mazowe district Zimbabwe from 2012 to 2016. Landsat imagery and MODIS burned fire products were used archive all the objectives. Specifically, the study intends to:

- Mapping the spatio-temporal pattern of veld fires in Mazowe district from 2012 to 2016 using remote sensing techniques.
- Mapping the relationship of burnt area and land cover classes
- Mapping the relationship of burnt area and land tenure systems
- Determining the trends of veld fire frequency in Mazowe district

1.6. Structure of the report

This study is comprised of five chapters. Chapter 1 consists of introduction of the study. Focus of remote sensing role in mapping veld fire and the study overview which consists of the problem statement, research questions, aims, objectives. Chapter 2 reviews literature on the scholarly work which has been conducted on fire frequency and burnt area mapping. This is followed by Chapter 3 which outlines the fully detailed study area, data collection and processing methods used. Chapter 4 consists of discussions and results. Conclusion and recommendations make chapter 5.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

In this chapter, scholarly work by different researchers that contributed to the veld fire frequency body of knowledge was reviewed. The following sub-themes will be reviewed; 1) spatio-temporary mapping of veld fires, 2) Fire occurrence and relationship with land cover classes and 3) veld fire frequency mapping in Mazowe district

2.2. Spatio-temporal patterns mapping of veld fires

Understanding and characterizing the spatial and temporal fire regimes is essential for improving our knowledge on vegetation species composition (Hardtke, *et al.,* 2011; Buthelezi et al, 2016). Veld fires cause a lot of damage to the environment negative effects on humans (Dube *et al*., 2015). As noted by Mkwananzi (2007) humans contribute most of the veld fires, and it is believed that they are responsible for 95% of all the forest and veld fires. Fires that occur over lengthy time periods have collectively been identified as fire regimes and are defined by factors such as frequency, severity, intensity, spatial pattern and seasonality (Gill 1975; Buthelezi *et al*., 2016). Local people use fire to manage resources. According to (Dube *et al*., 2015) veld fires had varying negative impacts on humans, livelihoods and the natural environment, leading to severe loses. Therefore, mapping and monitoring fires can assist in the implementation of effective management strategies and equip land managers with necessary information for regulatory requirements (Chu *et al*., 2015). Previously Zimbabwe has been relying on traditional methods in spatial-temporal pattern mapping such as field surveys and hand drawn maps. Ground surveys are inaccurate and in consistence since they do not give enough information on size and the exact location (Hussin *et al*., 2008). Remote sensing provides cheap, consistent and unbiased observations of fire activity by providing essential information such as the area, timing location and spatial extent of the veld fire (Archibald *et al.,* 2009).

Spatial temporal mapping of burnt area across different landscapes was successfully implemented. In developed countries many studies implemented successfully the remote sensing techniques in mapping spatial-temporal patterns of veld fires using different Sensors such as Landsat and MODIS fire products

In more recent study, Goodwin (2013) used series of Landsat image to quantify fire activities in the state of Queensland, Australia. The analysis have proven the capabilities of satellite images in mapping spatio- temporal patterns of veld fires

Remote sensing techniques have also been implemented in mapping spatio-temporal patterns of veld including Africa. Buthelezi *et al.*, (2016) assessed spatial patterns of fire regimes on the different vegetation in Kwazulu Natal Province, South Africa. Ten MODIS (MCD45A1) burnt area images from 2003 to 2014 were used in the analysis. The study noted that there was a general increase in area burnt between 2004 and 2009 and after that the study observed decrease in area burnt. They also investigated the association between fire occurrence and vegetation types using the combination of GIS and remote sensing techniques. The results indicated that the KZN Sandstone Sourveld recorded the highest total area burnt (80%) in the year 2009, the KZN Coastal Belt and the Eastern Valley Bushveld had the lowest burnt area with less than five percent <5% and the Ngongoni veld recorded high total area burnt throughout the study maintaining over 60% from 2005 to 2010.Other studies in Africa

2.3. Relationship between burnt area and land cover classes

Understanding the association between burnt area and land cover classes is mandatory in fire management. As observed by Bowman *et al., (*2011) human land use changes have profound impacts on fire regimes by changing the fuel loads and ignition rates, leading to altered fire patterns in many parts of the world. Fires are vital in landscape disturbances which interact in a complex way with land cover and land use change (Eva *et al*., 2000). The amount of fuel and its spatial distribution are basic factors in explaining fire ignition and propagation, because the discontinuity of fuel load will produce changes in fire-propagation rates (Burgan *et al.*, 1998; Llorent *et al.*, 2002; Bajocco *et al.*, 2008).

Applications of remote sensing techniques have been used in different parts of the world to quantify between land cover classes and wildfires. Bajocco *et al*., (2007) quantified the association between land cover classes and annual burnt area in Mediterranean region of Sardinia, Italy from 2000-2004. The analysis used fire history data for Sardinia, Italy. The results obtained from the analysis indicated that grasslands and shrublands have higher fire frequency

Low fire frequencies were recorded agriculture classes. In Eastern Spain Costafreda-Aumedes *et al., (*2013) quantified the association of local landscapes heterogeneity and wildfire occurrence. The results showed significant relationship between local spatial patterns and from land cover and fire occurrence.

From all the veld fire frequency mapping research, there is no study that have quantified the relationship between land cover classes and burnt area in Zimbabwe .Thus there is a need for this study to quantify the relationship.

2.4. Veld Fire Frequency mapping in Zimbabwe

Fire frequency can be defined as annual percent area burned with a study area (Senici, 2010). Remote Sensing products have increasingly become vital in veld fire management. Understanding remote sensing products have facilitated crucial prediction and decision making policies world over in fire prevention and management. According to Chigurah *et al*., (2010) terrestrial savannah ecosystems are able to rejuvenate through coppicing and seeds, though they are composed of ever changing varieties. Because of their inherent ability to regenerate, terrestrial savannah ecosystems are perceived to be fire tolerant. Widespread biomass burning has become the major factor in changing the environment hence, affecting these savannah ecosystems. Studies carried out in Southern Africa have resulted in fire being perceived in two diverse ways, whereby fire is viewed as important process and hazard of the environment.

Lack of enough resources by the Environmental Management Agency of Zimbabwe to properly cover all areas in terms of monitoring fires has prompted the need to implement spatial mapping and detection tools to frequently monitor bush fires at least cost whilst covering wide areas. EMA (2011) observed that about 80% of veld fires are associated with areas where A1 and A2 farm models (former large scale commercial farming area) are, indicating that a shift in agricultural practices has stimulated the outbreak of veld fires. Africa is the most continent affected by veld fires the compared to other continents (Navashni 2003,FANRD, 2010) for this reason some people are now referring it to as a fire continent and has primarily because much of the African, used to be covered by dense savannahs but they have been destroyed the fires that have been occurring frequently (Bond *et al*., 2003).

The current dry spells being experienced in Southern Africa facilitates the fires, has continued to impact heavily on its fire frequency (Kusangaya *et al.,* 2013). Masocha *et al*., (2011) noted that, frequent burning of the savannah results in land degradation and loss of biodiversity for example through invasion by alien invasive species. Taking into account all these issues, there is a call to facilitate in developing effective and reliable methods that can produce credible results. Furthermore Southern Africa as a region is experiencing high fire frequency highlighted that, despite the known fact that Southern Africa incurs high fire frequency in the whole world and worst biomass burning in the world, there is still a great need in terms of more research, especially at local management levels.

The fires reduced the quantity of all pastures essential for the cattle restocking program (Magadzire *et al,* 2013). The damage caused by veld fires has negative impacts on economic recovery. Despite the known fact that the Miombo which mostly dominate Zimbabwe forests is a fire dependent and tolerant ecosystem, some researchers discovered that an altered fire regime due to an increase in fire frequency, intensity, extent and late season fires, has the capability to alter the composition and structure of the Miombo, as well as transform the woodland to grassland, (Masocha *et al.,* 2011; Ryan *et al.,* 2011). Hence, it becomes crucial to analyze the potential risks the veld fire crisis in Zimbabwe may have on the Miombo.

Statistics have also shown that fires which occurred in areas which are not reachable were not documented, due to members of community reluctant to report the to EMA offices (EMA 2011). Records with missing information thus weakened the capability of the fire management practices. The magnitude of the veld fire crisis, combined with the lack of financial resources and ineffective collection of fire statistics, forms the basis for the development of a timeous and inexpensive system that can monitor fire occurrence in Zimbabwe, as well as fill in the gaps in existing fire records (Magadzire, 2013). Therefore, the implementation of remote sensing applications in resolving the current need for fire statistics in Zimbabwe becomes very crucial.

To determine the impacts of veld fires on vegetation, burned area mapping has become one of the most important tools to use. This tool promotes the rebuilding of a fire historic veld fires information of veld fire occurrence in a region because it gives the time of occurrence, size and damage within a given area because it gives the time, location and extent of fire damage over an extended period of time (Magadzire *et al*, 2013). Archibald *et al*., (2010) elaborates that the data obtained from mapping of the burned area enables to analyze the fire frequency study hence, making it possible to determine seasonal and daily patterns of fires.

Not much detailed statistics of fire occurrences of the study area is available, hence the need to carry out the investigations in this area. However, from the fire map of Zimbabwe it can be observed that Mazowe District falls within high fire prone regions as well as high cultivation and high natural forests areas. Therefore there is need for up-to-date information, for example, accurate data on the patterns of area burned and the fire frequency status of this area, which remote sensing techniques can provide.

2.4. Remote sensing in mapping burnt areas

Since the evolution of remote sensing and techniques of observing earth from space, remote sensing has become a vital tool for the scientific community and natural resources, because its ability to collect data from bands that are not assessable (Kennedy *et al.*, 2009; Ruize *et al*., 2014). Remote sensing techniques can be of important in mapping burned areas following a veld fire. Remote sensing images have capacity of mapping fire frequency and area burnt in especially on regional levels (Daldegan *et al.*, 2014).. According to Ruiz *et al*., (2014) burned area mapping area provides information on the fire seasonality, frequency of occurrence, location and quantification of the burned area, which is essential for developing environmental management. Burn area scar mapped using remote sensing techniques gives information on the location, patterns of the affected areas (Liew *et al*., 2001).

In developed countries like United States of America and Australia, Large wildfires occurring along interface pose risks to both life and property and are cause of major

socio-economic concern (Mell, 2010; Schroeder, 2016). In response MODIS was among the first active fire products produced by NASA which lead to improvement and developing of more active and burned products (Justice, 2002). MODIS were the first in a family of remotely sensed fire data sets produced from a new generation of moderate resolution (1km), fire capable sensors on-board terrestrial satellites. The MODIS algorithm uses its spectral, temporal as an advantage for mapping burned areas (Roy, 2005).

Remote sensing has been successfully used around the world for mapping the burnt area using different satellites. Gitas *et al* (2004) used remote sensing techniques to map burned areas in Mediterranean Creus region of Spain. The analysis used NOAA-AVHRR imagery and object based classification method. To determine the extent of the total area burnt, the analyses calculated the area burnt and the perimeter and validate the results using fire frequency from Catalan Environmental Department. The study concluded that the total area burnt was 6900ha and the results were 90% in agreement with the fire from the database. The results also concluded that object based classification produced good results in area burnt.

Ruiz *et al*., (2014) used remote sensing methods to map burnt area burnt in North America Boreal Forest. The analysis used terra three MODIS burned products which are MODIS LTDR, MODIS Burned Area (MCD45A1) to map the veld fires from 2001 to 2011.The results were validated using data from Alaska Fire Service (AFS) and Canadian Forest Service National fire Database (CFSNFD). The results of the study indicated that the total area burnt from 2001 to 2012 was 28.56 million hectares,2014 was the most affected year with burnt area amounting to 5.62 million hectares and the lowest area burnt was 2001 with only 0.62 million hectares. Other studies include Mitri *et al*., (2004) used objected-oriented model to map area burnt in the Mediterranean region of Greek island of Thasos using Landsat TM imagery.

In Southern Africa some studies were carried out using remote sensing techniques to map burned area. Hudak *el at* (2004) used Landsat imagery to map fire scars in southern Africa in Madikwe Game Reserve which is located on the South Africa and Botswana boarder. A supervised classification of parallelepiped was used to map burned and unburned areas

from 1992-2002.The results indicated that Madikwe Game Reserve had highest frequency while the other part that falls in Botswana had the lowest frequency and the part that falls in South Africa had the intermediate frequency.

Zimbabwe is still experiencing high fire frequency because up to date no research has been done specifically using remote sensing to map burnt area Masocha *et al*., (2011) noted that more study is still required on veld fires since the previous studies are poorly documented.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Introduction

The chapter provides brief description of the Mazowe district (Figure 1), the data collection, the methods that were used in this study, and the steps that were followed in data pre- processing and data processing

3.2. Study Area

Mazowe district covers an area of approximately 4662 km2. The climate is characteristic of hot wet summers and very cold dry winters because of the vast mountains and hills within and around the area. Very high temperatures ranging between 26°C–35°C experienced around during dry season accompanied by strong dry winds which make it very conducive for veld fire outbreaks (Metrological Department Zimbabwe 2016).

Mazowe district is characteristic of high hills and mountains which prompt high topographic rainfalls which range from 700 mm to 1000 mm, hence high vegetation cover (fuel load) is greatly promoted. The vegetation of this area is mostly consist grassland and forest. Large volumes of vegetation are observed along streams and within Mazowe valley were the Mazowe Dam is located.

The major economic activity in the district is farming, crop production and livestock production. Previously the district was mainly occupied by white commercial farmers and as such they treated the land as private property such that land cover was always preserved. However from the beginning of the accelerated land reform program, the population in this district has greatly increased leading to change in settlement patterns. Thus the fire out breaks is believed to have increased due to the land ownership change

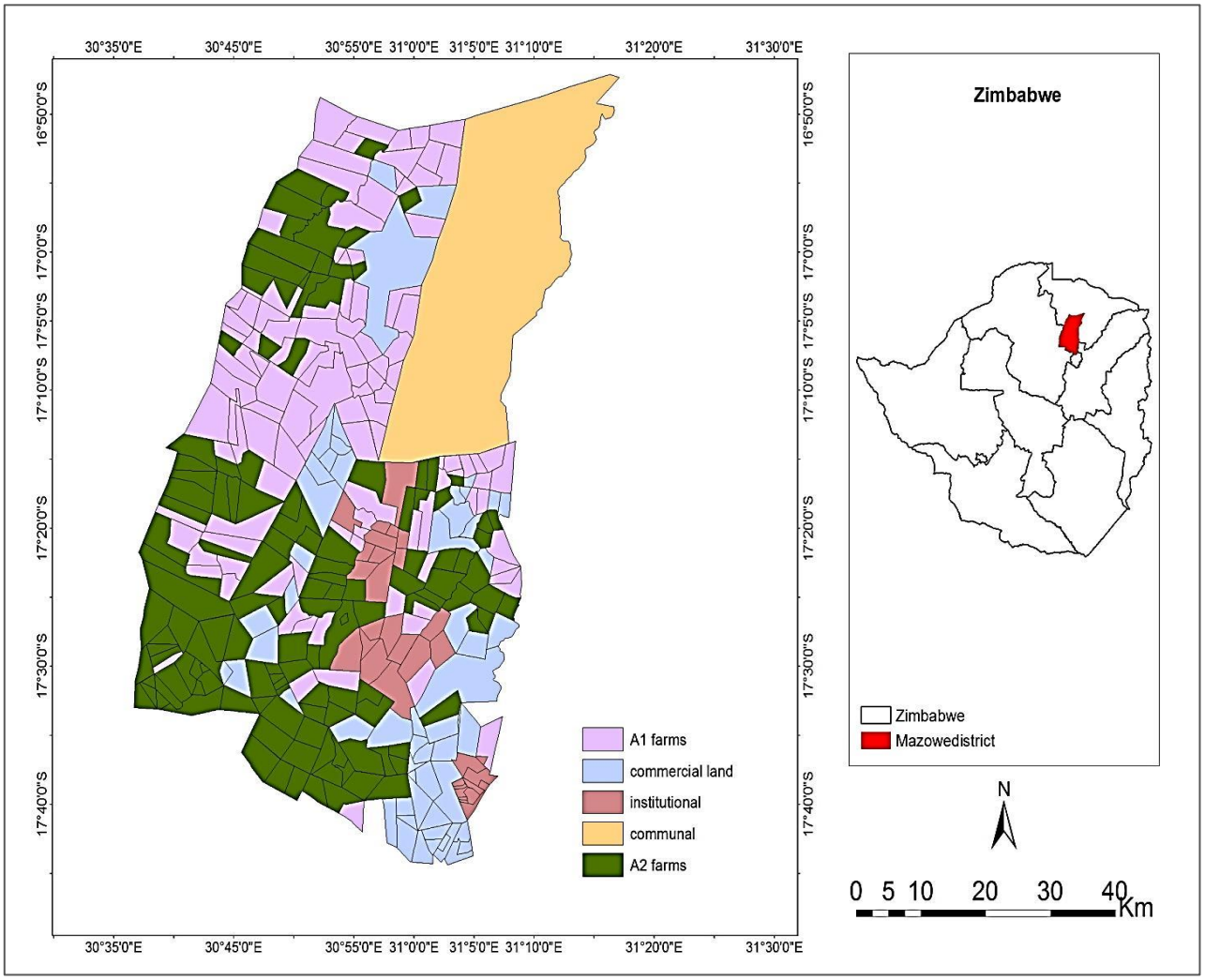


Figure 1: Location map of Mazowe

3.3. Data Collection

Landsat, MODIS Burned product, fire reports and Climate data were collected for the study. Fire occurrence reports from 2012 to 2016 which is the period of the study were collected from the Environmental Management Agency of (EMA). District boundaries data were collected from the Mash Central Provincial lands office.

Software Packages Used

- ENVI 5.3 (Environment for Visualizing Images) for classification
- ERDAS 8.6 (Earth Resources Data Analysis System) for gap filling
- ARCGIS 10.3(Aeronautical Reconnaissance Coverage Geographical Information System) for spatial analysis

3.3.1. MODIS fire products Acquisition

The Near Real –Time MODIS active fire product data were downloaded for free from the Earth data (FIRMS) platform from 2012 to 2016. The data were downloaded for each fire season covered in the study. MODIS active fire product offer data on specific dates on fire occurrences.

FIRMS produce daily near-real time science quality fire location hotspots data from standard MODIS MOD14 (Terra) and MYD14 (Aqua) and Thermal Anomalies products level 3 version 5 (Justice *et al*., 2011). MODIS burned fire products has 250 m to 1 kilometer spatial resolution. The MOD14A2 (Terra) and MYD14A2 (Aqua) daily level 3 8-day summary fire products are tile-based, with each file spanning one of the MODIS tiles, 326 of which contain land pixel. Each tile is assigned a horizontal (H) and vertical (V) Coordinate ranging from 0 to 35 and 0 to 17 respectively (Giglio *et al.*, 2013).

The MOD14 and MYD14 product is defined in the MODIS orbit geometry covering an area of approximately 2340 by 2030km in the acrossmand along-track directions, respectively (Giglio *et al*., 2013). The burned area products MOD14 and MYD14 data were downloaded from the Land Processes Distributed Active Archive Centre (LP-DAAC) (nasa.gov). Fire detection is performed using contextual algorithm (Giglio *et al*., 2003) that exploits the strong emission of mid-infrared radiation from fires (Dozier *et al*., 1981; Matson *et al*., 1981, Giglio *et al*., 2013). The algorithm examines each pixel of the MODIS swath, and ultimately assigns to each of the following classes missing data, cloud, water, non-fire, fire and unknown (Giglio *et al*., 2013). FIRMS is primarily aimed at supporting natural resources managers, researchers planners and policy makers by helping them to understand when and where fires occur and delivering the fire information in near real-time and easy to use formats (nasa.gov). Terra was launched on 18 December 1999 and Aqua was launched on 4 May 2002. High quality hotspot/active fire observations are available from November 2000 onwards (nasa.gov).

3.3.2. Landsat Imagery Acquisition

The Landsat imageries were collected from the United States Geological Survey library (Table 1). The imageries were downloaded freely from (usgs.gov). Cloud free two Landsat ETM+ images and four Landsat OLI were acquired from 2012 to 2016. The images that are close to the end of fire (end of October) season were collected. The multispectral characteristics of Landsat image make it suitable for fire mapping savannah (Hubak *et al*., 2003). Landsat images have spatial resolution of 30 m, which enables it to have the greater ability of mapping small fires scares .Advantages of using Landsat imagery in mapping veld fires include; wide spatial coverage per scene 187*187 in this study one image was enough cover the study area, Landsat imagery is freely available and Landsat imagery provides global coverage on regular basis

Table 1: Landsat Imagery acquired for the analysis

Path/Row	Landsat sensor	Pre-fire Season	Post-fire Season	Gap-fill
170/72	Landsat ETM+	22 April 2012	October 15 2012	Pre 08 May 2012 Post 31 October2012
170/72	Landsat OLI	05 May 2013	28October 2013	---------
170/72	Landsat OLI	24 May 2014	31October 2014	--------
170/72	Landsat OLI	25 May 2015	16September 2015	----------
170/72	Landsat OLI	13 May 2015	7 October 2015	----------

3.4. Remote Sensing data processing

The remote sensing images processing were performed using ENVI 5.3 software. ENVI is commercial software for general image processing and advanced image processing image and remote sensing analysis (Petropoulos *et al*., 2010). The main image processing carried out included classification and reclassification. Landsat 7 images were subject to gap filling, due to the scan-line corrector which failed in 2003 permanently which resulted in loss of 22% of information (Chen *et al*., 2011). One method of recovering lost information is to combine data from the adjacent scenes (El- Kawy *et al*., 2010). The reason of doing this procedure is that the gaps could be filled by data from the adjacent (USGS, 2003).In the analysis gap filling was done for 2012 Landsat 7 images for both pre and post fire season.

Gaps were filled using ERDAS software. The images were first converted from tiff format to the image (*img) which compatible in ERDAS software. A model with a conditional statement was build which fill gaps by taking values from an adjacent scene filling gaps of the image. For 2012 pre fire season image an EMT+ scene acquired on 22 April was to gap fill the image acquired on 22 April. For 2012 post fire season image, 15 October was used to gap fill 31 October image.

The radiance calibration process was used to convert digital numbers to radiance, and the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) algorithm was used for atmospheric correction (Jia *et al.,* 2014). FLAASH was developed to provide accurate, physics based derivation of atmospheric properties, which was derived from MODTRAN4, to incorporate those same quantities into a correction matrix, and finally to invert 'radiance-at-detector' measures into the 'reflectance-at-surface' values (Cooley *et al*., 2002). Study would cover the whole of Mazowe District which is estimated to be 4662 km^2 in area and the study period stretches from 2012 to 2016. Thus the study would prefer to use two series Landsat imagery. Landsat imagery has 30m spatial resolution which gives much detail for mapping burnt scares. Landsat 7 was launched on 15 April 1999 (Jensen *et al.,* 2007) and Landsat 8 was launched on 11 February 2013 (Capderou *et al*., 2014). Therefore the study used Landsat 8 to map fire scars from 2013 to 2016.

The fires in Zimbabwe are seasonal; the fire season starts from May to October. The fire season coincides with the dry season. For mapping burned areas in Mazowe District; the month of October was used for each year to acquire satellite data because this is the period which is the last month fire season in the savannah ecosystem. The assumption is that the burned area detected from the satellite imagery was the true representation of all the fires for the season. Also, this study assumes that little or no vegetation regrowth would have occurred at this time since October is usually just before the beginning of the rainy season. The MODIS Fire products were used to validate the burned area map during classification.

3.4.1. Land cover image Classification

Image classification involves identifying pixels which have the same characteristics and statistical groupings, checking similarities in digital numbers and spatial orientation to produce meaningful map (Mesev, 2010). Images acquired in May were used for land cover classification. Supervised support vector machine classification was used in this study to classify the land cover classes. Research that have been done before have indicated that SVM classifier produce credible results using few training sites (Pal *et al.*, 2006). One hundred and eighty region of interest (RoiS) points (180) were generated which were spread fairly disturbed across the study area in ENVI5.3 software. For each Landsat image was classified into six land cover classes namely; water bodies, forest, grassland, cropland, bare soil and built-up. From the one hundred and eight points, one hundred and twenty (120) points were used as training sites, twenty points per each of the six classes. Sixty points were used as testing sites, 10 points per land cover class (Saglam *et al.*, 2008).

Supervised machine learning method of SVM which is based on statistical learning theory was used (Vapnik *et al.*, 1995; Petropoulos *et al.*, 2010). SVM is commonly non parametric used classifier that has no assumption on the distribution made regarding the underlying distribution. The support vector machine uses optimization algorithm to detect the optimal boundaries between classes (Huang, 2002). SVM classifier finds the optimal hyperplane that utilizes the shortest distance of training sample and the separating hyperplane (Melgani *et al.*, 2004). The term optimal separation hyperplane refers to the boundary that is used for decision which reduces misclassification (Mountrakis *et al.*, 2010). SVM uses the hyperplane to classify by assigning a set of unknown points to a class which have the shortest distance of class from hyperplane (Chapelle *et al.*, 1999). Training data sets are used to develop the hyper- plane and it is validated by training sets (Oommen *et al.*, 2008). According Cortes *et al.*, (1995) to the hyperplane minimizes the risk of misclassification. Results obtained from previous studies have shown that SVM produces good results compared to other classifying methods with high accuracy level both producer accuracy and kappa (Congalton *et al.*, 1992).

3.4.2. Burnt area classification

This study used ENVI 5.3 software for image classifying burnt areas. One hundred region of interest (RoiS) points (n=100) were generated which were fairly disturbed across the study area in ENVI software for each Landsat image covering burnt and unburnt areas. Seventy points were used as training sites, thirty five points per each class burnt and unburnt respectively. Thirty points were used as testing sites, fifteen points per each class burnt and unburnt respectively. Training sites were used for classification while testing sites were used for accuracy assessment

Burned areas maps for Mazowe district were produced from one October Landsat imagery per fire season using supervised classification method of maximum likelihood. Burnt scars shows difference with the unburnt classes in the visible (0.4-0.7µm), near infrared (0.7-1.5µm) and middle infrared (1.5-4.0µm) areas of electromagnetic spectrum (Fuller et *al*., 2000). Mapping fire scars using remote sensing using remote sensing imagery make full use of the distinct between fires affected vegetation and vegetation which is health (Maingi *et al*., 2005). Thus the band combination of band 7 Shortwave Infrared (SWIR) 2, band 4 Near Infrared (NIR) and band 2 Green (7-4-2) were used to map the burnt and the unburnt in this study for Landsat 7 image and Landsat 8 band combination of band 7 Shortwave Infrared (SWIR) 2, band 5 Near Infrared (NIR) and band 3 (7-5-3) were used. ML classifier uses the assumption that spectral values of training pixel follow a Gaussian distribution and uses the variance and covariance (Bastarrika *et al.*, 2011; Oumar *et al*., 2015). The pixel is given to the class with highest chance of being a member (ESRI, 2010). The assumption is that the pixel with no value is considered to be long to the group with maximum chance of being a member (Jia *et al*., 2015). The images were classified into two classes burnt and unburnt. The image was subset to save time of computing (Petropoulos *et al.*, 2010). Validation of classification was done using the MODIS fire products. Only fire events that were detected at 95% or more confidence interval from the FIRMS were used in the study. Five annual burnt maps with two classes burnt and unburnt areas over the entire study area for the period covering fire seasons from 2012 to 2016 were produced.

3.5. Relationship between total area burnt and land cover

The analysis and the relationship between land tenure and the fire frequency of the Mazowe district was undertaken in Arc map 10.3. Spatial analyst tools of overlay and intersect extension were utilized for this study. The annual burnt maps were converted from raster data format to vector format which is compatible in Arc Map for spatial analysis. Vector layers were reclassified for each annual burnt map to form Boolean images containing zeros and ones, representing unburnt and burnt respectively. Reclassification process involves replacing old values in an input cell with new values (ESRI, 2010). Using the overlay each land cover class was intersected with annul burnt layer for each season. Overlay process involves combing two or more layers together which are in the same reference system (Chirugah *et al*., 2010). The results of each image were analyzed using a histogram to produce a fire occurrence histogram of each land cover class for each fire season. Furthermore to determine land cover class which is prone to fires, sum of area burnt in each land cover class was computed in square kilometers (km^2) in ArcGIS for all the years.

3.5.1. Relationship between total area burnt and land tenure

Procedure used for this analysis is the same as that was used in determining the association of annual area burnt and land tenure systems. The annual burnt area maps and the land tenure were acquired from different sources thus; they were standardized to the same projection.

3.6. Fire frequency analysis

The fire frequency analysis was done in Arc Map 10.3. The vector layers representing annul burnt areas were rasterized using the feature to raster tool in Arc Toolbox to form Boolean images (containing zero and ones) zero representing unburnt area and one representing burnt areas. A raster model separates the grid cells into a regular grid of cells in certain order, whereas a vector model uses lines or points determine areas (Goodchild *et al*., 1990). The five Boolean annual burnt raster layers were added to determine the number the fire frequency of each pixel over the study period. A spatial analyst tool of map algebra raster calculator arithmetic operator of addition was used to add raster layers produce a fire frequency map for five years.

3.7. Accuracy Assessment

Classification accuracy was performed in ENVI 5.3 software. For pre-fire season fairly distributed testing points on each LULC class were used and for post-fire season fairly distributed testing points on burnt and unburnt classes were used. The accuracy of classification was assessed using the classification accuracy statistics, of kappa statics, error matrix and overall (Congalton *et al.*, 1999; Petropoulos *et al.*, 2011). The overall accuracy, which is given in percentage, represents the chances that a randomly selected point was classified correctly on the map (Adam *et al.*, 2014). Overall accuracy assessment is determined by following formula below**:**

$$\text{Overall accuracy} = \frac{\text{Correctly classified}}{\text{total number of sample}}$$

Kappa statistics measures the difference between the actual agreement, between the classification method used for classification and reference data versus the probability of agreement between reference data and a random classifier (Petropoulos *et al.*, 2010). When kappa coefficient value is 1 it indicates that the agreement was perfect between the training data and the classification and when the kappa coefficient value is equal to 0 it means that there is no agreement (Dorn et al., 2015). The kappa coefficient is given by the following formula:

$$\text{Kappa} = \frac{\text{Observed accuracy} - \text{chance agreement}}{1 - \text{Chance agreement}}$$

The producer's accuracy shows the chances that the classifying method had accurately labelled the image pixel (Adam *et al.*, 2014). It is also known as commission of errors, which is given in percentage % (Petropoulos et al., 2010).

The accuracy assessment was done to check the quality of classification in order to check whether there is an agreement between classified image and data collected from the field ("ground truth") this was done using classification error matrix (Kusangaya *et al.*, 2015).

The flow chart shows the data processing steps employed in this study to achieve the objectives (Figure 2)

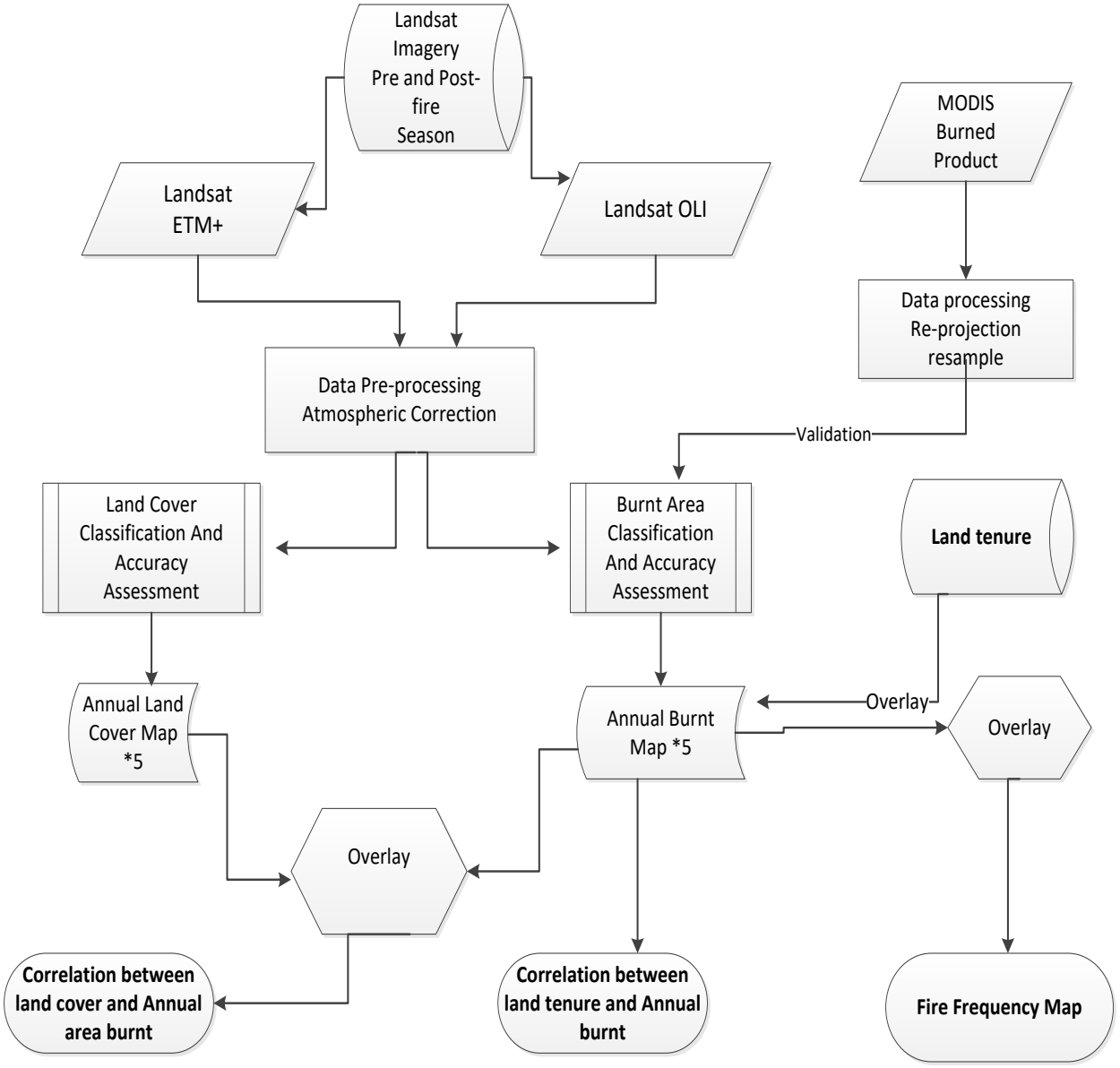


Figure 2: flow chart

CHAPTER FOUR- RESULTS AND DISCUSSIONS

4.1. Mapping spatio-temporal patterns of veld fires in Mazowe district

The burnt area graph below (figure 3) below illustrates there was a major decrease burnt area in Mazowe district from 2012 to 2013. According to (EMA) 2012 the decrease was attributed by the measures that were put in place by the management. Area burnt increased from 437.62km² in 2013 to 586.88km² in 2014. Burnt area decrease from 586.88km² in 2014 to 403.62km² in 2015 and from 2015 burnt area decreased from 403.62km² to 381.81km². The year 2012 experienced the highest area burnt throughout all the land cover classes and land tenure systems. The lowest area burnt was experienced in 2016. The burnt area was decreasing gradually, this shows that the fire management measures which were implemented by EMA in 2013 were slowly bearing fruits. Most of veld fires in Mazowe district were found to occur in grasslands associated with A1 and A2 farms.

The gradual decrease in area burnt might have been attributed by the increasing of population. The increases in population have effects on fires indirectly large population turn to have more cattle which decrease fuel load by grazing *(*Archibald *et al*., 2009).

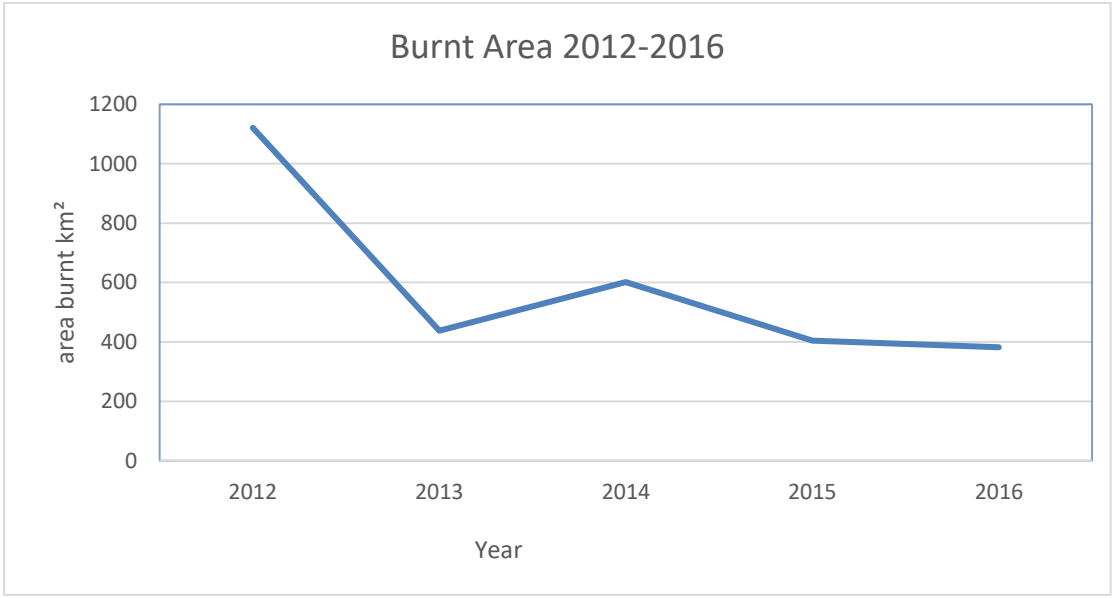


Figure 3: Burnt Area 2012-2016

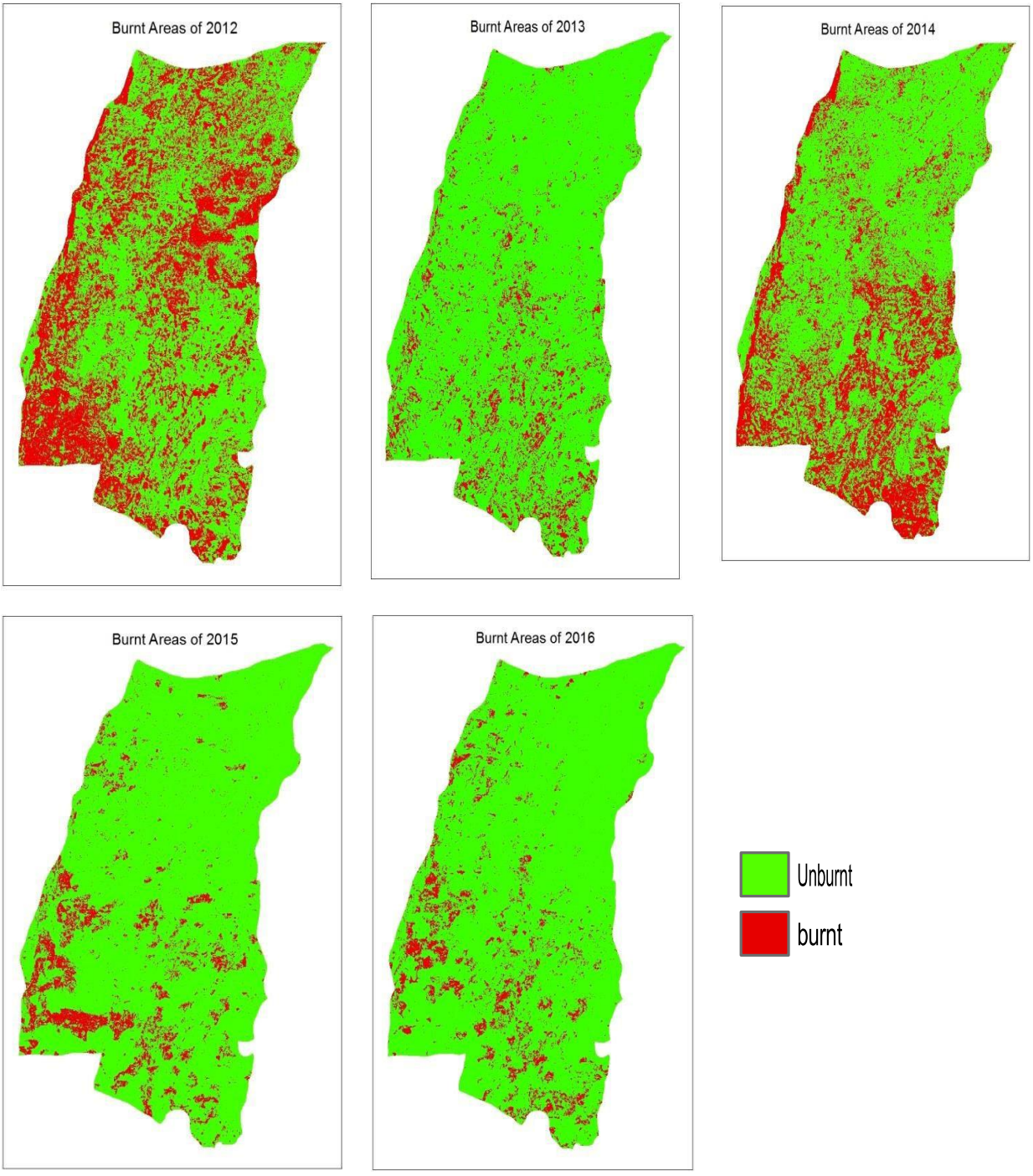


Figure 4: Burnt areas in Mazowe district from 2012-2016

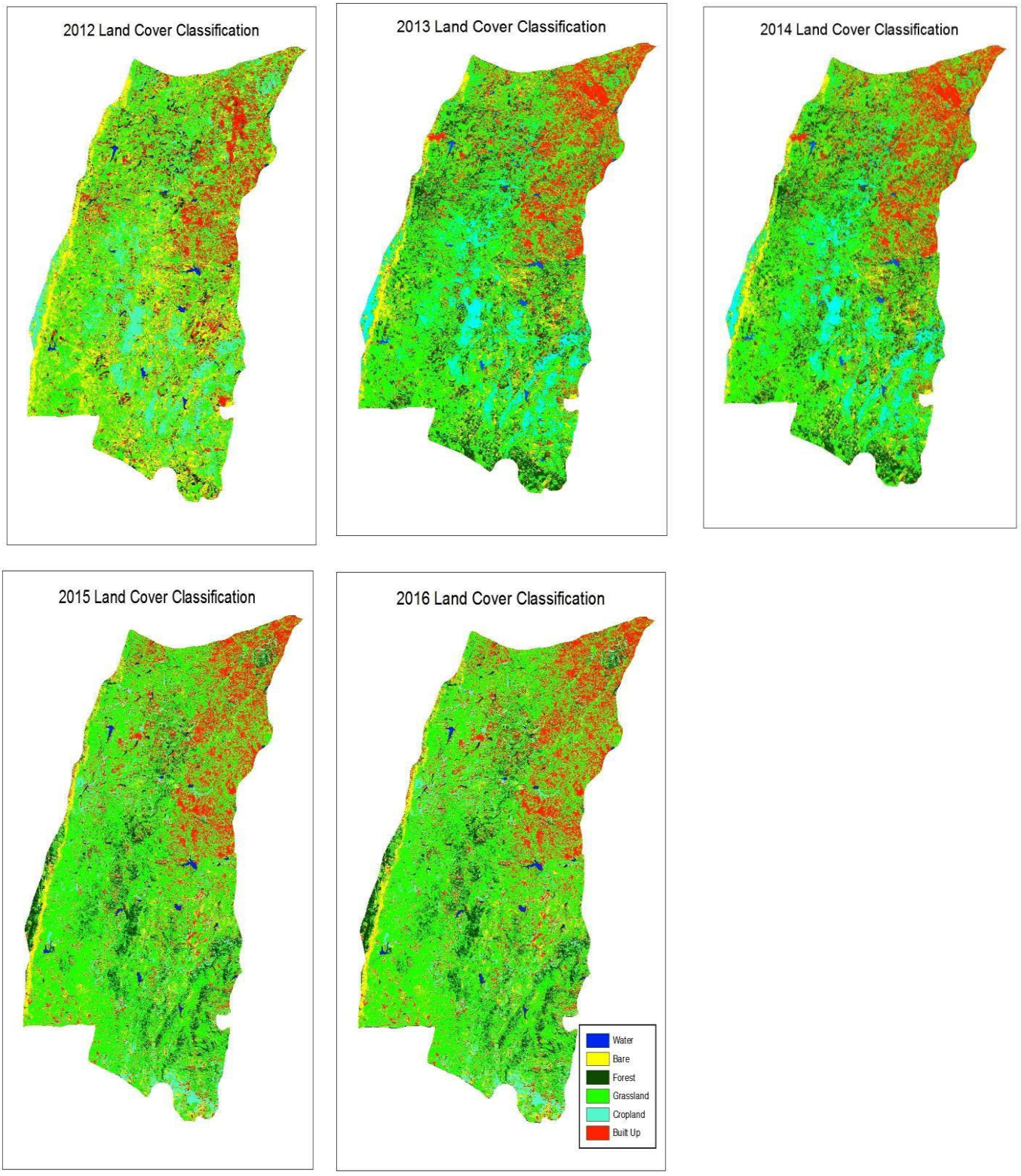


Figure 5: Land cover classification 2012-2016

4.2. Accuracy Assessment

A confusion matrix also referred as an error matrix was constructed in ENVI 5.3 to validate the classification for both pre-fire (Table 2) and post-fire (Table 3 season imagery. The confusion matrix assesses the quality of classification of using reference data (Campbell *et al.*, 2002). The classifications were done using the SVM and MLC classifiers respectively. Thirty ground control points per class which were fairly distributed were used as testing sites for validation. The overall accuracy for both pre and post-fire season ranged from 85% to 94%.

Table 2: Accuracy assessment for land cover classification

Year	Overall Accuracy	Kappa Coefficient	Accuracy Type	Cropland	Forest	Grass	Bare soil	Water	Build up
2012	86.58	0.86	Producer Users	89.37 88.68	81.08 71.43	84.33 87.5	91.32 95.23	86.20 89.28	77.66 90.90
2013	88.59	0.88	Producer Users	92.20 86.67	88.03 85.62	90.36 77.52	92.11 96.15	73.44 97.92	70.00 86.42
2014	89.76	0.89	Producer Users	94.89 84.59	82.23 86.20	84.59 84.80	95.10 96.15	88.67 88.68	73.68 89.74
2015	84.68	0.84	Producer Users	89.44 80.08	77.92 83.91	70.92 75.47	90.36 89.29	90.91 89.29	78.43 81.22
2016	91.00	0.90	Producer Users	94.43 88.63	90.57 79.11	87.80 83.72	93.23 97.33	82.45 97.92	83.24 95.06

The 2012 classified image in the table above had 86.56% overall accuracy of and 0.86 kappa coefficient. The bare soil class had the highest producer and user's accuracy of 91.32% and 95.23% respectively. The forest class had 81.08% producer's accuracy and 71.43% user's accuracy, while build-up had 77.66% producer's accuracy and 90.90% user's accuracy. Bare soil class had and 95.2% for producer's accuracy and user's accuracy 91.32%. Grass yielded producer's accuracy of 84.33% and user's accuracy of 87.5%.

The 2013 accuracy assessment yielded an overall accuracy assessment of 88.59% and kappa coefficient 0.88. The bare soil class had the highest producer of 91.32% and user's accuracy 95.23%. The cropland class had the producer's accuracy of 92.11 and the user's accuracy 96.15%. Water body, Grass and build-up class had the producer's accuracy and the user's accuracy of 73.44%-97.92%, 90.36-77.52% and 70%-86.42% respectively.

The 2014 classified images yielded 89.76 % of overall accuracy assessment of and 0.89 kappa coefficients. The bare soil accounted the 95.10% producer's accuracy and user's accuracy 96.15%. Other classes ranged from 82.23% to 88.68% in producer's accuracy and user's accuracy. The build-up class had the least accuracies with producer's accuracy of 73.68% and user's accuracy 89.74%

2015 classification yielded 84.68% overall accuracy and 0.84 kappa coefficient. Classes produced high producer's accuracy and user's accuracy ranging from 70.92% to 89.29%. Like previous years bare soil produced the highest with 90.36% and 89.29% producer's accuracy and user's accuracy of respectively. Build-up areas had lowest producer's accuracy of 78.43% and 81.22% of user's accuracy.

2016 image classification produced highest accuracy with of 91 % of overall accuracy and 0.90 of kappa coefficient. Bare soil class had the highest producer's accuracy of 93.23% and 97.92% of user's accuracy. Other classes produced high accuracy which ranged from 82.45% to 97.30%

Table 3: Accuracy Assessment for burnt and unburnt classification

Year	Overall Accurac	Kappa Coefficien	Accuracy type	Burnt	Unburnt
2012	98.07	0.97	Producer Users	97.67 96.77	98.28 98.76
2013	95.62	0.95	Producer Users	95.23 92.16	95.82 97.5
2014	95.58	0.95	Producer Users	95.12 91.98	95.82 97.5
2015	93.80	0.93	Producer Users	92.68 89.20	94.36 96.25
2016	97.38	0.97	Producer Users	94.17 99.22	98.59 96.73

Overall accuracy assessment and kappa coefficient of post fire season was high. Overall accuracy assessment was ranging between 93.80 % and 98.07% and the kappa coefficient ranged between0.93 to 0.97. The accuracy was above the recommended one of 80%, thus the classification represents the true representation of the ground features

4.3. Relationship between total areas burnt and land cover classes

Land cover maps (figure 4) and burnt area map (figure5) were used to quantify the association between land cover classes and burnt area map. Water body, build up and bare land were excluded from the analysis because are not affected by fire. Burnt area map for each season was intersected with three land cover classes which are crop land, forest and grassland. Total area burnt for each of intersection between a land lover class and the annual burned area map was calculated.

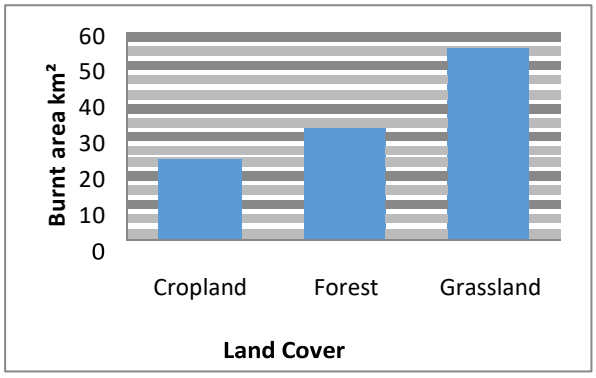
The histogram below (figure 6) correlation between land cover classes and the annual burnt in 2012 indicates that 57 km² was burnt i n grassland. The total area burnt in grassland and cropland amounted to 34.72km² and 24.11km²respectively. In 2013 the histogram shows a decrease in all land cover classes grassland amounting to 24.40km² while forest amounted to 16.32km² and cropland and 24.40km²

For the year 2014 the histogram figure 5 shows that there was an increase in amount of burnt in all land cover. Burnt area in grassland, forest and cropland amounted to 27.76km², 18.4km² and 14.86km² respectively. In 2015, the form the histogram reveals that the burnt area in all the three land cover classes decreased. Area burnt in grassland amounted to 20.01km², forest amounted to 13.20km² and amounted to 10.98km². Area burnt decreased in all land cover classes with grassland amounting to 17.30km², forest amounting to 11.76km² and crop land amounting to 7.30km².

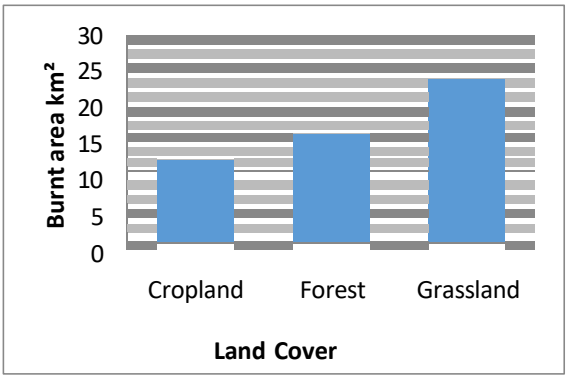
As shown by the results, grassland has high correlation with the burnt area followed by forest then cropland. In all the years grasslands recorded high area burnt due to the abundance of fuel which facilitates high spread of fires. Forest and cropland h a v e relatively low fuel. As observed by Bajocco *et al*., (2007) fuels in grasslands dry very fast therefore it can burn fast as compared to fuels in the forest which take ages to dry resulting in taking long period of time to burn.

As noted by Moreira *et al.,* (2001) number of fires incidences are positively correlated the size of population and farming practices, etc. Thus the total area burnt in the cropland was the least compared to other land cover class because conditions in cropland are not conducive for the veld fire to spread. In agriculture the fuel distribution is discontinuous and the presence of human will help to suppress the veld fires before they spread. The overall results obtained show association between fuel load, presence of humans and veld fires. We found that most of the veld fires occur in grasslands compared to other land cover classes, the results corresponds to the findings of (Giglio *et al*., 2006) in South America and Australia. The results obtained may be explained by the fact that grasslands in Mazowe district dries in summer and it can catch and spread fires easily. Grasslands are lower in communal areas, thus the total area burnt is very low.

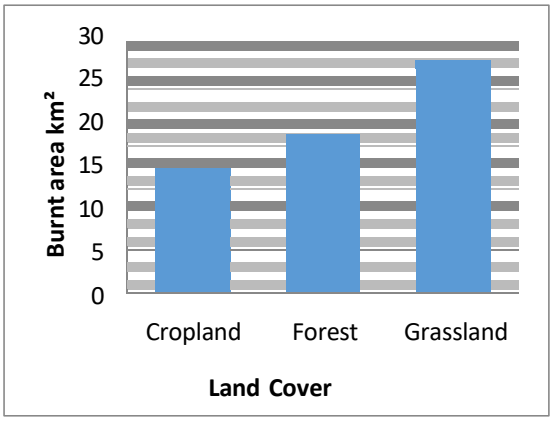
2012



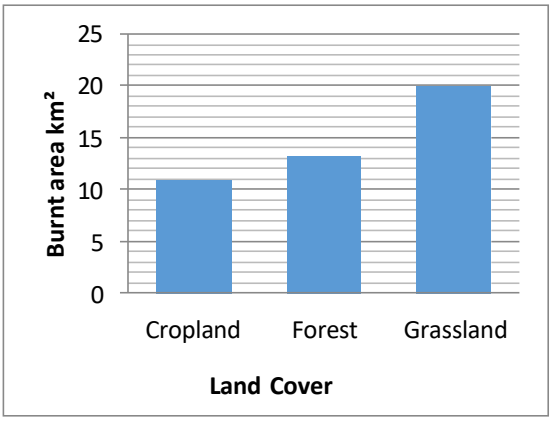
2013



2014



2015



2016

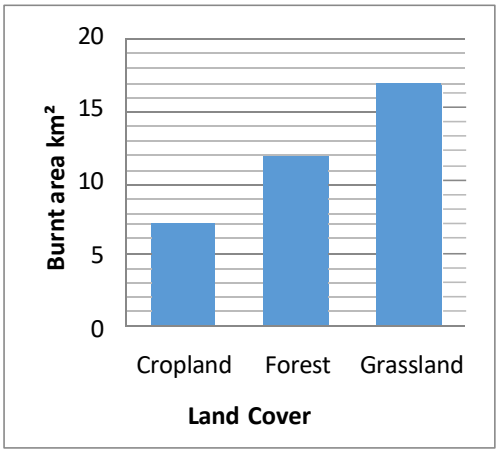


Figure 6: Total burnt area in land cover classes from 2012 to 2016

4.4. Relationship between total areas burnt and land tenure

A land tenure map was used for this analysis for quantifying the association between land tenure and burnt area map. Burnt area map for each season was intersected with the five land tenure which are A1, A2, communal, Intuitional and Commercial. Total area burnt for each intersection between land tenure and the annual burned area map was calculated.

The annual burnt area intersect land tenure system maps of Mazowe district from 2012 to 2016 in figure 3 and the total area burnt in land tenure in figure 4 indicates that in 2012 A2 farm land tenure system total burnt areas amounted to 112.73 km². Burnt areas in A1 farms land tenure system amounted to 298.90 km² commercial farms burnt areas amounted to 194.73km², institutional land tenure burnt areas amounted to 112.73km² and communal land amounted 26.83 km².

For the year the 2013 the burnt area intersect land tenure system map shown in figure 6 and the total burnt for each land tenure in square kilometers. As illustrated the total area burnt in A2 farms amounted to 186.11 km², whilst A1 farms, Commercial farms, Institutional and communal the total burnt area amounted to 109.82 km², 81.04 km², 44 km² and 15.84 km² respectively. The total burnt area decreased in all land tenures from 2012 to 2013.

The annual area burnt intersect land tenure map of the year 2014 as shown in figure 6 and the total area burnt in square kilometers (km²). The histogram (figure7) illustrates that a total of 305.63 km² burnt in A2 farms land tenure system, 195.92 km² area was burnt in A1 farms, 100.99 km² was burnt in commercial farms, 64.49 km² areas was burnt in intuitional and 35.37 km² area was burnt in communal lands tenure system. The total area burnt increased in all land tenure systems from 2013 to 2014.

The annual area burnt intersect land tenure map of land of the year 2015 as shown in figure 6 and the total area burnt in square kilometers (figure 7). The histogram (figure 8) illustrates that the total area burnt A2 farms was 243.43 km², the total area burnt in A1 was 76.23 km², the total area burnt in commercial farms was 45.44 km², the total area burnt in institutional was 30.39 km² and the total area burnt in communal lands was 8.32km².There was reduction in total burnt areas in all land tenure systems.

Figure 4 the annual area burnt intersect land tenure map of the year 2016 show that the total area burnt in A2 was 193.09 km², the total area burnt in A1 farms was 99.16 km², and the area burnt in commercial farms was 55.69km ², the total area burnt in institutional 29.90 km².

As observed by EMA (2011) that about 80% of veld fires are associated with A1 and A2 farm models (former large scale commercial farming area), indicating that a shift in agricultural practices has stimulated the outbreak of veld fires. As expected, from all the burnt area maps A2 and A1 farms model have the highest fire frequency. Communal tenure has lowest fire frequency in all burnt area maps. The land use in communal tenure system does not produce conditions that are suitable to veld fires outbreak. According to Chirugah *et al*., (2010) in communal land tenure the practices are not conducive for veld fires, practices such peasant farming, overgrazing and deforestation by villagers cause reduction o f dead dry fuel amount thereby minimizing the chances of veld fire.

Veld fires were recorded in all land tenure. Resettlement land tenure system A2 and A1 have highest fire frequency whilst non resettlement land tenure systems commercial farms, institutional and communal have low fire frequency. Most of the fires in A1 and A2 farms are a result of poor land clearing practices and lack of proper fire management.

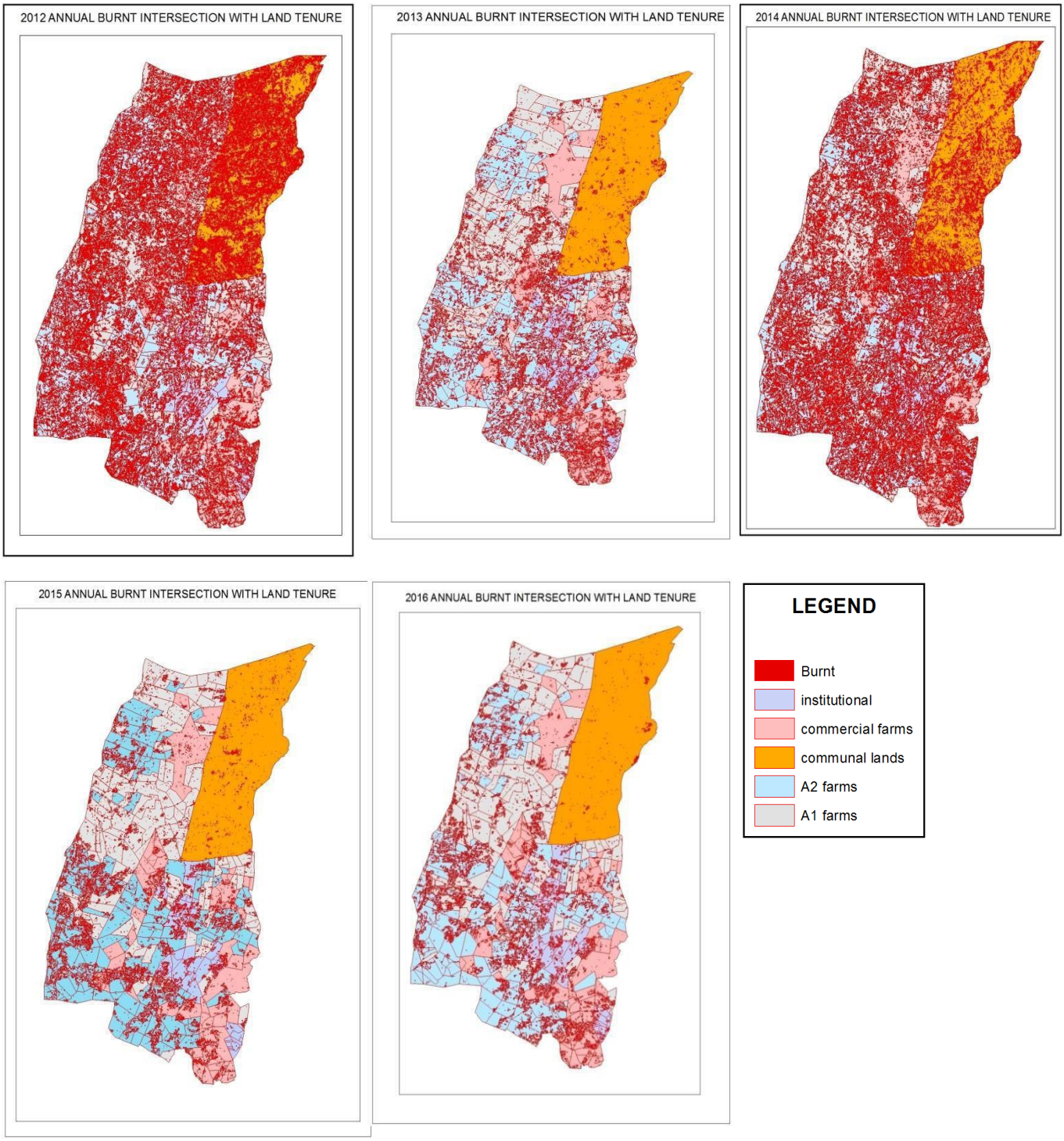
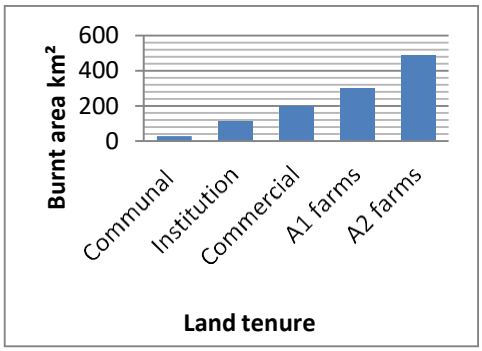
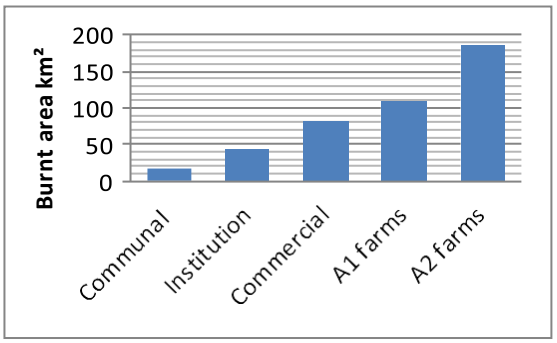


Figure 7: Total burnt area in land tenure systems from 2012-2016

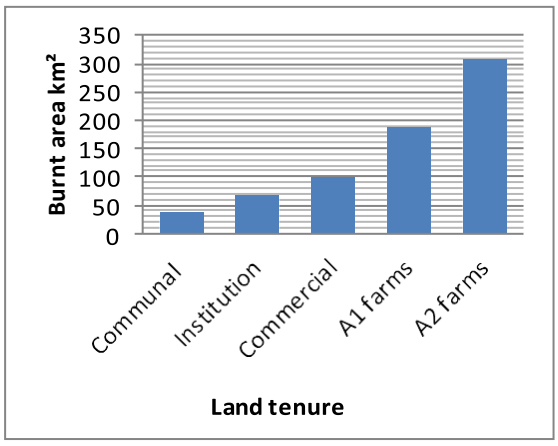
2012



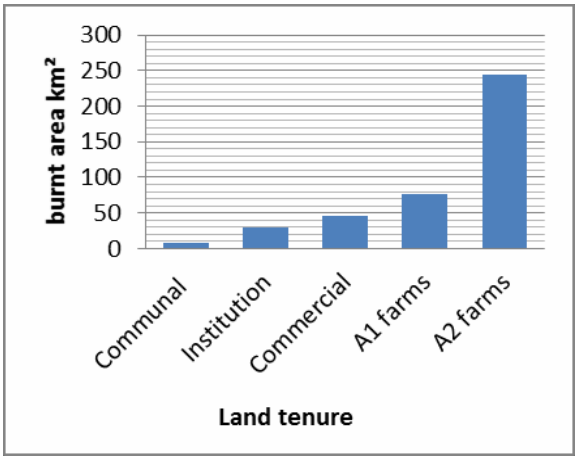
2013



2014



2015



2016

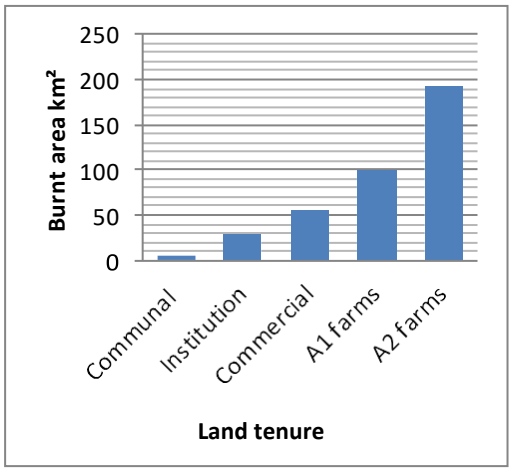


Figure 8: Total area burnt in land tenure systems 2012-2016

4.5. Determining the trends of veld fires in Mazowe district

Five annual area burnt maps were summed in ArcMap to produce the fire frequency map (Figure 9). The fire frequency of Mazowe district ranged from 0 to 5 fires. Total annual burnt (Table 4) in Mazowe district ranged from 24km² to 276.93km². The fire frequency (class 1) covered the largest area while fire frequency covering the smallest area was (class 5). The highest fire frequency was observed in grassland and forest land cover classes associated with A2 and A1 land tenure. In these lands cover classes farmers use fire frequently to simulate pastures regrowth. Farmers in Mazowe district also use fire to burn crop residues in preparation of farming season, due to poor fire management most of the fires becomes uncontrolled and spread. The lowest fire frequency occurred cropland land cover class associated with communal land tenure due to less grass fuels. Intermediate values of fire frequency where observed in commercial farms and institutional associated with cropland because they are adjacent to A1 and A2 where the fire frequency is and with poor fire management practices. The chances of having fire occurrence in Mazowe district are very high, thus it is very important to manage the fire occurrence.

Table 4: Fire frequency class and size (km) in Mazowe district 2012-2016

Fire Frequency Class	Size (Square kilometers)
0	241.01
1	276.93
2	147.47
2	127.08
4	102.17
5	24.10

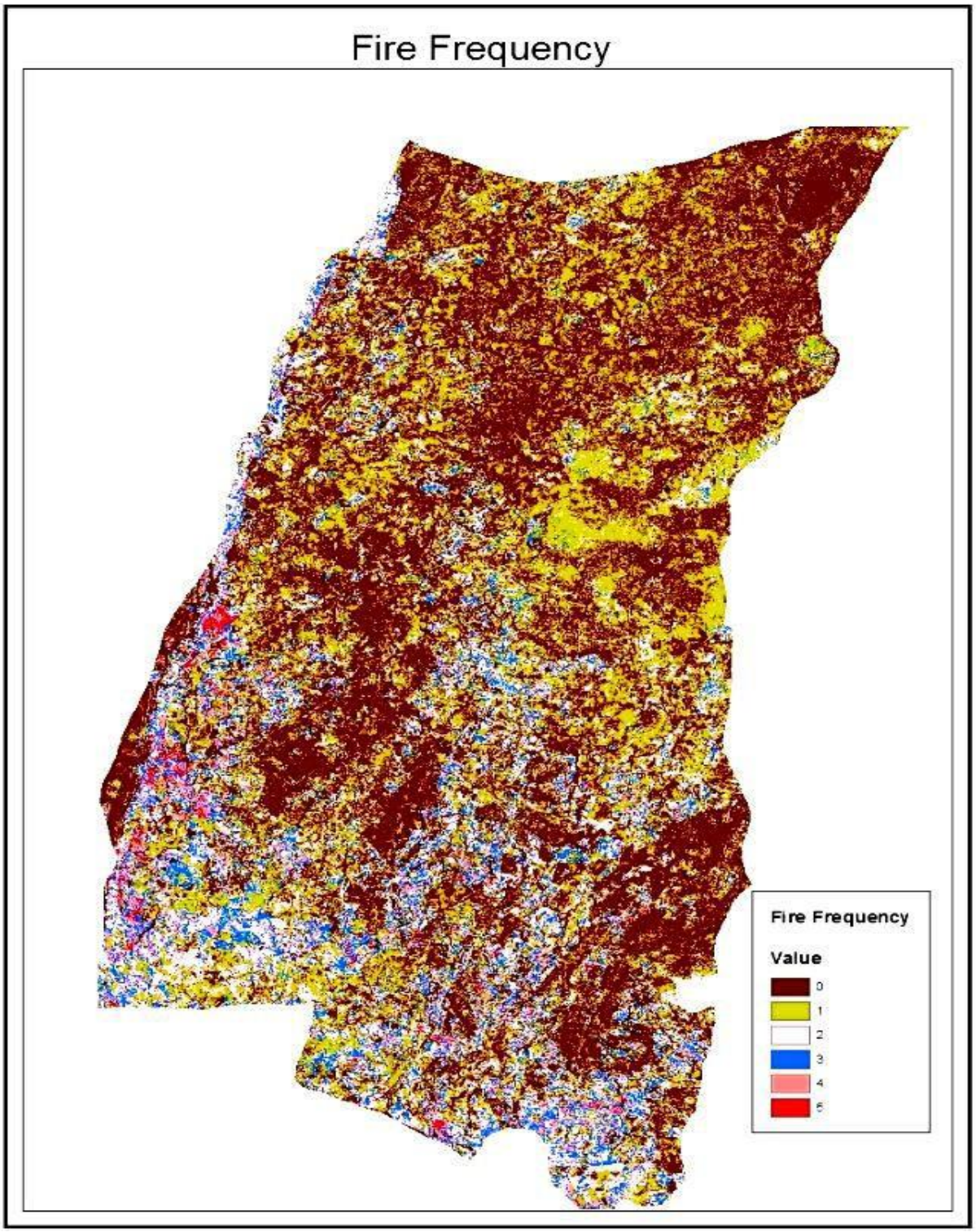


Figure 9: Fire frequency in Mazowe district from 2012-2016

The areas with highest fire frequency greater than three (>3) in Mazowe district were found on the boarder of the district specifically on south, south west and central parts of Mazowe district. The areas with low fire frequency lower than two (<2) in the study area were found in the north to central, some patches in south east and North West. Areas with the highest fire frequency areas are associated with A2 and A1 farms while low frequency areas are associated communal, intermediate fire frequency was observed in institutional and commercial farms

4.6. Limitations of the research

Despite the favorable results and completing the analysis in time, a number of limitations were incurred during the course of the analysis. Some of them are

i) The course spatial resolution of MODIS products does not show detailed fire scars, small fire scares less than 250 m were not captured

ii) The use of Landsat 7 images, a lot of time was consumed gap filling the missing data caused by sensor which failed

iii) Acquiring cloud free Landsat imagery for pre-fire season, the period coincides with the rain season was problematic

iv) Failure to acquire the climatic data from the Meteorological Service of Zimbabwe due to the high cost, climatic variables help to explain the relationship between the fire occurrence and the weather variables such as relative humidity, temperature and the wind speed

CHAPTER 5-CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

This chapter consists of conclusion and recommendations of the analysis. The study analyzed fire frequency using the combination of Landsat imagery and MODIS burned product to quantify the association between land tenure systems, land cover class and fire occurrence

5.2. Conclusion

In this analysis, remote sensing techniques were used to map veld fire frequency in Mazowe district of Zimbabwe using MODIS burned product and Landsat imagery. Two Landsat imageries were used for each season, one to map the land cover classes to map annual burnt areas. MODIS fire products were used to validate the classification of burnt and unburnt classes. Association between and land cover/ land tenure and annual area burnt were quantified and fire frequency of Mazowe district from 2012 to 2016 was calculated.

This study has successfully achieved objectives one whereby spatio-temporal patterns of the veld fires were mapped over the period of five years. The outcome shows that there was gradual decrease in the area burnt from 2012 to 2013. Then after 2013 there was a gradual decrease to 2016. Objective 2 was achieved, assessing the strength of association between land cover classes and burnt areas. The results obtained reviewed that grasslands are more associated with burnt area due to the presence of fuel load which facilitates the spread of veld fires. Forest was intermediate because of the discontinuous fuel load and the cropland was the lowest because of the fire management practices and available of humans who can help in fire suppression. The third objective was also answered; determining the degree of veld fire frequency in Mazowe degree. The results of the fire frequency indicates that areas in the south ,south west and some central parts of the area recorded highest fire frequency burnt greater than the three to five times over the study period of 2012 to 2016.

5.3. Recommendations

The research demonstrated how remote sensing techniques especially the combination of MODIS burned product and Landsat imagery was successfully used mapping veld fire frequency. This view, it is therefore vital for the EMA and other stakeholders to adapt the remote sensing techniques to map and analyze the fire frequency. This approach will help the EMA to identify the fire prone areas. The areas should be given preferences so that before the fire season begins, resources will be put it in place.

This study analyzed the fire frequency in Mazowe district from 2012 to 2016 .The results show that A1 farms, A2 farms and grassland are more prone to the veld fires. Thus there is a need for EMA and all stakeholders to develop strategies that can help to curb the veld fires in those land tenure system and land cover classes

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