



A SPATIO-TEMPORAL ASSESSMENT OF VEGETATION VARIABILITY
AND DEGRADATION IN PALAPYE, BOTSWANA USING NORMALISED
DIFFERENCE VEGETATION INDEX (NDVI) TIME SERIES DATA FROM
1998 TO 2016

BY

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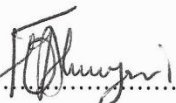
A Thesis submitted to the College of Science in Partial Fulfilment of the Requirements of the
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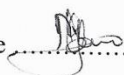
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I, Margaret Ontibile Kgomo declare that this thesis is derived from my original research work conducted within the framework of the United States Agency for International Development (USAID)/Botswana International University of Science & Technology (BIUST) funded Land Degradation Index Mapping (LDIMapping) project (SERVIR/E&S/2014/004). It is submitted for the degree of Masters of Science in the Botswana International University of Science and Technology (BIUST), Palapye, Botswana. It has not been submitted before for any degree or examination in any other university.

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CERTIFICATION

The undersigned certifies that she has read and hereby recommends for acceptance by the Faculty of Sciences a thesis titled “A spatio-temporal assessment of vegetation variability and degradation in Palapye, Botswana using normalised difference vegetation index (NDVI) time series data from 1998 to 2016” in fulfilment of the requirements for the Master of Science Degree in Environmental Science (specialising in *Geographic Information Science and Remote Sensing*) in BIUST.



Prof. Dr. Felicia O. Akinyemi
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ABSTRACT

Vegetation plays a vital and important role in regulating climate, water balance and energy. This research examines vegetation variability and degradation in semi-arid Palapye, eastern Botswana. These were assessed over an 18 year period (1998 to 2016) using Remote Sensing based Normalized Difference Vegetation Index (NDVI) time series data. NDVI has been widely used as an indicator of vegetation growth because it measures the amount of plant greenness from the spectral responses measured in the red and infrared bands of the electromagnetic spectrum.

The annual variation in vegetation growth cycle, derived as average NDVI from July to June the following year over the study period was assessed. Vegetation anomaly maps identifying how and where vegetation development deviates from the normal in comparison to the long-term average conditions were produced annually and for the year 2015/2016. The latter compared the amount of plant greenness for a particular month relative to the historical average of all years for that particular month. These were indicated as large increase, small increase, no change, large decrease and small decrease.

Vegetation conditions were below the average in 1998/1999 and 2002/2003 which coincided with drought stricken years. For the year 2000/2001, the increase in plant greenness was above the average conditions because of ample rainfall as this year had the highest rainfall ever recorded in Palapye.

Having established the spatial and temporal trends in vegetation variability in the long and short term, levels of vegetation degradation were calculated from the time series average NDVI using the regression based Vegetation Degradation Index (VDI). A VDI map was produced and categorised into four vegetation degradation classes, namely: low degradation, medium degradation, high degradation, and relatively undegraded. Nine sites representing these varying levels of degradation were selected for validation. These sites are Mogapinyana, Moeng, Lesenepole, Mahibitswana, Malaka, Maunatlala, BIUST, Lecheng and Morupule. For example, the highly degraded nature of Lecheng was confirmed as quarries and burrow pits for mining limestone, sand, clay and stone for road construction were found. The relatively undegraded vegetation category covers 44.3% of the study area, 51.3% for the low degradation, 4.35% for medium degradation and 0.05% for high degradation.

Validation of results was conducted using meteorological data, ground based vegetation data and socioeconomic data. The relationship between vegetation and rainfall in the 9 sites was investigated. That rainfall (water) is the key limiting resource constraining plant development in semi-arid regions is confirmed as the association between NDVI and rainfall at most sites was positive. Furthermore, vegetation sampling was conducted in the 9 sites to determine species composition, frequency and density in order to validate the VDI map. The aim was to relate the occurrence of plant species in the sampled sites to their level of degradation. The most abundant species are *Colophospermum mopane* with a percentage occurrence of 42.8% and *Dicrostachys cinerea* with 18.3%. For example, *Colophospermum mopane* which is known to be tolerant of shallow soils in hot, dry low-lying areas occurred in all 9 sites and was densest in Lecheng which represented a highly degraded area. As a rangeland degradation indicator species, *Dicrostachys cinerea* was densest in Maunatlala and Malaka which are medium degraded areas respectively. As dryland communities depend more on land resources for survival, the land gets degraded through interactions between the socioeconomic and environmental systems. Focusing on farmers as the predominant land users in Palapye, face to face interviews were conducted with 136 farmers. Their responses were used in better understanding how vegetation has changed over time in Palapye. Ninety two percent (92%) of the respondents indicated the climate variables to have changed from good to worse especially the variability in rainfall.

Results further show that parts of Palapye have NDVI values as high as 0.7 to 0.85 which are unusual values for its semi-arid nature. With the Botswana economy dependent on beef export and wildlife tourism, it is imperative to understand vegetation variability and degradation over time. This study provides empirical evidence of vegetation degradation and contributes to the existing limited literature on degradation at the local level. Because vegetation cover varies with time, and vegetation is prone to degradation as a consequence of biophysical and anthropogenic factors, this study demonstrates that Remote Sensing affords its monitoring on a regular basis and in a cost-effective manner.

Keywords: Vegetation degradation, vegetation variability, Normalised Difference Vegetation Index (NDVI), plant density, rainfall, climate change, Palapye, drought and local knowledge.

Research statement

To fill the knowledge gap as little is known about the extent of vegetation variability as well as the extent of vegetation degradation in Palapye and its surrounding areas.

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CHAPTER ONE

INTRODUCTION

1.1 Research Background

“Globally, recognition is growing that land sits at the centre of the food, energy and water nexus. Land plays a crucial role in providing food and water security, building resilience to climate change and contributing to its mitigation, as well as supporting biodiversity and helping to meet energy needs (Thomas et al., 2012). At the same time, land degradation and its manifestation in drylands, desertification, are still widespread – jeopardising livelihoods and sustainable development” (Fleskens and Stringer, 2014).

Land degradation has been highlighted as a key development challenge (UNCCD, 1994; Lal et al., 2012; Doha Amendment to Kyoto Protocol, 2015; Paris Agreement, 2015) on global climate change. Land degradation is among the most serious environmental issues at global, regional, and local scales (Kosmas et al., 2014). Being a global problem, land degradation impacts more of the poor rural inhabitants of low and middle-income countries (Barbier and Hochard, 2016; Safriel and Adeel, 2005; Reynolds et al., 2007). In arid and semi-arid areas, land degradation may be a result of various factors including climatic variations and human activities (UNCCD, 1994; Eckert et al., 2015). Millennium Ecosystem Assessment (MEA) of 2005 has identified land degradation as the most challenging environmental problem in drylands as it impacts on societies and natural resources globally. The concept of Zero Net Land Degradation was proposed as the basis for a future protocol for the UNCCD, which aims to reduce the rate of land degradation and increase the rate of restoration of already degraded land (Easdale, 2016; Jackson and Prince, 2016).

Millions of hectares of land per year are being degraded in all climatic regions, and it is estimated that 2.6 billion people are affected by land degradation and desertification in more than a hundred countries, influencing over 33% of the earth's landscape (Adams and Eswaran, 2000). Nkonya et al., (2016) has however indicated land degradation to stretch to about 30% of the total global land area in which about 3 billion people reside in the degraded lands. At the same time, there is increasing severity and extent of land degradation in many parts of the world (Tesfa and Mekuriaw, 2014) including 41% of drylands in Africa which is home for 269 million people (Hubert, 2005; McDonagh et al., 2009). Studies have indicated

humid areas of the world to account for 78% which is the highest world's total degraded land (Gerber et al., 2014). Globally, studies show land degradation and desertification to affect more than one billion people (Kosmas, 2014).

Land degradation has become a global problem occurring in most terrestrial biomes and agro-ecologies, in both low income and highly industrialized countries (Nkonya et al., 2016). The problems of land degradation have been identified to be serious in areas where communities' livelihoods depend on land productivity for food production and products from forests (Vu et al., 2013) with greater dependency in drylands than in any other ecosystem (Mueller et al., 2014). As such, land degradation is widespread in sub Saharan Africa affecting 20 to 50% of the land and some 200 million people (Tesfa and Mekuriaw, 2014). However, in the year 2000, Lesotho had the unenviable reputation of having the most severely degraded land on the continent (Stocking and Murnaghan, 2000). Ancient writers were also aware of land degradation as evident in the Bible in the book of Jeremiah chapter 12, verses 10 and 11 reflecting the ruining of the vineyards and trampling of the fields by the shepherds, turning the pleasant field into desolate desert or wasteland. (Halbac-Cotoara-Zamfir, 2015).

Land degradation is severally defined in the literature. McDonagh et al (2009) defined land degradation as the reduction in the capacity of the land to perform ecosystem functions and services (including those of agro-ecosystems and urban systems), that supports society and development. On the other hand, Nkonya et al (2011) defined land degradation as the loss of beneficial goods and services derived from terrestrial ecosystems, which include soil, vegetation, other plant and animal life, and the ecological and hydrological processes that operate within these systems. Vogt et al (2011) defined land degradation as the persistent reduction of the land's biological and/or economic production capacity. The Millennium Ecosystem Assessment (MEA, 2005) has since referred to land degradation as the reduction in the capacity of the land to perform ecosystem goods, functions and services that support society and development, while desertification is the same process in arid and semi-arid environments (collectively, the drylands). All these definitions point to a state of the land losing its capacity to provide the expected functions or the services intended. Stocking and Murnaghan (2000, pp 9) described land degradation as a composite term that "has no single readily-identifiable feature, but instead describes how one or more of the land resources (soil, water, vegetation, rocks, air, climate, and relief) has changed for the worse". There are different types of land degradation including vegetation degradation. Vegetation as an

important aspect of rangeland management, plays a vital and important role in regulating climate, and maintaining the water and energy balance (Van der Ent et al., 2010). Being the ground cover that is provided by plants and the most abundant biotic element in the biosphere (Moleele et al., 2001) vegetation is an essential element of the land surface system that links soil, air, water, and other environmental components (Foley et al., 2000).

1.2 Causes of Land Degradation

As an interaction between human and biophysical factors, land degradation occurs when one process or a combination of factors cause reduction of the productivity of land (UNEP, 1992). Inappropriate land use results in the degradation of soil, water and vegetative cover, as indicated by UNEP (1992). When degraded, affected areas become more susceptible to the effects of climate change such as increased temperature and drought conditions. The degradation of an ecosystem may not translate directly or immediately into a noticeable loss of ecosystem services and benefits, but can sustain some level of degradation before reaching a threshold after which ecosystem function declines (Gerber, 2014).

The root causes and consequences of land degradation have been indicated by Snel And Bot (2003) to be poverty and food insecurity combined with harsh climatic variations, therefore, involving two interlocking, complex systems being the natural ecosystem and the human social system (World Meteorological Organisation - WMO, 2005; Njihia, 2010). The biophysical factors which include climate conditions, topography and the type of soil (Gerber et al., 2014) have direct impact on the land. The unsustainable land management techniques such as agricultural activities, infrastructure development, harvesting of natural resources, drought and wild fires also drives land degradation (Svensson, 2005).

Climatic variations are recognised among the major factors contributing to land degradation, since they exert a strong influence over dryland vegetation type, biomass and diversity (Gang, 2014). On this note, WMO (2005) has indicated precipitation and temperature as determining the potential distribution of terrestrial vegetation that constitute the principal factors in the genesis and evolution of soil. Precipitation influence vegetation production, which in turn controls the spatial and temporal occurrence of grazing and therefore favouring nomadic lifestyle (Njihia, 2010). Climate change has since been indicated to affect vegetation mainly through changes in precipitation and temperature (Gang, 2014). It is therefore, very important to understand the respective roles of the different climatic factors

that contribute to land degradation. Climate variability, climate change and land degradation are intimately linked and are generating unexpected effects such as increased occurrence of weather conditions (Sivakumar and Ndiang'ui, 2007). The WMO (2005) has however noted climatic stresses to account for 62.5% of all the stresses on land degradation in Africa. Zhihui et al (2015) however identified the underlying causes of land degradation to include population density, economic development, land tenure, and access to agricultural extension, and infrastructure. In order to understand the linkages between the proximate and the underlying causes of land degradation, the degradation outcome, or type must first be evaluated and the processes that cause the specific type of degradation be identified (Svensson (2005).

1.3 Global Assessment of Land Degradation

Land degradation is a global problem with different environmental problems affecting different regions (Kosmas et al., 2014). For the assessment of land degradation to be accurate and reliable, it is important to use multiple methods at a range of scales including to incorporate the perceptions of those who use and manage the land (Reed et al., 2008). The most common perspective on land degradation is what farmers see happening to their land – symptoms such as soil erosion and salinity (De Jong et al., 2011). Stocking and Murnaghan (2000) gave examples of women getting increasingly worried about the scarcity of firewood and water and the burden of having to travel longer distances to collect them. Whereas a male herder of livestock in the same village will have concerns in searching for elusive dry season pastures. This indicates that a reduction in the potential resource of the land can only be defined in relation to the uses people have for it (Warren, 2002; Tarrason et al., 2015). This has so far led to the global assessment of land degradation involving a wide range of methods, including expert judgement, remote sensing and modelling.

A number of efforts have however attempted to assess land degradation at the global scale. The Global Land Degradation Assessment (GLADA) projects of Food Agricultural Organisation (FAO) used Geographical Information System (GIS) and Remote Sensing (RS) information to map land degradation between 1981 and 2003 while (World Overview of Conservation Approaches and Technologies (WOCAT) network initiated efforts to help prevent and reduce land degradation through sustainable land management practices in 1992 (Gerber et al., 2014). The Global Land Degradation Information System (GLADIS) assessed global land degradation using a combination of biophysical and socioeconomic indicators

such as biomass, soil, water, biodiversity, economic and socio-cultural (Nachtergaele et al., 2011).

Apart from the global assessment of land degradation, some studies were focussed at the country or regional levels. According to Nkonya et al (2011), Niger experienced major land degradation problems, particularly due to overgrazing, which made the country to lose 8% of its Gross Development Product. A study conducted by Bishaw (2001) indicated Ethiopia's agricultural productivity to have been reduced because of the effects of soil erosion on cultivated land. This was because of the soil loss, deterioration in fertility and moisture storage capacity. The high intensity of rainfall was also observed to have increased soil erosion in the area. Tesfa and Mekuriaw (2014) also noted the effects of land degradation in Ethiopian highlands to have lowered the livestock production by shrinking grazing land and washing away fertile soils resulting in grazing land covered by unpalatable pastures and grasses with low nutritive value. Sub-Saharan Africa, with the highest rates of poverty in the world, has since been indicated to have experienced the most severe land degradation over the last decade (Nkonya et al., 2016).

1.3.1 Global assessment of vegetation degradation using remote sensing

Earth observation technologies play an important part in studies, modelling and monitoring of environmental phenomena, at various spatial and temporal scales (Seboka, 2016). These technologies are very important in implementing the early warning, support systems and strategies for natural resource management by decision makers (Adeola et al., 2015). This technology is known as remote sensing, and it is simply defined as the science (and to some extent, art) of acquiring information about the earth's surface without actually being in contact with it (Xie et al., 2008). This is done by sensing and recording reflected or emitted energy and processing, analysing and applying that information (Canada Center for Remote Sensing, undated). Satellites provide daily global coverage of the earth's surface while remote sensing sensors capture data about an object or scene remotely (Xie et al., 2008).

Since objects (including vegetation) have their unique spectral reflectance features, they can be identified from remote sensing imagery according to their unique spectral characteristics (Xie et al., 2008). This means that every material has its own strength of reflection when exposed to electromagnetic waves. Satellite remote sensing has been used in forest studies as a method for monitoring the earth's terrestrial photosynthetic vegetation activity in support of

phenological and biophysical interpretations (Chiang and Chen, 2011). Satellite images are therefore very useful to identify changing conditions over time.

Most land-degradation processes affect the vegetation cover, and for this reason, vegetation dynamics, which is relatively easy to quantify using Earth Observation, has been widely adopted as an indicator of land degradation on regional and global scales as this approach has the strength of being repeatable and transferable between scales and regions (De Jong et al., 2011). Furthermore, GIS has historically been used as a tool for analysing natural resource information (George and Korte, 2001). GIS was developed and established in 1969 by Environmental Systems Research Institute, Inc. (ESRI), which is a world leader for the design and development of Geographic Information Systems (GIS) software (Scott and Janikas, 2010). As a tool that allows for the superimposition, analysis, manipulation, storage, retrieval and display of datasets from various sources, GIS can be used in understanding the spatial variability of the vegetation (Adeola, 2015). Remote Sensing data and techniques, in combination with GIS are therefore, fundamental to analyse and characterise land cover and its changes (Fichera et al., 2012) including vegetation greenness, because satellite remote sensing provides greater amounts of information on the geographic distribution of land cover, along with advantages of cost and time savings for regional size areas (Imam, et al., 2016).

Because land degradation and desertification has been ranked as a major environmental and social issue for the coming decades, the observation and early detection of degradation is a primary objective for a number of scientific and policy organisations, with remote sensing methods being a candidate choice for the development of monitoring systems (Higginbottom and Symeonakis, 2014). Degradation may be assessed qualitatively and quantitatively (Reed and Stinger, 2016). The expert opinion considers the symptoms and or consequences of degradation while the quantitative approach uses measures such as the spectral reflectance (De Jong et al., 2011). Furthermore, applications of remote sensing for desertification assessment are most often based on a quantification of vegetation density or vigour as a proxy of different processes that take place in a degrading land (Chabrillat, 2006). Remote sensing is very important as it offers global special continuous monitoring. Based on the Global Assessment of Human Induced Soil Degradation (GLASOD) methodology, vegetation cover, organic matter, and soil-water content can be determined from remote sensing data (Singh et al., 2010) Vegetation cover and quality vary with time (Gomez et al.,

2016), therefore making Remote Sensing suitable for its monitoring in a timely and cost-effective manner.

Vegetation degradation is a major type of land degradation that is widespread, particularly in drylands. Studies have used the Normalized Difference Vegetation Index (NDVI) to measure and analyse changes in vegetation cover and ecosystem productivity as proxies for land degradation. The NDVI has been used as the basis of assessment although other indices have also been used. Liu and Kogan (1996) used NDVI and Vegetation Condition Index (VCI) from NOAA AVHRR data to map time series of potential drought areas on the continental and regional scale for South America. The threshold values for the NDVI and VCI were set and the pixels with values below the thresholds were defined as drought areas. Diouf and Lambin (2001) assessed dryland land cover modification in Senegal using a combination of remote sensing and field based measurements to compute rain use efficiency (RUE). They found that NDVI alone did not reveal trends in degradation, but that RUE was the most likely indicator to reveal trends inland cover modification.

Wessels et al (2004) have used productivity indicators to assess vegetation conditions in South Africa. They showed that moderate resolution NDVI data, integrated seasonally for 1985 to 2003 could be used to detect degraded area. The study revealed that for various land capability units with uniform soil, climate and vegetation, the productivity of degraded area was consistently lower than non-degraded areas relative to rainfall. Archer (2004) used 14-year time series NDVI and rainfall data in studying the role played by different stocking practise in impacting biomass in the Karoo, South Africa. The study revealed that once the climate signal in the form of rainfall was removed from the NDVI data, some grazing strategies lead to consistently lower vegetation cover values than others (Archer, 2004; Gibson, 2006).

Karnielia et al (2011) applied space and ground observations to explore the ability of remote sensing techniques in assessing the effect of grazing on vegetation degradation in the steppe biome of Mongolia. Pairs of comprising of an ungrazed (fenced-off) area and a heavily grazed area were examined with the enhanced vegetation index (EVI) computed from Landsat-7 Enhanced Thematic Mapper Plus (ETM+) data. Alongside, field-observed biophysical variables (e.g. plant density, species composite, above-ground biomass (AGB), and percentage cover) and plant spectral reflectance data were collected. Plant density, AGB,

and percentage cover values were significantly higher in the ungrazed areas than in the adjacent grazed ones. However, the grazed areas had significantly higher EVI values than the ungrazed areas as unpalatable species had invaded the grazed areas, substituting the native grasses. Gong et al (2015) also evaluated trends in vegetation cover and phenology dynamics in the Inner Mongolia grassland by applying NDVI time series obtained by the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) during 2002–2014. The results showed that the cumulative annual NDVI increased to over 77.10 % in the permanent grassland confirming the grassland changes to be closely related to spring precipitation and increasing temperature at the early growing period because of global warming (Gong et al., 2015).

NDVI, which is the direct spectral response of vegetation vigour (Ndayisaba, 2016) has been developed to facilitate the interpretation of vegetation growth. Being the most common vegetation index used to study the spatial and temporal trends in vegetation dynamics (Yengoh et al., 2014), NDVI has been used widely to examine the relation between spectral variability and the changes in vegetation growth rate, therefore determining the production of green vegetation as well as detecting vegetation changes (Meeragandhi et al., 2015). The NDVI is readily available (Srivastava, 2011) and as vegetation phenology, it follows a relatively well defined temporal pattern (Zhang et al., 2003). Because the land cover varies with time (Yan et al., 2014) it is very important to monitor it on regular basis or from time to time.

Studies have been conducted on the use of remote sensing in land degradation (Gibson 2006 and Gwitira et al., 2015) and thus summarised in Appendix 5.

1.4. Vegetation Degradation and Variability

Communal ownership that lacks control and management (Abdi et al., 2013) as well as inappropriate land use and agricultural technology can severely affect natural resources, such as vegetation, causing irreversible damage and negative socioeconomic consequences (FAO, 2016). Vegetation degradation in drylands has been identified as one of the major environmental issues of the 21st century (Ravi et al., 2009) particularly to its impacts on food security and environmental quality (Myserud, 2006). Drylands, which includes hyper-arid, arid, semi-arid and dry humid areas characterised by low and irregular rainfall and high evapo-transpiration (FAO, 2015b), cover 41% of the terrestrial surface and are the home to more than a third of the world's population (Feng and Fu, 2013). The world's drylands are

mainly found in the belts approximately centred on the Tropics of Cancer and Capricorn, 23⁰ north and south of the Equator respectively (Grainger, 2013). Vegetation degradation in drylands, results in reduction in the available biomass, leading to decline in the vegetative cover (Masoudi, 2014). This is as a result of deforestation and overgrazing including climatic factors (Moleele et al., 2001). This degradation makes thorny weeds predominant in the once-rich pastures (Stocking and Murnaghan, 2000). Degraded areas include those that are suffering from bush encroachment as a result of heavy cattle grazing over a number of years (Moleele et al., 2001). Such degradation is a major contributory factor to soil degradation particularly with regard to soil erosion and loss of soil organic matter (FAO, 1999).

Land clearing, primarily for agriculture, has been perhaps identified as the single most important cause of environmental degradation, loss of species, including the depletion of ecological communities worldwide (Lindenmayer and Burgman, 2005). The drylands have so far been rendered susceptible to rapid degradation due to climate change, shifts in vegetation composition and accelerated soil erosion processes and disturbances (Mysterud, 2006). These processes are therefore considered to represent the major driving forces of changes in composition and density of vegetation (Tian et al., 2014). This degradation has been happening for decades which have so far prompted Kigomo (2003) to indicate the forests and woodlands of Africa to be crying for attention as they continue to degrade because of being dominated by the Sahara Desert in the north and Namibian and Kalahari Deserts in the south. These deserts have been indicated to be a result of anthropogenic activities. The African continent is spatially the most impacted, with more than 70% of its agricultural drylands being already desertified (Hoffman and Ashwell, 2001; Dreber et al., 2013).

Subsistence in the rural drylands areas worldwide depends on the effective and sustainable utilisation of natural resources, which are increasingly threatened by degradation, mainly due to extensive droughts and mismanagement (Dreber et al., 2013). As a non-renewable natural resource, land is used by people for food production through agriculture, hence impacted by degradation (Chasek et al., 2014) which negatively affects sustainable development and human well-being (Lu et al., 2015).

Vegetation variability which involves the changes in vegetation activity are driven by multiple natural and anthropogenic factors, which permanently change the spatiotemporal patterns of vegetation (Qui et al., 2014). This is because precipitation variability that is

caused by the climate variability pose serious challenges for semi-arid countries in southern Africa that depend on rainfall for their primary production (Mbereggo and Gwenzi, 2014). Precipitation variability further exacerbates crop failure as well as degradation of vegetation which are often the results of droughts of prolonged dry spell (Mangiarotti et al., 2010). On the other hand, planting is disrupted by excessive rainfall which happens in the early growing season (Mbereggo and Gwenzi, 2014). The global distribution of vegetation types as well as their biophysical and structural properties and spatial/temporal variations are therefore very important to understand (Solano et al., 2010).

1.4.1 Impacts and strategies used in mitigating the effects of vegetation degradation

Vegetation degradation has negative consequences on the productivity of land and the ability to provide for ecosystems services (Zhan et al., 2015). These impacts can affect any ecosystem, including agro-ecosystems, forestry plantations, rangelands, and urban areas (Ellis and Ramankutty, 2008; Gerber et al., 2014). These impacts are most felt in areas with high incidence of poverty (Nachtergaele et al., 2011). Overgrazing of vegetation by livestock and subsequent land degradation has been identified to be a widespread problem in the Sub-Saharan Africa (UNEP, 2014) which has even prompted farmers to develop some strategies of mitigating it as it leads to livestock loss. Vegetation degradation results in the shortage of palatable forage for livestock or decrease in plant cover, fodder quality and soil compaction (Dalelo, 2000). The availability of forage species in rangelands is closely linked to the livestock preference because it determines where grazing is located (Treydte et al., 2017).

In Africa and Australia, opportunistic movements of livestock and trading grazing rights have been adopted as a strategy in times of drought (Treydte et al., 2017). Moving livestock to neighbouring rangelands where resources are available is the most common practice (Treydte, et al., 2017). The southern Mongolian herders move livestock to northern Mongolia during drought and return to southern Mongolia when rainfall is abundant (Lee et al., 2015). Herders in Mali as well have adopted transhumance, forage stocking and sale of some animals in order to reduce their number in times of drought (Dembele, 2006). This allows the affected area to regenerate. In Botswana during times of drought, crop residues and commercial feed are used as alternatives (Mogotsi et al., 2013) which are barely available in Afar (Ethiopia) for livestock in drought times (Treydte et al., 2017). However, when the livestock populations decreases, this is reported to lead to an unintended resting period which

helps the land use to recover (Treydte et al., 2017) which is very crucial in Namibia (Muller et al., 2007).

1.5 Research Problem

1.5.1 Objectives of the study

The study was undertaken to examine the following objectives:

1. Vegetation variability in Palapye, an agro-pastoral region in eastern Botswana over an 18-year period

➤ What is the extent of vegetation change in Palapye?

2. How vegetation has degraded based on the Vegetation Degradation Index (VDI).

➤ What is the extent of vegetation degradation in Palapye?

1.6 Significance of the Study

The study contributes to improve our understanding of vegetation degradation in arid and semi-arid regions including the management practices that take place in degraded areas. The study therefore illustrates the utility in linking the remotely sensed imagery with the socio economic perceptions of land users as well as the ground truthing on vegetation degradation and variability. The study provides empirical evidence of vegetation degradation at local level and also contributes to the existing literature on the use of remote sensing in assessing and mapping vegetation degradation in semi-arid Palapye.

CHAPTER TWO

VEGETATION DEGRADATION IN BOTSWANA

2.1 Vegetation Degradation Assessment in Botswana

Vegetation reacts to a changing climate as well as being affected by climate, as such it has been identified as a feedback of climate change (Lin et al., 2016), as well as acting as an indicator of climate change (Liu and Ren, 2012). The most important driving factors of vegetation growth are climate variables. This makes rainfall to be considered as an important factor constraining vegetation growth in drylands (Fensholt et al., 2012; Lin et al., 2016). Botswana being a dryland area, it is also vulnerable to vegetation degradation with its arable land being less than 5% of the country and rangeland covering the remaining 95% (Darkoh, 1998). Botswana is estimated to have a land area of 582 000 square kilometres (SOER, 2002; James, 2014). Only about 29 000 square kilometres of land is cultivable of which irrigated area covers 1 300 square kilometres (James, 2014). The majority of poor Botswana live in rural areas (Totolo, 1999; World Bank, 2010), and dependant on natural resources for their livelihoods, and at the same time, heavy reliance on the country's natural resources for economic growth and rural livelihood has adverse consequences for the environment (James, 2014). Vegetation degradation that is prevalent throughout Botswana results from a multitude of factors such as physically related to climate while others are socioeconomic (Kayombo et al., 2005). It has been noted that 69% of the land in Botswana is degraded as a result of climatic factors and human activities (James, 2014) that leads to deforestation, overgrazing and erosion (PEM, 2011). This has therefore, made only 5% of arable land to be suitable for crop production (Totolo, 1999).

In Botswana, degradation studies have concentrated in the sandveldt (land characterised by dry sandy soil) areas of north central and northern parts of the country. The only study conducted in the hardveld (rocky soils usually located on the eastern side of Botswana) was by Ringrose and Matheson (1987) which dealt with spectral assessment of indicators of range degradation (Kayombo et al., 2005). The results of that study indicated that areas that appeared more degraded was as a result of 1980s drought.

In 1991, the Global Assessment of Soil Degradation described Boteti as an area of extreme human-induced wind erosion, recognized by the Government of Botswana as a desertification

hotspot (Mulale et al., 2013). Previous studies by scientists commissioned by the Government of Botswana in 1994 carried out a study for the United Nations Convention to Combat Desertification and found evidence of declining productivity in Boteti such as soil erosion, loss of vegetation cover and declining ground water level (Ringrose et al., 1996; Government of Botswana, 1994; Mulale et al., 2013).

In 1995, a study was undertaken by Dougill and Cox (1995) in the Kalahari to explore the links between grazing, ecological change and land degradation for a heavily grazed area. In particular, they examined the relationship between ecological conditions and soil properties and processes. The results showed that in typical Kalahari conditions, the ecological changes that had been brought about by grazing could not be linked with more fundamental changes in ecosystem function. Basic soil processes appeared relatively unaffected by grazing pressure outside the sacrifice zone, and there was no evidence to suggest that the resilience of the system was affected through soil degradation.

Another study was undertaken in 2005 by Kayombo et al (2005) which characterised agriculture-related land degradation in Eastern and Western Botswana (Bobirwa sub-District and Kgalagadi district respectively). This was done through assessing the impact of cultivation on soil quality and evaluating the effects of human and animal activities on range resources. The results showed that in Bobirwa sub-District, there was an overall decline in the availability of graze and browse species just like in the Kgalagadi district (Kayombo et al., 2005). Although drought was perceived to be the main contributor in the reduction of graze and browse species, the results indicated resource depletion to be related to intense resource use such as overgrazing, burning and poor land management practises (Kayombo et al., 2005). There was also a marked decline of veld products because of human population growth, over harvesting and poor management. Soil erosion was also experienced from both study areas mainly due to wind and water. In Southern Kalahari, Favretto et al (2014) noted the rangeland degradation has led to extensive bush encroachment, therefore reducing access to good quality grazing and economic returns, threatening the delivery of a range of provisioning and cultural services.

Dougill et al (2016) conducted the dual-scale analysis on farm-scale patterns of ecological change and land-landscape patterns of change in vegetation cover and animal distribution in southern Kalahari. These were presented from the ecological transects away from water

points, regional remotely sensed analysis of vegetation cover and animal numbers in the area. Satellite data analysis for the period from the year 2000 to 2013 from 250m resolution MODIS/NDVI time series database were used. The results indicated an increase in bush cover and density at the expense of the grass layer, with bush encroachment prevalent in sites dominated by *Acacia mellifera* and other species.

The land use intensification and implications on land degradation in Boteti area was studied by Sebegu et al (2017). Persistent woodlands deforestation as well as overgrazing by livestock in the rangelands of Boteti sub district area were reported in the study, as well as the degradation indicators identified within different land cover categories. Because of the drying up of the Boteti River, as well as the periodic drought that affected the country, these resulted in the new land use patterns emerging as an adaptation strategy against the drier environment which saw the communities having shifted from the flood recession farming into the dryland farming (Sebegu et al., 2017). Because vegetation degradation reduces the productivity of the land, it therefore affects those who depend on land as a basic resource for livestock, and crop production (Darkoh, 1998).

2.2 Study Location and Description

Palapye is situated in the Central District particularly to the east of Botswana. It is strategically located between Gaborone (270km north of the capital city) and Francistown (160 km south of Botswana's second city). The geographical coordinates of Palapye village are 22° 33' 0" South and 27° 8' 0" East at an elevation of 920m (Zhai et al., 2009). It is located by Lotsane River towards the central-eastern edge of Botswana. The study area falls within longitude 26° 53' 9" East to 27° 48' 17" East and latitude 22° 17' 35" South and 22° 47' 10" South.

The map of the study area shows Botswana and 16 of the 22 villages inside the area that makes up the Palapye Administrative Authority (Figure 1). The villages include Palapye, Lecheng, Moremi, Malaka, Mogapi, Mogapinyana, Kgagodi, Maunatlala, Tamasane, Diloru, Lesenepole, Mosweu, Mokokwana, Seolwane, Lerala, Majwaneng, Ratholo, Moeng, Gootau, Goosekgweng, Matlhakola and Topisi.

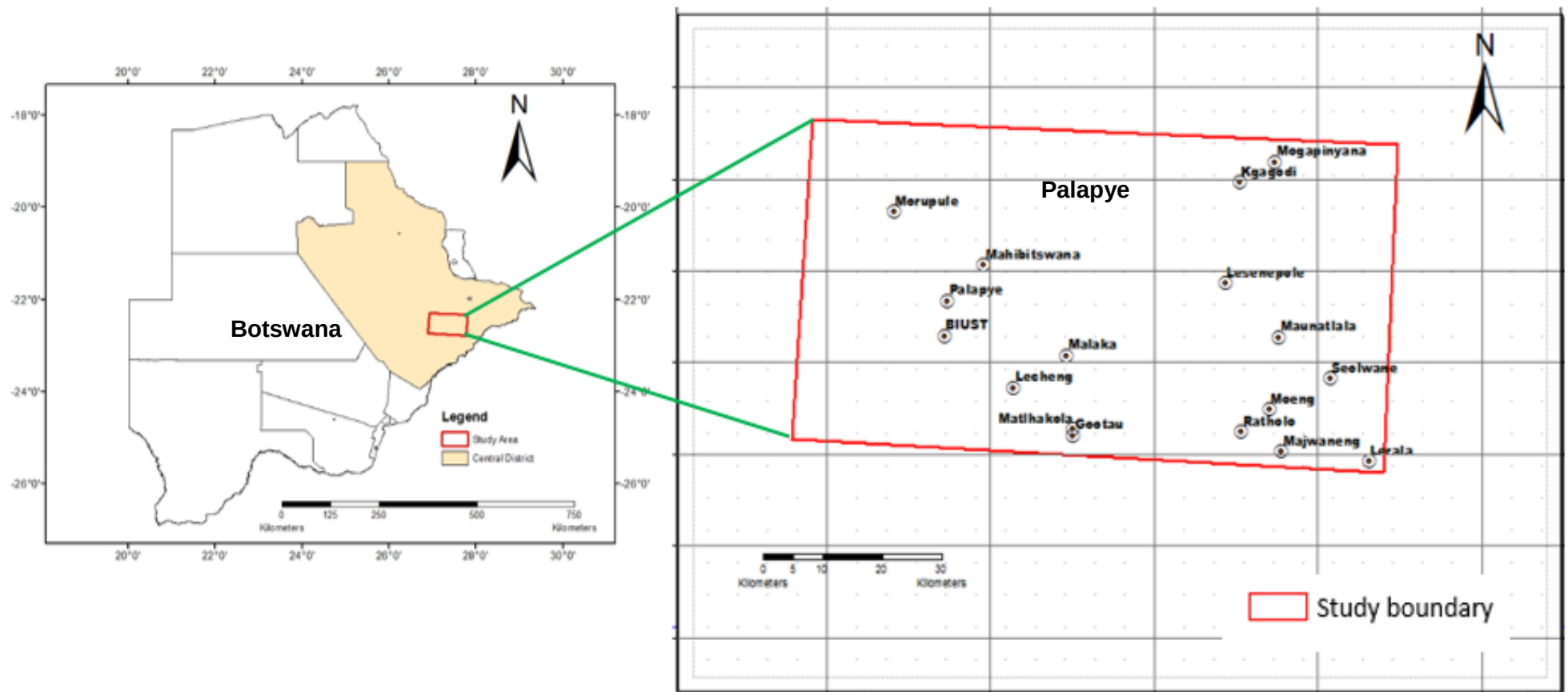


Figure 1: Palapye Study Area

A bounding box was drawn within Palapye Administrative Authority to represent the area of study which is 4,476km². The bounding box was used as there was no official boundary map for the study area. Palapye is the headquarters of Palapye Administrative Area and is situated 70km north of Tropic of Capricorn. Playing an economic role in the mining and energy sector, Palapye is rapidly expanding as a junction settlement. At the same time it is experiencing infrastructural development and is undergoing very rapid landscape transformation with sites including Morupule Coal Mine (MCM), Morupule Power Station (MPS) and Makoro Bricks as well as Botswana International University of Science and Technology (BIUST) present in the area among others. Arable and pastoral farming are also taking place in and around the study area. This study in Palapye Administrative Authority is therefore focusing on examining vegetation dynamics over an 18 year period using Normalised Difference Vegetation Index (NDVI), as well as examining how vegetation has degraded in the area, basing on the VDI. The strategies on coping with the degradation is also identified from the communities through the use of local knowledge. The local knowledge from the communities is very important in the socioeconomic aspect because it includes the social setting that has shaped the practices which are responsible for the communities' production, articulation and use of knowledge (Puri, 2007) in the area.

2.3 Biophysical Context

2.3.1 Climate

The climatic condition of the Central region is generally semi-arid which is common throughout the country. It is slightly specific in that for Palapye area which is in eastern part of Botswana, it is more of a tropical semi-arid region (Zhai et al., 2009). The area is dominated by winds from the east, east-northeast to west, west-southeast, usually of speeds between 0.5 and 8.7m/s. Ecosurv and GIBB Botswana (2007) has indicated the summer months in the study area to be from mid-September to mid-April and are very hot with day time temperature reaching up to 40⁰ C, while winter months are from May to July and are usually mild and dry. The average annual maximum temperature is between 28°C and 30°C and the average minimum temperature is between 14°C and 16°C (Ecosurv and GIBB Botswana, 2007). January is the warmest month while July has the lowest average temperature of the year. Rainfall occurs between the months of October and March which is usually erratic and unpredictable, reaching an average of 424mm annually (Zhai et al., 2009). Dry season commences from mid-April until September with the driest month being August with 0mm precipitation (Ecosurv and GIBB Botswana, 2007).

2.3.2 Topography

Apart from the Tswapong hills that stretches over 70 km range and about 15km wide and rise at an elevation of 400m above the surrounding plains (UNESCO, 2015), the study area is dominated by low relief plain with Lotsane River cutting across. Morupule River on the western side of the study area is a tributary to Lotsane River.

2.3.3 Soils

Soils are mostly Arenosols and Luvisols and are characterized by orange colour, fine grain size and sandy silt loam texture with low clay content (Ecosurv and GIBB Botswana, 2007). Soils in the eastern part of the Central District belongs to the Limpopo Unit, and are of mixed texture and depth whose agricultural potential is reasonably good (Earthtec, 2008). The area is therefore comprised of grazing area for livestock with a large proportion of land used for subsistence agriculture.

2.3.4 Fauna and flora

The vegetation of the area is considered to be of Mophane mixed tree and Shrubland (Earthtec, 2008; Ecosurv, 2008). The common species include Mophane (*Colophospermum mopane*), Mohudiri (*Combretum apiculatum*) and Motswere (*Combretum imberbe*). Other tree species include Motsiara (*Terminaria prunoides*) and Mokomoto (*Commiphora edulis*). Species such as Mosu (*Acacia tortilis*), Moselesele (*Dichrostachys cinerea*) and Moretwa (*Grewia flava*) are also common in the area.

With continuous grazing going on in the area, the relationship between layers of trees and shrubs has been unbalanced causing trees and shrubs to become dominant than the grass that is mostly grazed (Ecosurv, 2008). Some antelopes such as kudu (*Tragelaphus strepsiceros*), impala (*Aepyceros melampus*), steenbok (*Raphicerus campestris*) and duiker (*Sylvicapra grimmia*) are found in the area. There is abundant bird life such as cape vulture (*Gyps coprotheres*), black eagle (*Circaetus pectoralis*), black stork (*Ciconia nigra*) and other bird species (Ecosurv, 2008).

2.4 Socioeconomic context of Palapye

Palapye village is the largest village among all villages in the administrative area. This has given the area an added advantage, in that it is a social, administrative and commercial center (Ecosurv and GIBB Botswana, 2007). The existence of MCM, MPS and BIUST are thriving

commercial investments. Two Artificial Insemination (AI) camps belonging to the Ministry of Agriculture (MOA), called Leupane and Morupule are located in the western part of Palapye. Land use in the area is residential and commercial in the villages, while pastoral and arable agriculture is in the entire area of the study where communal grazing of livestock is practiced. The most common livestock are cattle, goats, sheep, donkeys and chicken. Dryland farming which is common in Botswana is also practiced in the area though there are few horticultural projects in the eastern part of Palapye. These projects are irrigation based and use water from Dikabeya Dam. Bee keeping on the other hand is at its infancy in Lemone, Morupule and Palapye.

2.4.1 Increasing human and animal population

The population of Palapye Administrative Authority is around 41 086 as of the 2011 population and housing census (Central Statistics Office, 2011). The below chart (Figure 2) indicates the rapid growth of human population in Palapye from the year 1981 to 2011. From 1981 to 2011 (30 years), the population increased more than thrice the initial number. In the 21st Century, the inhabitants of Palapye increased from 26293 (12087 males, 14206 females) in 2001 to 41086 (21474 males, 19612 females) as of 2011 (Statistics Botswana, 2015a).

The area has been experiencing a phenomenal population growth over the years (Figure 2) and this is due to a number of factors including the designation of the village as the Serowe/Palapye Sub-district headquarters. The opening of MCM as well as the expansion of MPS including the existing of BIUST which has attracted a lot of people working and also looking for jobs in the area. Commensurate with this increased human population, there is increasing demand for land, energy, particularly for domestic use, food, water as well as facilities such as housing, schools, markets and hospitals (Conacher, 2009). Dembele (2006) also shared the same sentiment that an increase in population number causes an increase in the livestock number and causes extension of the farmland. All these make the population of Palapye to increase immensely as per Figure 2.

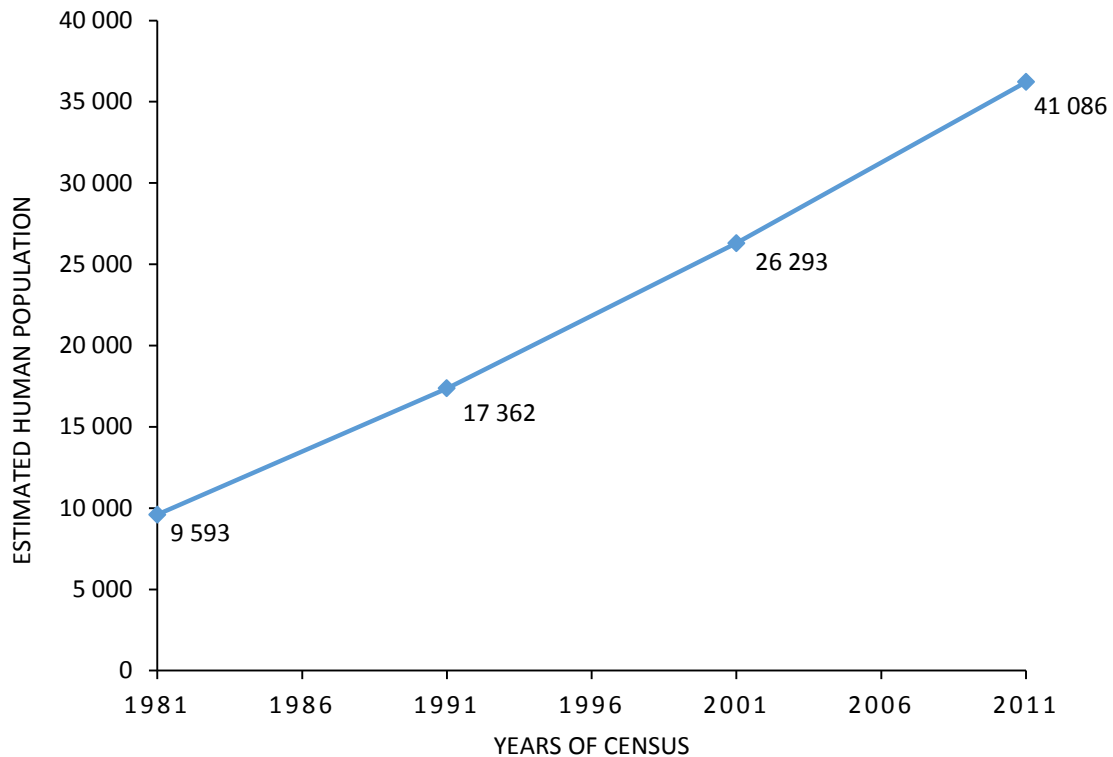


Figure 2: The growth of human population in Palapye from 1981 to 2011

Data Source: CSO (2011)

Because of the increase in human population, the rate of urbanisation, agriculture, industrial and mining activities coupled with climate change, Botswana faces a host of environmental problems including water scarcity, and pollution, land degradation, biodiversity loss, deforestation, desertification, climate change and many more (James, 2014). High population density is not necessarily related to the degradation, rather, it is what a population does to the land that determines the extent of degradation (WMO, 2005).

Alongside mineral export, Botswana's economy is based on beef export, therefore making pastoralism a means through which people make a living through livestock rearing (Maito and Odhiambo, 2013). The total population of cattle, goat, sheep, donkey, chicken, horse, and dog as of 2013 were 933091, 96309, 14149, 17175, 95289, 397, 14099 respectively (Statistics Botswana 2015b). Botswana depends on natural resources in rangelands as the basis for its cattle industry. However, these resources are being degraded at various locations (UN 1997). Because of high number of livestock especially cattle. Livestock carrying capacity in Palapye is 7 ha/Large Stock Unit (LSU) (Ecosurv and GIBB report, 2007)

indicating that one hectare of land supports 7 animals. Smit (2009) defined LSU as an animal with a mass of 450kg, which gains 0.5kg per day on forage with digestible energy percentage of 55%. For sustainable livestock production, the stocking rate of the area should be balanced with grazing capacity of the area (du Toit, 2010).

CHAPTER THREE

METHODOLOGY

This study assesses the extent of vegetation change as well as the level of vegetation degradation in Palapye sub-district over an 18 year period (1998 – 2016). This chapter discusses the sampling design, methods of data collection as well as the analyses conducted. Botswana NDVI was obtained from MESA where average annual NDVI maps as well as the vegetation condition anomaly maps from 1998 to 2016 were produced from Drought Monitoring System (DMS) software. The regression analysis statistics was applied in order to produce the vegetation degradation map in ArcMap software and for visualisation. Field trip was undertaken in order to validate the vegetation degradation map. The field data collection included vegetation sampling, meteorological data (rainfall) and the interviews on land users. The study employed mixed methods of both qualitative and quantitative data collection.

3.1 Data Sources and Collection

Eighteen (18) year time series NDVI data (1998 – 2016) from SPOT – VGT and Proba-V sensors (both with spatial resolution of 1km), produced by the Monitoring the Environment and Security for Africa (MESA-SADC) programme of the European Union and African Union was used to examine vegetation variability and degradation in the study area. Vegetation sampling was conducted (6th to 9th December 2016) to validate the degradation levels of vegetation as depicted in the VDI map. This was to see if the plant species identified in the sampling sites was related to level of vegetation degradation. Specifically, rainfall (1998 – 2015) from the Department of Meteorological Services was used to establish the relationship with NDVI. Land users being farmers were also interviewed (3rd to 13th March 2015, 23rd March 2015 to 10th April 2015) to better understand the changes in vegetation. The methodological workflow is therefore indicated in Figure 3.

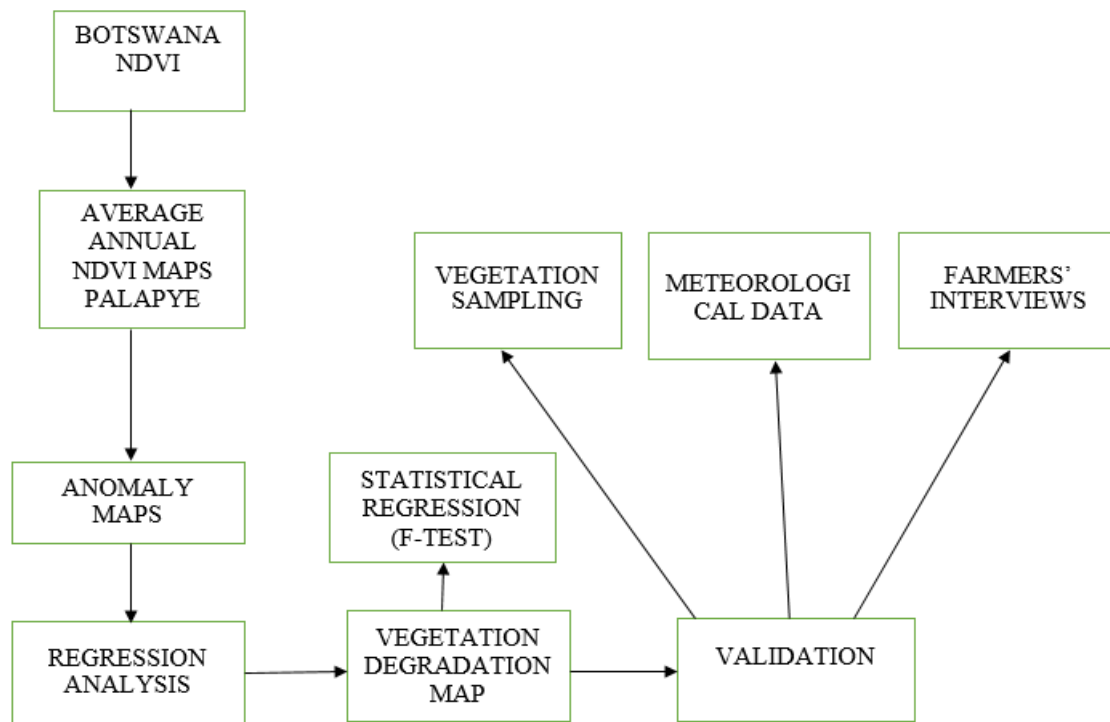


Figure 3: Methodological workflow

3.1.1 Normalised Difference Vegetation Index

NDVI was introduced to remote sensing community by Rouse et al., in 1974. NDVI which can be directly calculated from satellite data, and it is related to leaf greenness and percentage of vegetation cover and it is representative of plant photosynthetic efficiency, and fluctuations due to changes in meteorological and environmental parameters (Wenxia et al., 2014). The NDVI, derived from measurements of the optical reflectance of sunlight in the red and near-infrared wavelengths is therefore, highly sensitive to ecosystem conditions (Tottrup and Rasmussen, 2004). The NDVI measures and monitors plant growth and vegetation cover (Marumbwa, 2016) and is capable of capturing the severity of vegetation stress resulting from water deficit (Gwitira et al., 2015). It is based on the fact that photosynthetically active plants absorb a high proportion of incident radiation in the visible red portion of the electromagnetic spectrum but reflects a lot in the near infrared portion of the electromagnetic spectrum (Pu et al., 2008). The NDVI also provides information on the location and density of green vegetation (Jackson and Prince, 2016) including the detection of potential drought with stressed vegetation (Bhavani et al., 2016). As such, it is possible to utilise NDVI as a proxy for the vegetation response to precipitation variability looking at the close coupling between rainfall and the growth of vegetation (Anyamba and Tucker, 2005). The use of NDVI allows

transforming multispectral data into a single image band representing vegetation distribution, as the amount of green vegetation present in the pixel (Imam et al., 2016).

NDVI is computed as in the equation 1 below:

$$NDVI = \frac{NIR - R}{NIR + R} \dots\dots\dots (Equation 1)$$

Where: NIR is the near infrared; R is the red. This formula is based on the premise that vegetation reflects a lot of light in the red and near infrared bands, where other objects do not. When the vegetation is under stress, the reflectance in the visible part of the spectrum may increase while the reflectance in the near infrared may decrease (Gwitira et al., 2015; Khorram et al., 2016). NDVI is designed to standardised vegetation index values so that they are between -1 and +1, with 0 standing for no vegetation and negative values for non-vegetated surfaces such as water and snow (Pettorelli et al., 2005; Eckert et al., 2015; Imam et al., 2016). As such, it can be differentiated what are plants and what is not, and also which plants are healthy and which are not (Lee and Yeh, 2008).

The different images from NDVI easily track changes in the amount of leaf greenness for a particular period relative to the historical average or the previous year. As such, the technique highlights areas with comparatively reduced or increased plant growth (Gross, 2005). It is important to note that the NDVI images allow agricultural managers to analyse vegetation conditions for all season (Gross, 2005). The images can also be used to create land cover maps. NDVI is important because it is highly useful in detecting the surface features of the visible area which are extremely beneficial for policy makers in decision making (Meeragandhi et al., 2015). On the other hand, the vegetation analysis can be helpful in predicting the natural disasters to provide humanitarian aid, assess damage and also in designing the new protection strategies (Meeragandhi et al., 2015). Table 1 shows the values of different cover types from the electromagnetic spectrum.

Table 1: Typical values for various cover types

COVER TYPE	RED	NEAR INFRARED	NDVI
Dense vegetation	0.1	0.5	0.7
Bare dry soil	0.269	0.283	0.025
Clouds	0.227	0.228	0.002
Snow and ice	0.375	0.342	-0.046
Water	0.022	0.013	-0.257

Adopted from Holben et al., (1986).

NDVI is closely correlated with leaf biomass, leaf area index, productivity and potential photosynthesis (Wang et al., 2016) hence the NDVI used as a proxy for terrestrial vegetation productivity in studies of vegetation dynamics at regional and global scales (Nemani et al., 2014). The NDVI was based on vegetation data provided by the vegetation sensor on board SPOT satellites. Satellite data involves spatial assessment of NDVI as indicator of green vegetation (Seboka, 2016). SPOT-VGT provides high quality daily global coverage at 1km resolution with wide spectral range (Li et al., 2015). The SPOT Vegetation sensor is carried aboard SPOT 4 and 5 which were launched in 1998 and 2002, respectively. The sensor has instantaneous field of view of 1km and temporal resolution of 1 day and it is particularly valuable for studying agriculture, deforestation, and other vegetation changes on a broad scale (Xie, et al., 2008). The SPOT-VGT instrument has 4 spectral bands of BO (blue, 430 – 470nm), B2 (red, 610 – 680nm), B3 near infrared, 780 890nm) and short-wave infrared (1580 – 1750nm). The grey value of every pixel is linearly stretched by $NDVI = DN \times 0.004 - 0.1$, which convert the data range to 0.1. So, all values below 0.1 are therefore left out as they do not represent the vegetation (Li et al., 2015). NDVI is therefore, equal to the ratio of the difference between near infrared band and the red band to the sum of the two bands (Huang, et al., 2013). The SPOT-VGT images record the digital number (DN) between 0 and 255. Different datasets have therefore been used in different studies. Table 2 presents some studies on NDVI datasets.

Table 2: A summary of commonly utilised NDVI datasets.

Name	Sensor	Time-Span	Time-Step	Resolution
Pathfinder (PAL)	AVHRR	1981–2001	10-day	8 km
Global Vegetation Index GVI)	AVHRR	1981–2009	7-day	4 km
Land Long Term Data Record (LTDR)	AVHRR	1981–2013	Daily	5 km
Fourier-Adjusted, Sensor and Solar zenith angle corrected, Interpolated, Reconstructed (FASIR)	AVHRR	1982–1998	10-day	0.125°
GIMMS	AVHRR	1981–2006	15-day	8 km
GIMMS3G	AVHRR	1981–2011	15-day	8 km
S10	SPOT-Vegetation	1998+	10-day	1 km
EM10	ENVISAT-MERIS	2002–2012	10-day	1.5 km
SeaWiFS	SeaWiFS	1997–2010	Monthly	4 km
MOD (MYD)13 A1/A2	Terra (Aqua) MODIS	2000+	16-day	500 m/1 km
MOD13 (MYD)A3	Terra (Aqua) MODIS	2000+	Monthly	1 km
MOD13 (MYD)C1/C2	Terra (Aqua) MODIS	2000+	16-day/monthly	5.6km
MOD13 (MYD) Q1	Terra (Aqua) MODIS	2000+	16-day	250m
MEDOKADS	AVHRR	1989+	Daily	1 km

Adopted from Higginbottom and Symeonakis (2014).

The study focussed on data for 18 years. The NDVI derived from SPOT-VGT from July 1998 to June 2016 were obtained from Monitoring for Environment and Security in Africa (MESA) office in Gaborone. The year 1998 has 18 images (from July), while each year from

1999 to 2015 there are 36 images per year. For the year 2016, there are only 18 images (January to June). In total, the NDVI was extracted from 648 images. The annual NDVI (ANDVI) has been adopted due to its advantages in ease of calculation and smooth running (Dent and Bai, 2008; Li et al., 2015). The reason for starting in July until June the following year was to allow the rainfall season to be included in each year to see if there is a correlation between NDVI and rainfall.

3.2 Data Analysis

3.2.1 Vegetation variability

- What is the extent of vegetation change in Palapye?

In order to see the extent of vegetation change in Palapye, maps of average annual NDVI (1998 to 2016) were calculated using the Drought Monitoring System Software (DMS) from MESA. The produced maps include the following:

- ✓ Maps of annual average NDVI (ANDVI) for each year started from July to June. The NDVI difference tool in DMS was used to produce the ANDVI maps by calculating the NDVI difference (Equation 2)

$$NDVI_{diff} = NDVI_2 - NDVI_1 \dots\dots\dots \text{(Equation 2)}$$

Where $NDVI_{diff}$ is calculated between two time periods, e.g. between July 1998 ($NDVI_1$) and June 1999 ($NDVI_2$). For each year, the NDVI is calculated from July to June for the following year.

- ✓ Vegetation anomaly maps which identify how and where vegetation development is different from normal in comparison to the long-term average conditions.
- ✓ Current year maps (2015/2016) which shows the amount of vegetation growth for a particular month relative to the historical average of all years for that month
- ✓ ArcMap software was used to classify the final maps for visualisation

The cumulative NDVI values over the 18 year period were also extracted from the maps in DSM/ArcMap and imported into Microsoft Excel where tables and different graphs were plotted including the Z-score graph. The Z-score shows the NDVI departure from the mean, and the deviations within the 2 red lines are considered a normal vegetation season, whereas positive deviations above 1 means a good season and negative deviation less than -1 portends a bad season.

3.2.2 Vegetation degradation

➤ What is the extent of vegetation degradation in Palapye?

The extent of vegetation degradation is the VDI which is based on Regression analysis. VDI is the degree of vegetation degradation presented in values. This shows the state of vegetation, whether the vegetation is degrading or not, and if degrading, to what extent is it degrading. There is a linear relationship between ANDVI and time, and the slope of the trend line is estimated as in Equation 3 following Li et al., (2015).

$$SLOPE = \frac{n \times \sum_{i=1}^n (i \times ANDVI_i) - \sum_{i=1}^n i \times \sum_{i=1}^n ANDVI_i}{n \times \sum_{i=1}^n i^2 - (\sum_{i=1}^n i)^2} \dots\dots\dots \text{(Equation 3)}$$

Where i represents the year and n represents the total years. $ANDVI_i$ is the average NDVI for each year.

To evaluate the VDI as shown in equation 4, a significant threshold is then used to separate ANDVI change from no change. The regression model of ANDVI with time is examined with F-test on a 5% significance level.

$$VDI = \begin{cases} SLOPE \\ 0 \end{cases} \times (-1000) \quad (SLOPE < 0, F > F_{0.05}) \dots\dots\dots \text{(Equation 4)}$$

If the SLOPE is < 0 and $F > F_{0.05}$, there exists significant ANDVI reduction, the SLOPE is the value of Vegetation Degradation Index (VDI). Otherwise, the ANDVI is not significantly changed or is increasing, indicating no vegetation degradation in the area (Li et al., 2015).

If SLOPE is > 0 , ANDVI presents an increasing and positive trend. On the other hand, if SLOPE is < 0 , there is a reducing trend of ANDVI. The F-test was analysed in the Matlab

software to examine the significance of the vegetation degradation map. The significance was analysed per pixels in the map. The F-test map was plotted such that statistically insignificant pixel with p-value less than 0.15 (below 85%) were masked out as these pixels indicate there is no degradation and are less important for the discussion. F-test is very important in terms of determining the significance of the results. The SLOPE values were categorised into four degradation classes as follows: 0 = relatively undegraded 1 – 10 = low degradation; 10 – 20 = medium degradation and; >20 = highly degraded.

For the interviews, data from face to face interviews was entered as a spreadsheet in Microsoft Excel to be produced as percentages, graphs (bar and pie charts) and tables.

3.2.3 Meteorological data

The daily precipitation data from 1998 to 2015 which was collected from the Department of Meteorological Services was summed up and entered into excel to produce graphs on the average rainfall for 17 years excluding 2016 where the rainfall data was not available. Rainfall values were plotted together with the NDVI values in order to produce graphs showing the correlation between NDVI and rainfall. Maunatlala (medium degradation) and Lecheng (high degradation) did not have rainfall records and in their stead, Matlhakola and Moremi precipitation data were analysed as medium and high degradation respectively. The only available rainfall data available was for Moeng (1998 – 2013), Lesenepole (1998 – 2010), Malaka (2002 – 2007), Matlhakola (2003 – 2008), Moremi (1998 – 2013), Morupule (2007 – 2015), Mahibitswana (1998 – 2014), BIUST (1998 – 2014) and Mogapinyana (1998 – 2009). Being a compliment to remote sensing, rainfall data is important as it provides products for assessment of agro-climatic situations as well as being useful to detect vegetation anomalies (Marumbwa et al., 2016).

3.2.4 Vegetation sampling

The entire study area was reclassified into 4 vegetation degradation categories, i.e., strata, based on the Vegetation Degradation Index (VDI) values that were derived from the regression slope of each raster cell. These being relatively undegraded, low degradation, medium degradation and high degradation. Field visits were undertaken for vegetation sampling at 9 sites selected. Representing the low degraded area are Lesenepole and Mahibitswana, medium degradation are BIUST, Maunatlala and Malaka, and high

degradation are Morupule and Lecheng. Moeng and Mogapinyana were included to represent the relatively undegraded areas. Vegetation assessment was done in order to validate the results that were produced such as the vegetation variability and Vegetation Degradation Index maps. The areas that were identified to be of low degradation were It is however important to note that the appropriate sampling technique depends upon the type of data needed (Noori et al., 2014). As such, a stratified random sampling method was used to ensure that the study area is properly sampled, i.e. each degradation class as a stratum has equal chance of being sampled and that vegetation sampling plots are not poorly distributed. To minimise a situation where certain species are over- or under represented, quadrats were implored in this process as it can be used for inventory in most plant communities (Cox, 1990). In this way, vegetation cover can be easily estimated, plants counted, or species identified and listed (Fidelibus and MacAller, 1993).

Two quadrats of 50 by 50 meters for each degradation category per site were used for vegetation inventory with the exception of Palapye where 3 sites were selected as it is the main town. For the study, site centroid coordinates were obtained from the VDI map and established in the field using a Leica Zeno field Global Positioning System (GPS) receiver. Steps followed are as follows:

- Measure the quadrat with a measuring tape before plant identification and counting.
- Put 4 poles in each corner of the quadrat to be sampled. The 4 corners were then marked with a red tape in order to be visible.
- Coordinates of each corner were then taken.
- Photos of the quadrat were taken.
- The area was then divided into 2 equal halves and marked with a red tape.
- The plant species in each half were identified, counted and recorded.
- Grass species were also identified and the most dominant ones were recorded.
- The ground cover of each quadrat was estimated.

One hundred percent (100%) inventory of vegetation species composition and abundance was conducted in each quadrat (the 2 halves of the quadrat) to make sure a total count was conducted. In these quadrats, plants species were identified and counted. Species unidentified on the field were placed in a plant presser and later identified in the lab. The main goals of the inventory were to identify dominant species and the species density per sampling site in

comparison to the degradation class. The measuring tape and the red tape (Figure 4) were used in dividing the quadrat that was sampled.



Figure 4: A measuring tape and a red tape used in delineating a quadrat

Data from vegetation sampling was recorded and analyzed in Microsoft Excel for the occurrence, frequency and density of each tree species. For each plant species that was identified in the quadrat, the number of individuals was counted and recorded as the occurrence for each site. Frequency was calculated as the number of quadrats in which species occur divided by the total number of quadrats sampled.

$$Fa_j = M_j \div m \dots \dots \dots \text{(Equation 5)}$$

Where M_j is the number of points where species j occurs, and m is the total number of points

The relative frequency was calculated by dividing the species' frequency with the total number of frequency for all the plant species multiplied by 100 percent

$$Fr_j = Fa_j \div \sum_{k=1}^p Fa_k \times 100\% \dots \dots \dots \text{(Equation 6)}$$

Where the denominator is the sum of the absolute frequencies for all species, k is the species number, and p is the total number of species.

Density of each species was calculated by dividing the number of individual plant species by the area of the quadrat (2500m²).

$$D_j = N_j \div Q_a \dots \dots \dots \text{(Equation 7)}$$

Where N_j is the number of occurrences of species j in a quadrat and Q_a is the area of the quadrat. This measure was used because each species could be consistently recognised and counted per unit. This value was then extrapolated to the density of known individuals per hectare. This was done by multiplying the density per square metres with 10000 in order to convert metres to hectares

The average density of each species was calculated per site. This was calculated in metre square (m²) as well as in hectares (ha). When converting average density in m² to the average density in ha, the equation 8 was used:

$$\text{density (m}^2\text{)} \times \frac{10000}{2500} \dots \dots \dots \text{(Equation 8)}$$

Where 10000 is the conversion of m² to ha and 2500 m² is the area of a sampled quadrat. The average density of each species in the study area was then calculated by the addition of the number of individual plant species per unit area (2500m²) of a quadrat divided by the number of quadrats. The graphs showing the occurrences of plant species per site were then produced.

3.2.5 Perceptions of land users

Knowledge of the natural world is not confined to science. Human societies all across the globe have developed rich sets of experiences and explanations relating to the environment they live in (Nakashima et al., 2000). This knowledge and skills have been developed outside the formal education systems and enables the community to survive (de Guchteneire et al., 2003). The fact that the communities have survived till today is an indication that they have developed indigenous mechanisms and strategies to cope with environmental degradation through mitigation and adaptation (Nyong et al., 2007). Pulido and Bocco (2014) are also of the opinion that a positive attitude towards conservation would develop if land users perceive a potential economic benefit from such practice. And at the local level, people act according

to household conditions and local economic opportunities. So, it was imperative for land users to be interviewed in order to get their side of the story in terms of vegetation degradation (Table 3).

Table 3: Number of farmers interviewed

Farmers	Number
Arable	31
Pastoral	3
Mixed (arable + pastoral)	92
Bee keeping	6
Horticulture	4
TOTAL	136

According to Department of Agriculture, the study area had 1200 farmers comprising of subsistence arable farmers, horticulturists, beekeepers, and 303 pastoralists in the whole of Palapye sub district. Of these, 136 farmers were selected using a systematic random sampling method, land users were selected to reflect all categories of agricultural practice in the study area.

Interview questions were typed in a paper having written in English and administered in Setswana which was the preferred language of the respondents. The study employed mixed method of both qualitative and quantitative. The quantitative approach involves the collection of numerical data in order to explain, predict, and/or control phenomena of interest via statistical analysis, with the assumption that the result can then be expressed as a numeric value (Glatthorn & Joyner, 2005; Moswete, 2009). On the other hand, the qualitative approach involves the collection of extensive narrative data in order to gain insights into the phenomenon of interest and the data are analysed by coding and production of a verbal synthesis (Moswete, 2009). Onwuegbuzie & Leech (2007) have indicated the goal of qualitative researcher not to make inferences about the underlying population, but to obtain insights into a particular educational, social, and familial process and practices that exist within a specific location and context. Both qualitative and quantitative research techniques were drawn from the views and approach of Cresswell & Clark (2011) who believed that

employing multiple methods in data collection helps to improve the probability that findings and interpretations will be credible.

In this study, face to face interviews with farmers, and voice recordings of historians were integrated concurrently in order to increase the potential of understanding the research problem and data validity (Moswete, 2009). Instruments used for data collection are Appendices 1, and 2. This included semi-structured questions for farmers, and voice recording of historians respectively.

Face to face interviews - The survey technique using face to face interview for farmers was applied. This method is best suited for studies that have individual people as the unit of analysis (Maxfield and Babbie, 2016). It is credible as it was also used by Anim and Chauke (2014) to investigate the environmental degradation differences among rural farming communities in the Limpopo Province of South Africa. Oladele (2011) as well used this method to determine the constraints to livestock identification and trace-back system use for disease monitoring among cattle farmers in Botswana. Among other researchers who used the same technique, in his dissertation is Mbaiwa (2008) who investigated the tourism development, rural livelihoods, and conservation in the Okavango Delta of Botswana. The technique is widely used for research as it is appropriate for measuring unobservable data about a population too large to observe.

Data was collected from 3rd to 13th March 2015 in Palapye East and West, and from 23rd March 2015 to 10th April 2015 in Lecheng area. Palapye East is composed of Mahibitswana, Dikabeya, Bonwakathako and Patikwane, while Palapye West included Morupule, Phuduhudu, Lemone, Masuakoloi, Molapowadipitse and Setatse west. Lecheng included Setatse east, Dikakabale, Dikakabalane, Mahututu, Dinonong, Mhate, Kokobedi, Dithadana and Makobeng. The interviews were administered to 136 farmers. A head of the household or if absent, a spouse or whoever was available in the household or ploughing field was requested to participate. Prior to administering the questionnaire, a pre-test was conducted on 2 farmers (1 male in Palapye West and 1 female in Palapye East) on the 18th and 19th February 2015. This was to address the potential problems associated with interpretation of questions, whether respondents understood the questions and also to see the amount of time required for each interview. It also helped in restructuring the questions before being administered to the rest of the farmers. The questions were written in English and

administered in Setswana while the responses were written in English. However, different types of farmers were interviewed. The semi-structured interviews' advantage is that at times free response questions were asked to dig deeper to get the farmer's insight about a particular issue under discussion (Mbaiwa, 2008).

Each interview lasted between 1 hour 30 minutes and 2 hours per farmer. As the fieldwork was conducted during the growing season, with crops still in the ploughing fields, most of the farmers were found and interviewed in their fields. The interview was meant to find out about degradation in the area. Therefore, the information needed was in relation to the socioeconomic characteristics of land users, their settlement and land tenure, anthropogenic activities that might drive degradation in and around their area, types of farming, natural resources use, market access and services to household, perception of land degradation and climate change, local knowledge, institutions and policies as well as the general information.

Audio recording of oral history - Oral history is the formal, rehearsed accounts of the past presented by tradition-bearers about the old days' past times (Shopes, 2011). It is the testimony of living people about their experiences and comprises individuals' memories which would be lost at death (Allen and Montell, 1991). Oral historians have first-hand knowledge of a number of experiences (Janesick, 2007). Oral sources have been identified to study subjects in which written records are either lacking or too voluminous (Thomas, 2014). The value of oral history method of inquiry lies with an appreciation that understanding the past can guide people in the decision-making for the future (Miller-Rosser et al., 2009). A method of audio recording was used to get information from oral historians. Oral history is useful in revealing the past experiences or knowledge or simply wisdom of activities that have taken place in the area in terms of farming, loss of vegetation, as well as the origin of Palapye village. Shopes (2011) emphasised that most people throughout history have learnt about the past through the spoken word. As such, oral history places emphasis on the significance of temporal context and memory of interviewing people about their past experience (Bornat, 2012). Oral history asks and answers questions about long-term memory and lived experience, with the potential to uncover more than the basic facts of *who*, *what*, *where*, and *when*, thus making it an appropriate method for asking the questions (Taylor, 2007). Audio recording gives an accurate summary of the interview as all answers captured as well as the comments by the researcher are saved. The recordings can be re-winded and listened to repeatedly in order to get clarity of the interview. The proponents of an oral

history approach argue that by talking directly to people about their memories, past aspects of their lives will be revealed, which otherwise might be overlooked through lack of documentation or public record (Bornat, 2012). A verbatim voice recorder was used to record the oral interviews.

Before each interview, the researcher explained to the narrators the purpose of the interview as well as the goals of the project. Reasons for recording were also explained. The researcher also made historians aware that whatever is being recorded would be used in the project and can be listened to when the need arises. Seven elders aged 65 years and above who were identified by diKgosi and farmers committees were interviewed, 2 at their households, 2 at the Kgotla while 3 were found at their ploughing fields. This involved 2 from Lecheng, 1 from Lemone, 1 from Masuakoloi, 1 from Bonwakathako and 2 from Palapye Kgotla being diKgosi who oversee all activities of chieftainship in the whole of Palapye Administration Authority. The historians were identified as people having vast knowledge about changes in Palapye and surrounding areas over time, also very knowledgeable and experienced in farming. They are as such the doers of the experience or the eye witnesses of the events (Baylor University Institute for Oral History, 2016). Open- ended questions directed to the oral historians were read from Appendix 3. They included *Tell me about.... Why...? Why not...? How...?* The researcher probed for details such as *Describe... Explain... How often... Tell me more ...* There were also follow up questions like *what else... Who else... What other reasons...?*

While oral history also approaches questions about how and why as well as what, Taylor (2007) has indicated the interview to go beyond that, searching out nuances of lived experiences that are not necessarily found in standard historical documents. Baylor University Institute for Oral History (2016) has indicated oral history to help round out the story of the past, and helps in understanding how individuals and communities experienced the forces of history. This also teaches what has changed and what has stayed the same over time, and preserves for future generation a sound portrait of who people are in the present and what they remember about the past. Oral history is distinguished from other forms of interviews by its content and extent as it seeks an in-depth account of personal experience and reflections with sufficient time allowed for the narrators to give their story the fullness they desire (Oral History Association, 2009). Data from audio recorded interviews was

transcribed and analyzed as themes. Through observations, some pictures were taken which helped in data analysis by complementing on what the respondents have said.

3.3 Field Observation

The research also utilised observations as another method during data collection. This happened where the administration of both interviews was concurrently carried out with observing the condition of the farms. This method was very useful as it justified what the respondents said during the interview especially if it was in relation to degradation, establishing what was going on in the study area. The problems which were highlighted by farmers and historians such as bare land, formation of gullies, growth of unpalatable species, were witnessed first-hand. This method therefore, made it easy for the researcher to believe what was said by the respondents as it could be seen straight away. Perkins et al (2013) also used the same method of observation for a land degradation status study in Rakops, Mopipi and Mokoboxane in Boteti sub district.

3.4 Triangulation of Methods Used in this Research

This is the use of multiple methods or data sources in research to develop a comprehensive understanding of the phenomena (Patton, 1999) and also to test the validity through convergence of information from different sources (Carter et al., 2014). The method of triangulation also provides a better understanding of research problems than only one method. Brown et al., (2008a, 2008b) and Steven et al (2003) indicated the importance of combining data from more than one observing system as this fill gaps in observation, especially when global applications focusing on vegetation responses to climatic and anthropogenic factors over time are used. However, there are different types of triangulation, being theory triangulation, data source triangulation and method triangulation (Carter et al., 2014) including investigator triangulation (Denzin, 1978; Patton, 1999). Method triangulation has been identified to involve the use of multiple methods of data collection about the same phenomenon (Polit & Beck, 2012) and it is frequently used in qualitative studies. This method may include interviews, observation, and field notes (Carter et al., 2014). Investigator triangulation has been identified to involve the participation of two or more researchers in the same study to provide multiple observations and conclusions.

Denzin (1978) has indicated this type of triangulation to bring both confirmation of findings and different perspectives, adding breadth to the phenomenon of interest. The theory triangulation uses different theories to analyse and interpret data (Denzin, 1978; Patton, 1999). With this type of triangulation, different theories or hypotheses can assist the researcher in supporting or refuting findings, while data source triangulation involves the collection of data from different types of people, including individuals, groups, families, and communities, to gain multiple perspectives and validation of data (Carter, 2014).

As for this study, triangulation of methods has been employed. This involved the use of multiple methods of data collection about the same phenomenon being NDVI data collection, vegetation sampling and interviews. Nkonya et al (2016) has also indicated the importance of employing different methods as it helps to analyse in more detail the aspects of vegetation degradation that cannot be captured using global or regional-level data, especially due to the diverse nature and process of vegetation degradation under different biophysical and socioeconomic characteristics at the local levels.

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3.5 Local Knowledge in Adaption to Vegetation Degradation

The Global Forum for Health Research (2004) has defined local knowledge as the knowledge that people in a given community have developed over time, and continue to develop. This knowledge has a great cultural significance (Carvalho and Frazão-Moreira, 2011) and is based on experience, often tested over centuries for use, adapted to the local culture and environment, embedded in community practices, institutions, relationships and rituals, held by individuals or communities and it is dynamic and changing (Warburton and Martin, 1999). This knowledge may be generated locally and be about local situations and circumstances. Equally, it may originate from elsewhere, but be locally adapted to match local circumstances (Global Forum for Health Research, 2004). As such it can be difficult to know where the knowledge originated. This knowledge has been identified to be often the product of many minds, spread over generations and geographical areas, being added to or adapted as it develops over time (Global forum for health research, 2004). However, FAO (2004) indicated local knowledge as a collection of facts and relates it to the entire system of concepts, beliefs and perceptions that people hold about the world around them. This includes the way people observe and measure their surroundings, how they solve problems and

validate new information. It includes the processes whereby knowledge is generated, stored, applied and transmitted to others (FAO, 2004).

The African Studies Center (2000) has further found the local knowledge to be working well in some parts of southern Ethiopia, where the consumption of wild-food plants seems to be one of the important local survival strategies. This appears to have intensified because of repeated climatic shocks that have hampered agricultural production, leading to food shortages. Increased consumption of wild-foods allows people to better cope with erratic, untimely rains. Studies have shown that people from southern Ethiopia are able to face several consecutive years of drought, without facing severe food shortages, famine and general asset depletion (FAO, 1999). The key to this survival strategy is the collection and consumption of wild plants. Therefore, local knowledge is considered to be important to rural activities and practices, such as cattle transhumance, agricultural techniques (crop rotation, irrigation methods, multi-use parcels and partial harvest), land management (ownership, land holding fragmentation, terraces, natural or artificial boundaries), rituals and ceremonies, oral traditions and symbolism, communitarian features and settlement patterns (Carvalho and Frazão-Moreira, 2011).

FAO (2004) has noted the importance of local knowledge as the main asset the local people invest in the struggle for survival to produce food, provide for shelter or achieve control of their own lives. This knowledge also provides problem-solving strategies for local communities, especially the poor and represents an important component of global knowledge on development issues (African Studies Center, 2000). The proponents of neo-populist theory which advocates for local people participation using bottom-up approaches in research and development (Sillitoe, 1998) present convincing arguments that local people have accumulated a wealth of knowledge over time, based on long-term experiences that can complement scientific knowledge in environmental conservation (Roba, 2008). Major emphasis is placed on the roles local knowledge and local management play in conservation (Berkes et al., 2000) and protection of the land from degradation. Additionally, there is growing interest on how local knowledge and management practices can be used in collaboration with standard scientific methods for improving understanding of the environment (Dahlberg, 2000; Reed et al., 2007).

Furthermore, the local knowledge is developed and adapted continuously to a gradually changing environment and is passed down from generation to generation and closely interwoven with people's cultural values (FAO, 2004). This knowledge has been found to form part of global knowledge, has a value and relevance in itself and can be preserved, transferred, or adopted and adapted elsewhere (FAO, 2004). When indicating the importance of local knowledge in his study on impacts of rangeland policy in Botswana, Basupi et al (2017) indicated the knowledge to foster better articulation and understanding of pastoralists' tenures that lack in administration systems, at the same time contributing to sustainable land management policy toolkits in rangeland environment.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Vegetation Variability

4.1.1 Yearly average NDVI

Vegetation variability, i.e. the annual average state of NDVI from July 1998 to June 2016 (Figure 5) keeps changing over the years. These results show the spatial distribution of plant growth over time and aid the tracking of changes in the amount of plant growth for a particular period relative to the historical average of 18 years or a previous year (Minamiguchi, 2005). Thus the technique highlights areas with comparatively reduced or increased plant growth (Gross, 2005). The use of NDVI allows agricultural and/or rangeland managers to analyse vegetation conditions for all seasons using NDVI based vegetation difference maps (Gross, 2005). Annual average maps from 1998 to 2016 (Figure 5), represent the expected growing cycle of vegetation each year. Often average maps are favoured to monitor vegetation anomalies because they normalise annual variations in plant growth (Marumbwa, 2016). This highlights the areas with reduced or increased plant growth therefore making it ideal for assessment of the difference in vegetation vigour at critical periods throughout the growing season (Marumbwa, 2016).

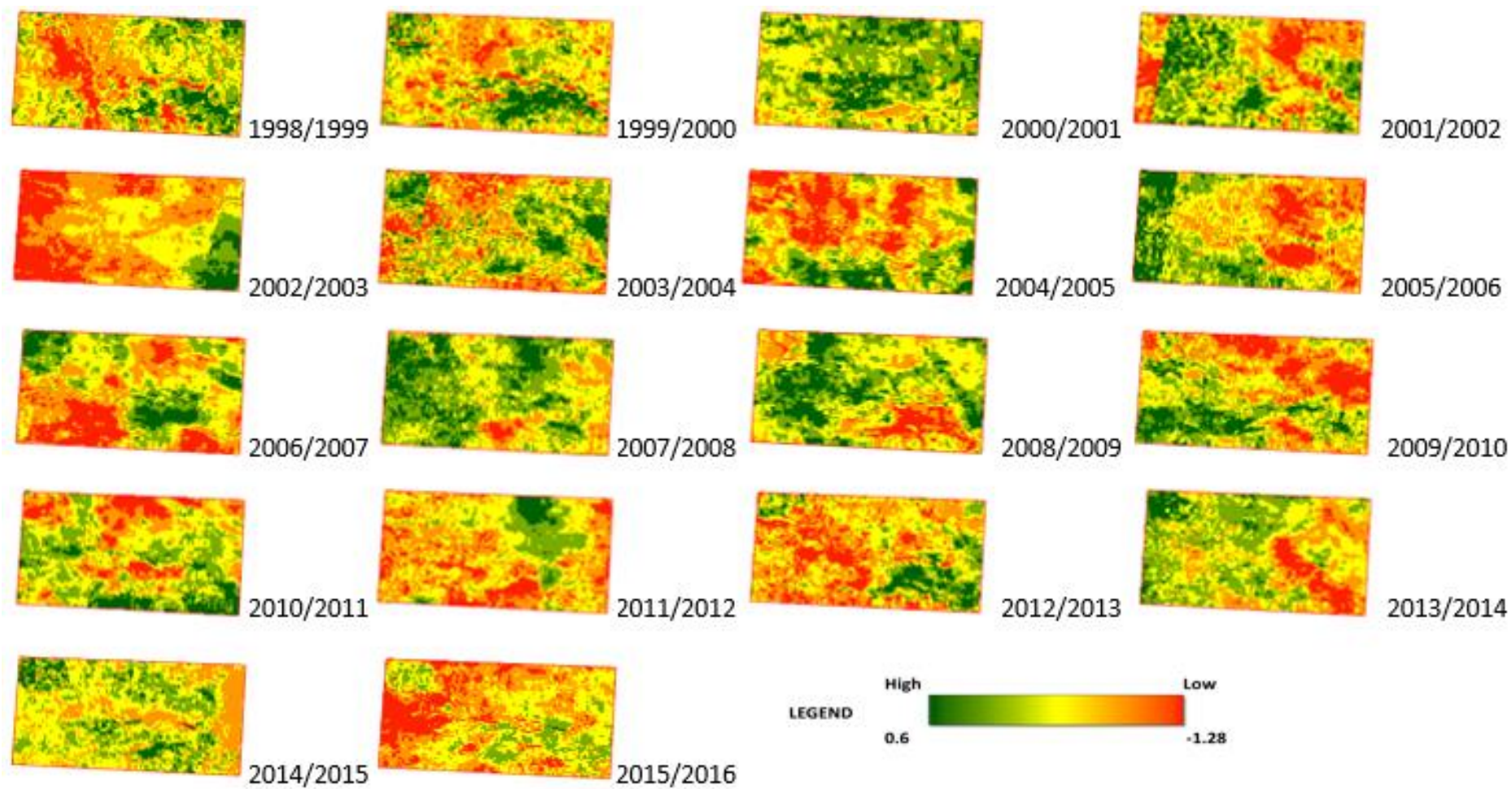


Figure 5: Yearly average NDVI for 18 years (1998 to 2016).

Even though Botswana is being classified as semi-arid (Batisani, 2010) the year 2000 and 2009 recorded floods in the country (World Bank, 2010) therefore, including the study area. This is the reason why 2000/2001 and 2009/2010 images look more greenish representing large NDVI increase. The year 1998/1999 and 2002/2003 which were pronounced drought years (World Bank, 2010) including 2014/2015 show the decrease in vegetation growth, with year 2014/2015 indicated to be the worst drought conditions in 30 years (News24, 2015). However, Sunday Standard Newspaper (2015) indicated the year 2014/2015 to be the worst drought in 34 years. In Botswana, drought has been found to be more extreme in the south of the country while moderate drought has had a high frequency in areas elsewhere (World Bank, 2010). With the return of normal rainfall for 2008/2009 and 2003/2004, the recovery of rangeland production was found to be good after 2002/2003 drought, as observed by the increased greenness. This observation supports the study that was conducted by

Ringrose et al., (1997) assessed range degradation and recovery during and after the droughts in the 1980s. The study indicated about 25% of the country to have been potentially degraded. However, vegetation cover increased by 6.5 % over a 10 year period with the return of rains. Setshwaelo (2001) also indicated that the length of drought periods determines whether the extent of degradation is reversible or not. The relationship between vegetation and precipitation becomes evident when the vegetation greenness increases with the increase in rainfall (Lin et al., 2016) as well as during the drought years that show decreased NDVI.

4.1.2 Vegetation Z-score of Palapye

Z-score values represent the departure from the mean and expressed in a normalized form for ease in comparing results from different time periods (Sweet, 2016). Standardized anomalies (z scores) of the annual NDVI from 1998 to 2016 show the position of each yearly NDVI value relative to the mean value for that particular year in the 18 year time series. The Z-score (Figure 6) summarises 18 years of vegetation anomaly into a simple graph. This graph enable the users to see how the vegetation growth performance deviated from average conditions over the 18-year period. Thus, Z-scores above zero mean have a positive value and those below zero have a negative value, vegetation conditions. Between the red lines in Figure 6, the values are acceptable as they lie within the normal variation of NDVI. The years 1998/99, 2001/02, 2002/03, show negative deviations less than -1, therefore, indicating reduced plant vigour. The year 1998/1999 and 2002/2003 were considered drought years in Botswana

(World Bank, 2010), hence showing up as negative deviations in the Z-score. The years 2001/2002 and 2004/2005 as well show a negative deviation, even though the country was not declared drought stricken. These years are below normal conditions, which relate to drought or water stress conditions.

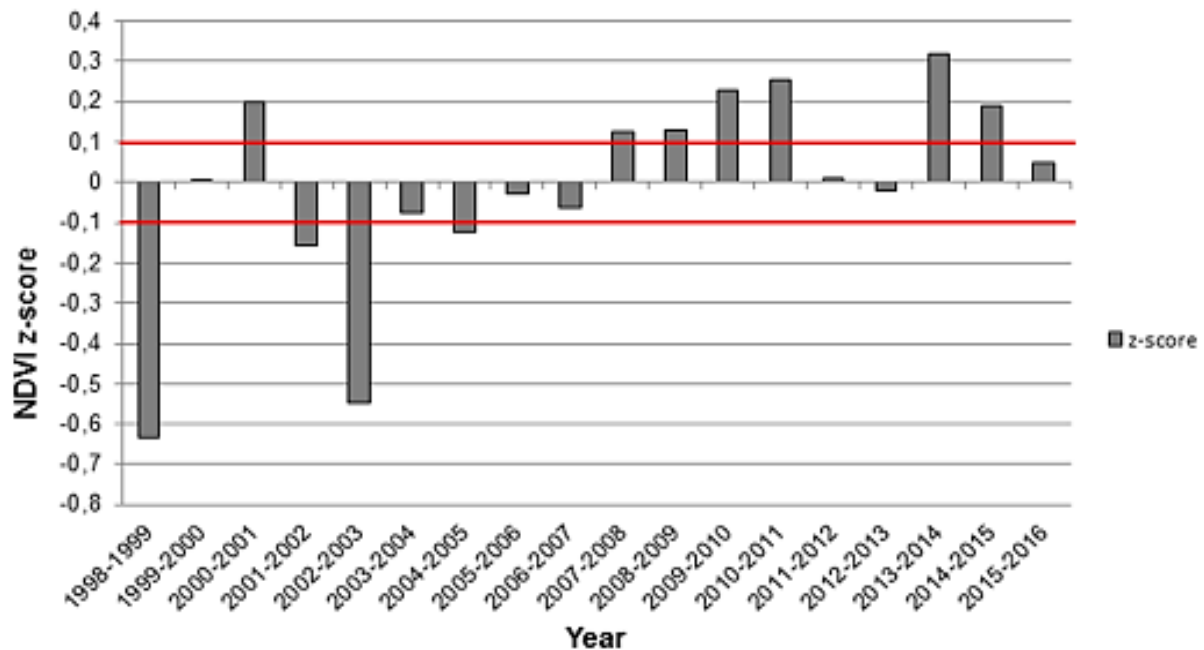


Figure 6: The vegetation Z-score

The year 2000 and 2010, were ravaged with floods (World Bank, 2016), hence the increasing values of NDVI in the year 2000/2001, 2009/2010 respectively. The year 1999/2000 had the highest rainfall in the entire series of 18 years yet does not have the highest NDVI values. Even though the year 2013/2014 has the highest NDVI, it had less rainfall than the year 2000/2001. The rainfall above normal conditions may results in good vegetation growth but may also results in floods in case of rainfall (FAO, 2011). The year 2014/2015 was declared a drought year, (News24, 2015; World Bank, 2016). The president of the Republic of Botswana declared a general countrywide drought in 2015, the first drought since 1984 which resulted in a special budget passed by parliament to cater for the drought (Botswana Daily News, 2015). But the year 2014/2015 does not show negative NDVI values. These results are in line with the study by Mberego and Gwenzi (2014), who found that the 1991/92 season, which was referred to as the most extreme drought (Manatsa and Mukwada, 2012) was not the most prolonged period of negative NDVI anomalies in Zimbabwe (Mberego and Gwenzi, 2014). In 2015/2016, there was indeed considerable reduction in vegetation growth in

comparison to 2013/2014, and 2014/2015, which showed the vegetation to be still within the normal condition range. This might be partly explained by the early rains of summer 2015/2016 which started in September hence contributed to NDVI increase therefore reducing the severity of the dry spell which followed in the months of October till December before the above normal rains recorded in February and March 2016 (Akinyemi 2017). This therefore, shows the importance of NDVI in monitoring and predicting the postseason vegetation conditions for smallholder farmers who rely on natural vegetation for livestock and other services (Mbereggo and Gwenzu, 2014). NDVI does not entirely depend on rainfall, as some woody plants do have long deep roots to extract underground water even in times of drought (Fensholt et al., 2013).

4.1.3 Vegetation anomaly

Vegetation anomalies are deviations from normal behaviour and they describe and quantify differences between images at the same scene at different times (Hegazy and Kaloop, 2015). Vegetation anomalies simply is the current NDVI compared to long-term average, and basically give a qualitative indication of how ‘good’ or ‘bad’ the current season is when compared with other seasons or with the average situation (FAO, 2011). Chiang and Chen (2011) have however described vegetation anomaly as the significant change of vegetation vigour due to natural and/or anthropogenic factors. The NDVI anomalies maps (Figure 7), identify how and where vegetation development is different from normal. The anomaly maps relate to one specific time (dekad, month, or season).

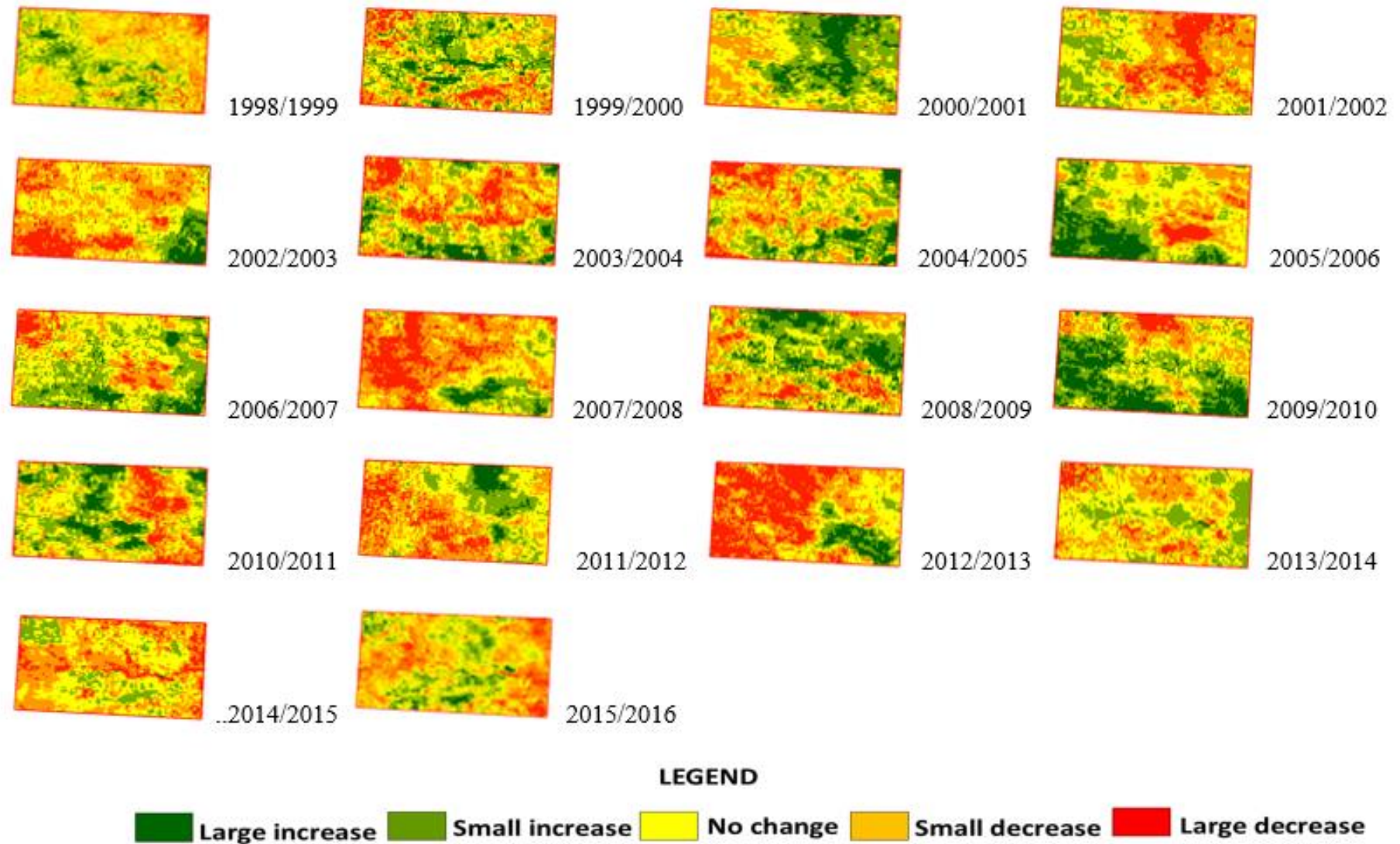


Figure 7: Vegetation anomaly from 1998 to 2016

For the 18-year period, the anomaly maps (Figure 7) show decrease in vegetation growth which was most pronounced in the years 2002/2003, 2007/2008, 2011/2012 and 2012/2013. The decrease in vegetation growth in these years was as a result of the drought that had stricken the country. Areas showing positive NDVI trends mostly coincided with areas indicating an increase in vegetation growth, as well as areas showing negative NDVI trend coincided with a decrease. Whereas, in the year 2000/2001 and 2009/2010, NDVI increased because of ample rainfall in the years 2000 and 2009, which resulted in floods in some parts of the country.

Drought is a recurrent climatic phenomenon across the world, therefore affecting humanity (Masih, et al., 2014). As a semi-arid country, droughts have been common in the past, one in four years is a drought year as indicated by World Bank, (2010). Drought triggers negative impact in the environment as such, a sharp decline in rainfall and a heatwave caused a dramatic 70% drop in land under cultivation (News24, 2015) in 2015 in Botswana. With significant decline in rainfall distribution coupled with scorching heat wave, the level of water was observed to be relatively low resulting in reduced inflows into the dams (Botswana Daily News, 2015).

Because of low rainfall, farmers in the area experienced low to no yields at all, with 72% of farmers interviewed indicating lack of rainfall as the main cause. Being a consequence of a reduction in the amount of rainfall over an extended period of time, drought is often associated with other climatic factors including high temperatures (Sivakumar and Stefanski, 2007), and can last for months or years (Wilhite and Buchanan-Smith, 2005). A similar study was conducted in Taiwan in 2011 (Chiang and Chen, 2011), using time-series MODIS NDVI as the primary spectral indicator for monitoring of forest health and detection of vegetation anomaly based on 10 year dataset (2001-2010). The results revealed the vegetation anomalies to be an effect of land use changes such as deforestation and agriculture expansion, also with cases of drought spells of 2002, landslides and wild fires (Chiang and Chen, 2011).

The positive anomaly was observed in 1999/2000, 2000/2001, 2008/2009 through 2009/2010 as well as the year 2000/2001 and 2009/2010. The year 1999/2000 and 2008/2009 is not surprising with increased NDVI as rainfall that caused floods started in the year 2000 and 2009 respectively. Increase in NDVI indicated rainfall had positive impact on the vegetation while NDVI decrease signaled low rainfall or drought. Anomaly maps are therefore very

important as they give an indication about the location and extent of the areas of potential concern as per reduced crop production or pasture availability (FAO, 2011).

4.1.4 Current year NDVI (2015/2016)

The Figure 8 shows the state of NDVI of the current year (2015/2016). The maps of the months of September, October and November have the largest decrease in NDVI. It has also been indicated that the month of November 2015 was the driest month of November of the last 35 years in Southern Africa including southern Botswana (Rembold et al., 2016). In Botswana, rains usually start in the month of October up to March, which signals the beginning of the growing season (Bonifacio, 2016). For the current year, the vegetation started improving from December to June, where Rembold et al (2016) indicated end of December and January rainfall to have improved pastoral vegetation conditions that resulted in small increase in NDVI therefore, indicating a strong relationship between precipitation and NDVI (Ndayisaba, 2016). The 2015/2016, which is the current season, coincided with the peak of a strong El Niño in the Pacific Ocean, therefore causing irregular rainfall distribution over the entire Southern Africa (Rembold et al., 2016).

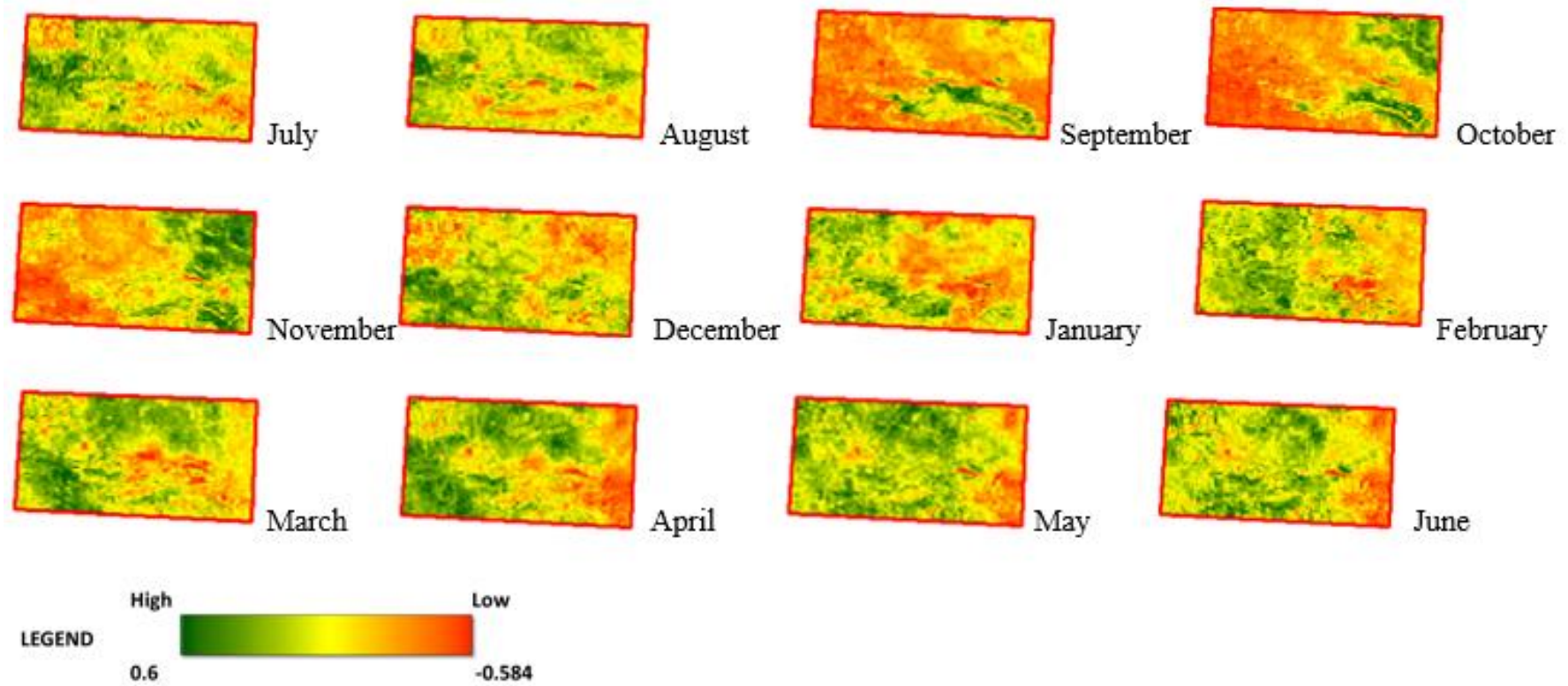


Figure 8: NDVI as per the current year (July 2015 to June 2016)

This led to drought conditions in Southern Africa starting in the second half of 2015, including the study area. The year 2015 was so bad it resulted in the country (Botswana) being drought stricken (Botswana Daily News, 2015). Other countries including Zimbabwe, Ethiopia, Kenya among others were also hard hit, with South Africa experiencing the worst lowest rainfall in 2015 since 1904 (Makube, 2016). Globally, studies show that the 2015 El Nino is not the only phenomenon affecting agricultural areas but 1996-1998, 1991-1992, 1994-1995, 1997-1998, 2002-2003, 2004-2005, 2006-2007 and 2009-2010 were also affected (FAO, 2014). This therefore, makes the knowledge of current vegetation dynamics imperative in making the ability to make accurate predictions of ecological changes essential for minimizing food scarcity in developing countries (Ndayisaba, 2016).

4.1.5 Time series graphs

The vegetation performance time series charts help to understand the development of vegetation on a long-term basis (Marumbwa, 2016). By comparing the current year NDVI with the long-term average NDVI (Figure 9), it helps to determine if the current vegetation condition is better or worse than the long-term (Minamiguchi, 2005).

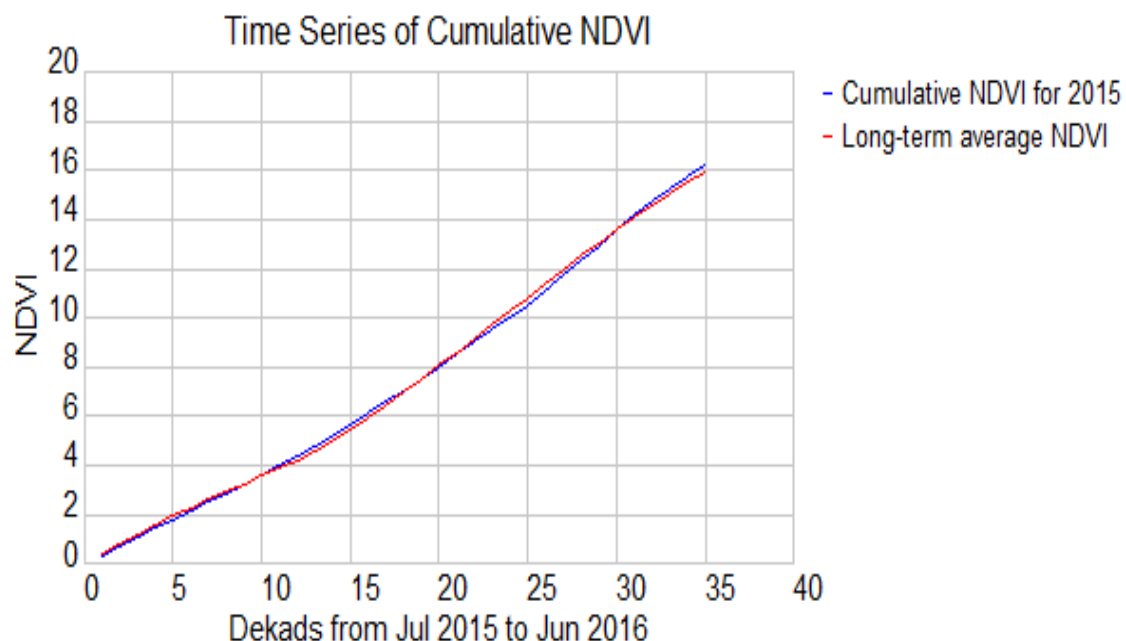


Figure 9: Cumulative NDVI for the current year compared to the long-term average

This graph assesses the difference in vegetation vigour at critical periods throughout the season. In this case, the vegetation for 2015/2016 is almost similar with the long term

average. This means that the vegetation performance of the current year is almost similar to the long-term vegetation performance from the start to the peak season.

Time series graphs (Figure 10) are useful for estimating the growth period or vegetation development and also for observing the beginning of the dryness or drought stress during the growing season (MESA, 2016).

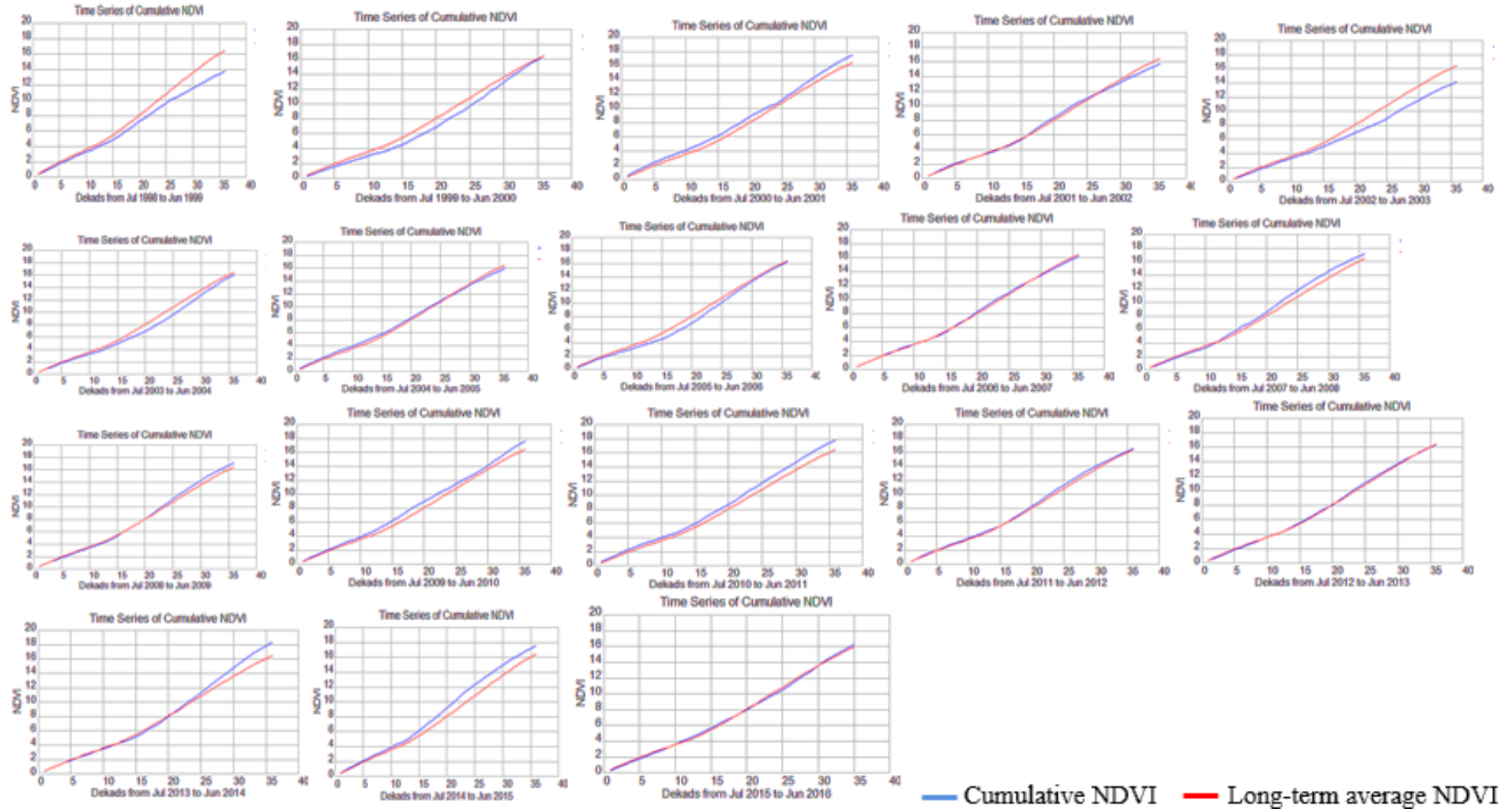


Figure 10: Time series graphs from 1998 to 2016

These graphs show at the same time, the development of vegetation over the years through NDVI and are very helpful as they provide information on possible stress situations. The vegetation performance time series charts do help in understanding the development of vegetation on a long-term basis. When NDVI values start to increase, it signals the start of the growing season and the maximum NDVI indicates the end of vegetation development. It is also very important to note that NDVI departure from the short or long term average (comparing current year NDVI with the historical average NDVI) is useful to monitor positive and negative deviations during the growing season and assesses the relative vegetation condition of the entire growing season (Minamiguchi, 2005).

The NDVI time series charts have been identified as an efficient means to monitor reflectance of vegetation greenness in a defined area over a longer period of time (Minamiguchi, 2005). This approach extracts zonal NDVI average values from each image from the time series and visualizes these values as a chart (Gross, 2005). The annual graphs can be compared to an average trend calculated from a historical archive. The NDVI chart is also useful in early identification of a poor start of growing season as well as failing growing seasons. Such presentation of data enables policy makers to easily pinpoint areas which need urgent attention especially for drought which is a recurrent natural phenomenon in many arid and semi-arid regions of the world (Klisch and Atzberger, 2016) including Botswana.

For the 18 year period when compared to the long-term average, the NDVI has shown to be either below the long-term average, almost similar or above the long-term average. The year 1998/1999, 1999/2000, 2002/2003 and 2003/2004, have shown to be below the long-term average while the year 2000/2001, 2009/2010, 2010/2011, 2013/2014 and 2014/2015 are above long-term average. Seven (7) years are almost similar to the long-term average, being 2001/2002, 2004/2005, 2006/2007, 2007/2008, 2008/2009, 2011/2012, 2012/2013, 2013/2014 and 2015/2016. For the below average years, 1998/1999, 2002/2003, the country pronounced to be affected by drought hence not surprising for the low NDVI. The years 2000/2001 and 2009/2010 which most parts of the country were seriously affected by floods (World Bank, 2010) proved to be above the long-term average, further confirming vegetation to be very sensitive to climatic fluctuations. The study by Rousvel et al., (2013) was also based on the comparison between vegetation and rainfall of bioclimatic ecoregion in Central Africa. The results showed a strong similarity between temporal patterns of NDVI and

rainfall, further confirming that the NDVI can be considered a sensitive indicator of the interannual variability of rainfall (Rousvel et al., 2013).

4.1.6 Vegetation degradation map

The vegetation degradation map was produced to show how the study area has been degraded (Figure 11).

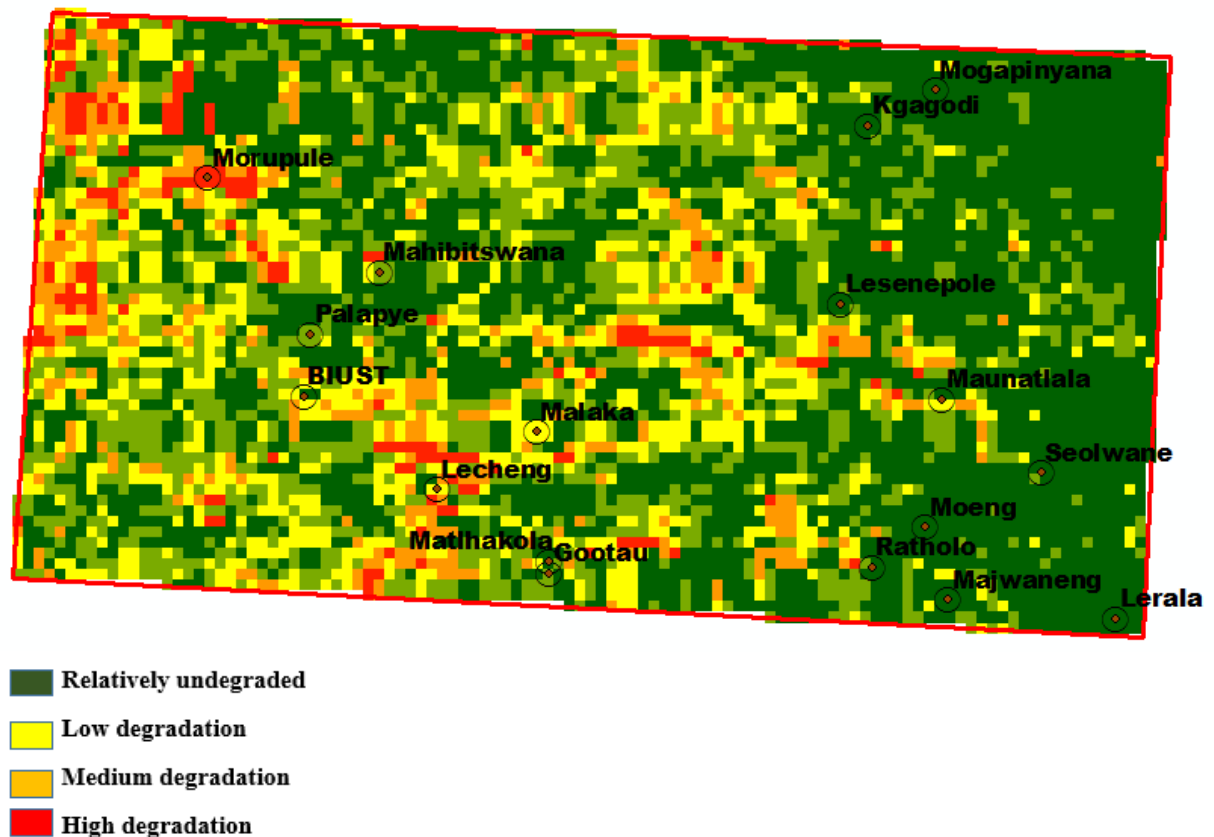


Figure 11: The vegetation degradation map

The vegetation degradation map (Figure 11) indicates which areas have been degraded and which are not. The increasing NDVI which is the positive trend or the relatively undegraded area is more towards the eastern side of the study area. Even though the eastern side is residential, pastoral and arable, the greenness is still being maintained. The negative NDVI trend which indicates low, medium and high degradation is more pronounced towards south and south west. The reason might be because there are more anthropogenic activities going on than on the eastern side. Coal mining at MCM, coal-fired electricity generation at MPS and clay brick manufacture at Makoro are situated within the area showing degradation. Botswana has extensive coal reserves with approximately 900000 tonnes of coal produced

annually from 1997 to 2008 (Department of Mines, 2008). Annually the MPS uses about 600000 tons of coal and produces about 102000 tons of ash, including 82000 tons of fly ash (inlet fly ash) and 20000 tons of bottom ash (Zhai et al., 2009). Mining and combustion of coal is often associated with environmental contamination and pollution, because coal pollutes when it is mined, transported to the power plant, stored, and burned (Union of Concerned Scientists, 2011; Zhai et al., 2009).

A study undertaken in Jharia coal-field in India by Saini et al (2015) indicated dense vegetation to have decreased while sparse vegetation has increased, therefore making it to be in line with the results of the Palapye degradation map, further putting more weight on the reasons of degradation in the east and south of the study area where MCM is located.

Land conversion is ongoing in Palapye with settlement expanding and encroaching mostly into agricultural lands. For example, buildings are constructed for residential, commercial and institutional uses as well as development of infrastructure such as the expansion of the North-South Carrier water pipelines. The 2 500 hectares of land were allocated for the establishment of Botswana International University of Science and Technology. A land user specifically mentioned this to have reduced the available grazing area. The railway line and the famous A1 road that link the 2 cities of Gaborone and Francistown also pass through the western side of the study area therefore attracting a lot of people as well as other anthropogenic activities that further degrade the area. Settlement expansion indicating the conversion of agricultural and forest land to urban uses has since been identified as a major form of global environmental change (Liu and Yang, 2015). The degradation map shows the relatively undegraded areas, low degradation, medium degradation as well as the high degradation areas. So, some areas which fall under these classes of degradation were as such chosen to be sampled. Farmers perceived the changing of environment looking at the sampled areas where they resided.

Vegetation Degradation Index map was produced as it indicates the degree of vegetation degradation (Li et al., 2004) in the area. The VDI values indicate the degree of vegetation degradation over a period of 18 years (Figure 12).

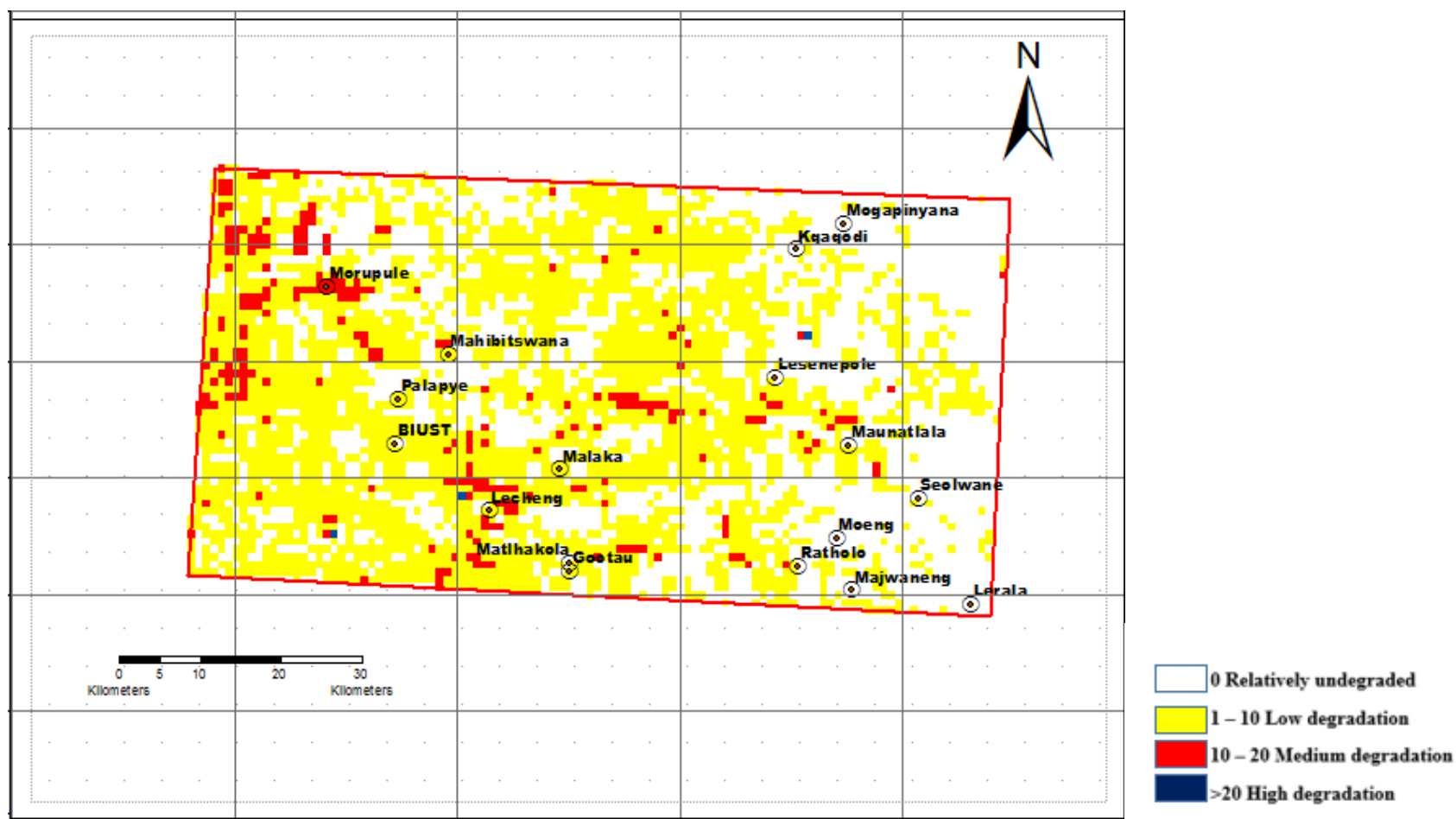


Figure 12: The Vegetation Degradation Index map showing level of vegetation degradation

The 0 degradation means the area is relatively undegraded (represented by the white colour), 1 – 10 means the area is of low degradation (yellow colour), 10 - 20 means the area is medium degraded (red colour), while >20 means the area is of high degradation (dark blue colour). The low degraded area covers 51.2% of the study area which is more than any other degradation class. The medium degraded areas which cover 4.3% are where there are major anthropogenic activities are. This includes industries such as the Morupule Coal Mine and Botswana Power Station as well as Makoro bricks manufacturing. The highly degraded area covers 0.1%, which are the 3 hot spots of high degradation (dark blue) being Radisele, Lecheng and Lesenepole. These have been identified as having quarries. Quarries are areas which resources such as marble, limestone, sand and granite are extracted for industrial use (McCandless, 2013) and these areas have been subjected to physical and environmental degradation (Dal Sasso et al., 2012). Quarries are frequently abandoned once their resources are depleted. McCandless (2013) has further indicated the majority of quarries to be located fairly close to urban environments due to the expense of transporting raw materials into the city for industrial use in buildings and roads. This has since made inhabitants of nearby quarries to be subjected to air and noise pollution (from trucks and machinery) including the destruction of the landscape.

Many countries are coming up with the rehabilitation of quarries. In New York, Brownstone Park Gardens utilize the empty quarry sites into parks that have become beloved by locals and tourists (Lawlor, 2015). Chinese Groundscraper Hotel, provides permanent and temporary housing that both yield sustainable practices (Zhang, 2012). The Bellwood Quarry in the city of Atlanta has been transformed into a practical reservoir that assists in salvaging water for the entire city of Atlanta (Singleton et al., 2013). Rehabilitation of quarries can yield so many positive social, economic, and environmental benefits into the society after their resources are depleted.

The relatively undegraded area covers 44.1%. Even though the rangelands of arid and semi-arid areas of the world are facing the possibility of declining into degraded areas because of challenges of over utilization (Sebego et al., 2017) the study area has shown signs of degradation, but the conclusion might be that the area is not really degraded like how it is perceived by the land users.

The predominant land use system in Africa is agro-pastoralism (Hein, 2006) with 30.2 million km² area of land, in which the rangelands cover approximately 30% while arable land is 8% (FAO, 2015a). More than 35% of the arable land in Africa is however considered to be degraded (Khan et al., 2015) therefore, making the rainfed farming to be sensitive to changes and variability because of climate (Nyakudya and Stroonsnijder, 2015). This therefore, makes the 55% degradation (51.2% of low degradation and 4.3% of high degradation) in the study area, to be included within the bigger degradation of Africa. In 2016, The Center for Development Research also carried out land degradation research on 12 world regions including India, Argentina, Central Asia and other parts of Africa. The results indicated 28% of the African land to be degraded with poor communities suffering the most while 33% of grassland and 25% croplands worldwide has experienced degradation (Pelz, 2016). The results of the study further indicated countries such as Malawi, Kenya and Tanzania to have lost 216 million euros, 1. 1 billion euros and 2. 3 billion euros respectively because of degradation.

Even though other countries in other continents have been busy looking for strategies to improve land management and prevent land degradation, it has been indicated Africa to be lagging behind yet this degradation has been estimated to cost the continent an estimated 56 billion euros annually (Pelz, 2016). On the contrary, farmers in the region of Tigray in Ethiopia, have restored more than a million hectares of degraded land while farmers in Niger and Mali are protecting trees and shrubs growing naturally in order to increase on-farm tree species (DeWitt et al., 2015). Furthermore, Africa has the largest restoration opportunity in the world with more than 700 million hectares of degraded land (the size of Australia) (DeWitt et al., 2015).

The F-test map (Figure 13) was plotted such that statistically insignificant pixel with p-value less than 0.15 (below 85%) were masked out (white colour). These are the pixels that indicate there is no degradation and are less important for discussion.

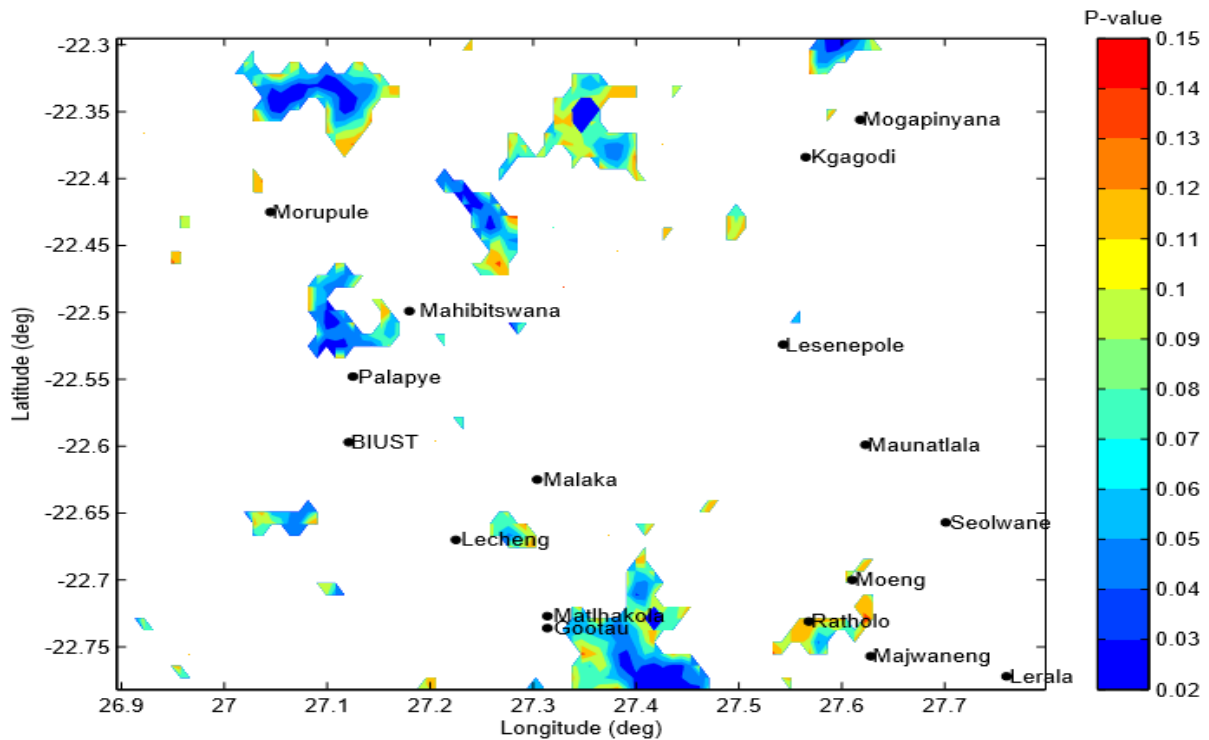


Figure 13: The vegetation degradation F-test map

The colour bar is the p-values that range from 0.02 (dark blue) to 0.15 (dark red). The blue indicates the most significant ones. For example, the 0.02 p-value signifies 98% significance while the 0.15 signifies 85%. This means that values from 0.02 to 0.15 are statistically significant as they range from 98% to 85% confidence level. The closer the significance level is to 100%, the better the confidence in the findings regarding the calculated vegetation degradation and proximity to truth. The relatively undegraded areas indicating where vegetation is not degraded are mostly the masked out pixels especially in the eastern part of Figure 13.

Eckert, et al (2015) applied the same methodology when examining whether MODIS NDVI satellite data time series can be used to detect land degradation and regeneration areas in Mongolia. They analysed the variability and autocorrelation in order to determine the significance of trends. The trends derived from the analysed time series vectors were found to be significant in more than 50% of the country. The study conducted by Li et al (2015) on the effects of urbanisation on vegetation degradation in the Yangtze River Delta of China was also examined by the regression model of ANDVI with time by using F-test on a 5%

significance level. The extent of vegetation degradation was found to be smaller in areas of high elevation where human activities are limited (Li et al., 2015).

4.2 Validation of Vegetation Variability

Ground-truthing was conducted to verify the status of vegetation in the vegetation degradation map analyses as per the sampling points (Figure 14).

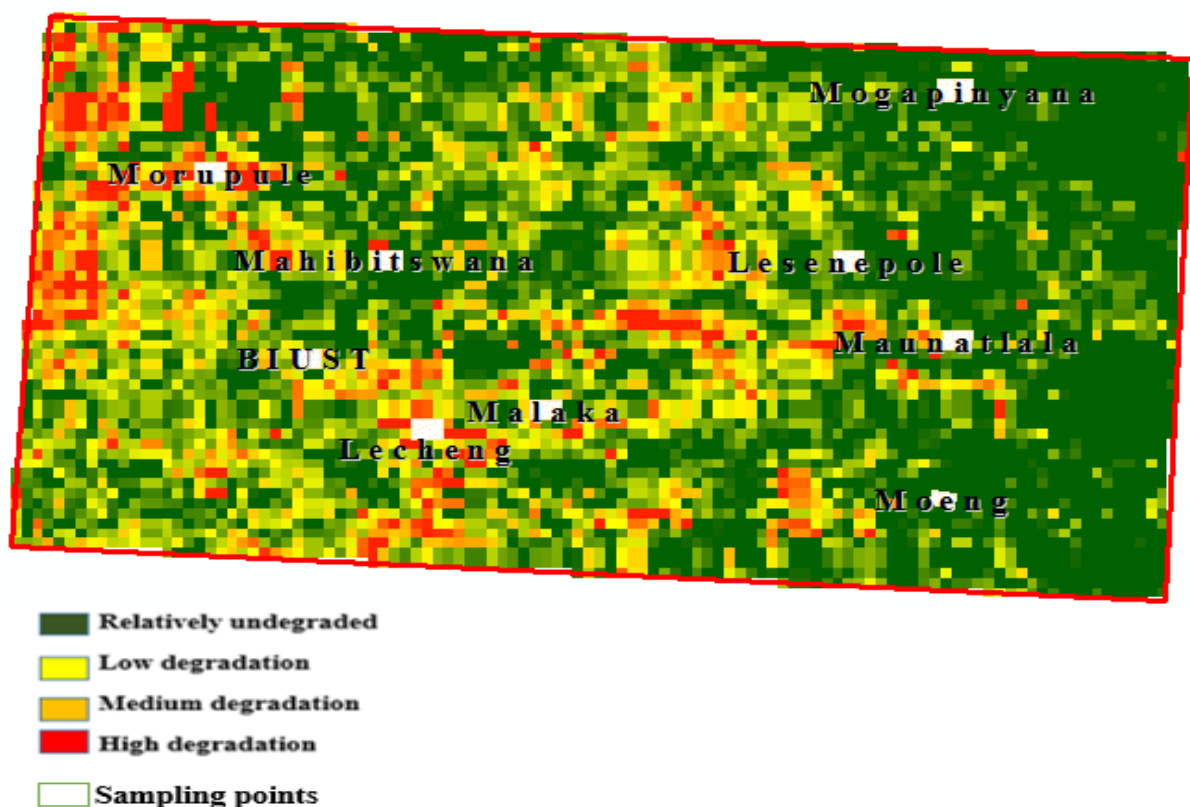


Figure 14: The vegetation sampling points

The vegetation sampling was done in 9 sites (Figure 14), being Moeng and Mogapinyana representing relatively undegraded, Lesenepole and Mahibitswana (low degradation), BIUST, Malaka and Maunatlala (medium degradation) and Lecheng and Morupule representing high degradation. The vegetation sampling results were tabulated as names of plant species, frequency and density of all identified species. To better capture socioeconomic drivers, land users' perceptions of degradation were gathered through interviews conducted in the study area. This included the historians for better understanding how vegetation has degraded over time.

4.2.1 Meteorological data

Rainfall - Rainfall plays an important role in rangelands production as well as the agricultural production. The vegetation is largely influenced by the amount of soil moisture with rainfall as the main source. The meteorological data provides the rainfall data that is useful in assessing the current climate as well as the early detection of anomalies (Marumbwa, 2016). Rainfall is a main limiting factor for crop and pasture development in arid and semi-arid regions of the world (Fensholt et al., 2012). Funk and Budde (2009) have since noted most studies on precipitation and NDVI in Southern Africa to be limited to rainfall months focusing on famine early warning and crop yield. It is very important to monitor the current rainfall with respect to the long-term as it gives an early detection of a poor current rainfall performance hence early detection of unfavorable vegetation growing conditions (Marumbwa, 2016). It is therefore worth noting that rainfall data contributes a lot to the remote sensing information hence used in the study for validation. Vegetation is known to be very sensitive to climatic fluctuations and has control over the flows of water, carbon and energy between land and atmosphere (Sonfack et al., 2013). In most drylands, water is particularly scarce and a valuable commodity, hence Gessner et al (2013) indicating vegetation development during the growing season to depend on water provided by rainfall. Here is a map of the average rainfall from 1998 to 2015 in Palapye (Figure 15).

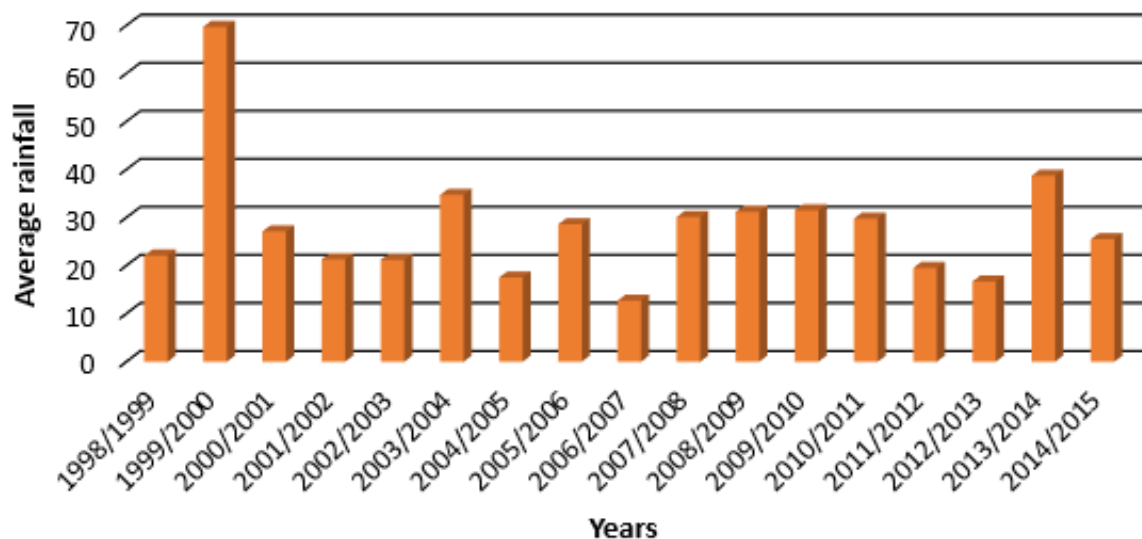


Figure 15: Average rainfall for the year 1998 to 2015 (Source: Botswana Department of Meteorological Services)

The rainfall data for 2015/2016 was missing hence not appearing in the graph. The year 1999/2000 experienced 69.7mm which is the highest average rainfall in the entire series and

seconded by 2013/2014 with 38.7mm. The year 2006/2007 had the lowest rainfall of 12.7mm, with 2012/2013 having an average of 16.7mm of rainfall, a bit higher than 2006/2007. The year 2013/2014 has the second highest rainfall which is even more than that of 2009/2010 which received 31.5mm bearing in mind that floods were reported in 2000/2001 and 2009/2010. The year 2013/2014 also has high NDVI values than 1999/2000.

Naturally, precipitation is a very complicated variable (White et al., 1991) with its description involving a large range of temporal and spatial scales (Mbereggo and Gwenzi, 2014). Rainfall is viewed as an important climatic factor for agricultural production in Africa (Akinyemi, 2017), hence its decline from 1981 (Parida and Moalafhi, 2008) has become a limiting factor to dryland farming in Botswana (Chipanshi et al., 2003). In Botswana, inter-annual rainfall variability is high, as water deficiency is a primary problem in arid and semiarid areas. In Swaziland, changing rainfall patterns have been perceived to affect agricultural production (Orchard et al., 2017). In Botswana, the first rains used to come in July/August for 60 years, but now occurring in October/December, therefore making ploughing unpredictable (Orchard et al., 2017). This has also increased the occurrence of drought (Orchard et al., 2017).

Because the study area is experiencing the orographic effect in rainfall (Akinyemi, 2017), similarly a study by Manatsa and Mukwada (2012) has also revealed the orographic effect of rainfall as a result of the Eastern Highlands as well as the Great Dyke mountain chains in Zimbabwe that enhances and or suppresses some precipitation generating mechanism. The spatiotemporal patterns of rainfall variability is therefore very important as it helps in developing adaptation strategies to mitigate the associated risks as well as increasing the resilience of local communities against future climate change impacts (Seo, 2012; Mbereggo et al., 2013).

According to the socioeconomic survey, the decrease in rainfall in the study area was indicated by 72% of farmers who perceived an increase in drought frequencies, thus driving vegetation degradation. They indicated the prolonged years of no rainfall which led to drought to have affected crop production as well as pastures. Where crops have been badly affected by drought, pasture production is also likely to be reduced. Output from natural pastures tends to be less vulnerable to drought than crop production (FAO, 2016). This is because drought occurrence in agro-pastoral areas in Botswana have more severe impacts on

crop production than on animal production (FAO, 2016; Akinyemi, 2017). This was also mentioned by farmers in Limpopo basin of South Africa who have more than 30 years of farming experience. They perceived temperatures as increasing and rainfall as decreasing, and noticed changes in the frequency of droughts and floods (Gbetibouo, 2009).

Respondents in the study area were very much aware of the climatic factors as contributing to vegetation degradation. They mentioned it as a major factor alongside anthropogenic activities in driving vegetation degradation in their area. As such, their perception is that climate have changed from ‘good’ to ‘bad’ since settling in the area (Figure 16). 92% of the farmers indicated good climate by the time of settling in their area and 72% value current climate as very bad. Usually the local people may not understand the concept of climate change, but they observe and feel the effects of decreasing rainfall, increasing air temperature, increasing sunshine intensity and changes in rainfall pattern (Chifamba and Mashavira, 2011).

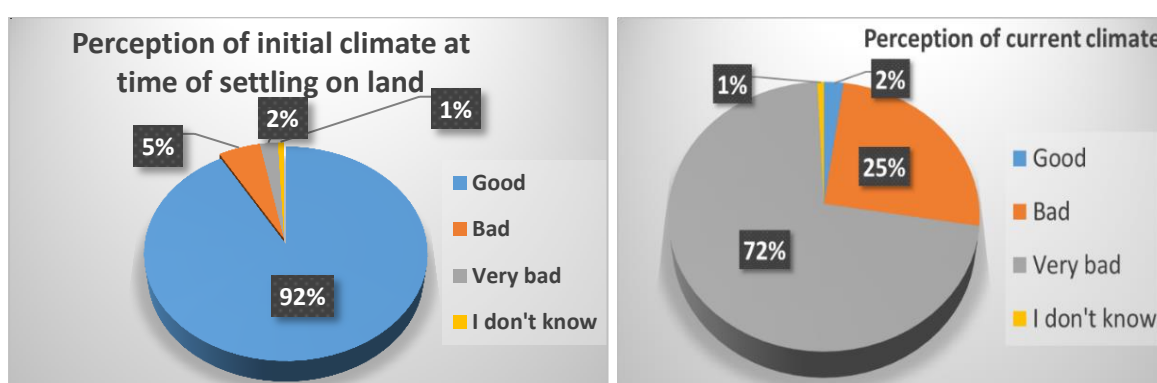


Figure 16: Perceptions of farmers on current and initial climate of settling in their area

However, Sonfack et al (2013) are of the opinion that climatic change has taken an immense toll on the environment of our planet and has since become one of the most important issues within the global change debate, hence farmers’ awareness.

Because rural populations are exposed to the impacts of climate variability on agricultural production (Ndayisaba, 2016), farmers in the study area constantly stressed the declining agricultural activities. Climate change disturbs agricultural activities, therefore affecting agricultural production (Khan, 2015). This results in low productivity affecting farmers differently, such as individuals who earn income directly from agricultural production or indirectly by participating in various jobs in the system that agricultural production supports

(Garrett, 2005). Even though agriculture is essential when considering the relationship between society and the environment (Kuldna et al., 2009) it has however been identified to have complex linkages with land degradation (Hazell and Wood, 2008).

Relationship between NDVI and rainfall - With climate change, alterations of the seasonal distribution of precipitation patterns and a high frequency of extreme events are expected. As such, there is a likelihood for the vegetation dynamics to respond to these changes. In order to understand the impacts of precipitation on NDVI, the rainfall and vegetation data for 9 sampling sites were plotted to compare their distribution over 18-year period. Rainfall is presented in bars to better separate it from NDVI (Figure 17).

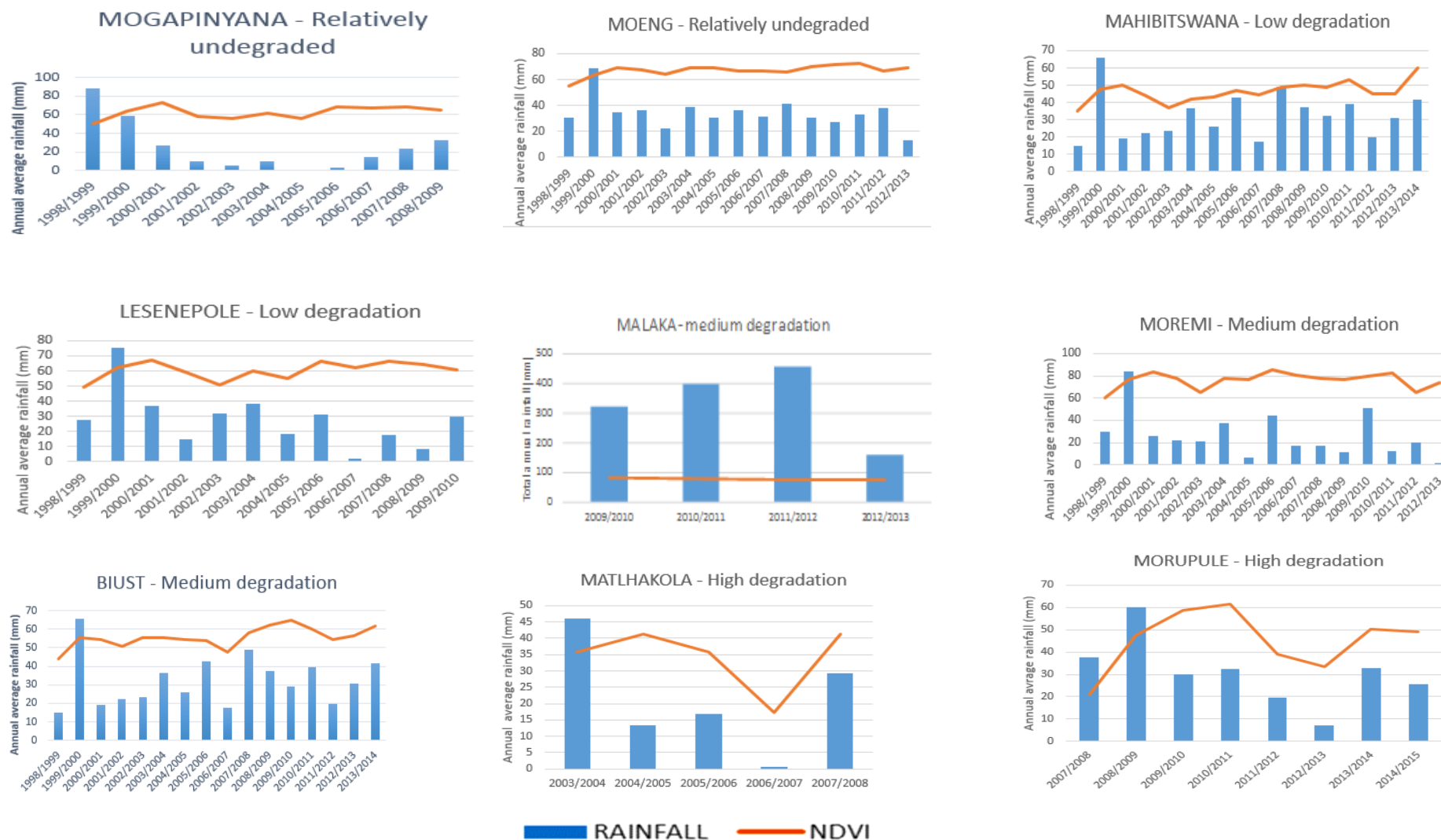


Figure 17: Relationship between rainfall and NDVI for sampled sites

For all the degradation classes, being relatively undegraded, low degradation, medium degradation and high degraded sites, the results show there is increase in NDVI in areas that the rainfall increases as well as the decreasing NDVI where there is decrease in rainfall. Vegetation greenness follows spatial and temporal precipitation pattern which was also observed in the study conducted by Van Cotthem (2013) who studied the vegetation, land use, desertification and climate change in Northeast Brazil. Also Erasmi et al (2009) that found a high temporal variability of NDVI as well as high correlation of NDVI and precipitation in the semi-arid region of the Caatinga in Northeast Brazil. Gessner et al (2013) observed similar patterns of sensitivity of vegetation to precipitation anomalies in areas receiving 100–400 mm of rainfall annually in Central Asia (Dubovyk et al., 2016).

The positive response of vegetation to rainfall in the study area is exceptional in Malaka village which is of a medium degradation. This could be partly due to gaps in the rainfall data hence Malaka had only 4 years (2009 to 2013). However, the area is known for its water springs and gouges, hence indicating springs as a reflection of high water table (de Marne, 2007). So, the reason of no change in NDVI relative to change in rainfall might be because the underground water plays a big role in making NDVI not to change with rainfall. The vegetation might not be influenced only by surface water. The mostly dense plant species in Malaka is *Dicrostachys cinerea* seconded by *Colophospermum mopane*. The 2 plant species are known to thrive in places that are degrading, especially from overgrazing. These plants also do well in less fertile shallow soils that receives less rainfall. This makes Malaka unique among the sampled areas in terms NDVI in responding to rainfall. The sites of Lecheng, Malaka and Matlhakola were missing the rainfall data for the year 1999/2000, hence no information on the precipitation and NDVI that year.

A positive rainfall was observed in the year 1999/2000 in Moremi, Mahibitswane, BIUST, Mogapinyana, Lesenepole and Moeng (because of floods). As a result, an obvious greening up for these sites was observed in the year that followed (2000/2001). Because Palapye is situated between Matepilepi hills to the northwest and Tswapong hills to the southeast, there is orographic effect on rainfall distribution (Akinyemi, 2017). So, this makes Palapye to experience precipitation even in difficult times of less rainfall in the country. This was evidenced by some fields in Lecheng and Masuakoloi which had good crop harvest despite of the 2015 drought. NDVI and rainfall estimates are two independent data sources. If NDVI and rainfall show the same type of anomaly, we say that the evidence for such an anomaly is

positive or negative. The higher NDVI values correspond to an increase in vegetation greenness which is controlled by a combination of vegetation type, health, photosynthetic activity and canopy density (Sonfack et al., 2013).

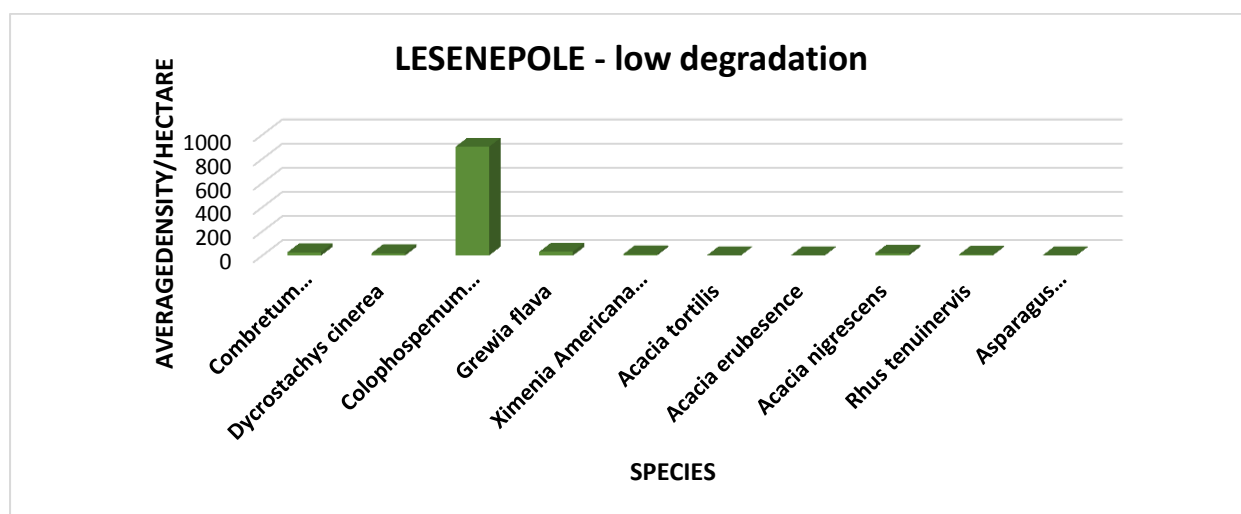
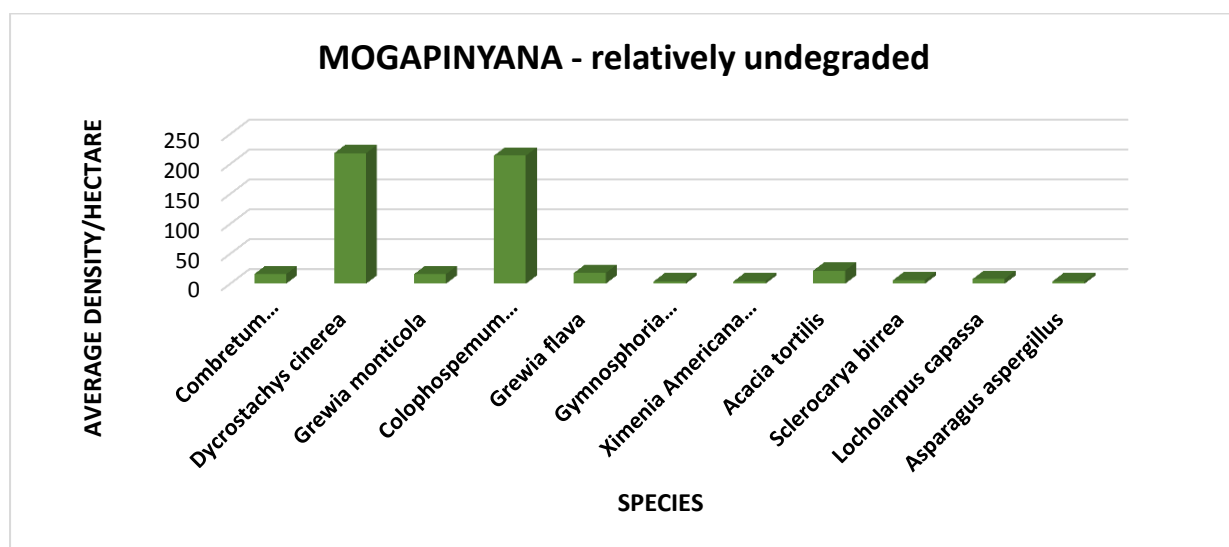
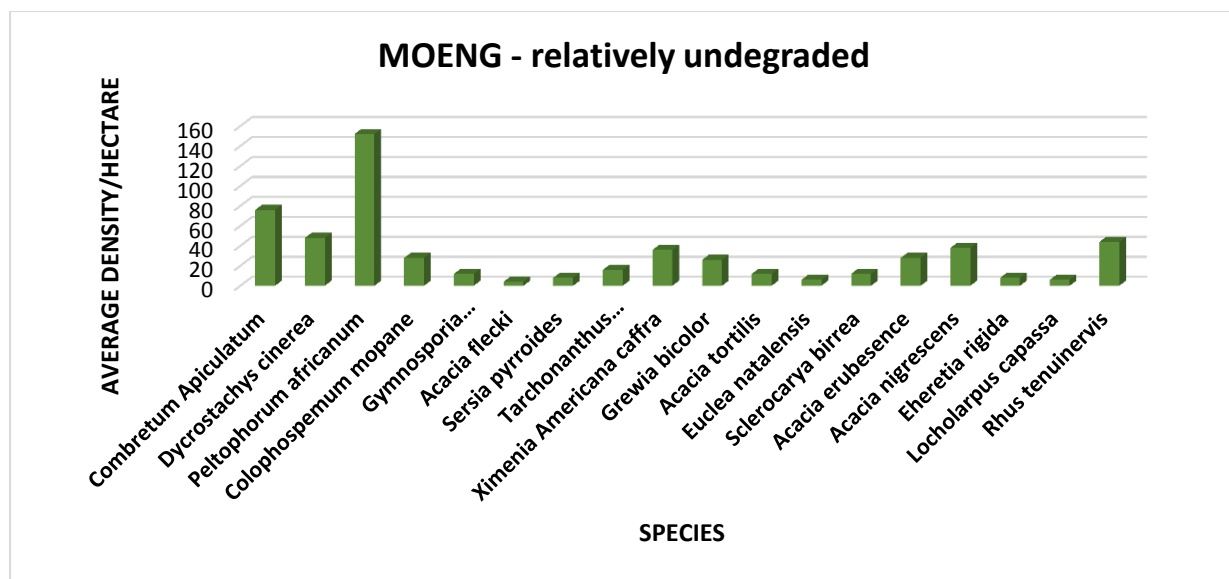
4.3 Validation of Vegetation Degradation

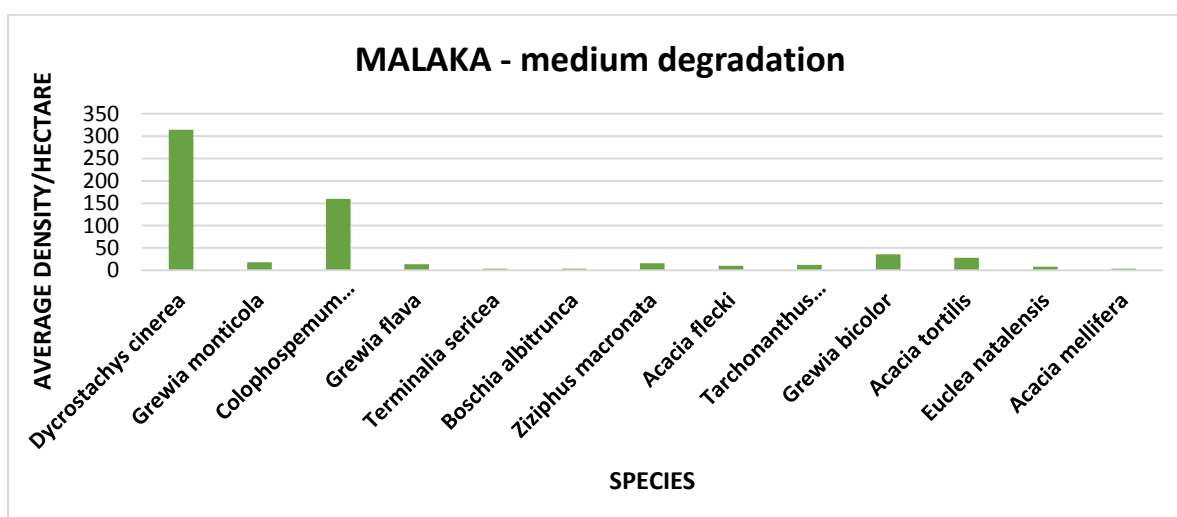
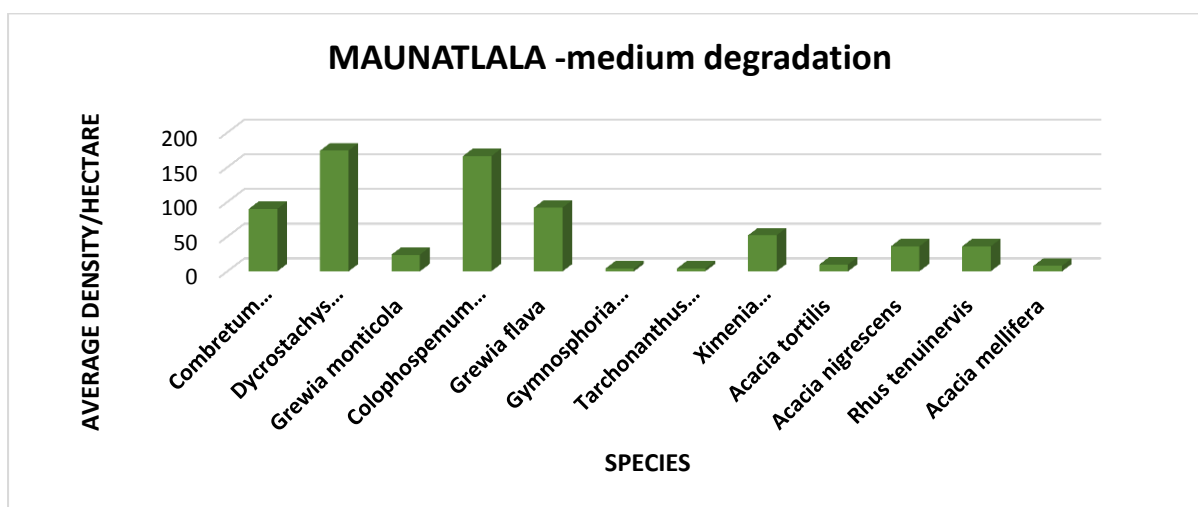
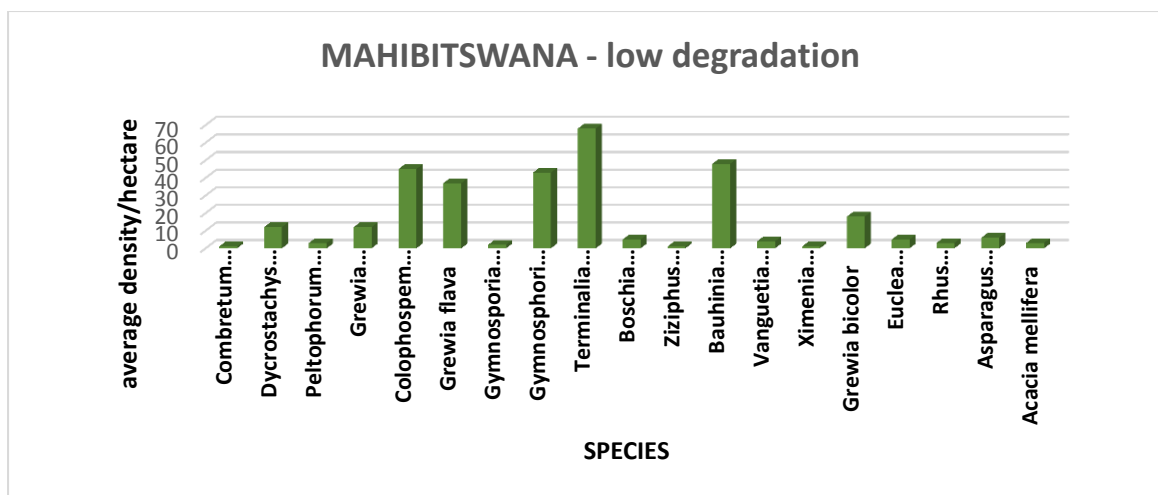
4.3.1 Vegetation field survey

Thirty-three (33) tree species with a total of 3444 individuals occur in the 9 sampled areas (Table 4). Since trees are measured in hectares, the sampled areas were therefore converted from meters squared to hectares. The most abundant species was *Colophospermum mopane* with 42.8% followed by *Dicrostachys cinerea* with 18.3%. *Colophospermum mopane* is known to appear in shallow and impermeable sub soils (Orwa et al., 2009) in the hot, dry low-lying areas of Africa (FAO, 2011). This plant species appeared to be the densest than all other species. The species occupies areas receiving low to moderate rainfall at low lying altitudes, with high temperature, therefore estimated to account for about 30% – 35% of the 1.5 million km² of savannas in southern Africa (Makhado et al., 2014). Therefore it is not surprising that the species appear in all the 9 sampled sites being favoured by the high temperatures that the country experiences including the poor shallow soils (Orwa et al., 2009). Since the sampled area was measured in meters, the average density in m² of all species identified has therefore been summarised as graphs (Figure 18). The graphs show number of individual species per unit area, which is per hectare.

Table 4: Plant species composition, frequency and average density

SPECIES	OCCURANCE	FREQUENCY	AVERAGE DENSITY/ha
<i>Colophospermum mopane</i>	1474	16	338
<i>Dycrostachys cinerea</i>	534	18	125
<i>Ximenia Americana caffra</i>	240	18	73
<i>Combretum Apiculatum</i>	151	11	58
<i>Grewia flava</i>	174	16	46
<i>Gymnosphoria boxifolia</i>	95	11	42
<i>Grewia bicolor</i>	72	6	36
<i>Terminalia sericea</i>	37	6	28
<i>Sersia pyrroides</i>	16	10	25
<i>Acacia nigrescens</i>	48	8	4
<i>Bauhinia petersiana</i>	22	13	32
<i>Ozoroa reticulata</i>	9	9	22
<i>Grewia monticola</i>	24	6	19
<i>Rhus tenuinervis</i>	42	5	26
<i>Terminaria prunoides</i>	6	5	16
<i>Acacia tortilis</i>	37	8	14
<i>Acacia erubescence</i>	16	8	12
<i>Ziziphus macronata</i>	7	3	14
<i>Peltophorum africanum</i>	89	4	61
<i>Euclea natalensis</i>	22	4	12
<i>Boschia albitrunca</i>	28	6	14
<i>Gymnosporia senegalensis</i>	10	4	9
<i>Asparagus aspergillus</i>	14	6	11
<i>Sclerocarya birrea</i>	9	2	9
<i>Acacia mellifera</i>	11	5	8
<i>Locholarpus capassa</i>	5	6	7
<i>Tarchonanthus camphoratis</i>	11	4	9
<i>Acacia flecki</i>	7	2	6
<i>Eheretia rigida</i>	2	4	8
<i>Berchemia discolor</i>	1	3	4
<i>Acacia nilotica</i>	1	1	4
<i>Vanguetia infausta</i>	3	1	5
<i>Acacia erioloba</i>	1	1	4





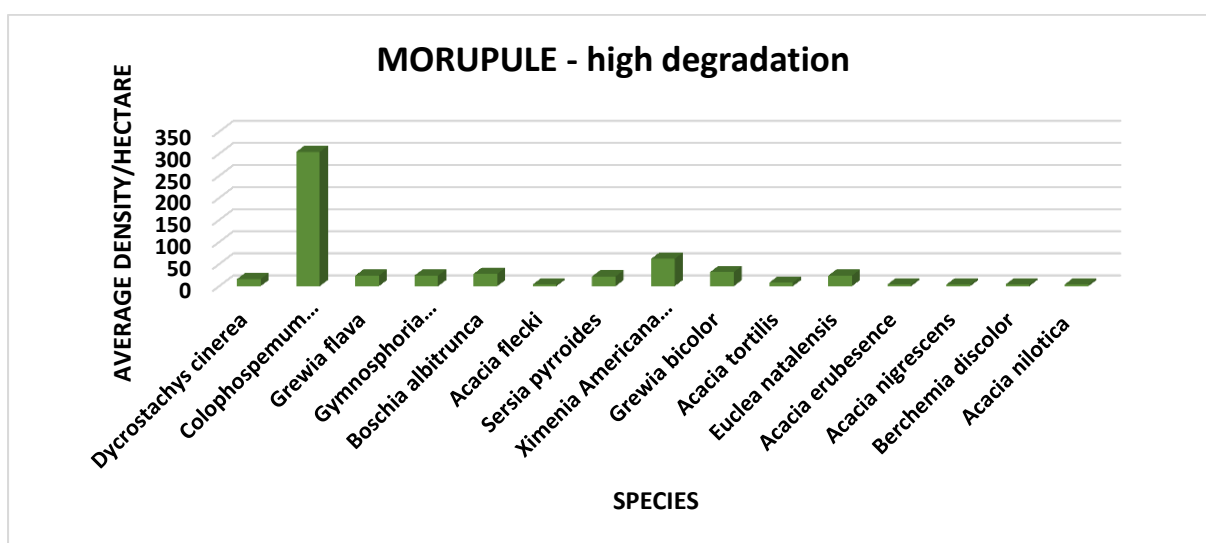
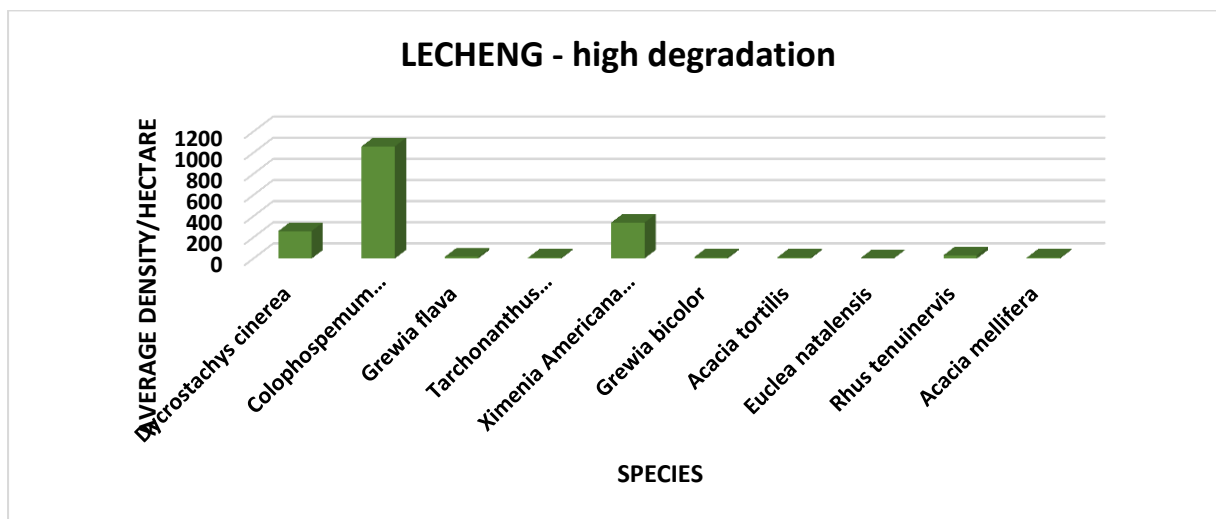
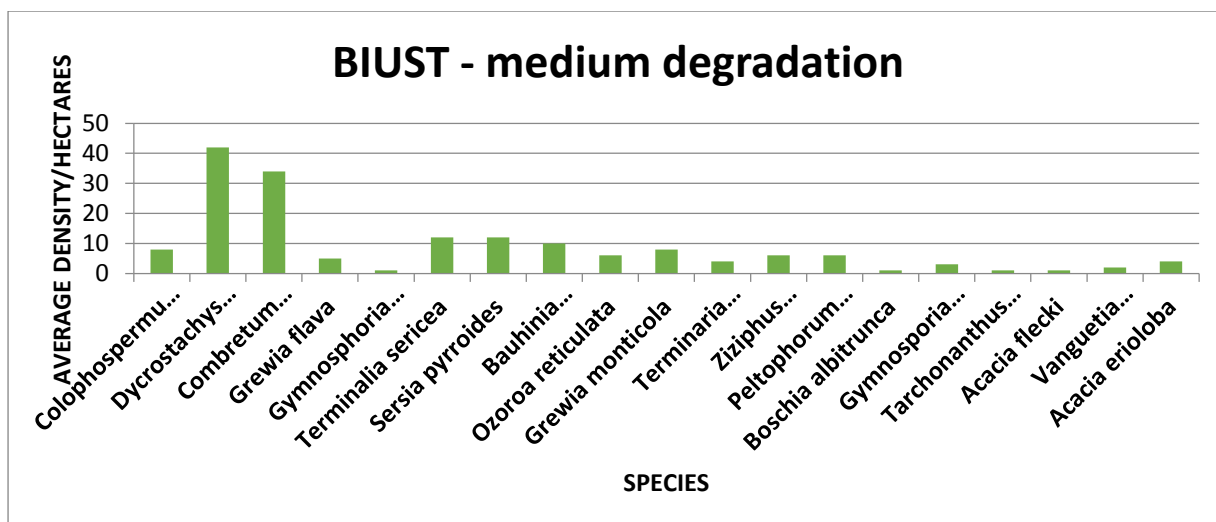


Figure 18: Density of Plants per sampling site

Plants as degradation indicator species. The vegetation status has usually been used as indicators. For example, low forage has been used as indicators of an approaching drought by farmers in Botswana (Mogotsi et al., 2011b; Treydte et al., 2017). Plants also have different ability to either tolerate or resist grazing. The high resistance is from plants of low nutritional value while for active defence they develop spikes or are toxic (Mysterud, 2006). In all the sites, there was the presence of unpalatable species such as *Dichrostachys cinerea*. This species is of highest frequency (number of individuals within a sampled area) in sites such as BIUST, Malaka, Maunatlala (medium degradation sites) and Mogapinyana in the relative undegraded site. The species occur 631 times in the sampled area, therefore covering 18.3% of the 9 sites sampled. *Dichrostachys cinerea* is an indicator of overgrazing in low rainfall areas as it is drought resistant (Orwa et al., 2009; Teketay et al., 2016). This species is known to be a very aggressive plant that outcompetes other plants species such as grass for light and water (Teketay et al., 2016) because of its shallow roots (Orwa et al., 2009). It has high reproductive potential and can multiply very quickly as it has very prolific root suckers and can generate from very small root cuttings (Teketay et al., 2016).

Historians were asked on how vegetation has changed; “*How was the vegetation like 10 years ago and why has it changed?*” and “*How was the vegetation like 50 years ago and why has it changed?*” The vegetation was indicated to have been reduced because of low or no rainfall, high population as well as increasing livestock. Veld fires were also indicated to have affected vegetation in the area as it used to burn every year. *Peltophorum africanum*, *Terminalia sericea*, *Acacia erioloba*, *Acacia nilotica*, *Acacia flecki* including thatching grass such as *Eragrostis pallens* (Motshikiri) were plenty in the area before, but they were mentioned to be very few species by the time of interviews. These responses by the historians were almost similar to these questions, which serve to further confirm responses with the aid of triangulation. In Lecheng, it was mentioned that the dominant plant species used to be Mopane but it has since been reduced because of clearing land for cultivation. It was mentioned that there were a lot of Morula trees in Palapye village but there were no such trees before. The narrator suspected livestock such as cattle, goats and sheep to have brought it from somewhere else as they eat morula fruits which the seeds are later regurgitated.

Relatively undegraded areas - Mogapinyana and Moeng sites appear to be relatively undegraded (Figure 19 and 20), in the degradation map this is because of the presence of *Sclerocarya birrea* which has a big canopy cover. This plant species appears only in these 2

sampled sites of Mogapinyana and Moeng, within the study area. In Mogapinyana, it has a density of 6 while in Moeng is 12. Even though this species is less dense than *Colophospermum mopane* and *Dichrostachys cinerea*, the canopy of *Sclerocarya birrea* covers a larger area hence less visible bare ground from the satellites. For the species presence in the relatively undegraded site of Mogapinyana and Moeng, *Dichrostachys cinerea* is also found to be present in both areas Moeng and Mogapinyana with a density of 218 and 48 respectively. The reason might be that even though the Mogapinyana site was fenced, it used to be open for human activities hence overgrazing taking place. Thorny species usually become predominate in once-rich pastures (Stocking and Murnaghan, 2000) hence their presence in degraded and once degraded areas.



Figure 19: Canopy cover of *Sclerocarya birrea* in a relatively undegraded area of Mogapinyana.



Figure 20: The picture of a relatively undegraded site of Moeng

Low degradation areas - The sites of low degradation are Lesenepole and Mahibitswana. The density of species appears to be relatively different. The most dominating species is *Colophospermum mopane* with a density of 900 and 45 respectively. *Dicrostachys cinerea* was also cited in the 2 areas (density of 20 in Lesenepole and 12 in Mahibitswana) signifying overgrazing even though the area is of low degradation. In Mahibitswana, *Cynodon dactylon* (carpet grass,) grows along the discharged treated wastewater stream from Palapye Waste Water Treatment. Two percent (2%) of the farmers claim to have abandoned their ploughing fields because of the carpet grass that has invaded their fields (Figure 21). The weed is reported to be very tedious to remove and the farmers claimed to have low or no crop yield, loss of income and reduction in the available land for cultivation. *Cynodon dactylon* is adapted to survive both extended dry periods and flooding conditions (GISD, 2010). It is a very competitive and invasive potential agricultural weed (Newman, undated) and is commonly used as a lawn grass. However, one farmer claimed to be very comfortable with the waste water as it irrigates her crops. Due to Palapye's semi-arid nature, this is a water resource used for construction and watering livestock and crops, therefore making it an effective form of both wastewater disposal and utilization (FAO, 2015b).



Figure 21: *Cynodon dactylon* in one of the farmers' field.

Medium degradation areas - BIUST, which is of medium degradation, had diverse plant species or has high number of plant species (18 different species) than any other sampled sites. With the high species richness in the area, this might be because of fire that took place sometimes in 2014. The burnt branches were also visible in the area during vegetation sampling. *Combretum apiculatum* species is of a high density in BIUST than in all the sampled areas. With the presence of *Combretum apiculatum* (density of 34) in the area, ecologically this is a sign that there was fire in the area as the species is known to be thermotolerant (Teketay et al., 2016). This was also discovered in Mokolodi Nature Reserve in South-eastern Botswana when it was found that *Combretum apiculatum*'s recovery from heat shock (as it has the ability to withstand the 50° heat stress) by germination and growth was higher (Teketay et al., 2016). Also within BIUST, a pond was discovered, and it is from the waste water treatment plant from the university. The three medium degraded sites are BIUST (Figure 22), Maunatlala and Malaka Figure 23 and 24 respectively.



Figure 22: A picture taken from BIUST quadrat



Figure 23: A picture taken from a quadrat in Maunatlala



Figure 24: A picture taken from Malaka site

High degradation areas - The 2 sites of Morupule and Lecheng appear to be highly degraded. *Colophospermum mopane* has a density of 304 in Lecheng while Morupule has 1060. This species is denser in Morupule than Lecheng even though both areas are of high degradation. In Southern Africa, this woodland species covers a total area of 555 000km² (Makhado et al., 2014). Ecologically, the species is associated with shallow soils or impermeable sub soils (Orwa et al., 2009). Soil erosion is evident in the highly degraded area of Morupule (Figure 25), hence high reflectance from the satellite indicating high degradation. The problem of soil erosion in the site, might be exacerbated by the area being below the hill as there is too much runoff from uphill. There was virtually no grass in the site which might be related to the high runoff, which is very erosive in nature therefore, leaving degraded off soils behind (Eckert et al., 2015). In Lecheng (Figure 26), soil erosion was not visible except that the area is sandy. This sand might be the reason for high reflection in the satellite. The availability of grazing in Morupule and Lecheng might have been a problem, as, apart from and *Colophospermum mopane* only a few plants were identified such as *Dicrostachys cinerea*, *Gymnosporia boxifolia* and *Ximenia Americana caffra*. These plant species are known as encroachers or the increasers because they increase with increase in grazing (Fensholt et al., 2013). Treydte et al (2017) have since indicated that with high grazing pressure in drylands, fresh grass re-growth is often prevented by soil erosion and compaction as a result of nutritious grass species

disappearing. This might be the reason why no fresh grass was identified in the highly degraded Morupule site.



Figure 25: The high degraded Morupule site (A picture showing the shallow soils of Morupule)



Figure 26: The high degraded Lecheng site (A picture taken in Lecheng site)

It has also been noted that degradation and large cattle herd have rapidly diminished grazing resources in Ethiopia, South Africa and Argentina (Kropfl et al., 2013) which farmers in the area perceived the same. Unpalatable species such as *Datura stramonium* and *Striga asiatica* were noticeable in the study area which signified bush encroachment and reduction in the quality of rangelands (Favretto et al., 2014) therefore making the situation undesirable (Kleijn and Muller-Scharer, 2006). When these impacts are combined with prevailing drought conditions, the results are poor quality and death of livestock, which has also been mentioned by farmers. These can be very severe, as an elderly farmer in Lemone reported to have lost half of his cattle herd in 2013. MEA (2005) has also associated the decline in fodder due to overstocking and range mismanagement. The reduced vegetation cover from overgrazing, fuelwood collection and deforestation that has been attributed by farmers in the area, does not only affect livestock, but have also been identified by UNEP (2007) to increase the amount of dust particles suspended in the atmosphere which increases the chance of people exposed to this condition to respiratory ailments and allergies.

Through their perceptions, 86% interviewed indicated pastoral agriculture to be associated with vegetation degradation. Through overgrazing, the respondents indicated the land to become bare, therefore exposing the soil to all forms of erosion. The compacted soil will then lead to soil being easily washed away leading to formation of gullies. The explanation behind

farmers' perceptions is that they are the people who are on the ground, who are observant in their everyday farming activities. These are the people who get first-hand information on what is happening in their ploughing fields as well as in their areas of grazing. By observation, the area of study had patches of bare land, which was not easy for the researcher to tell if it was a result of overgrazing or no rainfall. Even though livestock was in good condition, farmers were adamant that since there was no rainfall, their livestock were going to be affected because of no forage. This also happened in the Niono area of north-west Mali where between 50% and 70% losses of draft animals was experience over the period of 1983-84 (FAO, 2015a). The Niono high losses were caused by pasture shortages exacerbated by herds from further north on their way to southern pastures. One farmer from Masuakoloi also claimed the same thing that the grazing pressure in their areas was caused by cattle from somewhere else that come to graze in their area. He further said that even though their cattle would do the same, those coming from somewhere else were exacerbating the problem.

Because of low rainfall, land users such as beekeepers indicated little vegetation in the area of study which causes bees to migrate from their bee hives to somewhere else in search of flowering plants. So, loss of vegetation cover results in loss of bees, therefore affecting the income of beekeepers. However, it has been noted that 75% of the leading food crops and 35% of global food production is dependent on pollinators (Klein et al., 2007; Morandin and Kremen, 2013) therefore making bees the primary crop pollinators (Morandin and Kremen, 2013). Some studies on bees in disturbed habitats indicated that exotic plants receive more visits than native plants by native bees because of greater attraction and rewards (Brown et al., 2002; Morandin and Kremen, 2013). When examining plant-pollinator interactions in invaded and un-invaded networks, Vila et al (2009) found that pollinators interacted more with exotic species than they did with native species in invaded areas, but found no clear effect on whether the greater visits to exotic plants negatively impacted visits to native plants.

4.4 Coping with Vegetation Degradation

The availability of forage species in rangelands is closely linked to the livestock preference because it determines where grazing is really located (Treydte et al., 2017). Overgrazing of vegetation by livestock and subsequent land degradation has been identified to be a widespread problem in the Sub-Saharan Africa (UNEP, 2014) which has even prompted farmers to develop some strategies of mitigating it as it leads to livestock loss. In Africa and Australia, opportunistic movements of livestock and trading grazing rights have been adopted

as strategies in times of drought (Treydte et al., 2017). As a result, farmers in the area of study have indicated to avoid livestock from perishing by reducing their numbers through selling, while those in Lecheng area move their livestock to Tswapong hills where they believed to always have forage. Moving livestock to neighbouring rangelands where resources are available is the most common practice (Treydte et al., 2017). The same thing is practised by southern Mongolian herders who move livestock to northern Mongolia during drought and return to southern Mongolia when rainfall is abundant (Lee et al., 2015). Herders in Mali, as well have adopted to transhumance, forage stocking and sale of some animals in order to reduce their number in times of drought (Dembele, 2006) in order to allow the affected area to regenerate.

In Ethiopia, pastoralists avoid livestock losses during severe drought by moving with them to different foraging background (Treydte et al., 2017) which is the same as in Lecheng area where farmers indicate to move their livestock to Tswapong hills where it is believed to always have forage. Some farmers however have indicated lack of free land unlike in the past where they were at liberty to move around their livestock in times of drought. They attributed lack of free land to the increased human population. As a result of overgrazing, farmers claimed to avoid livestock from perishing by reducing their numbers through selling, while those some purchase feed for livestock and also slaughter their animals in times of drought so as to reduce their numbers and be able to feed the few. They attributed lack of free land to the increased human population. In Botswana, during times of drought, crop residues and commercial feed are used as alternatives (Mogotsi et al., 2013) which are barely available in Afar (Ethiopia) for livestock in drought times (Treydte et al., 2017). However, when the livestock populations decreases, this is reported to lead to an unintended resting period which helps the land use to recover (Treydte et al., 2017) which is very crucial in Namibia (Muller et al., 2007).

These strategies have proved to be effective and that is why the people continue using them to date (Treydte et al., 2017). The importance of these adaptation strategies has however been noted by Gorjestani (undated) who felt the need for the knowledge to be constantly used, challenged and further adapted because it is a key element of the social capital of the poor and the main asset in their efforts to gain control of their own lives. Interventions are also needed to create conditions that enable people to try to overcome the obstacles and take actions to help themselves. Traditional knowledge about how local populations have coped

with vegetation degradation or previous droughts has the potential of providing important guide for addressing current and future climatic events (Nyong et al., 2007). As such it is very important to consider the local knowledge at all times especially when mitigating the effects of degradation. The local knowledge in land and water management acquired over time has previously worked out for farmers in Chipinge, Zimbabwe to cope well with water shortage, drought and crop losses, but now this traditional approaches have become difficult to apply in recent years because of changing rainfall patterns (Chifamba and Mashavira, 2011).

4.5 The Effects of Policies

Policies and legal instruments have evolved and are still evolving to mitigate the impacts of human activities on the natural environment (Mulale et al., 2013). As such, it is always important to recognize the anthropogenic and biophysical causes of degradation at both national and local levels (Vu et al., 2013) whenever these policies are designed. Therefore, land users' awareness of land management policies in Botswana was examined.

The land users were interviewed on policies. Some of the questions were *“Are there any policies or procedures you are aware of, that have positively or negatively affected the land and how?”* The second question was *“If possible, which ones do you think should be amended?”* Among the policies and acts, the Forestry and Range Resources Act of 1968 and Tribal Land Act of 1970, were mentioned by farmers on a positive note. The Forestry and Range Resources Act of 1968 was mentioned to prohibit cutting down of trees was indicated to be a good idea as trees act as wind breakers. The act was also mentioned to be encouraging tree planting especially indigenous ones, to avoid bare land. On the other hand it was perceived as negative because it prevents cutting down of poles to make kraals. Five percent (5%) of farmers indicated it as negative because of late issuance of permits to sell veld products.

One historian farmer indicated that even though the Tribal Land Act was good, he felt it should be amended so as to give people the responsibility to take care and watch what happens in and around their yards. He went on to narrate how people come close to their yards and cut trees but would not say anything about it as the Act gives someone

responsibility for the inside of his or her yard only. He felt that it was a loop hole that encourages vegetation destruction. Most of the narrators were concerned about the high number of livestock especially cattle that affect the land through grazing. One of them indicated to always approach the department of Veterinary Services to suggest if there can be a policy that limits the number of cattle to be owned per farmer. But otherwise the historians were very happy with only these 2 Acts (Tribal Land Act and Forestry and Range Resources Act).

On the very negative part, which was mentioned by 90% of the stakeholders was the Tribal Grazing Land Policy of 1975. This policy was attributed to overstocking (Dougill and Cox, 1995) although initially it was aimed at stimulating better grazing control and range management and increase livestock productivity (Mulale et al., 2013). This led to the establishment of privately owned ranches in a bid to control the grazing pressure and ensured sustainable use of rangelands (Kgosikoma, 2012). The interest of small cattle farmers were safe guarded by shifting herds of the rich farmers from the commons to the ranches. When the policy was introduced, it was expected to improve the range condition of the commons. Instead, land users noted that areas around water points on communal areas were overgrazed due to cessation of traditional herding and opportunistic grazing. Farmers felt that since the implementation of the policy, overgrazing in communal areas has been on the increase, citing Boteti as one of the areas hard hit by this policy failure (Mulale et al., 2013). The fact that a policy has some unfavourable effects does not necessarily mean it is inconsistent with efficient use of resources (Chisholm and Dumsday, 1987).

CHAPTER FIVE

CONCLUSION

5.1 Summary of Findings

The variability of vegetation over an 18 year period in Palapye was considered using the NDVI. Over the 18-year period, the NDVI, which is the indicator of vegetation growth was found to be lowest in the year 1998/1999, 2001/2002, 2002/2003 and 2004/2005. Even though these years showed the negative NDVI, only the year 1998/1999 and 2002/2003 were pronounced to be years of drought in Botswana. The year 2014/2015 was indicated to be a drought year as well, but the NDVI values did not show the negative values. This might be due to the effect of the late rainfall that occurred towards the end of the 2015 cropping season. For the year 2000/2001, 2007/2008, 2008/2009, 2009/2010, 2010/2011, 2013/2014, 2014/2015 and 2015/2016, vegetation increased because of rainfall that occurred in the area. However, floods were experienced in the 2000/2001 and 2009/2010 in the area. The 18 years of vegetation anomaly summarised with Z-score showed the years 1998/99 and 2002/03, to have negative deviations of less than -1, therefore, indicating reduced plant vigour. These were considered drought years hence the negative deviations when compared to the long-term average. The year 2000 and 2010, were ravaged with floods hence the increasing values of NDVI in the year 2000/2001, 2009/2010 respectively. The year 1999/2000 had the highest rainfall in the entire series of 18 years yet did not have the highest NDVI values because of the lag period for vegetation to respond to rainfall and recover from the effects of droughts in the 1990s. Examining the regression model of ANDVI with time showed the statistical significance of between 85% and 98% confidence level between 0.02 and 0.15 p-values.

Nine sites being Mogapinyana, Moeng, Lesenepole, Mahibitswana, Malaka, Maunatlala, BIUST, Lecheng and Morupule were used for validation by considering the occurrence of plant species, frequencies and density as well as the rainfall data. The results showed the spatial distribution of plant growth over time for a particular period relative to the long-term average, which is the anomaly. Over the 18-year period, the analysis of correlations between NDVI and rainfall indicated significant positive correlation. Areas showing positive NDVI trends mostly coincided with areas indicating an increase in vegetation, as well as areas

showing negative NDVI trend coincided with the decrease in vegetation. Precipitation changes in the same time periods seem to have had an influence on vegetation variability.

Vegetation degradation is more pronounced towards the south and west of the study area. Vegetation degradation status stands at 44.3% for the relatively undegraded area, 51.3% for low degradation, 4.35% and 0.05 for medium and high degradation respectively. Using plants as indicator species, the areas of degradation show the plants that thrive in the degraded places. For example, *Dichrostachys cinera* which was found mostly in the degraded areas while *Colophospermum mopane* was found in the highly degraded, shallow and less fertile soils areas of Morupule and Lecheng.

The impacts and consequences of vegetation degradation affected the farmers. Once vegetation has been affected, livestock and crop production will be affected therefore having an impact on the lives of the people. The vegetation degradation map was statistically examined with F-test at 85% confidence level. The most significant pixel was at 98% while the least were at 85%.

5.2 Policy Implications of Findings

Agriculture still remains the most important sector in the study area despite the gradual ongoing urbanisation process. As evident from the occurrence of NDVI values as high as 0.7 to 0.85 in some parts of Palapye, vegetation conditions around the Tswapong hills are therefore good and can support agricultural activities in this semi-arid context. As vegetation degradation affects both arable and pastoral agriculture, government policies should therefore focus on minimising the impacts of the factors driving vegetation variability and degradation such as climate change and variability, human activities leading to deforestation.

5.3 Contribution of the Study

This study has contributed in the improvement of our understanding of vegetation variability, trend and degradation. With the Botswana economy dependent on beef export and wildlife tourism, it is imperative to understand vegetation variability and degradation over time. Thus, this is a major contribution of this study which provides empirical evidence of vegetation degradation. This study also provides empirical evidence of vegetation degradation at the local level, therefore contributing to the existing literature on vegetation variability and degradation.

5.4 Methodological Contribution

The mixed method research methodologies applied in the study spanned disciplines such as anthropology, geospatial, environmental, and natural sciences. It involved the use NDVI time series image data as well as ground truthing or validation of the Remote Sensing results. The validation involved the use of rainfall data, vegetation field survey and perceptions of farmers, as well as oral history. Vegetation survey revealed the plant species occurring in the degraded areas and was used in the verification of the results of the vegetation degradation map derived from the annual average NDVI. The plants species found, as indicators of degradation in an area were associated with the level of degradation.

Local knowledge from the interviews which is based on experience, has a role to play in conservation and protection of the land from degradation. Additionally, local knowledge and management practices can be used in collaboration with standard scientific methods for improving understanding of the environment. Local populations have coped with land degradation or previous droughts, therefore, they have the potential of providing important guide for addressing current and future climatic events As such it is very important to consider the local knowledge at all times especially when mitigating the effects of land degradation.

5.5 Future Research

Further similar studies in Botswana to compliment this effort on the use of Remote Sensing based indices such as the NDVI in vegetation degradation are needed. Since Botswana is prone to drought conditions, NDVI can be combined with other indices to detect stressed vegetation indicating drought conditions as well as to predict crop yield in support of the country's goal to tackle food insecurity.

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APPENDIX 1: FARMERS' INTERVIEW QUESTIONS

These questions are meant to find out about the land degradation in your area. Your kind assistance in responding to questions truthfully will be highly appreciated.

Section 1: General information

GPS position: Y/latitude..... X/Longitude.....

Altitude.....

Farmer ID (e.g. 001): Farmer name (optional) Date

Ward/Extension/Area..... Village.....

1. Gender/Sex Male ☐ Female ☐ (Code: Male = 1, female = 2)
2. Position in household: Household head ☐ Father/Mother ☐ Children ☐
Brother/sister ☐ Others(Code: Head=1, Father/Mother=2, Children=3,
Brother/Sister=4, Others=5)
3. If interviewee is not the household head, who is the household head?
.....
4. Age group: 15 – 24 ☐ 25 – 34 ☐ 35 - 49 ☐ 50 – 64 ☐ 65+ ☐
Code: 15-24 = 1, 25-34 = 2, 35-49 = 3, 50 - 64 = 4, 65+ = 5
5. Marital status Married ☐ Single ☐ Living together ☐ Separated ☐ Divorced ☐
Widowed ☐
(Code: Married = 1, Single = 2, living together = 3, Separated =4, Divorced =5,
Widowed = 6)
6. How many are you in your household?
.....
7. Level of education? No schooling ☐ Primary school standard Secondary
school form Vocational
.....Tertiary.....Others.....

Perception of land degradation and climate change

1. Have you heard about climate variability & change? Yes ☐ No ☐ (Code: Yes = 1, No = 2)
If yes, from where? Radio/TV ☐ Village loudspeaker ☐ Family ☐
Friends/neighbours ☐ Colleagues ☐ Training ☐ Project officer ☐ Extension officer
☐ Others.....
(Code: Radio/TV = 1, Village loudspeaker = 2, Family = 3, Friends/neighbours = 4,
Colleagues = 5, Training = 6, Project officer = 7, Extension officer = 8
Others.....)
2. How is the climate currently? Good ☐ Bad ☐ Very Bad ☐ I don't know ☐
(Code: Good = 1, Bad = 2, Very Bad = 3, I don't know = 4)

3. How was the climate when you first settled here? Good [] Bad [] Very Bad [] I don't know []

(Code: Good = 1, Bad = 2, Very Bad = 3, I don't know = 4)

4. What has changed in the climate since you came here? Reduced rainfall [] Increase scorching sun [] Drought [] Hunger [] Death of livestock [] Disease has increased unlike before [] Others (specify) [] (Code: Reduced rainfall = 1 Increase scorching sun = 2 Drought = 3, Hunger = 4, Death of livestock = 5, Disease has increased unlike before = 6, Others)

5. What has changed in the following?

No		Did this change compared to last year (12 months?) ¹	Did this change compared to the situation 10 years ago			
			Increased 1	No change 2	Decreased 3	Unsure 4
1	Rainfall amounts					
2	Temperatures					
3	Wind					
4	Sunshine/Heat					
5	Frequency of droughts/famines					
6	Frequency of drying of rivers					
7	Frequency of Hunger					
8	Incidences of human diseases					
9	Incidences of animal diseases					
10	Incidences of crop diseases					

1) (Code: Yes = 1, No = 2)

6. What do you consider the most serious climatic constraints related to your crop production?

No	Events	How severe? ¹				
		1	2	3	4	5
1	Drought					
2	Flood					
3	Heat wave					
4	Cold wave					
5	High temperature					
6	Off-season rain					
7	Storm					
8	Insects/Diseases					

9	Wild fire					
10	Changing rainfall pattern					
11	Other (Specify)					

1 = very severe, 2 = severe, 3 = moderate, 4 = not severe and 5 = Not very severe

APPENDIX 2: ORAL HISTORY (65+ years of age)

GPS position: Y/latitude..... X/Longitude..... Elevation.....
Oral historian ID (e.g. 401): Name (optional)
Date Ward/Extension..... Village.....
Organisation..... Position

1. When did the village of Palapye started?
2. Where were the people coming from when they settled here?
3. How do you think the village has changed compared to 20 years back?
4. How do you think the population has changed compared to 20 years back?
5. How was the vegetation like 10 years ago and why has it changed?
6. How was the vegetation like 50 years ago and why has it changed?
7. Can you name some of the disappearing or extinct tree species and why you think they are extinct?
8. What was the predominant type of vegetation cover 50 years ago?

APPENDIX 3: SYNTHESIS OF REMOTE SENSING RESEARCH WITH SUMMARY CHARACTERISTICS (STUDY, LOCATION, YEAR OF STUDY, INDEX USED, AND TEMPORAL PERIOD

AUTHOR	YEAR	INDEX/METHOD	LOCATION	STUDY PERIOD
Roghadan et al.,	2014	NDVI/SPI	Sharghi, Azerbaijan Province, Iran	2001-2011
Rhee et al.,	2010	NDVI/VCI	Arizona and New Mexico	2000-2009
Quiring and Ganesh	2010	NDVI/VCI	Texas	1992-1999
Brown et al.,	2008	NDVI/VCI/PASG/SVI	United States of America	1989-2005
Oikonomakis	2007	NDVI	Greece	2004-2004
Gu et al.,	2007	NDVI	Central Great Plains, USA	2001-2005
Bayarjargal et al.,	2006	NDVI/VCI/TCI/LST	Mongolia	1982-1999
Fox et al.,	2005	NDVI	South Africa	1985-2001
Anyamba and Turker	2005	NDVI	Sahel region	1981-2003
Masoud and Koike	2006	Vegetation indices, Tasseled cap, image differencing	Egypt	1987-2003, 3 images
Chikhaoui et al.,	2005	Spectral index (“Land degradation Index”), band ratios	Morocco	Snapshot
Herrmann et al.,	2005	Long-term average & monthly NDVI in relation to rainfall, trends in residuals	Sahel	1982-2003
Olsson et al.,	2005	Seasonal integrated NDVI trend per pixel in relation to rainfall	Sahel	1982-1999
Archer	2004	Seasonal integrated NDVI in relation to rainfall	South Africa, Karoo	1984-1997

		(“Detrended NDVI”)		
Budde et al.,	2004	Vegetation Integrated NDVI, local variance analysis, trends in residuals	Senegal	7 years
Evans and Geerken	2004	Accumulated annual maximum NDVI, rain-use efficiency, residual analysis	Syria	1981-1996
Geerken and Ilaiwi	2004	Accumulated annual maximum NDVI, rain-use efficiency, residual analysis	Syria	1981-1996
Li et al.,	2004	Integrated NDVI, rain-use efficiency stratified per vegetation type, Standard error of estimate, residual analysis	Senegal	1982-1997
Tappan et al.,	2004	Land-cover change per vegetation unit	Senegal	
Tong et al.,	2004	Land-cover mapping and “Steppe Degradation Index” with ancillary data	China	1985 and 199
Wessels et al.,	2004	Cumulative NDVI scaled per land capability stratification and related to rainfall	Limpopo Province, South Africa	Long-term (1985-2003)
Al-Bakri and Taylor	2003	Long-term Average NDVI, Vegetation condition index	Jordan	1981-1997
Ries and Marzolf	2003	Visual interpretation	Spain	1995-1998
Collado et al.,	2002	Image differencing of 2	Argentina	1982 & 1992

		images		
Gupta et al.,	2002	Visual interpretation	China (Mekong River)	
Wu and Ci	2002	Land-cover mapping and ancillary data	China	50 years
Diouf and Lambin	2001	Rain-use efficiency using integrated NDVI	Senegal	10 years
Weiss et al.,	2001	Coefficient of variation of inter annual NDVI	Saudi Arabia	12 years
Milich and Weiss	2000	Coefficient of variation of inter annual NDVI	Sahel	1980-1994
Tanser and Palmer	1999	NDVI versus Moving Standard Deviation Index using fence-line contrasts	South Africa	Snapshot in 1994
Nicholson et al.,	1998	Integrated NDVI and rainfall regressions	Sahel	1980-1995
Palmer and van Rooyen	1998	Change vector analysis between 2 bands, NDVI	South Africa, Kalahari	1989 and 1994
Weiss	1998	NDVI related to rainfall, Coefficient of variation of inter annual, NDVI	Saudi Arabia	12 years
Unganai and Kogan	1998	VCI/TCI	South Africa and Zimbabwe	1985-1995
Jury et al.,	1997	NDVI	Southern Africa	1981-1994
Santos and Negri	1997	NDVI	Brazil	1988-1989
Kogan	1997	VCI	Africa, Asia , South and North America	1990-1994
Liu and Kogan	1996	Vegetation indices (NDVI, Vegetation condition index) related to rainfall, threshold mapping	South America	1981-1987
Tripathy et al.,	1996	Albedo, NDVI time series, visual interpretation,	India	1984-1991

		image differencing		
Jacobberger-Jellison	1995	Albedo versus vegetation indices (NDVI, Soil Adjusted Vegetation Index, Leaf Vegetation Index)	Sahel, Mali	1986-1988
Lambin and Strahler	1994	NDVI, surface temperature, moving spatial mean	Africa	1987-1989
Nicholson et al.,	1994	NDVI/VCI	Botswana	1982-1987
Peters et al.,	1993	NDVI	New Mexico	1099-1989
Marsh et al.,	1992	NDVI, high resolution versus low resolution	Sahel	1989 several images

Adapted from Gibson (2006) and Gwitira et al (2015)