The impacts of heavy rains on the vegetation cover in the Limpopo Province of South Africa

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Dissertation submitted in fulfillment of the requirements for the degree of Master of Science in Environmental Science at the Mafikeng Campus North-West University

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October 2015

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Declaration

I Miss Azwifaneli Mulugisi (Student No: 2489962) declare that this dissertation for the award of Masters of Science in Environmental Science at the North West University, has not been previously submitted for a degree in this or other institutions, and that all the references contained in this study have been duly acknowledged.

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Acknowledgements

I am very much thankful to Prof L.G Palamuleni and Prof T. A. Kabanda for their academic guidance, counselling, encouragement and patience throughout the writing of this dissertation. Moreover, I thank the North West University Scarce Skill Fund and the National Research Foundation (NRF) for the financial support which enabled me to carry out this study. I am also very grateful to the family, my husband Mark and my children Ethan and Lloyd Horton, for enduring my fulltime absence from home, never forgetting my father Mr Mulugisi Michael, my brothers Thuso and Dzilafho Mulugisi and my aunt Colicia Mudau, for their emotional support. Also, the staff members, Masters Students of the Department of Geography and Environmental Sciences North West University need to be mentioned for their support of various forms.

Abstract

In arid and semi-arid environments like most parts of South Africa, the state of vegetation cover is an important indicator of the state of the environment. Climate variability coupled with different anthropogenic activities could affect vegetation cover at varying levels. This study aimed at assessing the pattern and magnitude of spatial and temporal vegetation cover changes before and after heavy rains in the Vhembe and Mopani Districts, Limpopo Province, South Africa. Utilising remote sensing methodology, Landsat TM images of 1995, 1997, 2005, 2007, 2010 and OLI-8 2013. Rainfall data for 1961-2011 were used to compute rainfall anomalies. Landsat classification of NDVI density classes for each image was computed for identifying vegetation cover changes. Classification of vegetation density based on NDVI categorised five major classes: non-vegetation (bare land or water), low density, medium density, high density and very high density classes. In addition, a correlation coefficient of heavy rainfall events and vegetation cover was done.

The study established that there have been substantial changes in vegetation densities before and after heavy rainfall has occurred in the area. The study area received above normal rainfall in 1996, 2006 and 2011. Performing vegetation cover change analysis for the above normal rainfall years', Vhembe and Mopani Districts showed similar patterns in vegetation cover change. This means that when vegetation cover increased in Vhembe District it also increased in Mopani District, though to a different degree. The change analysis showed an increase of 59.45 ha (5504.6%) for Vhembe and 0.81ha (90%) for Mopani in non-vegetation cover from 1995-1997 while, high and very high density decreased. Although some areas recorded a decrease in vegetation cover, there are also areas that had had an increase in vegetation during the study period.

Results of the correlation coefficient revealed a significant weak correlation of ($r = 0.44$ and 0.18) in 1996, ($r = 0.13$ and 0.29) in 2006 and ($r = 0.04$ and – 0.36) in 2011 in Vhembe and Mopani Districts respectively, between NDVI and Mean Average Rainfall (MAR) with a residual of 19.4% ($r^2 = 0.19$), 1.7% ($r^2 = 0.002$) and 0.2 % ($r^2 = 0.13$) in Vhembe District during 1996, 2006 and 2010 respectively. Similarly, Mopani District accounted for 3.2 % ($r^2 = 0.03$), 5.3 % ($r^2 = 0.05$) and 15.2 % ($r^2 = 0.15$) in 1996, 2006 and 2011 respectively, suggesting that other factors influence vegetation cover changes in the study area. Hence, vegetation density cover change could be attributed to socio-economic activities, such as agriculture, veld fires, settlement expansions, and overgrazing.

Land cover mapping and change detection studies are valuable especially for vegetation cover change. From the findings, the study recommended monitoring and analysing Land Use Land Cover Changes (LULCC) in order to understand drivers of the change in the Vhembe and Mopani District. These studies will make significant contribution towards the understanding of socio-economic drivers of vegetation cover change, and the impact on natural and human ecosystems.

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Abbreviations and Acronyms

CCRS:	Canada Centre for Remote Sensing
ITCZ:	Inter -Tropical Convergence Zone
DEA:	Department of Environmental Affairs
DN:	Digital Number
EEA:	European Environmental Agency
ENSO:	El-Nino Southern Oscillation
GCP:	Ground Control Points
MAR:	Mean Average Rainfall
NDVI:	Normalised Difference Vegetation Index
NIR:	Near Infrared
OLR:	Outgoing Longwave Radiation
RS:	Remote Sensing
RMS:	Root Mean Square
SAWS:	South African Weather Services
TM:	Thematic Mapper
UTM:	Universal Transverse Mercator
WMO:	World Meteorological Organisation

CHAPTER 1

1. INTRODUCTION

This study investigates the impacts of heavy rainfall events on the vegetation cover in the Limpopo Province, where two districts (Vhembe and Mopani Districts) are considered. The purpose of this chapter is to introduce climatic factor (heavy rainfall) affecting vegetation density in the study area. A background section puts the subject matter of the research followed by statement of the problem together with the aim and objectives of this research. The rationale provides the reason why the research of this magnitude should be conducted while the hypotheses provide the guiding framework of the research.

1.1. Background

The impacts of rainfall events depend on how it unfolds as much as on the final rainfall count. For example, rainfall that can fall accumulatively in certain area in 24 hours may not necessarily be defined as heavy rainfall, however, if the same rain falls within an hour in an intense downpour, can lead to soil erosion and land degradation. This type of rainfall can be classified as heavy rainfall (WMO, 2005). Intensification of heavy rainfall as discussed in climate change studies has become a public concern, but it has not yet been examined well with observed data, particularly with data on a short temporal scale like hourly and sub-hourly data and also on a small spatial scale (i.e. district level) (Dai *et al*., 2007). Thus, knowledge of the statistics of rainfall and rainfall extremes at a wide range of timescales is highly desirable. Large-scale analyses of rainfall have traditionally focused on accumulated amounts or time-averaged mean rates (Zhou *et al*., 2008), while other characteristics of rainfall, such as frequency and intensity, have been the focus of only recent studies (Trenberth *et al*., 2003; Dai *et al*., 2007; DeMott *et al*., 2007; Sun *et al*., 2006).

Changes in the frequency or intensity of extreme weather and climate events could have profound impacts on both human society and the natural environment. Indicators based on the observed daily precipitation during the second half of the twentieth century suggest that, on average, wet spells produce significantly higher rainfall totals now than a few decades ago (Alexander *et al*., 2006). Heavy rainfall events have become more frequent over the past 50 years even in locations where the mean precipitation has decreased or is unchanged

(Groisman *et al*., 2005). Recent research indicates that high rainfall intensity is the main contributor to sediment transport and soil erosion (Dhakal & Sidle, 2004; Jen *et al*., 2006; Boix-Fayos *et al*., 2007). However, the prediction of soil loss distribution and vegetation cover change still remains a difficult research challenge (De Vente *et al.*, 2005; Goel and Kumar, 2005) and is not the focus of this study.

Heavy rainfall can cause environmental impacts such as changes in vegetation cover following extreme rainfall events (Sharma *et al*., 2011). Heavy rainfall events, affect crop and agricultural production due to the detrimental effect that it provokes on most vegetation covers (Bailey-Serres and Voesenek, 2008; Colmer and Voesenek, 2009). Some plants can tolerate their roots being submerged in water, depending on the time of the year heavy rainfall occurs, the duration of the rainfall event, species sensitivity to rainfall and the type of soil the plants are growing in. Dormant plants are more tolerant than actively growing plants to heavy rainfall (Bailey-Serres and Voesenek, 2008). After heavy rainfall events, the area might be devoid of vegetation. The absence of vegetation cover on hill slope has profound effect on debris flow initiation mechanism and warming thresholds (Hong and Adier, 2007). Sparsely vegetated areas are commonly susceptible to erosion and hill deformation because loose surface soil in these areas is exposed to the full impact of rainfall and run-off (Baum and Godt, 2010).

Vegetation destruction during heavy rainfall is at times accompanied by soil erosion and can lead to shrinking of water volumes in lakes, rivers and dams (Feng *et al*., 2012). Damage due to heavy rainfall has been on the increase, resulting in loss of lives, property and agricultural products. In addition, debris flow on the non-vegetation slopes commonly form shallow landslides that occur only after significant excessive rainfall particularly in areas where precipitation is markedly seasonal (Baum and Godt, 2010). For most shallow landslides, heavy rainfall triggers slope failure because water reduces the shear strength and increases the shear stress in the soil layer. Extreme rainfall events are at times accompaned by storms which induce soil saturation, and therefore the reduction of the soil storativity affects the surface discharge to a smaller extent (Coe *et al*., 2008).

The physical and mechanical behaviour of the soil as well as the mechanism of rainfall infiltration have been widely studied (Lu and Godt, 2008; Montraslo and Valentino, 2008). There are numerous methods available for mapping and monitoring heavy rainfall events and their impacts on vegetation cover. For example, using statistical analysis such as time lapse series of rainfall; heavy rainfalls are captured as above normal rainfall events (Kabanda, 2004; Singo, 2008); and use of remote sensing (Frappart *et al*., 2006; Sakamoto *et al*., 2007) are captured as increase or decrease in vegetation cover (Gunnula *et al*., 2011). Satellite data are useful in delineating the boundaries of heavy rainfall events, identification of the sites ideal for taking structural measures to control floods, assessing spatial and temporal dynamics of land use as well as in vegetation cover (Reger *et al*., 2007; Serra *et al*., 2008). Several techniques are available for classifying images of heavy rainfall induced areas using remotely sensed data and improve the accuracy of land cover changes such as visual interpretation of satellite image, multi-spectral images classification, band ratioing and contextual multi temporal classification and object based classification (Cleve *et al*., 2008). Improved spatial, spectral and temporal resolution data from remote sensing are found to be appropriate for flood mapping and monitoring (Sharma *et al*., 2011), flood damage assessment (Dewan *et al*., 2007), land-use and land-cover changes (Munyati and Kabanda, 2009). The data may also help in flood forecasting by validating numerical inundation models (Gericke and du-Plessis, 2012), and rainfall run-off analysis (Machado and Ahmad, 2007).

Vhembe and Mopani Districts experience huge rainfall in austral summer between November and February (Crétat *et al*., 2010). Because of the predominance of rain-fed agriculture in the districts, large departures from the average seasonal cycle (either floods or droughts) may have detrimental effects on the economies and societies of the region. The spatial and temporal variations in precipitation have been observed in the North Eastern part of Limpopo Province by Kruger (2006) from 1910 to 2004. Variation in the rainfall trends have been linked to global climate change or local anthropogenic climate change (Munyati and Kabanda, 2009; Kabanda and Munyati, 2010; Kabanda, 2011; Nenwiini and Kabanda, 2013). Dyson, (2009) observed that rainfall resulting in flooding occurs from time to time in one part of South Africa or another.

In the year 2000, Southern Africa was characterised by severe damaging extreme rainfall events which were associated with the Tropical Cyclone Eline (Gereda, 2007; Nethengwe, 2007; Dyson, 2009; Kabanda, 2011), especially in the North Eastern part of South Africa (Vhembe and Mopani District), Southern Zimbabwe and Western Mozambique. Eline directly killed 200 people and left 500 000 people homeless in Mozambique. Continued flooding from Eline and tropical cyclone Gloria in South Africa, Mozambique and Zimbabwe (Gericke and du Plessis, 2012) killed an additional 700 people.

1.2 Problem Statement

Heavy rainfall may result in the destruction of vegetation cover which could accelerate hill deformation, soil erosion and landslides activities. These changes, may affect human settlements and their subsistence livelihood. In the study area, human settlements are smallholdings of 1-2 hectares, where a house is built and the remaining space caters for subsistence farming to sustain the family. Extreme rainfall events may have significant effect on agricultural potential which is the means of food security in the study area. Changes in climate and climate variation enhance recurrence of heavy rainfall events that will have detrimental effects on the local community. However, locally where the impact matters most, such studies have not been given wide attention. Therefore this study is devoted to fill that gap.

Vhembe District is characterised by steep slopes and mountain ranges such as Soutpansberg mountain range whilst Mopani District is situated in the low lying area within the province. Due to the steep slopes, the area is susceptible to erosion, hill deformation and landslides while the low lying areas experiences flooding during heavy rainfall. What was found to exacerbate the situation further, is the variation in seasonal rainfall in the study area (Newiini and Kabanda, 2013) due to fluctuation in the rainfall onset and cessation. Therefore, understanding the rainfall dynamics at local scale provided insight into the impact of heavy rainfalls on vegetation cover *vis-à-vis* landslide occurrences and flooding.

1.3 Research hypothesis

The research had the following hypothesis: Heavy rainfalls significantly alter the vegetation cover giving rise to soil erosion.

1.3.1 Aims and objectives

This research hypothesis was tested through a structured sequence of vegetation cover change analyses and heavy rainfall event thresholds. Accordingly, the objectives were set out as:

- to develop rainfall time series from 1961- 2011
- to determine heavy rainfall events and threshold for the study area
- to quantify vegetation cover change between years of heavy rainfall events
- to evaluate the relationship of derived heavy rainfall events and vegetation cover change

1.4 Description of the study area

The study area is situated in the North Eastern part of the Limpopo province of South Africa. It extends from 22°S to 24°S and 29°E to 31.5°E and covers an area of approximately 60,500 km^2. It shares the border with Zimbabwe and Mozambique through Kruger National Park to the north and east respectively, while to the North West is Botswana (Figure 1).

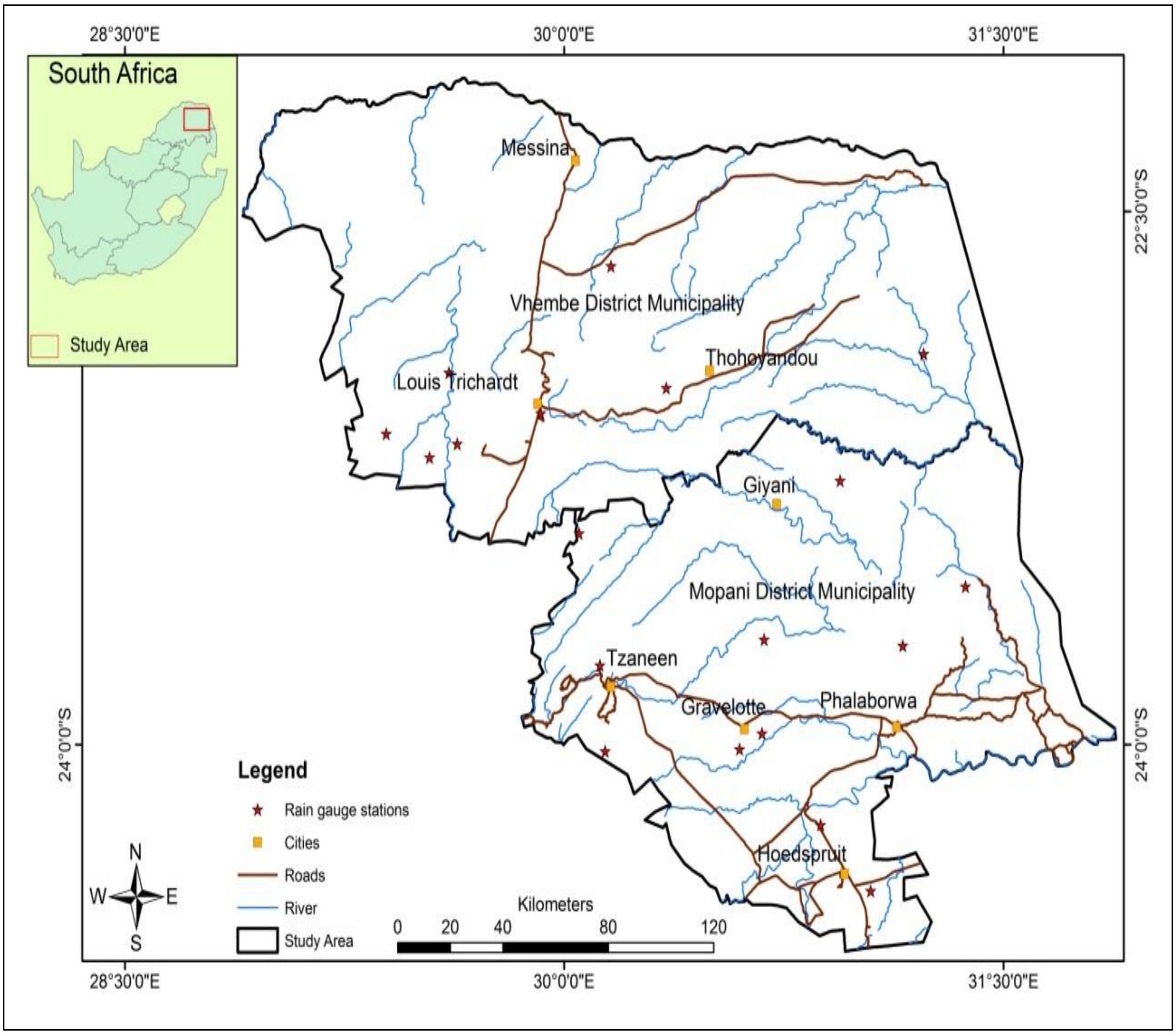

Figure 1: Map of the study area

The study is based in Vhembe and Mopani Districts of Limpopo Province. The case study areas (Thulamela and Greater Giyani municipalities) are purposively selected on the basis of their persistent heavy rainfall problems, their different physical landscape characteristics, and differential impacts from the great floods of year 2000. Vhembe District is characterised by steep slopes and mountainous range such as Soutpanesburg, while Mopani District is characterised by low lying areas.

Historically, Vhembe District is within the jurisdiction of the former Vendaland while Mopani District is within the former Gazankulu jurisdiction. Vhembe district derives its social and commercial services from Thohoyandou and Louis Trichardt which are the main towns in the district. Thohoyandou, the former capital of Venda homeland, is currently the administrative seat of the Vhembe District of the Limpopo Province while Giyani the former Gazankulu homeland is the administrative seat of Mopani District.

1.5.1 Rainfall

Rainfall plays a vital role in the development and distribution of vegetation cover but, the variability and extremes of either too much or too little rainfall can produce soil erosion that can lead to land degradation (WMO, 2005). Vhembe District is generally subjected to high rainfall due to its complex topography, especially the effects of the Soutpansberg mountain range while Mopani District experiences flooding because it features mostly low lying areas.

Vhembe and Mopani Districts, experience the bulk of their annual rainfall in the summer season from October through March (Figure 2), as the Inter -Tropical Convergence Zone (ITCZ) moves south (Kabanda, 2004). The peak rainfall months are January and February.

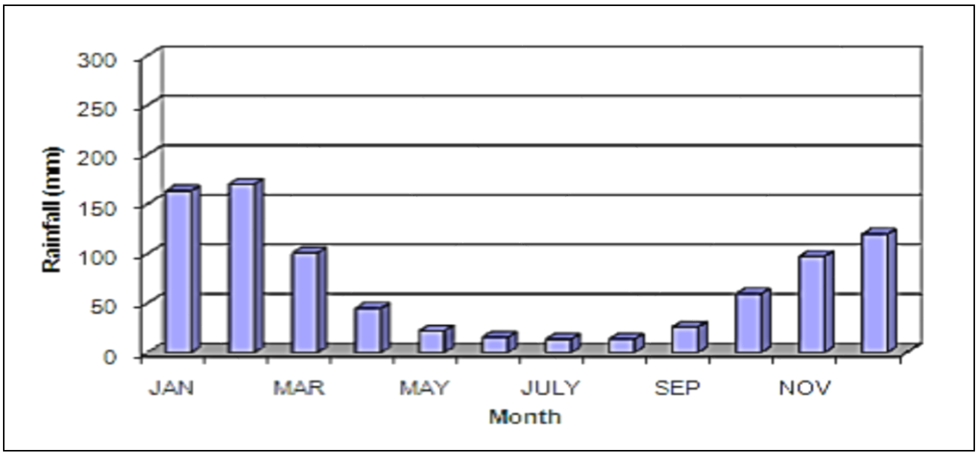

Figure 2: Average monthly rainfall for the Vhembe District and Mopani District (Source: Kabanda, 2004)

During some seasons, the area receives winter rainfall due to the propagation of frontal systems from the Atlantic Ocean to the North or North East of the subcontinent.

The study areas are characterized by high climate variability and are prone to flood and drought incidence (Kabanda, 2004; Reason *et al.*, 2005). The area is situated in the Eastern subtropical region and is generally characterised by hot humid, sub-humid and semi-arid climate. According to Nenwiini (2009), the area closer to or over the Soutpanesburg mountains is categorised as a humid component, experiencing 1200 mm of rainfall while the Western and North Western part of the study area experiences less than 500 mm rainfall. Generally, the Districts are semi-arid area and receive mean rainfall of 450 mm (Tshovhote *et al*., 2010). During winter, both Districts experience gusty winds (varying from 75 to 100km/h) (Semenya *et al*., 2013) with the temperature ranging from 16°C to 30°C during summer and 6°C to 14°C in winter (Singo, 2008).

1.5.2 Topography

The topographic features of the Districts affect the climate patterns such as the intensity, distribution and water drainage patterns (such as surface and ground water). The Districts have a topography that varies from zones of high mountains with Soutpansberg mountain range in the Vhembe district and Drakensburg Mountains in Mopani District to low lying areas (Semenya *et al*., 2013). These mountain ranges also exert a huge impact on the weather and climate of the study area (Kabanda and Munyati, 2010). Due to the mountain ranges, Vhembe and Mopani Districts are generally subjected to high rainfall and consequently flooding.

1.5.3 Soil

Heavy rains that lead to flooding may result in poor soil aeration because the supply of oxygen to flooded soil is severely limited. Oxygen deficiency is likely the most important environmental factor that triggers initiation and injury in plants (Bailey-Serres and Voesenek, 2008). The two Districts are characterised by different soil types which include sandy soils, clay soils and sandy-loam soils. These types of soil are not everywhere but are sparsely distributed across the Districts. The most common type of soil in the Vhembe District is fertile red loam soil though it often suffers from excessive run-off (Nethengwe, 2007). This soil type has high water holding capacity retaining water for long periods and is easily eroded by major erosive agents such as rain and wind.

1.5.4 Geology

Geology has strong influence over flood related parameters such as topography, soil types, soil infiltration, general hydrology and vegetation cover (Kabanda, 2004). Vhembe and Mopani Districts have diverse geological compositions whose broad terrain patterns are characterized by intrusive igneous, sedimentary and metamorphic rocks especially in the Soutpansberg and the Waterberg complexes (Kabanda, 2004). Generally, the Districts are composed of granite gneiss of the Precambrian age which is referred to as "Goudplaats" or golden plate gneiss (Nethengwe, 2007). Minerals found in the study areas include, complex flake granite, ironstone, marble, fire clay, sacrificial limestone, magnesium and barite mineralization.

1.5.5 Vegetation cover

Vegetation cover plays an important role in protecting the soil surface from raindrop splashing, soil aggregate stability, retaining and reducing surface water run-off. Once the vegetation cover is removed, raindrop impact initiates detachment of soil particles and causes the formation of a crust (EEA, 2002) which seals the surface and limits the infiltration. The Vhembe and Mopani Districts comprise of different vegetation species which include trees, biomes namely savannah, grassland and forest, four bioregions and twenty three different vegetation types (DEA, 2009). Among the trees, the most dominant are Acacia species which includes *Acacia sieberiana*, *Acacia tortolis*, and *Acacia caffra* and *Mopani*. Acacia woodlands provide valuable grazing from pods to supplement grasses in the dry season.

Alien vegetations are also found in the study areas that include exotic species such as *Lantana camara* (Lantana), *Acacia saligna* (Port Jackson willow), *Acacia cyclops* (Rooikrans), *Sesbania punicea* (Sesbania-red), *Azolla filiculoids* (Water fern), *Eichhornia crassipes* (Water hyacinth) and *Nicotiana glauca* (Wild tobacco) that have invaded large areas of arable land and displaced native species in the wetlands. Alien vegetation establish easily, and due to lack of natural predators or competitors, are able to multiply rapidly and to out-compete indigenous vegetation causing ecological disruption (Sinthumule, 2001).

1.5.6 Hydrology

The Vhembe and Mopani Districts are characterised by perennial rivers and non-perennial rivers that flow during heavy rainfall events and dry out when there is no more rainfall to sustain them. The Luvuvhu River is the second largest catchment in the Vhembe District, all the rivers in the Vhembe District flow into the Luvuvhu River before joining Limpopo River. The Limpopo River is the largest catchment in the Vhembe district and it forms the border between South Africa and Botswana and Zimbabwe before flowing through Mozambique to the Indian Ocean while Letaba River catchment is the largest in the Mopani District. Dams that have been constructed on some of the rivers collect water for use in the area and neighbouring regions. These dams include the Albasin, Nandoni, Mambedi, Barota, Damani, Vondo and Phipidi in Vhembe District and the Ebenezer, Magoebaskloof, Nsami , Middle Letaba, and Modjadji Dams in Mopani.

Wetlands are also found in the study area and they contribute to rainfall through evapotranspiration. Wetlands serve as an important source of water supply necessary for maintaining life of people as well as to support biodiversity (Sinthumule, 2001). They offer large quantities of water for industrial, agricultural and domestic use such as drinking, cooking and washing. Some wetlands are recharge areas for groundwater and some are discharge areas where groundwater flows into the wetland. In Vhembe wetlands are found in Matangari and Manini village and Isimangaliso wetland in Mopani. These wetlands provide people with direct benefits such as fibre for handcraft production, supply of domestic water, valuable land for crop cultivation, construction clay, fuel wood and fishing grounds. They also provide indirect benefits in the study area such as nutrient retention, erosion control, purification of water, groundwater recharge and flood control.

Ground water occurs in fractured and intergranular intestices in Sibasa Basalt and intergranular interstices of alluvial and talus deposits (Van Eeden *et al*., 1995). Over much of Africa, groundwater is the only realistic water supply option for meeting dispersed rural demand as it is not likely to be polluted and cheaper to access. Ground water is available throughout the study area. It plays a key role in the provision of safe drinking water, cooking, bathing and other domestic uses.

1.5.7 Economic activities of Vhembe District

Vhembe and Mopani Districts are generally subsistence farming with emerging commercial farming and eco-tourism activities. Among these, agriculture is the most fundamental in the economic, social development and stability of the Districts (GDP, 2002). The two districts produce tea, citrus and deciduous fruit. All these sectors utilize large quantity of water which is mainly replenished by rainfall which is perceived to be highly variable. Variations in the rainfall characteristics affect community activities in the Districts because they depend on rainfall for their farming, whether subsistence or commercial. As observed by Kabanda (2004), communities that live in areas that receive good rains, are able to grow some crops and keep a few domestic animals under limited climatic interruptions. However, long-term poverty is experienced in areas with insufficient rainfall and heavy rainfall because of the facts that the land is degraded as a result of land mismanagement and heavy rainfall.

1.6 Outline of the dissertation

This thesis is divided into six chapters. Chapter 1 is comprised of general introduction, which also outlines the research hypothesis and the objective of the study. Chapter 2 is the review from literature, in relation to the impacts of heavy rainfall and also remote sensing change detection techniques. Chapter 3 gives details of research methods used for this study. Chapter 4 is an examination of seasonal rainfall and heavy rainfall events in Vhembe and Mopani District. Chapter 5, is an investigation of change in vegetation cover after heavy rainfall using NDVI, change detection technique is also used. Recommendations and conclusions are presented in chapter 6 of this dissertation.

CHAPTER 2

2. LITERATURE REVIEW

In this chapter, previous work published by accredited scholars and researchers on the theme relevant to the impact of heavy rainfall and how the same influences vegetation cover in the Vhembe and Mopani are reviewed. Heavy rainfall in question may have been realised as an event; where rainfall of a single day caused flooding or the rainfall is a product of accumulation of a few days of continuous rain. Also to be reviewed here, are the remote sensing methods used by different authors.

2.1. Impact of heavy rainfall on the vegetation cover change

The interaction between vegetation cover and hydrological processes are frequently complex and dynamic. Recently numerous investigators have assessed the impacts induced by physical disturbances such as wild fires, earthquakes, heavy storms and typhoons on vegetation cover (Walker 2000; Manga and Wang, 2007; Koi, 2008). However the impacts of vegetation cover in response to heavy rainfall events is an area in which there is considerable uncertainty. In particular, investigations in quantifying the impacts of variations of heavy rainfall events (of different frequencies) on the vegetation cover is very limited (Sharma *et al.*, 2011; Bathrust *et al*., 2011). In an unprecedented global scale study, Bradshaw *et al*., (2007) analysed data from Africa, Asia, North, Central and South America. Working at the country level, they found that flood frequency is negatively correlated with remnant vegetation and positively correlated with the amount of vegetation lost. The authors thus linked flooding with the removal of vegetation cover. Vegetation removal during heavy rainfall is at times accompanied by soil erosion, removal of top soil and land degradation.

Many ecosystems in semi-arid regions have been under processes involving the loss of vegetation cover, productivity and species diversity (Okin *et al*., 2009) coupled with geomorphic processes, mainly soil erosion and land degradation (Reinhart *et al*., 2010; Ries 2010). In southern Africa, land degradation induced by both anthropogenic and climatic factors such as heavy rainfall is recognised as severe and is a prevalent environmental predicament (Wessels *et al*., 2007). It is estimated that 70% of South Africa has been affected by different types of erosion of high intensities (Le Roux, 2007). The Eastern Cape is ranked as one of the most degraded Provinces alongside with Kwa-Zulu Natal and Limpopo due to steep slopes and mountainous ranges.

In addition, debris flow on slopes and mountainous areas commonly form shallow landslides that occur only after significantly excessive rainfall particularly in areas where precipitation is markedly seasonal (Baum and Godt, 2010). Many areas in eastern parts of South Africa are prone to slope failure due to diverse terrain morphology comprising high mountains and steep valley slopes, high intensity rainfall, deep weathering associated with the humid climate and ancient land surface remnants, combined with a range of geological and structural influences (Singh *et al.*, (2007). Taiwan suffers disastrous typhoons and associated storms causing flooding almost every year and these disturbances cause vegetation cover changes affecting the watershed by removing soil (Lin *et al.*, 2008) and particularly landslide activities in mountainous watershed (Cheng *et al.*, 2007; Chen and Hawkins, 2009).

The majority of agricultural systems in South Africa and Africa at large are rain-fed. In the North Eastern parts of the Limpopo province, communities that live in areas that receive good rains are able to grow some crops and keep a few domestic animals under limited climatic interruptions (Kabanda, 2004). However, changes in rainfall may be associated with poverty increase in some areas. In Southern Africa, changes in rainfall have also been observed. For example, Nhemachena *et al.*, (2014) examined perceptions of rural communities on climate and its impacts on livelihoods. The results indicate that more than 64% of the rural communities perceived that the changes in rainfall have adverse impacts on the main agricultural crops such as maize, drought-tolerant crops (sorghum and millet), livestock, and forestry-based activities.

Heavy rainfall has remarkable effects on agriculture and might wipe out entire crops over large areas. Excess water can lead to other effects which may include soil water logging, anaerobicity and reduced plants growth (Gornal *et al.*, 2010). Indirect impacts may include delayed farming operations since agricultural machinery may not easily adapt to wet soil conditions (Kettlewell *et al.*, 1999). Rain-fed crop production is a dominant mode of food production in most of rural South Africa and important export destinations for South Africa's agricultural produce (Cooper *et al.*, 2008) in the SADC region are Botswana, Lesotho, Swaziland, Namibia, Zimbabwe and Mozambique with the last two having been the biggest regional trading partners in the 2009/2010 season (GDP, 2010). For this reason it is important to study heavy rainfall patterns and their variability in line with the agricultural production.

2.2 Heavy rainfall threshold

Heavy rainfall is usually defined using a daily amount exceeding a threshold value (Kharin and Zwiers, 2005; Semmler and Jacob, 2004). However, different threshold values apply for different parts of the world. Different studies have used different approaches to define rainfall thresholds. For example, on daily rainfall, some studies recommend that if there is rain of an amount of 1.0 mm, then it can be said that rain has occurred; the reason being that any rainfall amount of less than 1.0 mm evaporates instantly (Nenwiini and Kabanda, 2013). Bradley and Smith (1994), defined extreme rainfall events on the basis of mean annual number of days where 24-hr accumulation exceeds a given daily rainfall amount. Chen *et al*., (2007) defines a heavy rainfall event in Taiwan when more than 50 mm occurs in 24 h at one or more weather stations and an extremely heavy rain event when 130 mm occurs in a single day. While in southern Portugal, Fragoso and Gomes (2008) identified an extreme rainfall event when 40 mm occurred in 24 h. In South Africa, Dyson (2009) categorised daily heavy rainfall magnitude into three classes. They were classified based on the area-average rainfall, such that; a significant rainfall event is defined when the average rainfall exceeds 10 mm, a heavy rainfall event is when the average rainfall exceeds 15 mm and a very heavy rainfall event the average rainfall exceeds 25 mm. All these are considered in a 24-hour period of occurrence.

Heavy rainfall may be defined by interpretation of the gridded model output. Examples of recent inter-comparative studies of daily rainfall characteristics and extremes using this approach include Kharin *et al*., (2007), Sun *et al*., (2006), and Tebaldi *et al*., (2006). It is noteworthy that gridded observational analyses, even with relatively high resolution, already involve spatial interpolation and thus should represent an underestimate of extreme daily rainfall as compared to the point measurements. If the model grid precipitation data are treated as "areal averages" assigned to the centre point of the model grid boxes, one should first interpolate the model and observation data to a common grid and then compute the extreme rainfall indices for model evaluation. The same procedure should apply when two models with different resolutions are compared. Otherwise, the disagreement between two datasets could be solely due to the different grid size. The studies by Osborn and Hulme, (1998), and Iorio and Morena, (2004) adopted this assumption for model evaluation. This second approach also leads to the general notion that daily station rainfall data, by their nature as point measurements, are not directly comparable to the gridded model output (Hegerl *et al*., 2004; Tebaldi *et al*., 2006).

Climate studies of extreme events have used multiple models to further address the issue of possible model dependence and to provide a range of uncertainty from different model formulations (Hegerl *et al*., 2004; Kharin and Zwiers, 2005; Tebaldi *et al*., 2006). It has been acknowledged that the comparison between model grid output and station data is not straightforward (Kiktev *et al*., 2003; Hegerl *et al*., 2004; Wehner 2004) and that calculations of precipitation extreme indices could be sensitive to model resolution (Kharin and Zwiers, 2005).

Use of satellite images is known as a new technique to map and monitor heavy rainfall events and their impacts on vegetation cover. On the other hand, rainfall plays a key role on the condition of vegetation cover. Special distribution of land surface type has direct relationships with climatic conditions. Among different climatic factors, rainfall is considered as important and effective in rate and distribution of vegetation in semi-arid areas (Klein and Roehrig, 2006).

2.2. Remote sensing application

Remote Sensing (RS) could be generally defined as the science of acquiring information about the Earth's surface without actually being in contact with it (Canada Centre for Remote Sensing) (Baltsavias and Gruen, 2003). This is done by sensing and recording reflected or emitted energy from the solar system or sensor itself and the processing, analysis, and application of that information. Generally, the central concept of remote sensing includes the gathering of information at a distance and a science of detecting, acquiring and interpreting the change in incident radiation after interacting with an object (Campbell, 2002). The use of remote sensing techniques has great advantages because of their characteristics in the application to monitoring, evaluating and forecasting any change in vegetation. By using remote sensing techniques, the user can grasp the present situation, evaluate processes such as soil erosion and land degradation trends on a macroscopic scale, and also provide a scientific basis for the prevention and administration of vegetative change.

Change detection as defined by Hoffer (1978) means revealing any changes in temporal effects such as variation in spectral response and involves situations where the spectral characteristics of the vegetation or other cover type in a given location change over time.

Singh (1989) described change detection as a process that observes the differences of an object or phenomenon at different times. Over the years, a number of change detection techniques (image differencing, post classification comparism, hybrid change detection and image ratioing) have been developed and widely used for monitoring land vegetation cover changes. Numerous researchers have discussed the strengths and weaknesses of each of these technique (Singh, 1989; Nelson, 1983; Lu *et al*., 2004). Because of the impacts and interpretation of complex factors, different authors often arrived at different and sometimes controversial conclusions about which change detection techniques are most effective. In practice, it is not easy to select a suitable algorithm for a specific change detection project. Hence, a review of change detection techniques used in previous research and applications is useful to understand how these techniques can be best used to help address specific problems. When the study areas and image data are selected for research, identifying a suitable change detection technique becomes of great significance in producing good quality change detection results.

Many change detection techniques have been developed to detect vegetation change using remote sensing data (Cakir *et al*., 2006). However, despite the wide diversity of algorithms currently available, all of these techniques can usually be separated into two main categories: post-classification spectral change detection and pre-classification change detection. Post-classification methods involve the independent thematic classification of two different images taken on two different dates. Thematic maps are then further compared and analysed to map any type of changes uncovered (Jensen, 1996). Pre-classification spectral change detection involves the analysis of transformed images from two different dates. The transformation of different date images is the product of several specialized operations, among them multi-date image differencing, principal component analysis (PCA), normalized difference vegetation index (NDVI) differencing, etc. The transformed image contains spectral information about the changes taking place within the imagery, which then requires further processing to develop thematic change maps.

NDVI differencing is one of the most commonly applied pre-classification change detection techniques (Cakir *et al*., 2006; Klintenberg and Kruger, 2007). It utilizes NDVI images in which vegetated areas are spectrally enhanced using ratios or differences between red and near-infrared bands within an image by taking advantage of the different absorbance and reflectance characteristics of the vegetation in those bands (Jensen, 1996). Areas of change can be identified through the subtraction of the NDVI image of one date from the NDVI image of another date.

The studies on NDVI differencing have been done in Africa (Anyamba *et al*., 2002; Wessels *et al*., 2004; Scholes and Biggs, 2004). For example Anyamba *et al*., (2002) studied El Nino and La Nina events using NDVI anomalies over east and southern Africa during the period 1997-2000. Results detected a distinct contrast in vegetation anomalies during the warm 1997/98 and cold 1999/2000 ENSO events and an inverse relationship between SSTs of the central Pacific and NDVI anomalies over southern Africa were determined. A similar inverse relationship between southern African rainfall and Pacific SSTs has long been established. NDVI anomalies were used in Anyamba *et al*., (2002) to show that the drought of 1997/98 over southern Africa was not as severe as previous droughts associated with warm ENSO events. Anyamba and Eastman (1996) determined that vegetation variability over southern Africa is largely modulated by the ENSO phenomenon at time scales ranging from 4-7 years. Wessels, (2004) used NDVI to investigate land degradation in the Limpopo province of South Africa. The study looked at applicability of using coarse scale satellite imagery to identify degraded areas in certain zones of land capabilities in the Limpopo province. It was concluded that coarse scale NDVI data was suitable for identifying degraded human induced land cover changes in most of the land capability tested.

2.4 Rainfall and vegetation cover

Rainfall plays a key role on the condition of vegetation cover; hence, a detailed understanding between rainfall and vegetation dynamics is very important. To achieve a better understanding of the relationship between precipitation patterns and vegetation dynamics, several studies have analysed time series of precipitation data and vegetation indices like NDVI (Al-Bakri & Suleiman, 2004; Budde, *et al*., 2004; Richard and Rocard, 1998). NDVI is a measure of vegetation reflectance to visible band satellite sensor indicating vegetation cover. High reflectance is linked to green and vibrant vegetation while lower reflectance refers to brown vegetation or bare surface. NDVI has proven to be a robust indicator of biomass production and photosynthesis activity and has been related to rainfall (Gunnula *et al*., 2011)

Many studies have been carried out for identifying the relationships that could exist among different climatic variables and the vegetation characteristics. NDVI is found to be well correlated with physical climate variables such as rainfall (Cihlar *et al*., 1991). These relationships could vary in different regions across the world. Justice *et al*., (1985) showed that the application of the vegetation index approach provides unique insights on vegetation dynamics from regional to continental and global scales. Gondwe and Jury, (1997) investigated the sensitivity of vegetation to the summer climate over southern Africa using relationships between NDVI and satellite OLR as a measure of convective rainfall. As expected, they determined a significant inverse relationship between OLR and NDVI. The study found that the Zambezi Valley is less sensitive to climate impacts than the southern plateau, whilst the late summer is more sensitive than the early summer. The NDVI value reaches a minimum over southern Africa in September and rises sharply during October but is less variable during the austral summer. Jury *et al*., (1997) also established that vegetation-climate relationships are strongest during the late summer. Jury *et al*., (1997) used NDVI data as an indicator of climate variability over southern Africa. The study justified the use of NDVI as a measure of food production and obtained a time series analysis of area-averaged NDVI for crop growing districts of four countries in southern Africa: Namibia, Zimbabwe, Botswana and South Africa. The NDVI values were at their lowest corresponding to the worst droughts of 1982/83 and 1991/92. Correlations of NDVI values with maize yields were as high as 85% over a 13-year period.

Wang *et al*., (2001) studied spatial response patterns of NDVI to rainfall and temperature in the central Great Plains of the United States. The intraseasonal analysis of bi-weekly NDVI was of particular relevance to this study. It was established that precipitation is a useful predictor of NDVI and productivity and that temperature was not strongly correlated with NDVI in the central Great Plains (Wang *et al*., 2001). Davenport and Nicholson (1993) studied the relationship between rainfall and NDVI for East Africa and determined that the NDVI-rainfall relationship is strongest over the semi-arid bush land/thicket or shrub land zones but the wetter woodlands exhibit little correlation. The strongest correlation occurs for monthly NDVI and three-month mean rainfall for the two preceding months. The study suggested that a point of saturation is reached after which NDVI does not increase even with increasing rainfall.

It is recognised that NDVI data has only been available since the 1980s and hence previous studies used a limited set of data e.g. 1982-1985 in Davenport and Nicholson (1993), 1982-1987 in Farrar *et al*., (1994) and 1997-2000 in Anyamba *et al*., (2002). The data series used in these studies are too short to obtain conclusive results as regards interannual variability. Most studies over southern Africa have used monthly NDVI data (Gondwe and Jury, 1997; Jury *et al*., 1997; Anyamba *et al*., 2002) which is a coarse resolution to obtain useful responses at intraseasonal time scales.

2.5 Summary

This chapter defined heavy rainfall events and their impacts on vegetation cover. Relevant literature review on existing knowledge on remote sensing applications has also been presented. It has been determined in literature that NDVI has proven to be a robust indicator of biomass production and photosynthesis activity and has been related to rainfall. Various methodologies which are mainly statistical were employed in order to achieve the objectives of this study. This includes basic statistical techniques such as the mean and standard deviation used to determine heavy rainfall events and other remote sensing techniques which are discussed in detail in Chapter 3

CHAPTER 3

3. MATERIALS AND METHODS

This chapter presents the types of data and methods used in order to investigate the impacts of heavy rainfall on the vegetation cover in the study area. The main sources of data for this study include rainfall and remote sensing data. The chapter gives a detailed account of the sources and types of data, the methods of collection as well as the various analytical techniques employed in the study. In addition, it justifies the data analysis techniques employed to achieve the objectives of the study.

3.1 Data sources

Data sources include climatic data (daily and monthly rainfall data) and remotely sensed data.

3.1.1 Rainfall data

The data used in this study consists of daily and monthly rainfall from stations within Vhembe and Mopani District of the Limpopo Province and it was provided by South African Weather Services (SAWS). Although the area receives rainfall during summer and winter seasons, this study investigate the impacts of heavy rainfall on the vegetation cover during the summer rainfall season (October to March) because the districts experience most rainfall during summer season with peak in January and February. Rainfall data for this study is for the period of 50 years, from 1961 to 2011. The period of 50 years is long enough to comply with the World Meteorological Organisation (WMO) requirements (Singo, 2008). WMO define climate normal by convection that the mean of climatological variables should be over a 30-year period or more.

All rainfall stations around Vhembe and Mopani District were investigated. However, only rainfall stations with records from 1961 to 2011 were used in this study. For validation purposes data from selected stations with records spanning shorter periods were included in this study. Also, this was used mainly to capture data in cases where rainfall stations were replaced by new stations, with slightly different locations. Within the study period however, some rainfall stations had gaps because reporting was started late or rainfall was missed for some days. The gaps were filled using the interpolation from data of the nearest high correlating neighbouring stations. This is in agreement with the suggestions made by Nyenzi, (1984) and it helps to minimise the unwanted spatial inhomogeneity.

Rainfall data used was extracted from 30 stations in Vhembe and Mopani District that had recording period from 50 years (1961 to 2011) and beyond. The rainfall stations used in the study are presented in Appendix 1.

3.2. Methods of analysis

This section presents the analysis techniques used in analysing rainfall data such as time series analysis and remote sensing techniques (satellite images) in order to achieve the specific objectives of the study.

3.2.1 Rainfall time series

Time series analysis has two goals; modelling random mechanisms and predicting future series using historical data (Meher and Jha, 2013). Mean seasonal rainfall was obtained by summing the corresponding mean monthly rainfall, which was originally derived from different rainfall datasets. Different data sets were then averaged to produce a representative area-rainfall (period 1961 to 2011). Thereafter, the data was standardised to remove local effects, which could easily influence the variation in rainfall. The main local influences include the area orographic conditions and features of landscape configuration. Standardisation was used by computing monthly long term mean and standard deviation to produce standardised rainfall data for the areas. This process was used to identify wet and dry periods within the study period. The anomalies with positive values feature wet spells while those with negative values imply dry spells. Anomalies with values greater than +1 are termed extreme wet spells while those with lower than –1 are termed dry spells. Mean rainfall was calculated using Equation 1:

$$\overline{X} = \frac{\sum x_i}{n} \qquad \text{(Equation 1)}$$

where: $\overline{X}$ = arithmetic mean,

x_i = series of rainfall data set

n = number of observations.

In this study x_i represents rainfall data while n is the number of observations which is 50-years

The standard deviation was computed using Equation 2:

$$\sigma = \sqrt{\frac{\sum(\bar{x} - x)^2}{n-1}} \qquad \text{(Equation 2)}$$

where: σ = Standard deviation

Σ = Sum

$\bar{x}$ = Mean

From equation 1 and 2

$$Z = \frac{(x_i - \bar{x})}{\sigma} \qquad \text{(Equation 3)}$$

Where:

Z = standardised anomaly index ; x_i = series of rainfall data set; σ = historical sample standard deviation; $\bar{x}$ = Mean

3.2.2 Rainfall threshold

The Limpopo Province of South Africa which includes Mopani and Vhembe Districts experiences summer rainfall at the same time as the Gauteng province (October – March) (Kabanda, 2004; Reason and Keibel, 2004; Dyson, 2009). Also, the rainfall systems that affect both Limpopo and Gauteng provinces during summer are the same. These systems include synoptic circulation such as deep low pressure and associated troughs at 850 hPa (Dyson, 2009). Another synoptic feature that usually plays a major role in influencing the rainfall over both Limpopo and Gauteng Provinces is when the Indian Ocean high pressure system advects warm moisture towards the western side of the Ocean that eventually reach the said provinces (Kabanda, 2004). Apart from the synoptic weather system’s effect on these two provinces, the other factor is their proximity to each other. Therefore, this study adopted the definitions of heavy rainfall as proposed by Dyson (2009) for Gauteng Province. The study suggested that, for a significant rainfall event to occur, the average areal rainfall should exceed 10 mm; while a heavy rainfall event is when the average rainfall exceeds 15 mm and a very heavy rainfall event the average rainfall exceeds 25 mm in 24-hours. However, South African Weather Services issues advisories and warnings for heavy rainfall when more than 50 mm of rain is expected at any location (Rae, 2008). Therefore, in this study 25 mm areal average rainfall threshold was adopted with at least 50 mm at a single station.

It is of significance to spend some time performing quality control on the data. The raw rainfall data from SAWS have possible error information. Brooks and Stensrud (2000) explained how difficult it is to distinguish between rare interesting rainfall events and bad data, as these often look similar. Therefore, rainfall events where 24h rainfall at specific stations exceeded 75 mm and 115 mm were investigated for possible errors. It does happen from time to time that rainfall which was accumulated is not identified as such at raw data set. This was easily identified when there was missing data at one or more days of data sets followed by a day reporting very heavy rainfall.

After comparison with rainfall from surrounding stations, high rainfall value would then be accepted depending on whether the other stations received similar rainfall on that day. Errors were also removed from the data in the case where stations reported very heavy rainfall (75 mm and 115 mm) for several consecutive days while there was no indication from surrounding stations that this was also experienced. When rainfall at any station in Vhembe and Mopani Districts exceeded 75 mm and 115 mm on a particular day, the rainfall values at other stations were also analysed and compared. If the other stations reported high percentage of rainfall, the value was then accepted and used for analysis.

3.3 Remote sensing data

Remote sensing satellite data provide researchers with an effective way to monitor and evaluate land cover changes (Cleve *et al*., 2008). Map productions using satellite data benefit from all the advantages related to the use of digital data, its periodical acquisition, and coverage of large areas at a relatively low cost. Landsat TM images (30 m spatial resolution) were selected to determine the vegetation cover change. Selection of images was based on heavy rain events i.e. before heavy rainfall and after heavy rainfall episodes. Major floods occurred in 1996, 2000 (Nethengwe, 2007; Kabanda, 2004), 2006 and 2011 (Zuma *et al*., 2012). The Landsat TM images are acquired in the same season in order to minimise the impacts of seasonal differences of vegetation (Guo, 2011).

The procedure adopted in this research is shown in Figure 3 and forms the basis for deriving statistics of vegetation cover dynamics.

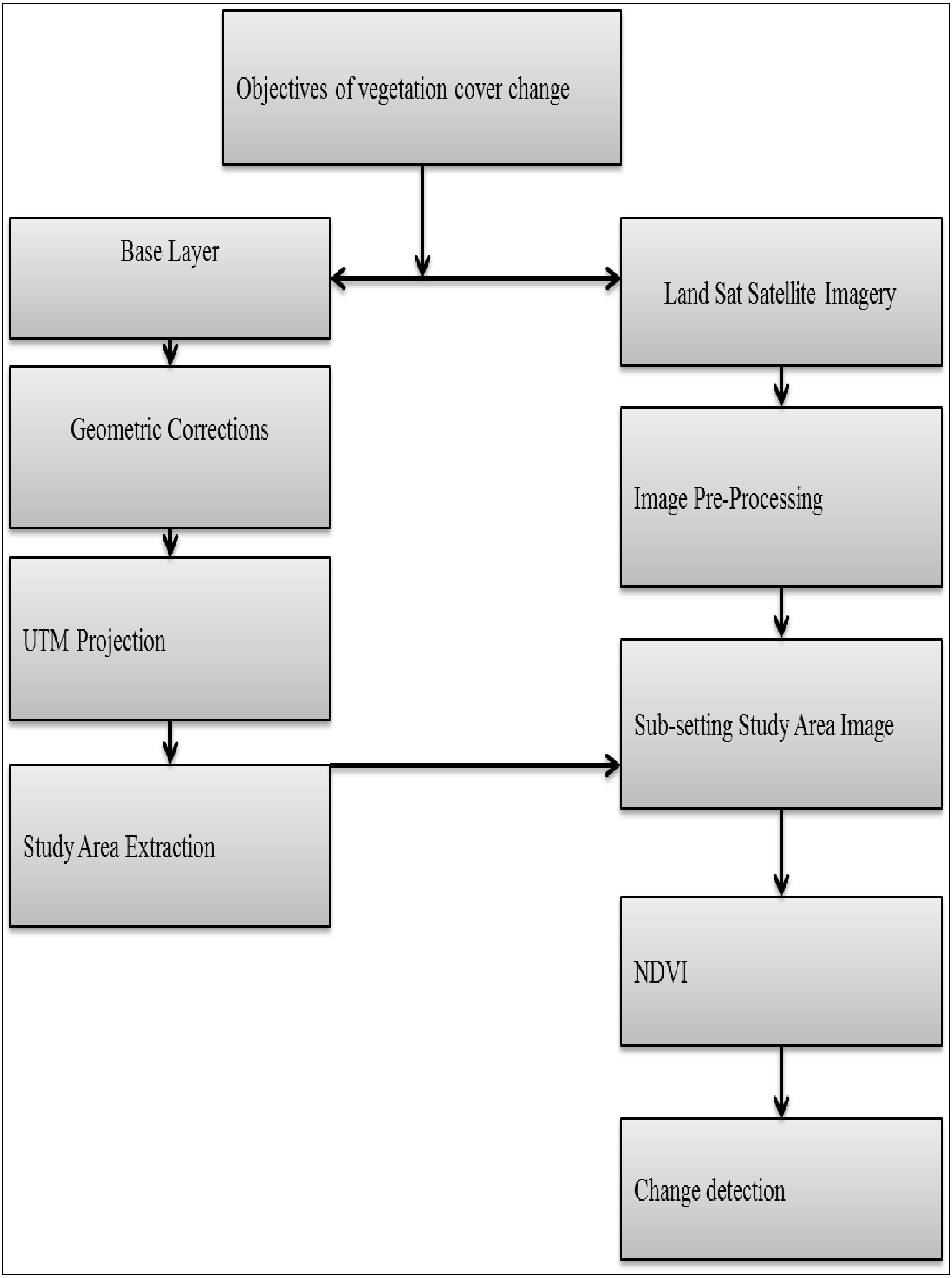

Figure 3: General sequence of land cover change analysis

3.3.1 Selection of satellite images

Landsat TM imagery 1995, 1997, 2005, 2007, 2010 and Landsat 8 OLI 2013, level 1G, were obtained from USGS. However, within the constraints of a limited number of suitable images in the archives, a strategy for selecting Landsat imagery for the development of vegetation cover maps for Vhembe and Mopani District was governed by cost free multi temporal images, vegetation phenology and image quality (cloudiness). Due to the amount of cloud cover during rainfall season and the period following heavy rainfall events, the satisfactory images were not obtained. Thus, the images obtained were for the winter season. Hence, May, June and July satellite images were chosen, as the images are cloud free, rainfall has diminished (Kabanda, 2004) and the effect of rainfall on vegetation is clearly visible on the image. Climate of the study area is semi-arid and receive mean rainfall of 450 mm occurring in summer and a marked dry winter season. Therefore cloud free satellite images are mainly available during cool dry period of May to August (Palamuleni *et al.*, 2011). All data were processed and projected to UTM (Universal Transverse Mercator) projection system. Table 1 shows the detailed description of the Landsat imagery that were obtained for use in this study.

Table 1: Characteristics of Vhembe and Mopani satellite images

Acquisition date	Satellite	Sensor	Path & Row	Resolution
30/06/1995	Landsat 4-5	TM	169/76	30m
02/07/1996	Landsat 4-5	TM	169/76	30m
05/07/1997	Landsat 4-5	TM	169/76	30m
09/06/2005	Landsat 4-5	TM	169/76	30m
12/07/2006	Landsat 4-5	TM	169/76	30m
17/07/2007	Landsat 4-5	TM	169/76	30m
06/05/2010	Landsat 4-5	TM	169/76	30m
10/06/2011	Landsat 4-5	TM	169/76	30m
08/07/2013	Land sat 8	TM	169/76	30m

3.3.2. Image processing

Pre-processing is aimed at correcting distorted or degraded data to create a more faithful representation of the original scene. This typically involves the initial processing of raw image data to correct for geometric distortions, atmospheric correction or normalization, image registration, and masking and to eliminate noise present in the data (Cheng *et al*., 2004). ERDAS 2014 and Arc GIS software were used for image processing in this study.

3.3.2.1 Geometric rectification

In order to match the pixel grids and remove any geometric distortions in the imagery, the first TM images were registered to a UTM map projection using a nearest neighbour resampling routine. Image-to-image registration was done to co-register all of the images to the base image with a Root Mean Square (RMS) error of less than 30 meters.

Landsat 8 OLI image (April 26, 2013) was registered to a UTM map projection (zone 35S, datum WGS84) using a nearest neighbour resampling routine to conform the pixel grids and to remove any geometric distortions. Based upon 15 GCP collected from topographic map (1:50 000), the resampling process maintained the original 30m resolution. The 1995, 1997, 2005, 2007 and 2010 images were co-registered to the 2013 image utilizing similar sets of GCP. In this study, the resultant root mean squared error (RMSE) was found to be 0.48 pixels. Several authors recommend a maximum tolerable RMSE value of 0.5 pixels (Sahebjalal *et al*., 2013; Jensen, 1996), but others have identified acceptable RMSE values ranging from 0.1 pixels to 0.2 pixels, depending on the type of change being investigated (Townshend *et al*., 1992).

3.3.2.2 Image subset

Landsat scenes, in some cases are much larger than a project study area. It is thus beneficial to reduce the size of the image file to include only the area of interest. This is important when utilizing multiband data. This reduction of data is known as sub-setting. Sub-setting the study area eliminates the extraneous data in the file and speeds up processing due to the smaller amount of data to process. This process cuts out the preferred study area from the image scene into a smaller more manageable file (Ó Fernández-Manso, 2015). In order to subset the study area from each of the Landsat scenes, a vector file defining the municipal boundaries (provided by Municipal Demarcation Board) with the same geo-referenced coordinates as the Landsat images (UTM zone 35S, datum WGS84) was imported into ERDAS imagine software. Figure 4 shows the subset of Landsat imagery with special focus of Vhembe (Thulamela) and Mopani District (Greater Giyani).

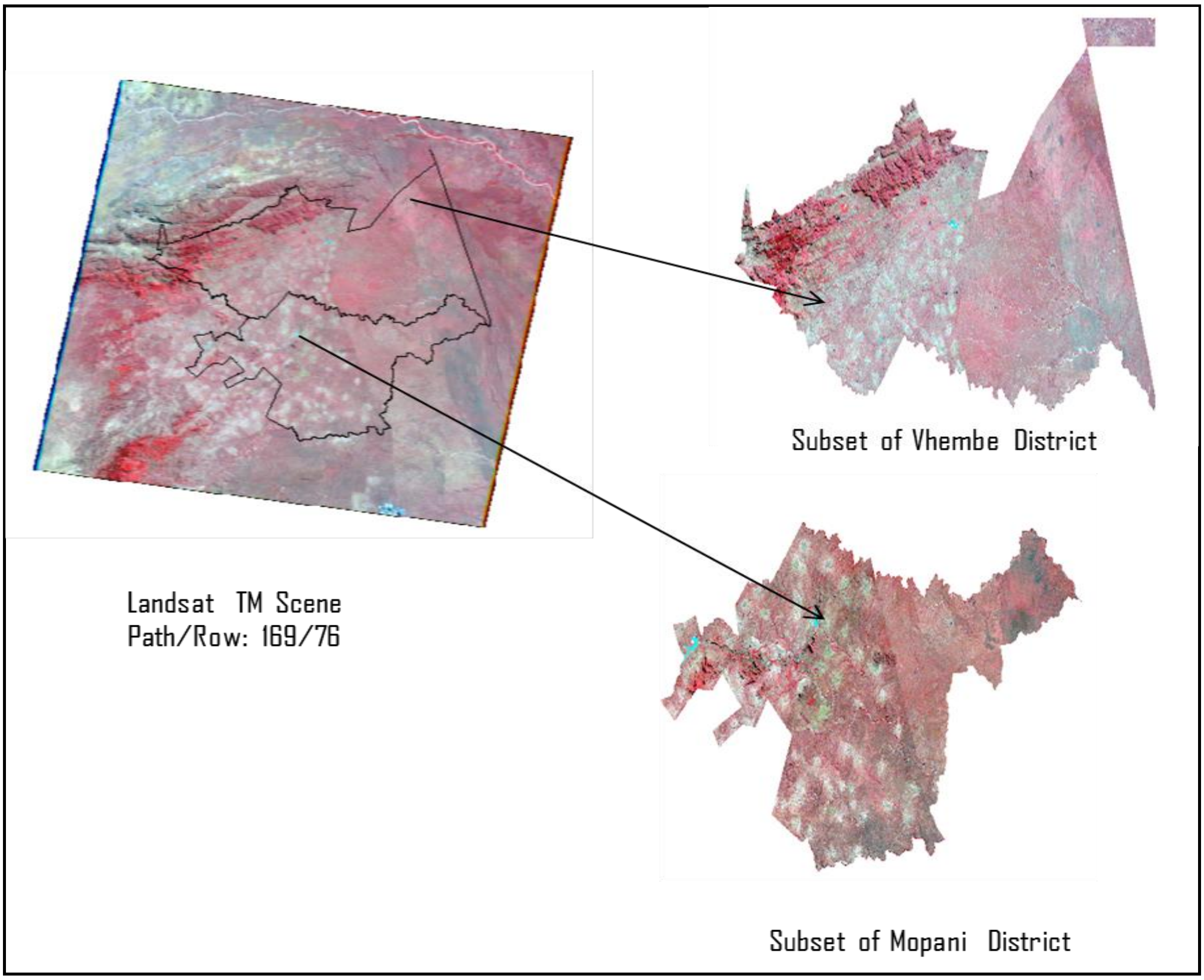

Figure 4: Subsets of Vhembe and Mopani districts

3.3.2.3 Image enhancement

Image enhancement involves improving the interpretability or perception of information in images for providing better input for other automated image processing techniques (Maini and Aggarwal, 2010). During this process, one or more attributes of the image (histogram equalise, histogram matching, logarithm transformation and threshold transformation) are modified. Histogram equalisation approach was employed to obtain the best visual display for interpretation and analysis. This method is desirable to find a point of transformation that transforms the original image into an enhanced image with a uniform histogram and individual images for the study area were therefore enhanced.

3.3.3 Normalized Difference Vegetation Index (NDVI)

Numerous vegetation indices have been developed to estimate vegetation cover from remotely sensed imagery. The vegetation index is a number that is generated by some combination of remote sensing bands. The most common spectral index used to evaluate vegetation cover is the NDVI (Geerken *et al*., 2005). The NDVI is derived from the red – near infrared reflectance ratio. The formula is based on the notion that chlorophyll accumulating within leaves of healthy green vegetation absorbs red wavelengths, whereas the mesophyll leaf structures and water within the leaf scatter near infrared. NDVI uses a set of transformation using Near Infrared (NIR) and Red bands (RED) as shown in Equation 4

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad \text{(Equation 4)}$$

NDVI values, which are unit less, range from –1 to +1, where positive values yield high amounts of vegetation, both deciduous and otherwise, whereas negative values correspond to sparse or non-existent vegetation, bare soil and clouds. For this study Landsat TM 4-5 was defined by (band4 –band3)/(band4 + band3), whereas for Landsat 8 OLI, (band 5 – band4)/(band5 + band4) is used to define NDVI for Vhembe and Mopani Districts (Jensen, 2005). In the resultant NDVI difference images, changes can be detected by the lower-end and higher-end tails of the NDVI difference-image pixel distribution histogram. However, several studies (Cakir *et al*., 2006; Klintenberg *et al*., 2007) have shown that NDVI techniques produce limited discriminating abilities in areas less dominated by vegetative ground cover types. For this reason, the NDVI difference images were density sliced to the four categories included: area with low, medium, high and very high NDVI values.

3.3.4 Classification accuracy assessment

Accuracy assessment is an essential and most crucial part of studying image classification. Vegetation cover maps derived from remote sensing always contain some sort of errors due to several factors, which range from classification technique to method of satellite data capture. In this study, accuracy assessment was derived using the Error Matrix and Kappa statistic, which are considered as the standard descriptive and discrete multivariate statistics respectively, in the remote sensing field (Fan *et al*., 2007). Error Matrix is also referred to as confusion matrix or contingency table expressed as the number of sample units such as pixels, clusters of pixels or polygons, which are assigned to a particular category relative to the actual category as indicated by the reference data (Singh, 1989). The basic principle of the Error Matrix is to compare two pixels or polygons in a remote sensing-derived classification and ground reference test information (Jensen, 2006). Ground truthing describe the process of verifying a satellite image with what is already known about the location on the ground. This was done using aerial photographs and field site information. The reason for using aerial photograph as reference data is because the satellite imagery that was used in this study dated 10 years, the interpretation and classification based on them could not be entirely checked against ground truth only. To assess the accuracy of each land-cover classification, a set of reference points was generated from ERDAS IMAGINE software, to compare NDVI density classification in the final thematic map.

3.3.5 Change detection

Change detection is used to compare images before and after information of changes in vegetation cover in the study area using an image differencing change detection approach. Image differencing is a technique that refers to subtracting a pixel's Digital Number (DN) on one date from corresponding pixel's DN on the second date, and produce a residual image which represents the change between the two dates (Singh, 2010). The basic premise for image differencing is that subtraction results in an image data set where values less than or greater than zero indicate areas of change (Jensen, 1986; Dobson *et al*., 1995). Image differencing is computationally simple, and threshold values can be easily modified for classification improvement (Muchoney and Haack, 1994). Lyon *et al*., (1998) compared seven vegetation indices from three different dates of MSS data for land cover change detection and concluded that NDVI differencing technique demonstrated the best vegetation change detection.

3.4 Correlation analysis

Correlation is the statistical technique which enables one to measure and determine the strength of relationship between two variables (Nikolić *et al*., 2012). Correlation analysis can help in assessing the degree of event to which one variable really influences another (Singo, 2008). In this study, correlation analysis was used to evaluate the relationship of derived heavy rainfall events and vegetation cover change. The formula for correlation co-efficient is expressed by Equation 5

$$r_{xy} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 (y_i - \bar{y})^2}} \qquad \text{(Equation 5)}$$

where: r_{xy} = Correlation co-efficient

x_i = Sum of the first variable (in this case rainfall)

y_i = Sum of second variable, (in this case NDVI)

$\bar{x}$ = Historical mean for rainfall

$\bar{y}$ = Historical mean for NDVI

Correlation co-efficient values range between -1.0 and +1.0. If the two variables were perfectly correlated, the correlation coefficient expressing the relationship would be 1.0. When the two variables are totally unrelated, the correlation coefficient is equal to zero. When there is a perfect inverse relationship between the variables, the correlation coefficient will be equal to -1. The correlation coefficient of 0.75 to 0.99 indicates a high degree of relatedness (Mashile, 2002).

3.5 Summary

This chapter outlined the materials and methods used and gave an elaborate explanation of the various steps used to execute the meteorological data (rainfall) and change detection analysis. Statistical techniques used here for computation of meteorological data analysis included the mean, standard deviation and correlation analysis.

CHAPTER 4

4. METEOROLOGICAL RESULTS AND DISCUSSION

This section presents the results and discussion of seasonal and daily rainfall analysis from Vhembe and Mopani District. Rainfall time series and heavy rainfall events are discussed. The results are presented in the form of tables, line and bar charts.

4.1 Seasonal rainfall characteristics 1961-2011

This section investigates rainfall characteristics observed in the study area by analysing the areas' mean seasonal rainfall data and to get a general picture of the mean pattern of the rainfall for the region. Daily rainfall data from the 30 rainfall stations of Vhembe and Mopani District for the period of 50 years (1961-2011) were computed into monthly rainfall data. The monthly rainfall data was then used to calculate average rainfall values for rainfall season of October to March for Vhembe and Mopani District as depicted in Figure 5. Monthly rainfall in this study is the main input for Standardise Precipitation Index (Narendra, 2008).

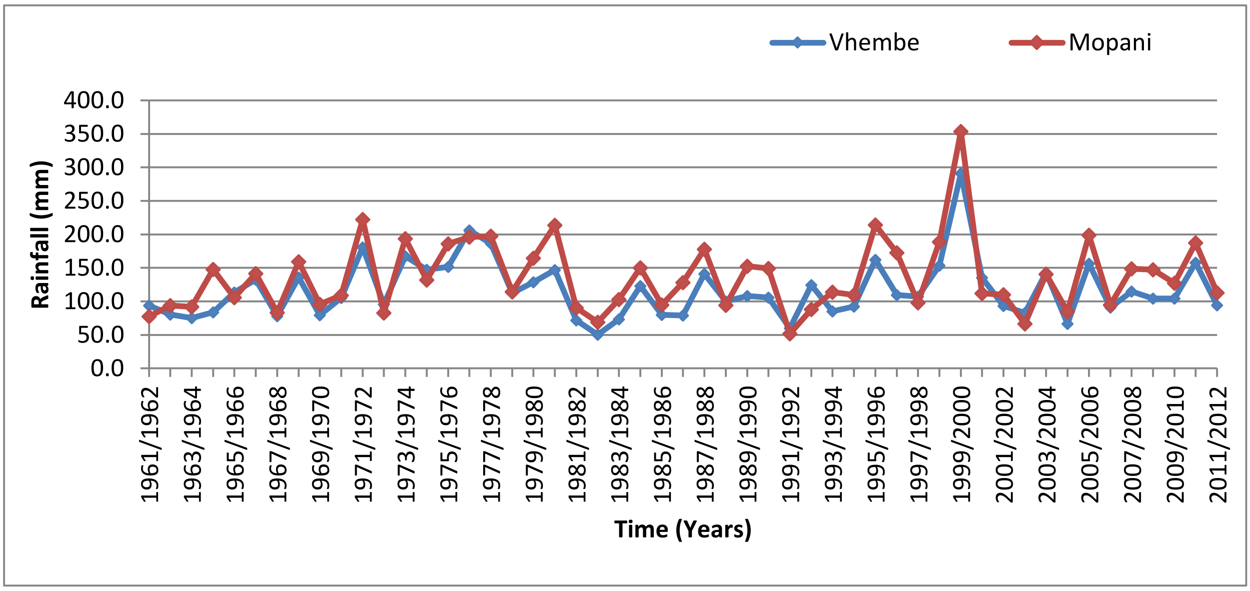

Figure 5: Vhembe and Mopani District rainfall time series

Figure 5 shows that the highest seasonal rainfall recorded in Vhembe District between 1961 and 2011, is 290.6 mm, that occurred in 1999/ 2000 season. The second highest rainfall was recorded in 1976/1977 with 208 mm of rainfall. The season which recorded the lowest rainfall was 1981/1982 with 50.5 mm, followed by 1991/1992 (59.5 mm). The mean seasonal rainfall was 116.0 mm with 62% of the study period recording above 100 mm.

Figure 5 is superimposed with Mopani District rainfall time series, however, the district features fewer rainfall stations compared to the Vhembe District. The reason for using few of Mopani District stations is that, most of the stations did not have records for the period of 50 years, while some of the stations had changed and had not been replaced. It is evident in Figure 5 that Mopani District recorded the highest seasonal rainfall of >353 mm during 1999/2000, and the second highest rainfall was recorded during 1971/1972 (222.5 mm). The lowest rainfall was recorded in 1991/1992 (51.7 mm) followed by 1982/1983 season with rainfall of 69.8 mm. The mean seasonal rainfall for all years from 1961 to 2011 is 122.6 mm with 75% of the study period recording above 100 mm.

4.1.1 Rainfall anomalies

This sub-section analyses the rainfall anomalies in order to determine quantitatively the level of departure from the expected seasonal rainfall. Seasonal rainfall anomalies were obtained using seasonal (October–March) mean, long term and standard deviation (See Equation 3) to produce standardised (anomalies) time series with respect to area rainfall for the period of 50 years (1961-2011). Anomalies are good indicators of extreme events such as floods or droughts.

The anomaly identifies events of normal, below normal or above normal with respect to the area rainfall. Mashile (2002) explained that the below normal condition means the rainfall amount received was less than the long term mean while an above normal condition means that the rainfall amount was much higher than the long term monthly mean. In this study the above normal episodes were defined as those years with rainfall anomalies having ≥1 standard deviation from the long term mean and below normal episodes are defined as years when rainfall anomalies are ≤ –1 standard deviation.

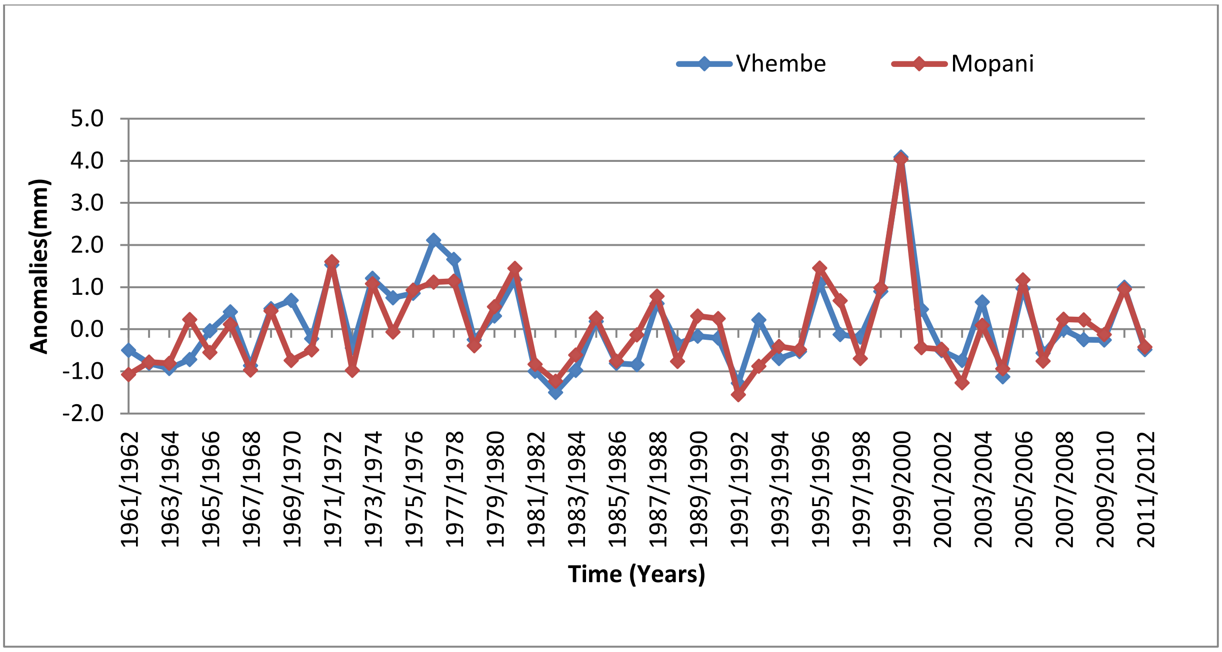

Figure 6: Vhembe and Mopani District rainfall anomalies

Figure 6 represent the standardised seasonal rainfall time series for Vhembe and Mopani Districts. The two districts experienced the wettest season in 1999/2000 and the driest season was 1982/1983 and 1991/1992. It is no surprise that the wettest season was 1999/2000 as tropical cyclone Eline invaded Southern Africa in February 2000 (Dyson and Van Heerden, 2001) and was responsible for a wide range of heavy rainfall over the sub-continent including Vhembe and Mopani District. Other particularly wet seasons are 1971/1972, 1973/1974, 1975/1976, 1976/1977, 1989/1980, 1995/1996, 1999/2000, 2005/2006 and 2010/2011. The dry episodes of 1982/1983 and 1991/1992 and 1997/1998 were caused by El-Nino events and they were the most intense. The El-Nino phenomenon takes place when surface temperatures in Pacific Ocean increases anomaly affecting rainfall decreases drastically and lengthening dry period. Boer *et al.*, (1999) stated that the sea surface temperature anomaly has a strong relationship with rainfall anomaly. Other dry years were experienced in 1967/1968, 1972/1973, 1981/1982, 1982/1983, 1991/1992, and 2004/2005 an 2006/2007 seasons.

4.2 Daily rainfall

Daily rainfall for Vhembe and Mopani District was analysed during the rainfall season from October to March during the period of 22 years 1990 to 2012. A sample of 15 rainfall stations from Vhembe and Mopani District were used to determine heavy rainfall events.

Daily rainfall was used to select heavy rainfall events that exceeded 25 mm in 24 hours with at least 50 mm rainfall at individual station (Dyson, 2009). These events might be single or cumulative; for example, if a single heavy rainfall event is preceded by a rainy day/s or is followed by some rainy day/s. Therefore, only rainfall that exceeded 50 mm at individual station and received an areal average of 25 mm for Vhembe and Mopani District were selected as heavy rainfall events and are presented in Figure 7.

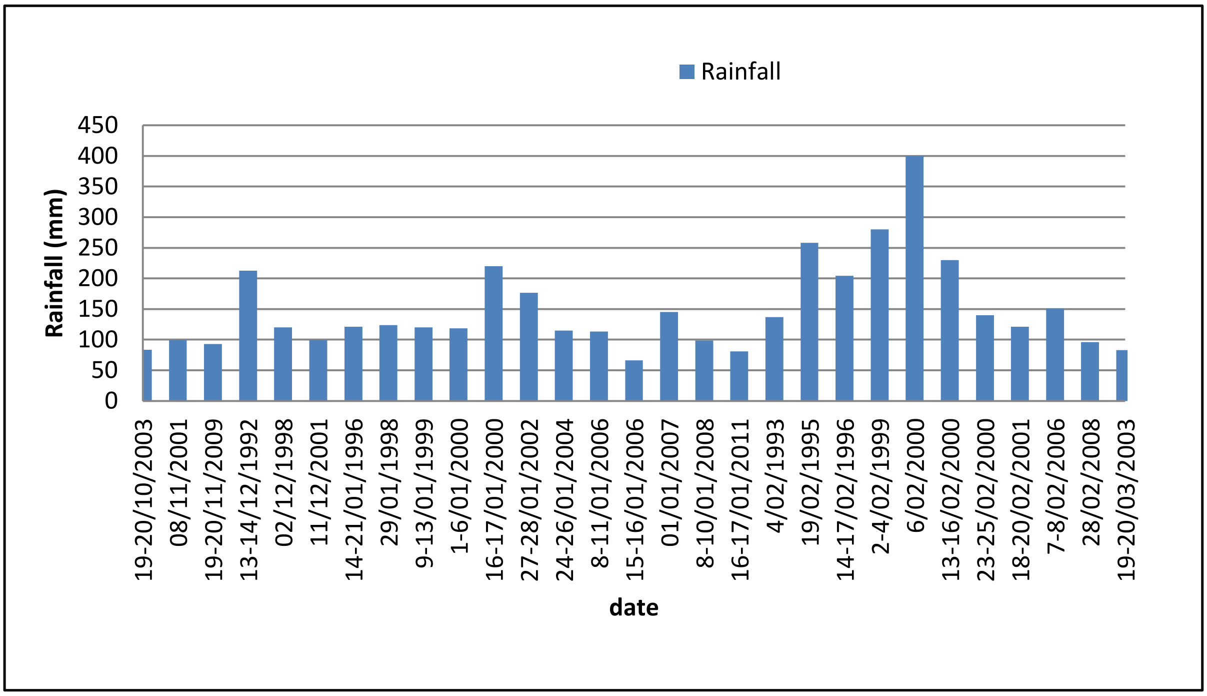

Figure 7: Vhembe daily rainfall events

Figure 7 shows that the highest daily heavy rainfall event occurred on the 06 February 2000 with a rainfall of 400 mm/d. It is evident that year 2000 experienced the highest number of heavy rainfall events where 16 days of heavy rains were experienced during January and February months. January and February months in the year 2000 saw devastating floods in Mozambique, Zimbabwe and Limpopo Province of South Africa. The weather system that contributed to these floods lead to substantially heavy rains which caused year 2000 to be the wettest summer since 1976. The second highest number of heavy rainfall events were experienced in 1996. A total of 11 days experienced heavy rainfall, with eight consecutive days in January and three in February months.

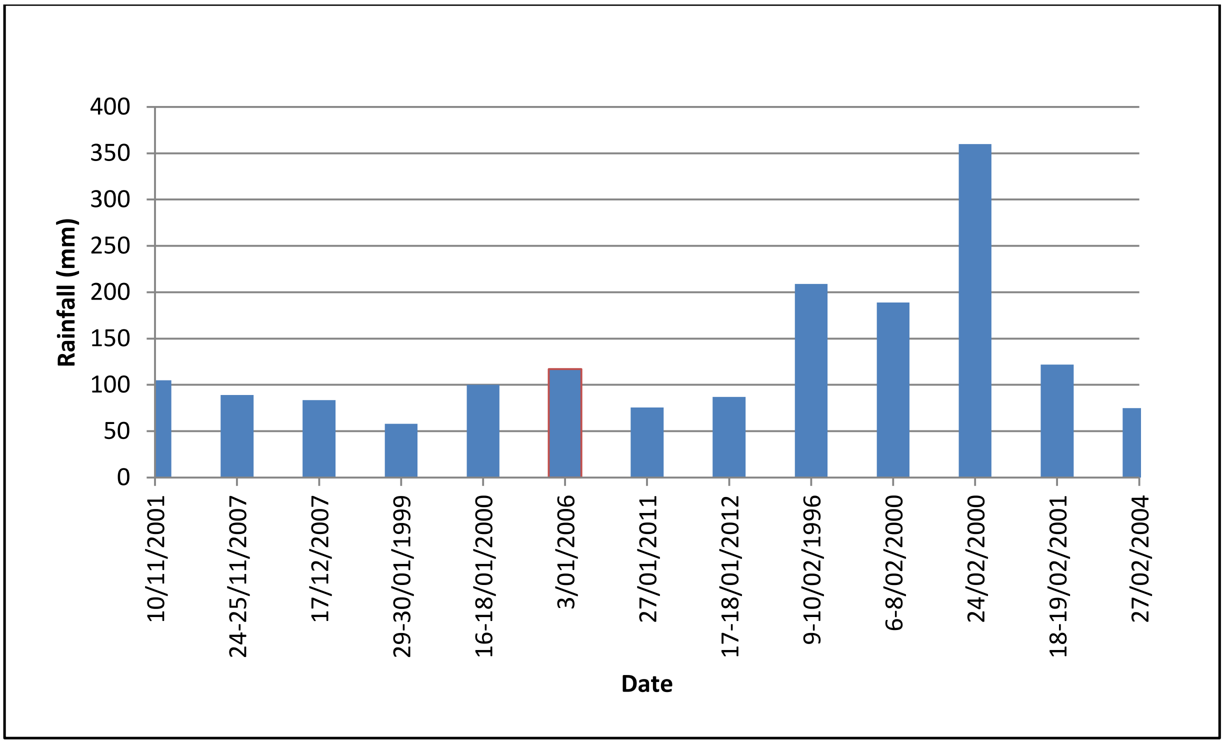

Figure 8: Mopani daily rainfall events

Mopani District experienced the highest daily rainfall on the 24 February year 2000 with a record of 360 mm/d (Figure 8). The second highest daily rainfall events occurred on 9/10 February 1996 (> 200 mm) and then 2006 which reported 117 mm in 24 hours. It is evident that the year 2000 experience highest number of heavy rainfall events with 3 consecutive days in January and 3 days in February months superseded the threshold of 50 mm/d.

Figures 7 and 8 showed heavy rainfall events from 1990 to 2012. The reason for using this period is that, heavy rainfall events are used in the selection of vegetation cover images for Chapter 5; prior to that period images to validate the vegetation cover were not consistently available. It is evident that both Vhembe and Mopani experienced the highest rainfall in the year 2000, followed by year 1996. Vhembe district received 12 days of heavy rains in 1996. The year 2006 received 8 days of rainfall in Mopani which recorded the third highest rainfall events. From these observations, 1996, 2006 and 2011 rainfall seasons were selected as the main heavy rainfall events and used for the selection of satellite images. Due to the amount of cloud cover during the period following a heavy rainfall event, satisfactory images were not obtained for 2000, hence they were not used in this study. Cloud free satellite images are mainly available during cool dry period which is from May to August (Palamuleni *et al.*, 2011). Thus May, June and July satellite images were chosen and used in this study.

4.3 Summary

This chapter presented the results of seasonal and daily rainfall in the form of graphs followed by a discussion and interpretation of the results. Rainfall characteristics of the study area, were investigated by analysing the areas' mean seasonal rainfall data. Subsequently, the daily rainfall was used to select the heavy rainfall events and satellite images for NDVI computation in both Vhembe and Mopani Districts. The subsequent chapter, (Chapter five) is a discussion of the relationship between heavy rainfall events and vegetation characteristics in the study area.

CHAPTER 5

5. VEGETATION COVER CHANGE ASSESSMENT

5.1 Introduction

Chapter 5 examines temporal changes in vegetation cover in Vhembe and Mopani Districts. Using Landsat classifications of NDVI density classes, a discussion of the before and after rainfall events in the study area is presented. Areal statistics and the direction of change in each vegetation density category class were derived. Correlation analysis results of vegetation density and heavy rainfall events are also discussed. The results are presented in the form of tables, bar charts and vegetation density maps.

The NDVI calculations were obtained for all the observation dates before and after heavy rainfall for both Vhembe and Mopani Districts. In order to decide the same division points for all NDVI results, temporary division points of each NDVI result were decided using natural breaks (jenks) algorithm provided by ArcGIS software. This method maximizes the differences between classes. The features are categorized into different classes by inserting divisions where there are relatively big jumps in the data values, if such jumps exist (ArcGIS 2007). NDVI was sliced using five density classes, one for non-vegetation (bare land or water) and four vegetated classes.

According to Gross (2005), very low values (≤ 0.1), correspond to barren areas of rock, sand or water, while moderate values (0.2 to 0.3) indicate shrub and grassland and tropical rainforest are represented by high NDVI values of > 0.4. In this study following the categorization by Gross, (2005), DN values of NDVI classes were categorized as non – vegetated from <0.1, low density from 0.1 to 0.2, medium density from 0.2 to 0.3, high density from 0.3 to 0.4 and very high density from > 0.4. NDVI classes were assigned mapping colours: non vegetation (red), low vegetation (yellow), medium vegetation (light green), high vegetation (green) and very high vegetation (dark green). The idea behind the characterization of NDVI classes is that NDVI is significantly influenced on the forest canopy fraction and vegetation chlorophyll content (Ahn, 2014). Lower NDVI would be expected in lowly vegetated areas that have low chlorophyll, and intermediate NDVI would be identified in evergreen forests having a moderate leaf surface (needles) with a moderate chlorophyll content (Ahn, 2014).

5.1.1. Vegetation density mapping in Vhembe district

The time-series NDVI results for Vhembe District were derived from the obtained Landsat images for analysing the vegetation changes within the study period. The computed NDVI classes ranged from non-vegetation to very highly vegetated areas. The results recorded areas where the vegetation density had increased, decreased or not changed and the outcomes are presented in Figures 9 to 14.

Figure 9 shows the NDVI density classes in 1995 and 1997 in the Vhembe District where non-vegetation and low NDVI density classes experienced an increase from 1995 to 1997. The non-vegetation class increased from 10 829.4 ha (0.2 %) to 605 341.1 ha (9.1 %) and the low density class from 806 821.1 ha (12.1%) to 3 386 621.2 ha (50.8%) from 1995 to 1997 respectively. In contrast, medium, high and very high density classes decreased from 22994471ha (34.4%) to 1696172 (25.5%), 2712913.3ha (40.7%) to 665408 (9.9%) and 836674.1ha (12.6%) to 308166.4ha (4.60%) between 1995 and 1997 respectively.

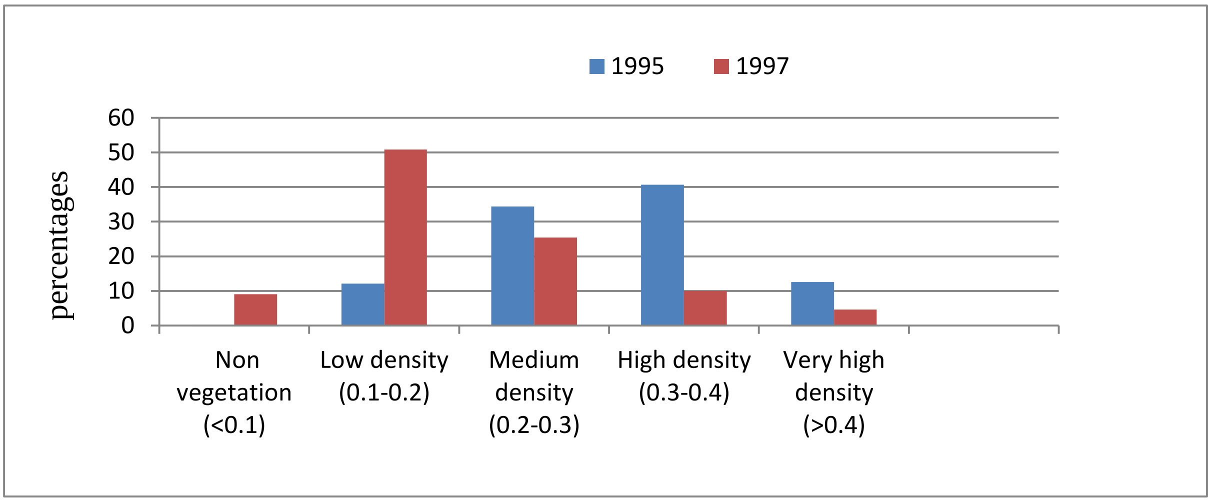

Figure 9: Vhembe District NDVI density categories - 1995 & 1997

Figure 10 shows the spatial distribution of vegetation in 1995 and 1997 for the Vhembe District. The area was dominated by high and very high NDVI density classes, (green and dark green) in 1995, which appear to have been replaced by non-vegetation and low density classes (red and yellow colors) on the central and eastern part in 1997 map. The north western part of the study area however, remained dominated by high and very high density classes.

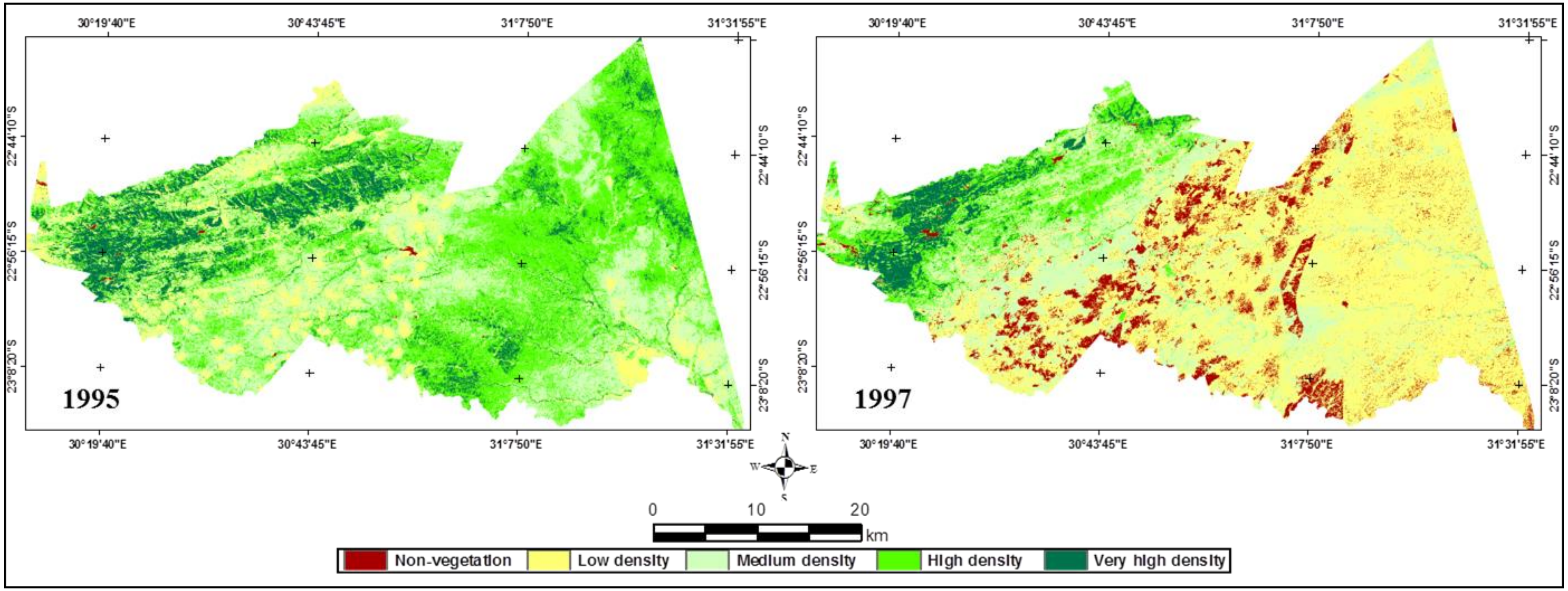

Figure 10: Vhembe District changes of vegetation cover categories: 1995-1997

Figure 11 presents changes of vegetation cover categories from 2005 to 2007 The categories of non- vegetated and low NDVI density classes have decreased from 108 698.2 ha (16.3%) to 26 150.0 (0.3%) and from 2 561 849 ha (38.5%) to 2 250 458.6 ha (33.71%) from 2005 to 2007 respectively. Medium, high and very high NDVI density classes have increased from 2005 to 2007. The medium density class increased from 1 803 819.1 ha (27.1%) to 2 719 885.1 ha (40.8%); while high vegetation density changed from 838 316.4 ha (12.6%) to 1 137 868.2 ha (17.1%) and very high vegetation density from 370 806.2 ha (5.6%) to 527 347 ha (7.9%).

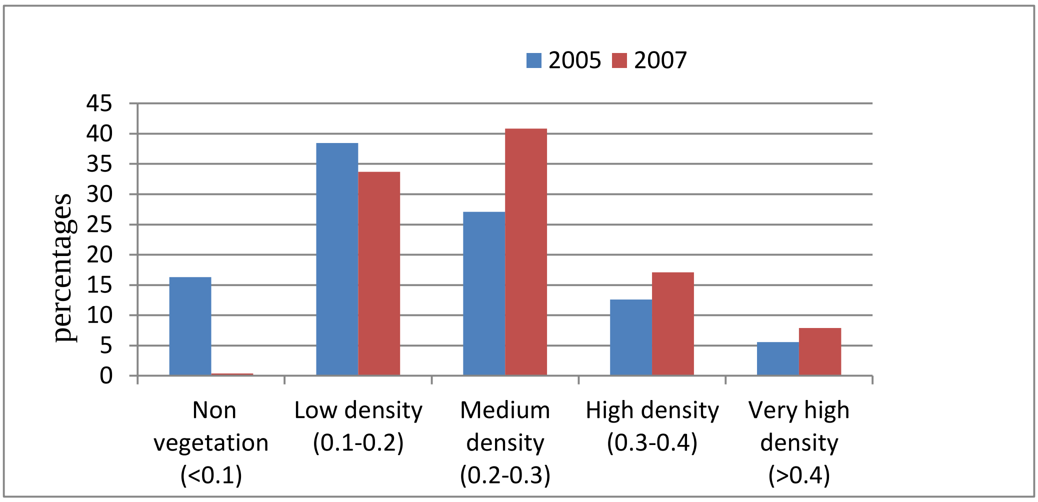

Figure 11: Vhembe District NDVI density categories - 2005 & 2007

Figure 12 represents the spatial distribution of NDVI in 2005 and 2007. It is evident that the eastern part of the study area in 2005 (marked with an A) was dominated by non-vegetation class, which changed by medium and high density in 2007 (marked with B).

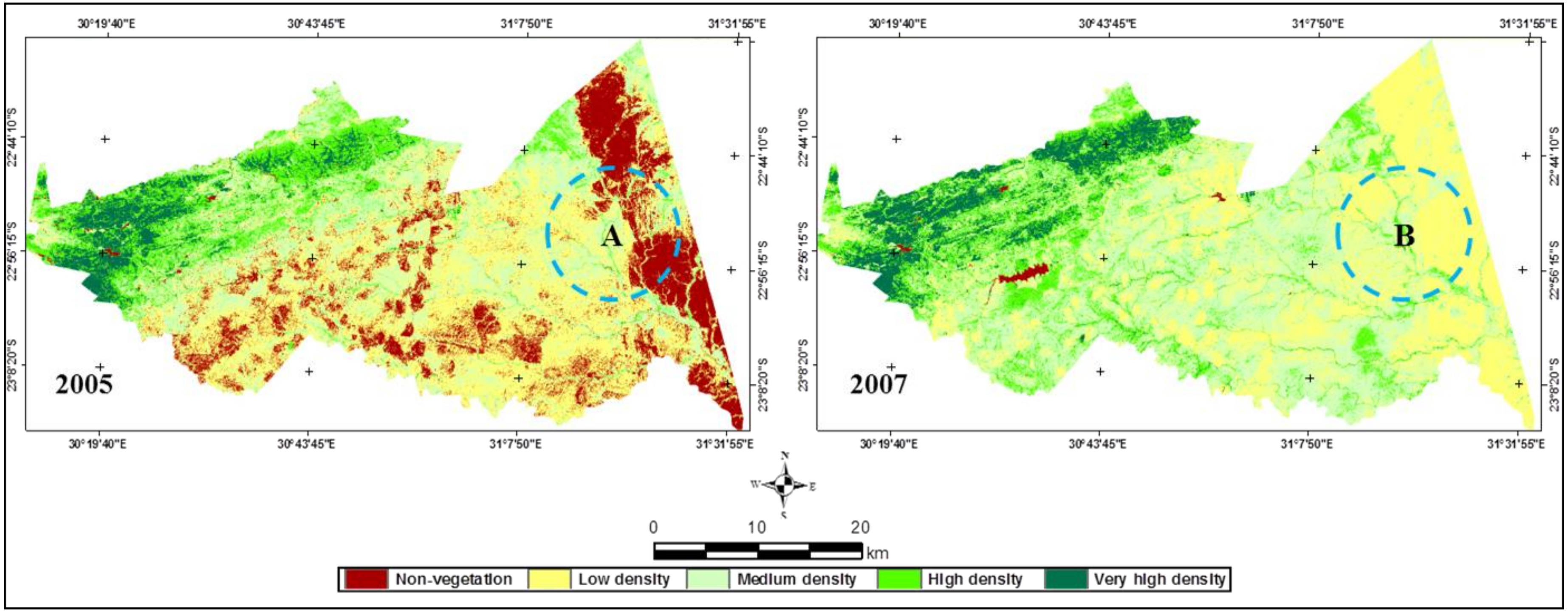

Figure 12: Vhembe District changes of vegetation cover categories during 2005-2007

Figure 13 represent Vhembe District changes in vegetation cover categories during 2010 and 2013. Vhembe District experienced increases in three NDVI density classes namely non-vegetation, medium and high density. The non-vegetation class increased from 27 319.2 ha (0.4%) to 41 195 ha (0.6) %, medium density from 2 775 379.1 ha (41.7%) to 2 817 571 ha (43.3%) and high density class increased from 1 388 749 ha (20.8%) to 1 657 406 ha (25.5%) between 2010 and 2013 respectively. In contrast, low density class decreased from 1 690 569.3 ha (25.4%) to 1 584 159 ha (24.47%) and very high NDVI density decreased from 779 692 ha (11.7%) to 561 377.9 ha (6.1%) during the same period.

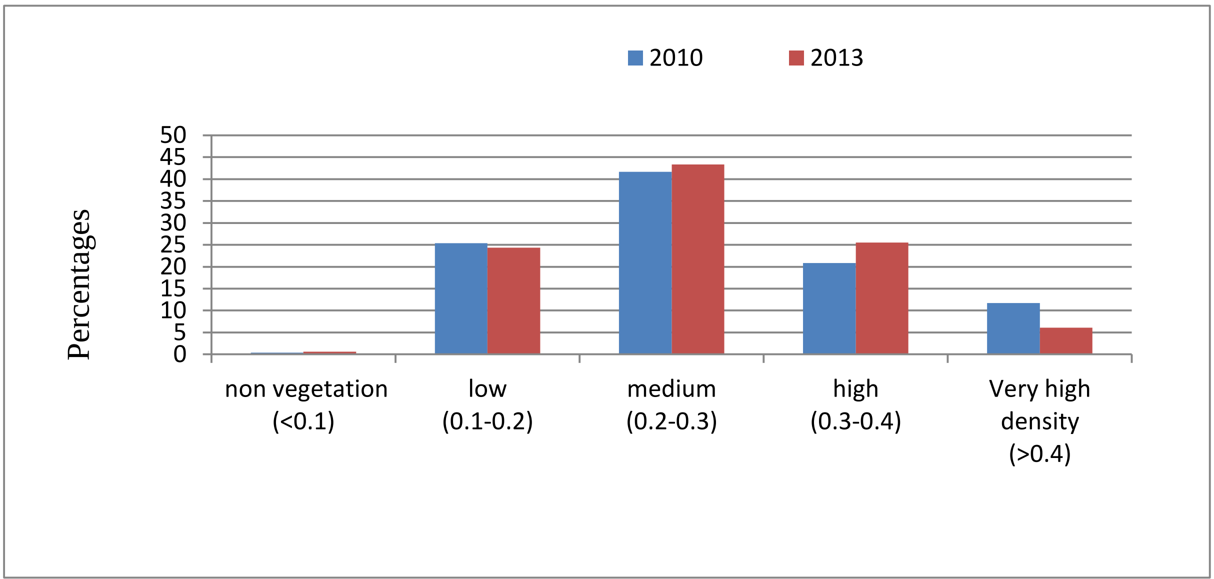

Figure 13: Vhembe District NDVI density categories - 2010 & 2013

Figure 14 shows the spatial distribution of vegetation in 2010 and 2013 for the Vhembe District. The area was dominated by very high NDVI density classes, (dark green) in the eastern part of the study area in 2010, which appeared to have been reduced and replaced by high density class in the 2013 map. The central part of the study area however, which appeared to be dominated by low density class in 2010,was replaced by medium and high density classes in 2013.

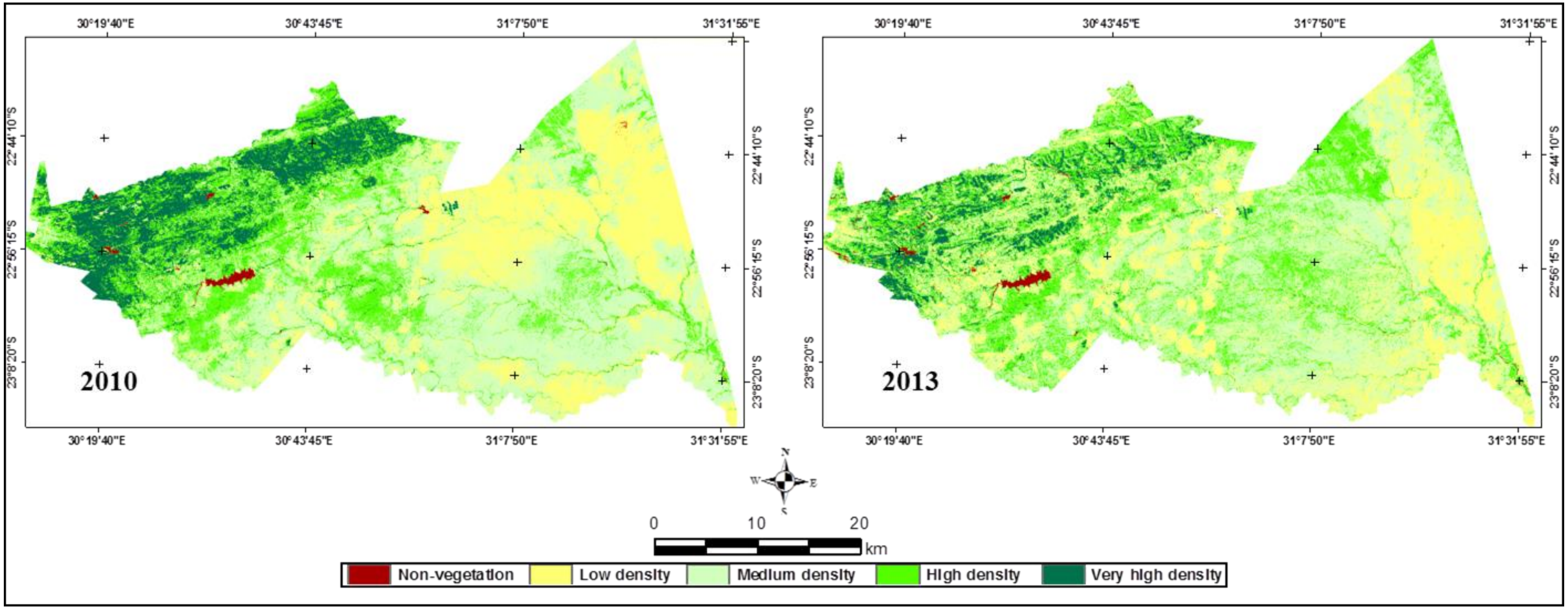

Figure 14: Vhembe District changes of vegetation cover categories: 2010-2013

5.1.2. Vegetation density mapping in Mopani District

Figure 15 shows changes in NDVI categories during 1995 and 1997 in the Mopani District. There has been an increase in non-vegetation areas, low and medium NDVI density classes. The non-vegetation density class increased from 9 030 ha (0.2%) to 17 165.2 ha (0.4%), while low density class increased from 584 800.2 ha (12.6%) to 650 161 ha (13.9%) and medium density class increased from 1 564 639.1 ha (33.65) to 2 182 912.5 ha (46.9%) between 1995 and 1997 respectively. High NDVI density class decreased in extent from 1 831 269.5 ha in 1995 to 1 562 235.1 ha in 1997 while very high density class reduced from 659 999 ha (14.2) % in 1995 to 237 263.7 ha (5.1%) in 1997.

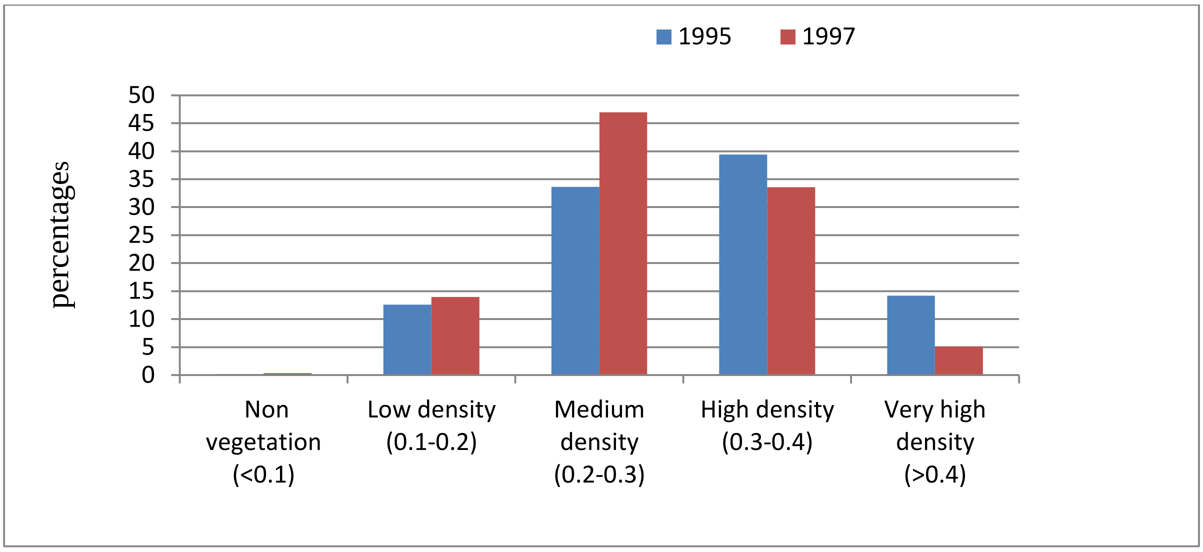

Figure 15: Mopani District NDVI density categories - 1995 & 1997

It is evident in figure 16, that the northern, eastern and the north eastern part of 1995 map was dominated by high and very high NDVI density classes which were replaced by low and very low density NDVI classes by 1997 (yellow and light green colour). The non-vegetation (water body), on the other hand, had increased, compared to the 1995 map.

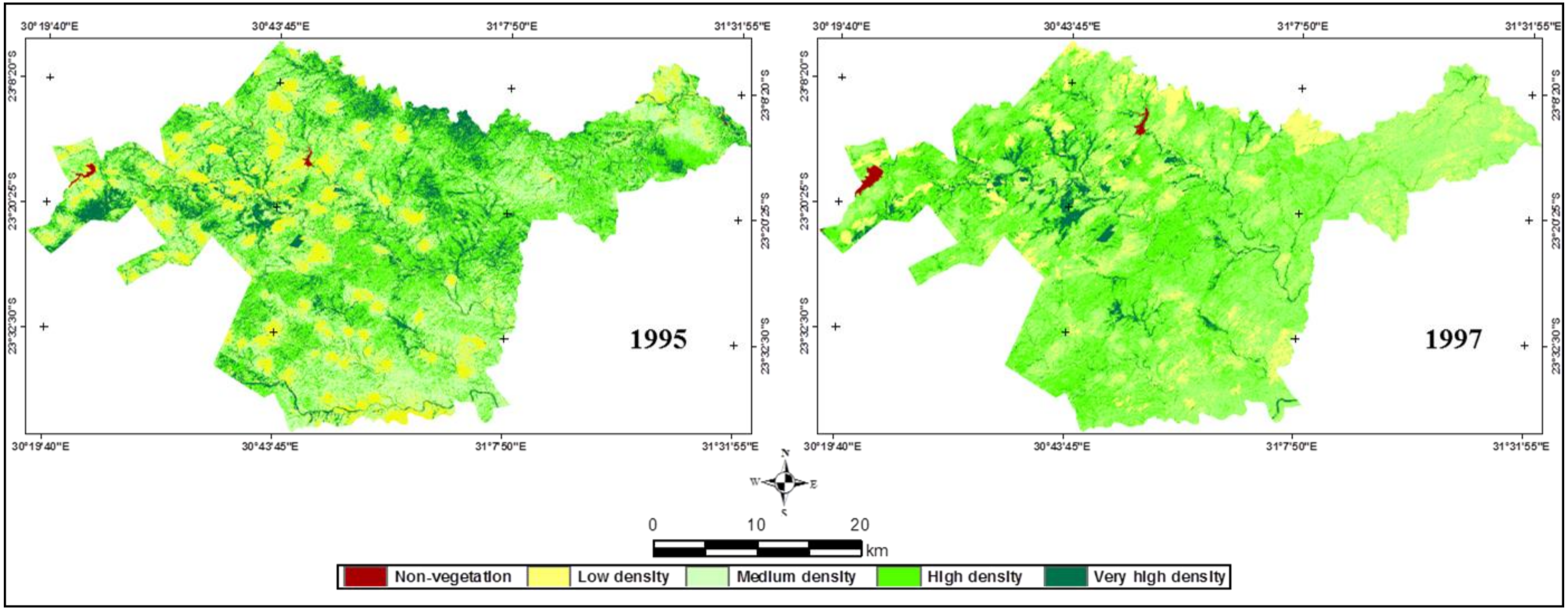

Figure 16: Mopani District changes of vegetation cover categories: 1995 & 1997

Figure 17 shows the Mopani District NDVI density categories with low, high and very high NDVI density classes experiencing increases. The low density class increased from 1 095 912.3 ha (23.6%) to 1 115 660.5 ha (23.9%), the high density class increased from 1 260 503.5 ha (43.6%) to 1 373 510.2 ha (38.6%) and the very high density increased from 251 258 ha (5.4%) to 354 498 (7.6%) from 2005 to 2007 respectively. In contrast, the category of non-vegetation area and medium NDVI density classes decreased from 2005 to 2007. The non-vegetation class decreased from 0.31% to 0.26% from 2005 to 2007, while medium density class decreased from 43.60% to 38.58%.

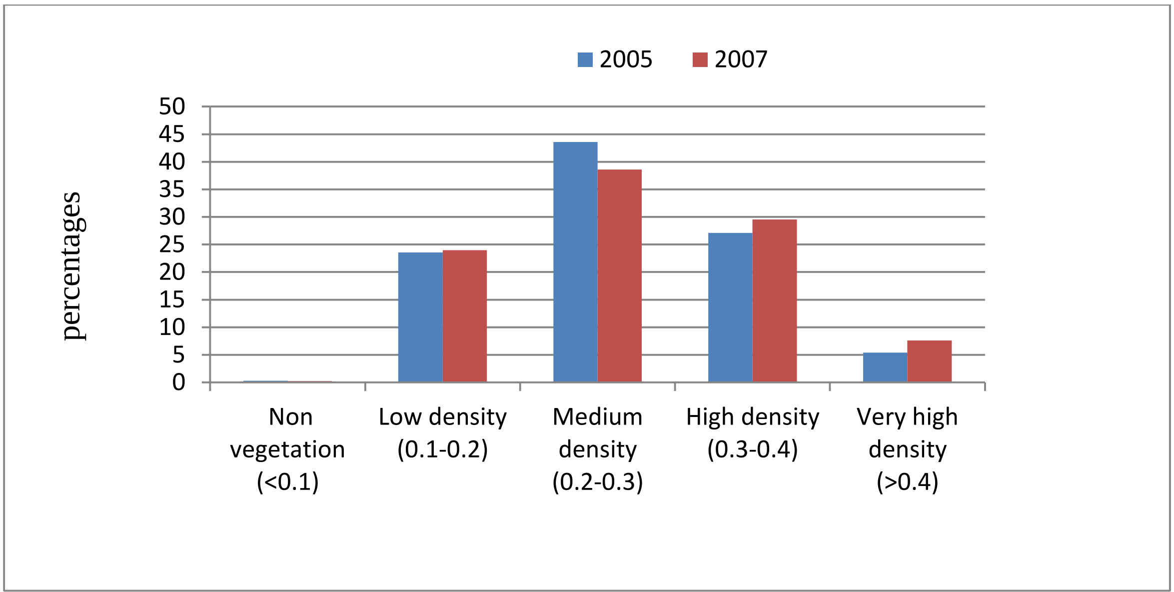

Figure 17: Mopani District NDVI density categories - 2005 & 2007

Figure 18 represents the spatial distribution of NDVI in 2005 and 2007. It is evident that the south eastern part of the study area in 2005 (marked with an A) was dominated by low density class, which changed to high and very high density in 2007 (marked with B). Overall, it is evident that the medium density class dominated the central part of the 2005 map, and was replaced by high and very high density classes in 2007.

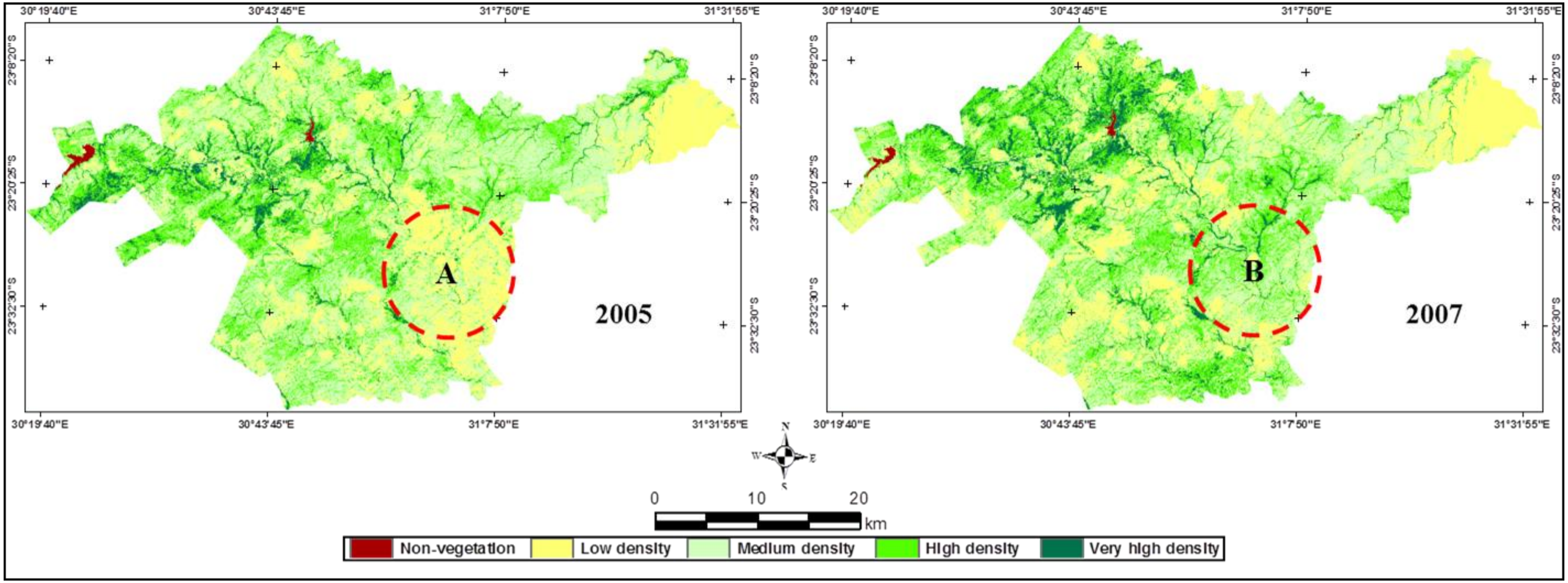

Figure 18: Mopani District changes of vegetation cover categories during 2005-2007

Figure 19 represents the Mopani District NDVI density categories between 2010 and 2013. The spatial extents of non-vegetation, high and very high NDVI density classes increased between 2010 and 2013. In contrast, low and medium density classes decreased. The non-vegetation class increased from 10 673.2 ha (0.2%) to 18 587.5 ha (0.3%), while the high density class increased from 1 404 671.1 ha (0.21%) to 1 554 223.9 ha (33.42%) and the very high density class increased from 42 9174 ha (9.2%) to 671 283.1ha (14.4%) from 2010 to 2013 respectively.

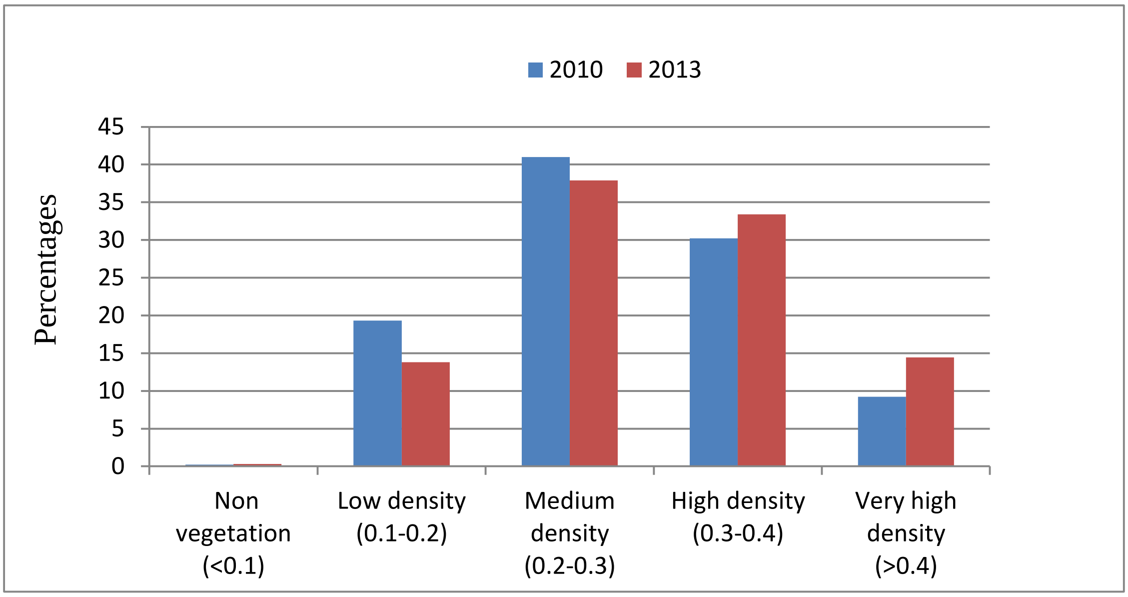

Figure 19: Mopani District NDVI density categories - 2010 & 2013

Figure 20 shows changes in vegetation cover categories during 2010 and 2013. The increased change was to the east and north eastern parts of the map which shows that in 2010 the Mopani District was dominated by low and medium density classes, which were replaced by high and very high NDVI density classes in 2013.

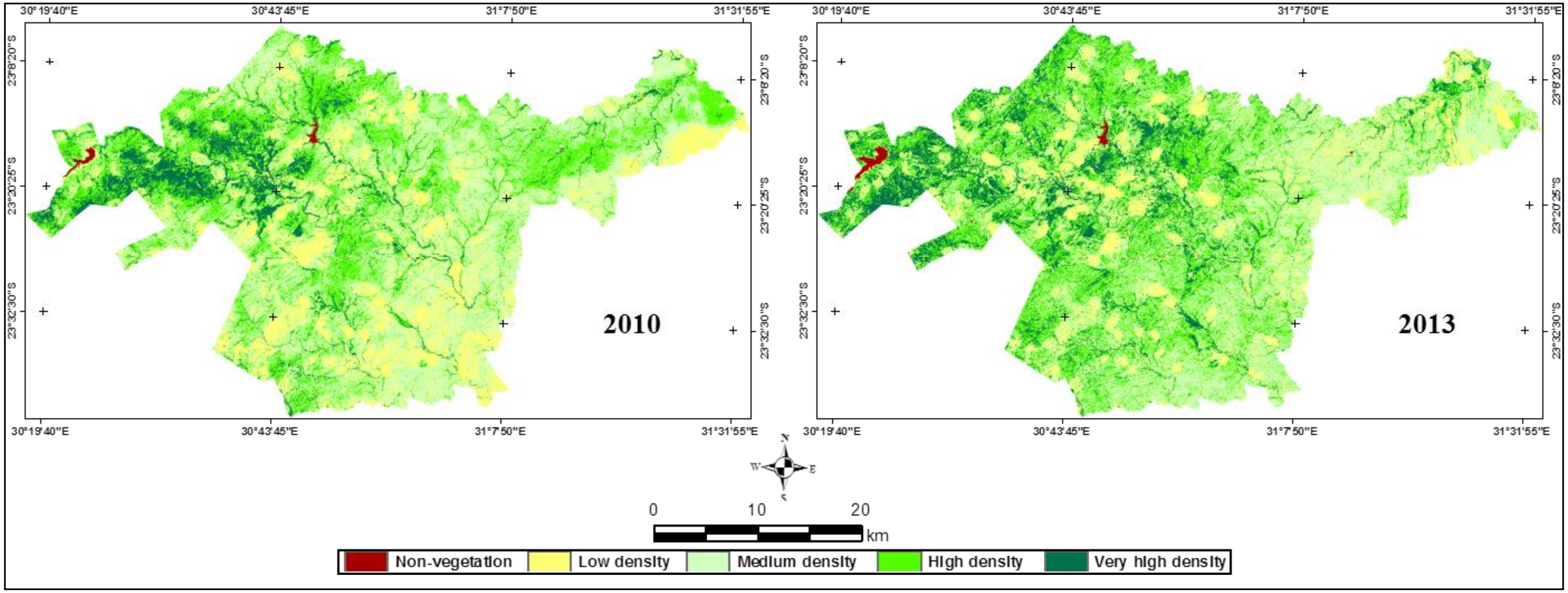

Figure 20: Mopani District changes of vegetation cover categories: 2010 - 2013

5.2 Accuracy assessment

Evaluation of the classification results is an important process in satellite image classification procedure. In doing so confusion/error matrices were used. It is the most commonly employed approach for evaluating per-pixel classification (Congalton and Green, 1999). Field visits for purposes of determining vegetation characteristics for use in image interpretation were undertaken for verification of changes as part of the classification accuracy assessment. Vegetation density characteristics were observed at 50 different sampling sites during the fieldwork phase, and site GPS positions and descriptive information on approximate canopy cover per 30 m plot were taken. Points were selected based on natural and manmade features on the ground, uniformly distributed, clearly visible, and easily accessible features on the images. Ground truth sites were selected using stratified random sampling scheme in Erdas. 200 randomly generated points were used for comparing classified pixel and reference points. The 50 reference points were verified by field visits and 150 reference points through comparison with aerial photographs. Visual interpretation of various features on the aerial photographs was done based on the shade, shape, size and location of the features. Collecting ground truth data through aerial photographs has an edge over conventional methods of survey because of its speed, accuracy and cost effectiveness (Awotwi, 2009). Using these reference data and the classified NDVI maps, confusion matrices were constructed for before heavy rainfall events in 1995, 2005 and 2010 periods (Appendix B). Table 2 and 3 presents error matrices for the classification of the Landsat TM for 2010 for Vhembe and Mopani Districts respectively.

Table 2: Error Matrix for the classification of the Landsat TM for 2010 in Vhembe District

NDVI Classes	Non-Vegetation	Low Density	Medium Density	High Density	Very high Density	Total	User's accuracy (%)
Non-Vegetation	36	0	0	0	0	36	100%
Low Density	2	32	0	0	0	34	74.4%
Medium Density	1	8	39	0	0	48	81.3%
High Density	1	0	2	39	0	42	92.9%
Very high Density	0	0	0	0	40	40	100%
Total	40	40	41	39	40	200	
Producer's accuracy	90%	80%	95.1%	100%	100%	0verall accuracy	**93.0%**

Overall Kappa Statistics**: 0.91%**

Table 3: Error Matrix for the classification of the Landsat TM for 2010 in Mopani District

NDVI Classes	Non-Vegetation	Low Density	Medium Density	High Density	Very high Density	Total	User's accuracy (%)
Non-Vegetation	31	0	0	0	0	31	100.%
Low Density	4	33	2	0	4	43	80.5%
Medium Density	1	3	39	1	0	44	88.6%
High Density	2	1	1	37	1	42	88.1%
Very high Density	0	0	0	0	40	40	100.%
Total	38	37	42	38	45	200	
Producer's accuracy	81.6%	89.2%	92.9%	97.4%	88.9%	overall accuracy	**90.0%**

Overall Kappa Statistics**: 0.87%**

The resulting NDVI maps of the three periods of 1995, 2005 and 2010 had an overall map accuracy of 97.5%, 95.5% and 90.0% for Mopani while, Vhembe had 89.0%, 96.5% and 93.0% respectively. This was reasonably good overall accuracy and accepted for the subsequent analysis and change detection. User's accuracy of individual classes ranged from 90.7% to 100 % in Mopani and from 77.6% to 100% in the Vhembe District. Producer's accuracy ranged from 92.1% to 100% in Mopani and 73.9% to 100% in the Vhembe District.

Non-vegetation and very high density classes were classified correctly at 100% in all the images (1995, 2005 and 2010) in both Vhembe and Mopani Districts. The low density class recorded the lowest user`s accuracy with values of 90.7% in 1995 and 85.3% in 2005 and 80.5% in 2010, in the Mopani District. This is possibly due to images being acquired during the winter season of the region (May-July), where the spectral signatures of low density and medium density have greater similarity leading to high spectral confusion. Also during this season most of the agricultural fields had been cleared and there was little chlorophyll in the vegetation making it difficult to distinguish the two classes. Due to the above reasons the 1995 and 2005 and 2010 classified images, 9.30% of low density were classified as medium density, while12.5% of low density class were classified as medium density in 2005 and in 2010, 23%,of low density was classified as medium density.

Vhembe district recorded the lowest user's accuracy of 77.6% in 1995 at high density class and 88.3% at medium density class in 2005 respectively. Kappa statistics/index was computed for each classified NDVI map to measure the accuracy of the results. Kappa values are categorised into three categories: a value greater than 0.80 represents strong agreement, a value between 0.40 and 0.80 (40 to 80%) represents moderate agreement, and a value below 0.40 (40%) represents poor agreement (Congalton, 1991). Vhembe District had an overall Kappa statistics of 0.89, 0.96 and 0.91 in 1995, 2005 and 2010 respectively. There was an overall Kappa Statistics of 0.99 for the 1995 image, 0.87 for 2005 and 0.95 for the 2010 image in the Mopani District. These results suggest that the overall classification accuracy for all NDVI maps is acceptable and correct values of an error matrix are due to true agreement between the classification and the actual NDVI density categories than chance agreement. Michener and Houhoulis, (1997), tested the accuracy assessment using various classification methods and found that temporal change classification based on changes in NDVI were more accurate than similar classification based on changes occurring in all spectral bands and that image differencing of NDVI data was the most effective method in discriminating affected vegetation.

5.3 Change detection

Differences between two correspondent NDVI images of the area acquired in two different years were calculated and the resulting image gave the changes in the vegetation amount and status. In this study, 1995 NDVI values were subtracted from the 1997 NDVI values; 2005 NDVI values were subtracted from 2007 and 2010 NDVI values subtracted from 2013 image and averaged using absolute differences, to obtain a single value for each pixel that represents a magnitude and direction of change. A critical element in image differencing change detection is defining the threshold values that indicate where significant change has occurred (Dobson *et al.*, 1995). Frequently, a standard deviation from the mean is established as the threshold value (Jensen, 1986). In other cases, a threshold value representing a "realistic amount of change" is empirically selected after examining histograms of DN values (Michener and Houhoulis, 1997)

In this study, in order to identify the changed areas in a different date image, a threshold technique based on differencing image histogram was selected. In this method, the significant changes were found in the tails of the histogram distribution while pixels showing no significant change had a tendency to be clustered around the means (Singh, 1989). A threshold was selected, where zero was considered as non-change while values greater than zero were considered increases in vegetation and less than zero was a decrease in vegetation. The vegetation cover change maps for Vhembe and Mopani Districts are presented in Figures 21 and 22 while the rate of change is in Table 4 to 7.

Table 4: Vegetation cover changes distribution of Vhembe District: 1995-1997; 2005- 2007; 2010 and 2013

NDVI Classes	1995		1997		2005		2007		2010		2013	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area	%	Area	%
Non-vegetation	10 829.4	0.2	605 341.3	9.1	1 086 918.2	16.3	26 150.0	0.4	27 319.2	0.4	41 195.0	0.6
Low density	806 821.1	12.1	3 386 621.2	50.8	2 561 849.0	38.4	2 250 458.6	33.8	1 690 569.3	25.4	1 584 159.0	24.4
Medium density	2 294 471.0	34.4	1 696 172.0	25.5	1 803 819.1	27.0	2719 885.1	40.8	2 775 379.1	41.7	2 817 571.2	43.3
High density	2 712 912.1	40.7	665 408.0	10.0	838 316.4	12.7	1 137 868.2	17.1	1 388 749.0	20.8	1 657 406.3	25.5
Very high density	836 674.1	12.6	308 166.4	4.6	370 806.2	5.6	527 347.0	7.9	779 692.1	11.7	561 377.4	6.2
Total	**6 661 708.9**	**100**	**6 661 708.9**	**100**	**6 661 708.9**	**100**	**6 661 708.9**	**100**	**6661708.9**	**100**	**6 661 708.9**	**100**

Table 5: Vegetation cover change rate of Vhembe District

NDVI Classes	1996 to 1997		2005 to 2007		2010 to 2013	
	Change		Change		Change	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Non-vegetation	+594 511.9	+5 504.63	-1 060 768.2	-97.59	+13 875.8	+50.79
Low density	+2579 800.1	+319.77	-311 390.4	+12.16	-106 410.3	-6.29
Medium density	-598 299.0	-26.08	+916 066.0	+50.78	+42 191.9	+1.52
High density	-2047 505.3	-75.47	+299 551.8	+35.73	+268 657	+19.35
Very high density	-528 507.7	-63.18	+156 540.8	+42.21	-218 314.2	-48.69

NB: (+) indicates increase, (-) indicates decrease

Table 4 represents vegetation cover changes distribution of the Vhembe District for 1995, 1997, 2005, 2007, 2010 and 2013, while table 5 represents the rate of change between 1995 and 1997, 2005 and 2007, and between 2010 and 2013 in the Vhembe District. The spatial extent of medium, high and very high density classes significantly decreased during 1995 and 1997 period, but non-vegetation and low density classes increased considerably high and very high density classes might have been replaced by non-vegetation density class. The non-vegetation density class accounted for 0.2% of the total area in 1995 which increased by 9.1% in 1997 (Table 4). Overall, the non-vegetation density class experienced the greatest rate of change with +5 505.63% increase change within Vhembe District from 1995 to 1997. This is evident in Figure 21, where the change cover map is dominated by an increase in non vegetation density class.

For the period between 2005 and 2007, in the Vhembe District there was a decrease in the vegetation cover's rate of physical expansion compared to the 1995 and 1997. For instance, non-vegetation density class decreased by -97.59% and low density class increased by 12.16% between 2005 and 2007 compared to 319.77% between 1995 and 1997. In contrast there was a general increase in medium (50.78%), high (35.73%) and very high density (42.21%) classes. The period between 2010 and 2013 depicted a decrease in low density (-6.29%) and very high density classes (-48.69%). In contrast, there was a general increase of non-vegetation, medium and high density classes with the rate of 50.79%, 1.52% and 19.35% respectively between these study periods.

Table 6: Vegetation cover change distribution of the Mopani District for 1995-1997; 2005- 2007; 2010 and 2013

NDVI Classes	1995		1997		2005		2007		2010		2013	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area	%	Area	%
Non-vegetation	9 030.0	0.2	17 165.2	0.4	14 672.2	0.31	12 168.1	0.26	10 673.2	0.2	18 587.5	0.4
Low density	584 800.2	12.5	650 161.3	14.0	1 095 912.3	23.6	1 115 660.5	24.0	898 725.1	19.3	643 023.0	13.8
Medium density	1 564 639.1	33.7	2 182 912.5	47.0	2 027 392.0	43.6	1 793 900.7	38.6	1 906 495.4	41.0	1 762 620.3	37.9
High density	1 831 269.5	39.4	1 562 235.1	33.6	1 260 503.5	27.1	1 373 510.2	29.5	1 404 671.1	30.2	1 554 223.9	33.4
Very high density	659 999	14.2	237 263.7	5.1	251 258.0	5.4	354 498.3	7.6	429 174.0	9.2	671 283.1	14.4
Total	**4 649 737.8**	**100**	**4 649 737.8**	**100**	**4 649 737.8**	**100**	**4 649 737.8**	**100**	**4 649 737.8**	**100**	**4 649 737.8**	**100**

Table 7: Vegetation change rate for Mopani District

	1995 to 1997		2005 to 2007		2010 to 2013	
NDVI Density Class	Change		Change		Change	
	Area(ha)	%	Area(ha)	%	Area(ha)	%
Non-vegetation	+ 8 135.2	+90.00%	-2 504.1	-17.12%	+7 914.3	+74.53
Low density	+65 361.1	+11.17%	+19 748.2	+1.79	-255 702.1	-28.64
Medium density	+618 273.4	+39.52%	-233 491.3	-11.35	-143 875.1	-7.54
High density	-269 034.4	-14.69	+113 006.7	+8.96	+149 552.8	+10.65
Very high density	-422 735.3	-63.97	+103 240.3	+41.00	+24 210.9	+56.44

From Table 6, there was a positive change i.e. an increase in non-vegetation, low density and medium density classes between 1995 and 1997. After 1995, the high and very high density classes decreased, which may have been replaced by the non-vegetation class. The non vegetation density class accounted for 0.2% of the total area in 1995 which increased by 0.4% in 1997 (Table 6). Nevertheless, non-vegetation constituted an overall increase change of 90% between 1995 and 1997.

The period between 2005 and 2007, showed a decrease in the non-vegetation density class. For instance, non-vegetation density class decreased by -17.12% compared to 90% increase between 1995 and 1997. There was also a decrease in the extent of the medium density class (-11.35%) between 2005 and 2007. In contrast, there was a general increase of high and very high density classes with increases of 8.96% and 41.00% respectively

Overall, the period between 2010 and 2013 witnessed the greatest rate of change within Mopani District. Both non-vegetation and very high density classes had increased by 74.53% and 56.44% respectively with subsequent decrease in the area covered by low (-26.64%) and medium density (-7.54%) (Table 7).

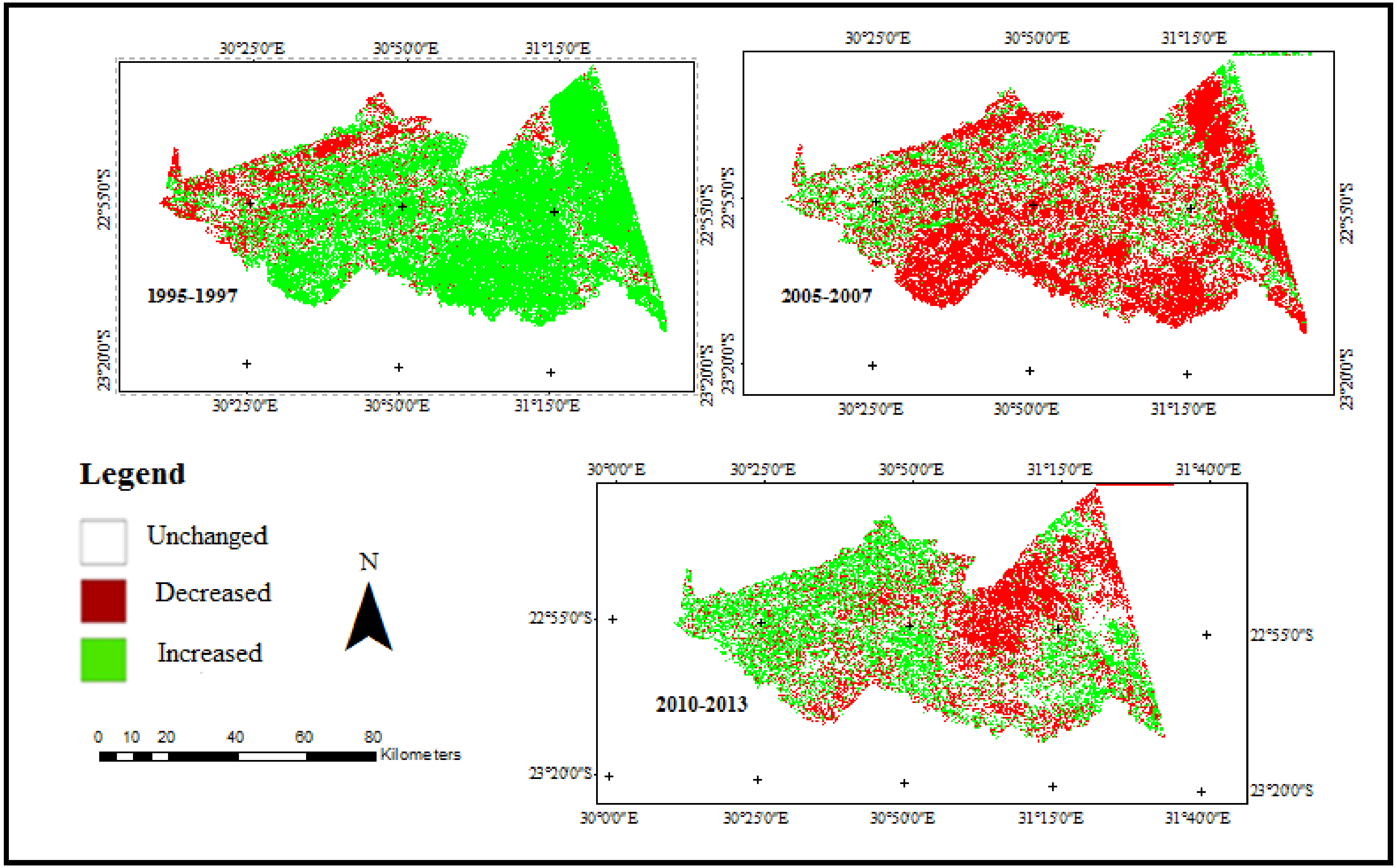

Figure 21: Vegetation cover change map for the Vhembe District

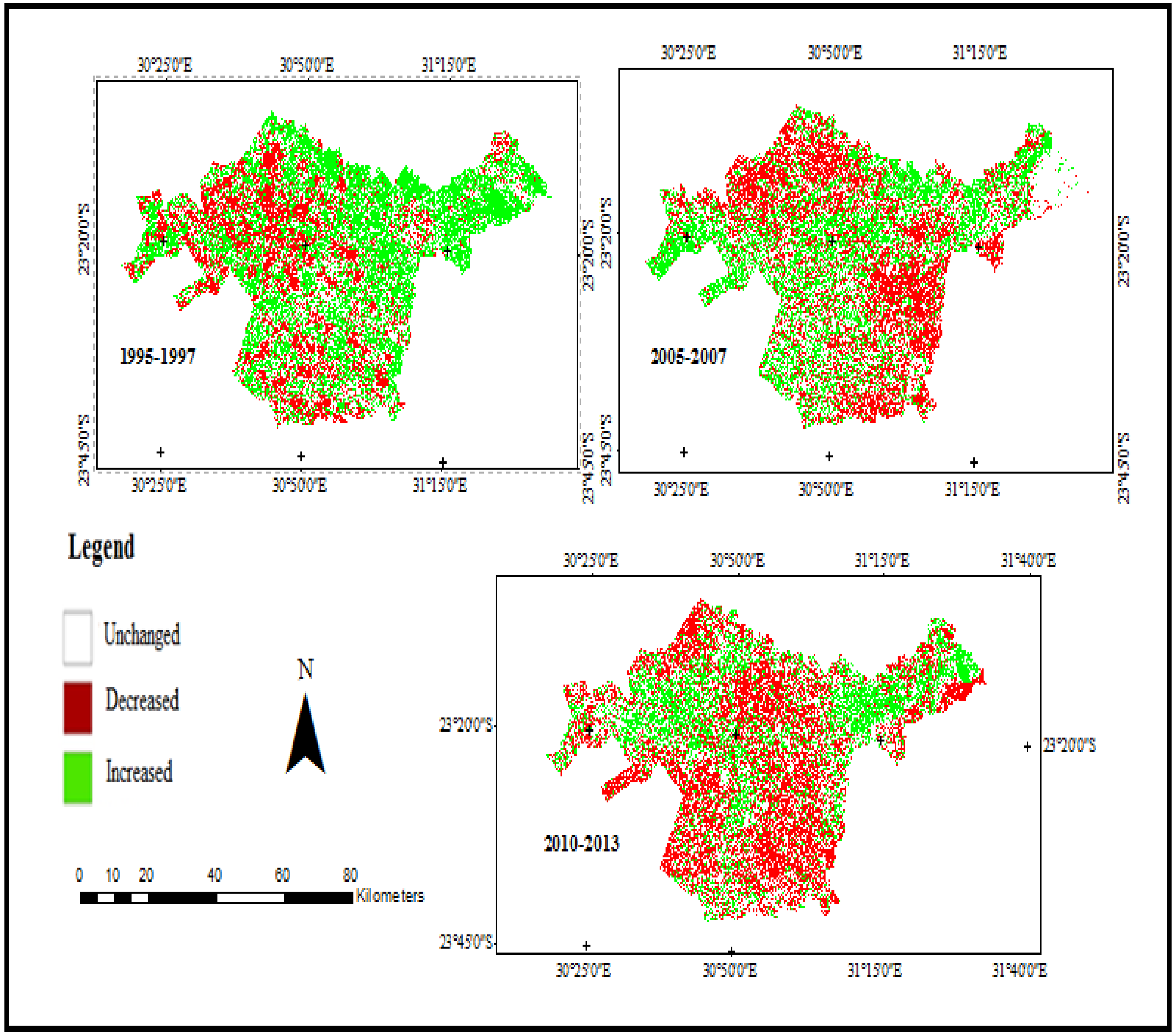

Figure 22: Vegetation cover change map for the Mopani District

5.4. The relationship between rainfall and NDVI during heavy rainfall events

In order to test the strength of the linear association between rainfall and NDVI, Pearson's correlation coefficients were computed and a linear regression analysis was also carried out with NDVI as the dependent variable and Mean Average Rainfall (MAR) as the independent variable. Thus, Mean Average Rainfall and NDVI derived from satellite imagery were correlated to determine their association during heavy rainfall events. NDVI derived during heavy rainfall events for Vhembe and Mopani District was used. Thus, rainfall and NDVI for winter season (May –July) was used to measure the relationship, as the rainfall had lessened and the effect of rainfall on vegetation was clearly visible on the images. Using a statistical package "STATISTICA", NDVI and rainfall were correlated to determine their relationship (Figure 23).

The results of the correlation analysis between NDVI and rainfall revealed a statistically weak significantly positive correlation between NDVI and Mean Average Rainfall (r = 0.44 and 0.18, $p < 0.05$) in 1996 for Vhembe and Mopani District respectively. The relationship was determined to be weak during the 2006 heavy rainfall event (r = 0.13 and 0.29) in Vhembe and Mopani. Similarly, a weak correlation between NDVI and rainfall was derived during the heavy rainfall of 2011 (r = 0.04 and -0.36, $p < 0.05$). Overall, there was weak correlation between NDVI and rainfall in both Vhembe and Mopani Districts indicating that vegetation activity in the area was not highly dependent on the amount of rainfall. These findings confirms the findings by Nicholson *et al*., (1990) and Lotsch *et al*., (2003) that NDVI is correlated best with accumulated rainfall of at least three months and that vegetation greenness in semi-arid environments is more strongly related to soil moisture; a function of accumulated rainfall over a period of time than to instantaneous rainfall.

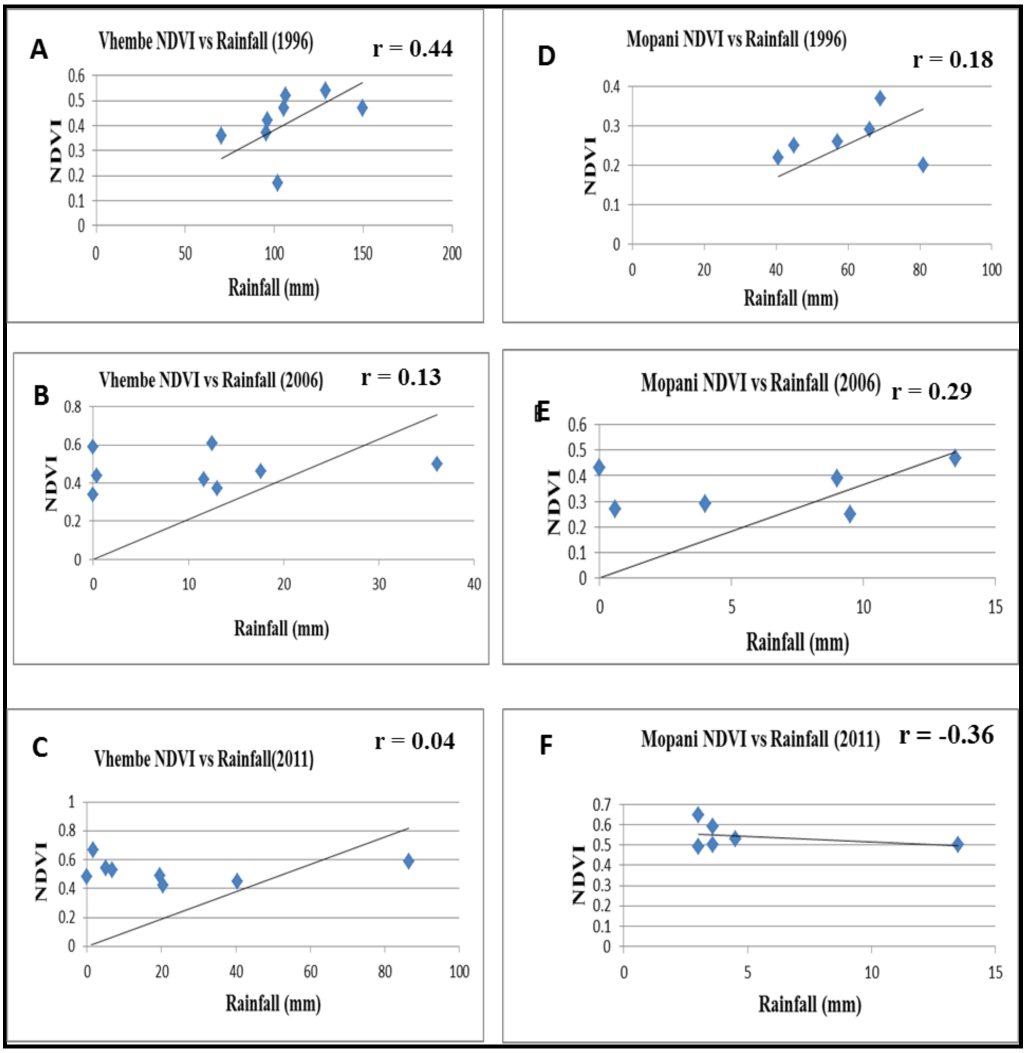

Figure 23: Linear regression between rainfall and NDVI in Vhembe and Mopani District during heavy rainfall events

5.5 Drivers of vegetation cover changes

According to Salkind (2000), a correlation co-efficient of 0.2 to 0.4, represents weak or low associations. Thus, correlation values for all heavy rainfall events in Vhembe and Mopani District were less than 0.4, which implies that there was some weak relationship between rainfall and NDVI. This means that between the two parameters, when the rainfall is high, a high NDVI may not be expected.

However, in order to measure how much rainfall influenced vegetation cover, the correlation coefficient values for all heavy rainfall events in Vhembe and Mopani District were used to determine the coefficient of determination and residual factors (Sharma, 1989). The coefficient of determination and residual factors gives a percentage of the influence of rainfall on vegetation cover. In this study, heavy rainfall events accounted for 19.4% (r^2 =

0.19), 1.7% (r^2 = 0.002) and 0.2 % (r^2 = 0.002) of total variance of vegetation cover change in Vhembe District during 1996, 2006 and 2010 respectively. Similarly, Mopani District accounted for 3.2 % (r^2 = 0.03), 5.3 % (r^2 = 0.05) and 15.2 % (r^2 = 0.15) in 1996, 2006 and 2011 respectively. This means that the remaining 80.6%, 98.3% and 99.8% for Vhembe and 96.8%, 94.7% and 84.79% for Mopani District during 1996, 2006 and 2011 respectively was not accounted for by heavy rainfall events. This may be due to inherent variability or to other unknown factors that affect vegetation cover.

The following sections discuss some of the factors that could influence changes in vegetation density in Vhembe and Mopani districts.

5.5.1 Climate

Although high and very high density classes decreased in 1995-1997 period, the western part of Vhembe District (the Soutpanesburg mountainous area) remained dominated by high and very high density (Figure 21). According to Nenwiini (2009), the area closer or over the Soutpanesburg Mountains is categorised as humid component or humid zone with the average annual rainfall exceeding 1 200 mm per annum . Generally, the area features evergreen montane forests especially over high altitudes (Mucina and Rutherford, 2006). However, the steep slopes experienced decrease in high and very high NDVI densities between 1995 and 1997. This could be attributed to the effect of possibly extensive run-off during heavy rainfall events and included the expansion of the stream channels, mass movement, and the almost complete removal of vegetation cover (Kofler, 2004).

The increase of the very high density vegetation cover class in Mopani District during 2005-2007 and 2010-2013 was evident along the river banks (Figure 22). It appears that these areas lie at the edge of the flooded areas suggesting that most likely the flood water flows slowly there. Moisture retention and mineral rich flood water could lead to a favourable vegetation response over time. River bank cultivation could also be attributed to the increase of NDVI along the rivers and dams.

5.5.2 ENSO phenomenon

Rainfall intensity preceding the date of image acquisition could strongly influence biomass availability and distribution. Inter-annual variability of vegetation conditions in Southern Africa, contrasting rainfall and NDVI measurements have been reported (Anyamba *et al.*, 2002). La-Nina wet phase is associated with extreme rainfall and flooding, whereas El-Nino episodes are associated with a dry phase with dry condition throughout Southern Africa. The El-Nino phenomenon had developed in March 1997 and extended to 1998 and resulted in significant warming of sea surface tempeartures in the pacific (Harsch, 1998). The decrease in high and very high density classes of vegetation cover in both Vhembe and Mopani could be explained by the El-Nino episodes. Tree mortality and die offs is among the most important forest responses to low rainfall induced El-Nino Southern Oscillation (Breshears *et al*., 2009).

Low rainfall can lead to many consequences which are associated with agriculture, forestry and ranching. Examples of drought induced agricultural impacts include, damage to crop yield, insect infestations, plant decreases and limitation of public land for grazing. Furthermore, forestry (high density class) is impacted by low rainfall, as commercial forests place a large demand on water resources. Within a downward shift of rainfall pattern, i.e., from 214 mm in 1996 to 97 mm in 1997, wetter areas where commercial forestry was traditionally undertaken may not have sufficient water available.

5.5.3 Anthropogenic factors

Climate change is one of the most important factors influencing spatiotemporal variation of vegetation. However, the impacts from human activities should not be neglected. Social and economic factors such as national policy, people's consciousness, agricultural modernization, economic level and life style change, might profoundly affect the vegetation cover in the study area (Vicente-Serrano *et al*., 2004).

5.5.3.1 Agriculture

Previous study by Munyati and Kabanda (2009) in 2006 in the Vhembe district revealed that vegetated forest plantations increased from 23 460.4 ha in 1990 to 35 380.7 ha. Similarly, in this study, the Vhembe and Mopani Districts experienced increases in high and very high density classes during the 2005-2007 periods. The forest plantation industry is an important economic activity in the area, and Vhembe and the south – eastern Mopani districts are noted as part of the planned 'forestry development cluster' in the 2004–2014 Limpopo Provincial Development Plan. The plantation industry provides employment not only directly in the plantations themselves but also in the 'down-stream' activities of saw mills and other timber processing facilities (Limpopo Provincial Government, 2004). The forestry industry generally plays an important role in poverty alleviation in South Africa (DWAF 2005) and is, therefore, socio-economically desirable. Thus, crops like pecan nuts, citrus fruits, lucerne, groundnuts, maize, watermelon and peaches are grown in the Vhembe and Mopani District agricultural valleys.

5.5.3.2 Social and economic factors

The Government's social improvement measures have seen an increase in household access to electricity and better housing. Despite increases in the use of electricity, wood is still commonly used as a supplementary energy source, based on the fact that wood is largely free whereas electricity is not. However, despite the increase in household access to electricity, wood is still preferred for cooking to electricity by most households, due to the costs involved in using electricity (Maphiri, 2009). Data from the 2007 Community Survey by the state statistics agency Statistics South Africa (Stats SA) show that between 34.9 and 58.3% of individuals in the 15–65 age group in the study area have no income. Forest exploitation for wood fuel in the area could be the reason for the decrease in medium and high density vegetation classes. Woodfuel collection preferentially is of dead and dry brunches, but as demand increases and begins to exceed the available dead wood resources, live woody stems and branches are cut for fuelwood, and over time this may bring about woodland degradation (Madubansi and Chackleton, 2007).

5.5.3.3 Economic level and life style change

The other perturbing factors that might have contributed to the decrease in vegetation cover from 1995 to 1997 and 2010 to 2013 in Vhembe and Mopani Districts is human settlement expansion. Although land use /land cover change was not employed for this study, vegetation cover is often reduced dramatically by LULCC (Ellis, 2013). When land is transformed from a primarily forest to a farm, the loss of forest species within deforested area is immediate and complete. Even when unaccompanied by apparent changes in land cover, similar effects are observed whenever relatively undisturbed lands are transformed to more intensive uses including livestock grazing, selective tree harvest and fire prevention (Prabhat, 2015). Population growth and other social factors are the main driving force of LULCC. According to Statistics SA (2011), the population density of Vhembe and Mopani Districts has been increasing, from 1 090 606 to 1 245 015 between 1995 and 2004. High population growth translates into rapidly increasing demands from the land in terms of food, shelter and energy (woodfuel) hence negatively impacting vegetation density.

5.5.3.4 Veld fires

Natural fires in southern African ecosystems are ignited by lightning although human activity is responsible for the majority of the fires in Africa particularly in grasslands and savannah biomes (Silva *et al*., 2003). The burning season lasts from May to October, with its peak in June/July (Palamuleni *et al*., 2011). Veldfires are sometimes deliberately triggered as part of the natural process which has a positive role in the vegetation structure and composition which helps recycle nutrients contained in old and dead trees. The frequency, extent and pattern of burning could reduce vegetation cover, thus exposing the land to agents of accelerated soil erosion and modification of various ecological processes.

5.6 Summary

This chapter presented the results of the pattern and magnitude of spatial and temporal vegetation cover changes before and after heavy rains in the Vhembe and Mopani District, using remote sensing techniques. The results from the NDVI density maps were used to analyse vegetation cover changes between 1995-1997, 2005-2007 and 2010-2013 in the two districts. Performing vegetation cover change analysis, Vhembe and Mopani Districts showed similar patterns in vegetation cover change. This means that when vegetation cover increased in Vhembe District it also increased in Mopani District, though to a different degree. The change analysis showed an increase of 59.45 ha (5504.6%) for Vhembe and 0.81ha (90%) for Mopani in non vegetation cover from 1995-1997 while, high and very high density decreased. The 2005-2007 change showed a decrease of non-vegetation cover with (-97.59%) for Vhembe and (-17.12%) for Mopani and increases of high and very high density class. In contrast, non vegetation cover increased with 50.55% and 74.53% in Vhembe and Mopani Districts from 2010 to 2013 respectively. Overall, the results showed that although some areas recorded a decrease in vegetation cover, there are also areas that had had an increase in vegetation during the study period. In addition, there was a weak and statistically significant correlation between NDVI and Mean Average Rainfall (MAR) suggesting that other factors such as socio-economic activities influence vegetation cover changes in Vhembe and Mopani districts. The next chapter (chapter 6) presents the conclusion and recommendations.

CHAPTER 6

6. CONCLUSION AND RECOMMENDATION

6.1 Introduction

The study was conducted in the two municipalities (Vhembe and Mopani Districts) in the Limpopo Province. The two districts were selected based on their characteristics with Vhembe District being characterised by steep slopes and mountainous ranges such as Soutpanesburg mountain range whilst the Mopani District is situated in the low lying area within the province. Historically, Vhembe District is within the jurisdiction of the former Venda land while Mopani District is within the former Gazankulu jurisdiction. The Vhembe district derives its social and commercial services from Thohoyandou and Louis Trichardt which are the main towns in the district. Thohoyandou, the former capital of the Venda homeland, is currently the administrative seat of the Vhembe District of the Limpopo Province while Giyani the former Gazankulu homeland is the administrative seat of the Mopani District.

6.2 Conclusion

Vegetation cover plays an important role in protecting the soil surface from raindrop splashing, it enhances soil aggregate stability, as well as retaining and reducing surface water run-off. Once the vegetation cover is removed, raindrop impact initiates detachment of soil particles and causes the formation of a crust, which seals the surface and limits infiltration. Vhembe and Mopani Districts comprise of different vegetation species which include trees, biomes namely savannah, grassland and forest, four bioregions and twenty three different vegetation types. Currently there is concern over the changes in vegetation cover in the study areas. With increasing human activities and climate change, it is crucial to detect anomalous conditions that could enhance and disrupt the vegetation and plant ecosystems in Vhembe and Mopani District. Therefore, a comprehensive assessment of the spatial and temporal distribution of vegetation cover change, is required to resolve present problems and avoid potential crises of the future due to vegetation cover degradation. Advances in hardware and software technology opened up opportunities to derive information from remotely sensed data with the use of free Landsat data policy. At national level the results of this study can be used to improve vegetation cover management strategies and utilisation of natural resources in the study area.

This study demonstrated the pattern and magnitude of spatial and temporal vegetation cover changes before and after heavy rains in the Vhembe and Mopani District, using remote sensing techniques. The main findings of the study were that a substantial change in vegetation densities from before and after heavy rainfall (1995-1997, 2005-2007 and 2010-2013) have occurred in the area. The non vegetation cover showed increasing trends during 1995-1997 and 2010-2013 periods with simultaneous decreases in high and very high density classes. On the contrary, the non-vegetation density class showed decreasing trends while high and very high density increased during the 2005-2006 period in both Vhembe and Mopani District. The study showed that although the two districts are characterised by different landscape characteristics, they showed similar trends of vegetation cover changes during the study period. Overall, the results showed that although some areas recorded a decrease in vegetation cover, there are also areas that had had an increase in vegetation cover during the study period.

In addition, there was a weak and statistically significant correlation between NDVI and Mean Average Rainfall (MAR) suggesting that other factors such as socio-economic activities influence vegetation cover changes in both Vhembe and Mopani districts; such socio-economic factors include the following:

- *Agriculture*, land clearing primarily for agriculture is perhaps the single most important cause of vegetation cover removal, even most land degradation and loss of both fauna and flora.
- *Veld fires* are sometimes deliberately triggered as part of the natural process which have positive roles in the vegetation structure and composition while they help recycle nutrients contained in old and dead trees. The frequency, extent and pattern of burning could reduce vegetation cover, thus exposing the land to agents of accelerated soil erosion and modification of various ecological processes.
- *Forest exploitation for woodfuel* in the area could be responsible for the decrease in the medium and high density vegetation classes. Woodfuel collection preferentially is dead and dry branches, but as demand increased and begin to exceed the available dead wood resources, fresh woody stems and branches were cut for fuel wood, and overtime this may bring about woodland degradation

- *Settlement expansions* cause enormous changes of vegetation pattern and fragmentation to the flora, fauna, hydrological relations and soil biological properties of the systems in time and space. Typical settlement expansion activities include ground clearing (removal of vegetative cover and topsoil) and compacting of soils by heavy duty vehicles.
- *Overgrazing* removes the vegetation cover over the soil and exposed soil gets compacted which lead to operative soil depth decline. So the roots can not go much deep in to the soil and adequate soil moisture is not available.

6.3 Recommendations

In view of the findings, this study recommends the following:

- Monitoring and analysing Land Use Land Cover Changes (LULCC) is important to understand drivers of the change and the positive or negative impacts likely at larger spatial scales especially in the Vhembe and Mopani District. These studies will make significant advances in furthering understanding of socio-economic drivers of vegetation cover change, and the impact of natural and human ecosystems.

- Land cover mapping and change detection studies are valuable especially for vegetation cover change. However, much research needs to be done to improve upon the results of vegetation and change detection studies. Vegetation cover change can be improved by using images acquired during the same season and month, to avoid the snapshot situation.

- In this study, some of the NDVI density classes presented particular problems for mapping from satellite imagery. From a remote sensing point of view, discriminating medium density class with area cleared under cultivation or logging activities proved to be difficult, where the spectral signatures of low density and medium density have greater similarity leading to high spectral confusion. Also during this season most of the agricultural fields have been cleared and there is little chlorophyll in the vegetation making it difficult to distinguish the two classes. Future studies, in this regards, must consider wet and dry season images, so that features that may not be captured in one season, are captured in another season.

- Vegetation cover change detection analysis adopting the use of different vegetation species that need shorter rainfall period and those that mature earlier should be undertaken.

- In this study, a strategy for selecting Landsat imagery for the development of vegetation cover maps for Vhembe and Mopani Districts was influenced by cost free multi temporal images, vegetation phenology and image quality (cloudiness). Due to the amount of cloud cover during rainfall season and the period following heavy rainfall event, the satisfactory images were not obtained. Thus, the images obtained were for winter season. Therefore, further studies should be done using radar images. Radar has special properties that make it a viable alternative to traditional optical remote sensing techniques. For instance, radar energy is capable of penetrating atmospheric conditions and has the ability to capture data through rainfall, fog, hail smoke and most importantly through clouds. However, improving the resolution of imaging radar requires that the antenna size is many times that of radar wavelength and this is extremely costly.

- Inadequate rainfall records and limited numbers of rainfall recording stations became the most important limitation in efforts to determine daily rainfall events. The challenge for further studies is the need to assure quality and prompt quality control on routine climatic data in government agencies to obtain long term rainfall records.

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APPENDICES

Appendix 1: Vhembe and Mopani rainfall stations

STATION NAME	STATION NO	LATITUDE	LONGITUDE	HEIGHT (MAMSL)
LOUIS TRICHARD	722693	2303	2954	961
ELIM-HOS	723070	2310	3003	808
KLEIN AUSTRALIE	723363	2303	3013	702
LEVUBU	723485	2305	3017	610
TSHAKHUMA	723513	2303	3018	1158
TSIANDA	723603	2303	3020	610
BELLEVUE	723656	2326	3022	610
SHINGWEDZI	725756	2306	3126	215
THATHE-BOS	766563	2253	3019	1250
RAMBUDA	766827	2247	3028	762
FOLOVHODWE	766842	2232	3029	823
PUNDA MARIA	768011	2241	3101	462
SHINGWEDZI	768382	2252	3113	366
MESSINA-MAC	809706	2216	2954	525
MARA	722099	2309	2934	894
UNA-AGRIC	722277	2307	2940	899
SUMBOUBERG	7631124	2234	2835	610
ENTABENI	766480	2300	3016	1376
PALMERYVILLE	766779	2259	3043	570
MATIWA	766509	2259	3017	1311
TSHIPISE	766276	2260	301	579
VOORPOED	723113	2323	3004	1065
SHIFERA	7231826	2303	3012	1214
BELVERDE	679135	2375	3008	975
VERGELEGENG	679141	2385	3008	1128
HANES-MERESKY H.S	679227	2378	3013	755
HANES-MERESKY N.S	680280	2367	3067	457
CONSOLIDATE MINE	680354	2390	3070	520
MOPANI	765607	2951	715	407
TZANEEN POL				

Appendix B: Error Matrix for classification of Landsat TM for 1995 and 1997 for Vhembe and Mopani District.

Appendix B1: Error Matrix for the classification of the Landsat TM for 1995 in Vhembe District

NDVI Classes	Non-Vegetation	Low Density	Medium Density	High Density	Very high Density	Total	User's accuracy (%)
Non-Vegetation	34	0	0	0	0	34	100%
Low Density	6	32	2	0	0	40	80%
Medium Density	0	1	34	2	0	37	91.9%
High Density	6	2	3	38	0	49	77.6%
Very high Density	0	0	0	0	40	40	100%
Total	46	35	39	40	40	200	
Producer's Accuracy (%)	73.9%	91.4%	87.2%	95%	100%	overall accuracy	**89.00%**

Overall Kappa Statistics**: 0.86**

Appendix B2: Error Matrix for the classification of the Landsat TM for 2005 in Vhembe District

NDVI Classes	Non-Vegetation	Low Density	Medium Density	High Density	Very high Density	Total	User's accuracy (%)
Non-Vegetation	39	0	0	0	0	39	100%
Low Density	0	37	0	2	0	39	94.8%
Medium Density	0	2	38	0	3	43	88.3%
High Density	0	0	0	39	0	39	100%
Very high Density	0	0	0	0	40	40	100%
Total	39	39	38	41	43	200	
Producer's Accuracy (%)	100%	94.9%	100%	95.1%	93.0%	0verall accuracy	**96.5%**

Overall Kappa Statistics**: 0.95%**

Appendix B3: Error Matrix for the classification of the Landsat TM for 1995 in Mopani District

NDVI Classes	Non-Vegetation	Low Density	Medium Density	High Density	Very high Density	Total	User's accuracy (%)
Non-Vegetation	37	0	0	0	0	37	100%
Low Density	1	39	0	0	3	43	90.7%
Medium Density	0	0	39	0	0	39	100%
High Density	0	0	0	40	0	40	100%
Very high Density	0	0	0	1	40	41	97.5%
Total	38	39	39	41	43	200	
Producers Accuracy (%)	97.4%	100%	100%	97.6%	93.0%	**Overall Accuracy**	**97.5%**

Overall Kappa Statistics**: 0.99%**

Appendix B4: Error Matrix for the classification of the Landsat TM for 2005 in Mopani District

NDVI Classes	Non-Vegetation	Low Density	Medium Density	High Density	Very high Density	Total	User's accuracy (%)
Non-Vegetation	36	0	0	0	0	36	100%
Low Density	4	35	0	0	2	41	85.3%
Medium Density	0	0	40	0	0	40	100%
High Density	0	3	0	40	0	43	93.0%
Very high Density	0	0	0	0	40	40	100%
Total	40	38	40	40	42	200	
Producers Accuracy (%)	90.0%	92.1%	100%	100%	95.2%	**Overall Accuracy**	**95.9%**

Overall Kappa Statistics**: 0.92%**

Appendix C: Correlation of rainfall and NDVI for Vhembe and Mopani District

Appendix C1: Vhembe District Correlation values

1996	Rainfall	NDVI
	149.5	0.47
	102	0.17
	129	0.54
	95.5	0.37
	105.5	0.47
	96.2	0.42
	106.5	0.52
	70.4	0.36
	correlation	0.442776

2006	Rainfall	NDVI
	36.1	0.5
	13	0.37
	0	0.59
	11.6	0.42
	17.6	0.46
	12.5	0.61
	0.4	0.44
	0	0.34
	Correlation	0.134884

2011	Rainfall	NDVI
	40.5	0.45
	20.5	0.42
	86.5	0.59
	19.5	0.49
	5	0.54
	1.6	0.67
	6.8	0.53
	0	0.48
	Correlation	0.046839

Appendix C2: Appendix C: Mopani District Correlation values

1996	Rainfall	NDVI
	66	0.29
	69	0.37
	57	0.26
	45	0.25
	40.6	0.22
	81	0.2
	correlatio	0.18308874

2006	Rainfall	NDVI
	13.5	0.47
	9.5	0.25
	0	0.43
	4	0.29
	0.6	0.27
	9	0.39
	correlatio	0.29761444

2011	Rainfall	NDVI
	3.6	0.5
	3.6	0.59
	3	0.65
	3	0.49
	4.5	0.53
	13.5	0.5
	correlatio	-0.3615367