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Monitoring changes in vegetation distribution to ascertain the extent of degradation in the savannas of Nkonkobe Local Municipality, Eastern Cape, South Africa.

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Clearance by Supervisor

I certify that the content of this dissertation was done by the undersigned student and has not been formerly submitted to any other university for an award of a qualification either in part or in its entirety.

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Abstract

Savanna degradation is an environmental problem occurring in most countries around the world and it poses threats to biodiversity conservation, the food industry, and other economic sectors. According to FAO, South Africa's rangelands exhibit the highest rate of fragmentation in comparison to range ecosystems in neighbouring countries including Lesotho and Swaziland, and consensus among researchers is that communal rangelands are more degraded than commercial rangelands. Although researchers and communities have identified the occurrence of land degradation in communal savannas at a local scale, land degradation has been poorly estimated because little has been done to quantify the extent and dynamics of perceived and observed changes associated with land degradation.

The main goal of this study is to provide empirical insights on the direction of changes in the communal savannas of Nkonkobe Local Municipality in order to inform policy formulation and implementation. Additional to the communal sites is a private farm included for comparative analysis of trends in communal and commercial savannas. Landsat imagery was used to map, assess, and quantify the extent of land degradation in Nkonkobe Local Municipality, over a period of 30 years between 1984 and 2014. Field investigations were undertaken in June 2015 to acquire reference data to guide supervised classification of Landsat images. Three algorithms (Mahalanobis-distance, Minimum-distance, and Maximum likelihood classification) were compared to identify a classifier that produced the best results. The maximum likelihood classifier produced the best results with classification accuracy levels of 95.24%, 89.66%, and 95.65% for Honeydale Farm, Thyume, and Sheshegu respectively. Regression analysis revealed that both communal and private lands have experienced statistically significant increases in bush encroachment and decreases in surface water. Communal savannas have been confronted more by expansion of built-up area, decrease in open grassland, abandonment of arable land, soil erosion, and a steady invasion by *Acacia Karroo* compared to the privately owned commercial farm. The land cover changes measured through this investigation suggest an environmental shift that threatens biodiversity and agricultural activity. The study provides empirically informed insights about the direction to which these savannas are changing with the hope that the findings will prompt formulation and implementation of effective policies.

Declaration by candidate

I Wonga Masiza declare that this dissertation is my own original work except where stated, and that it has not been submitted to any other University.

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Signature

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Date

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CHAPTER 1

1. Introduction

1.1. Background

Savannas across the globe are facing a major crisis that threatens biodiversity conservation, the food industry, and other economic sectors. Rangelands cover approximately two thirds of the earth's surface (von Wehrden et al., 2012), and provide goods and services to 38% of the world's population (Reynolds et al., 2007). Kiage (2013) defines African savanna rangelands as ecosystems whose vegetation is dominated by extensive grasslands in which a sparse distribution of trees and shrubs occur, and where the primary land use is agropastorialism. Two major industries, namely; the meat industry that feeds the world's large populations and the wool industry that uses fibre from sheep depend on rangelands for their products (Svoray et al., 2013). These ecosystems also provide important habitats for numerous wildlife species. Vegetation cover in savanna rangelands is important to landscape conservation, as it protects the soil by preventing the direct impact of weather elements such as rainfall, temperature, and wind (Oluwole and Sikhalazo, 2008). Healthy savannas consist of good quality and sufficient perennial herbaceous species and little or no occurrence of unpalatable plants. Savannas rangelands in good condition are resilient against degradation and are able to recover after a temporary setback. However, savannas all over the world are degraded due to rapid population growth, overutilization, and mismanagement (Dregne and Chou, 1992; Bai et al., 2008; Harris, 2010; Zietsman., 2011).

Savanna degradation may result from a single or combination of biophysical or institutional or anthropogenic causes. Ahmad et al., (2012) defined savanna rangeland degradation as a shift in species composition, loss of biodiversity, and decline in biomass production, less plant cover, low small ruminant productivity, and soil erosion. Palmer and Bennett (2013) point out that savanna rangeland degradation is no longer constrained to vegetation change and soil loss, but it is now defined as the decline in the capacity of land to carry out ecosystem functions and services that benefit society and support development. Throughout South Africa, savannas are plagued by soil erosion, drying up of water resources, loss of vegetation cover, and undesirable changes in species composition, such as invasion by alien plants and bush thickening (Zietsman, 2011; Palmer and Bennet, 2013; Munyati et al., 2011). The savanna rangelands of South Africa exhibit the highest rate of fragmentation and degradation compared to range ecosystems in neighbouring countries such as Lesotho and Swaziland (Naidoo et al., 2013).

This fragmentation and degradation extends from the communal areas of Eastern Cape and Limpopo, eastern escarpments of Kwazulu Natal, to North West and Northern Cape provinces (Hoffman and Ashwell, 2000; Palmer and Ainslie, 2006; Zietsman, 2011).

The arrival of European settlers in Africa had significant influences to land degradation and these include; introduction of exotic crops and farming methods, accelerated resource extraction, and changes to the native community and population structures (Kiage, 2013). The earliest studies investigating land degradation in the communal areas of Eastern Cape were undertaken at the beginning of the 20th century, with findings showing that the land was already affected by degradation in the form of overgrazing and soil erosion (Palmer and Bennet, 2013).

In South Africa, communal savannas are more degraded than commercial savannas (Meadows and Hoffman, 2003; Palmer and Ainslie, 2006; Ngcofe, 2009; Palmer and Bennett, 2013). Commercial savanna rangelands are privately owned grazing lands where systematic management schemes are preferred by farmers, while communal savanna rangelands are often open access and used for communal livestock grazing (Palmer and Ainslie, 2006). Unlike commercial rangelands where there is private and/or individual ownership, communal savannas are owned and managed by the entire community (Scogings et al., 1999). Communal grazing areas occupy 13% of the total farming area in South Africa, and support 52% of the country’s cattle population, 72% of the goats and 17% of the sheep (Palmer and Ainslie, 2006). Today, these areas have large human populations which are exerting increasing demands on rangeland ecosystem goods and services.

What will result from utilization pressure and exploitation of land resources in some areas remains unknown and insufficiently understood. Uncertainty concerning the extent and magnitude of land degradation is one of the issues contributing greatly to the lack of effective policies and poor management of savanna rangelands. This knowledge gap is a result of insufficient quantitative research, and has invoked the current debate around communal savannas of South Africa. This study is an attempt to enhance understanding of savanna rangeland degradation in rural areas by mapping the extent of land degradation in the savannas of Nkonkobe Local Municipality between 1984 and 2014 using Remote Sensing and GIS techniques.

1.2. Problem statement

The Eastern Cape Province, which is largely rural, is regarded as one of the three provinces worst affected by savanna rangeland degradation in South Africa (Hoffman and Ashwell, 2001). Evidence from both scientific research and visual observations shows that land degradation has reduced land productivity and functional capacity in communal savannas. Degraded communal savannas have been characterized by increasing areas of soil erosion, proliferation of woody plants (bush encroachment), development of bare soil surfaces, gullies and loss of vegetation cover, and substantial increase in unpalatable plant species and invasion by alien vegetation species (Munyati et al., 2011; Matsika, 2008; Ighodaro et al., 2013). However, there is still a lack of certainty as to what extent each of these degradation forms have spread. Although researchers and communities have identified the occurrence of savanna degradation and its causes in Nkonkobe Local Municipality, little has been done to quantify the extent and dynamics of the perceived and observed changes associated with land degradation. This explains why regional and local degradation have been poorly estimated (Wessels, 2005). One of the biggest hindrances to policy formulation and land management especially in rural areas is the paucity of up-to-date spatio-temporal data of communal rangelands. This drawback can be addressed through the development of properly planned monitoring systems to keep the authorities informed on the areas where severe land cover transformation is occurring and how it threatens biodiversity and land productivity (Matsika, 2008; Stuckenberg et al., 2013). This study addresses this problem by mapping and quantifying the extent of the perceived and observed changes associated with land degradation in Nkonkobe Local Municipality.

1.3. Objectives of the study

The main objectives of the study are to:

a. Map spatial and temporal savanna rangeland degradation in Nkonkobe Local Municipality between 1984 and 2014.
b. Provide empirically informed insights on the land cover changes detected in this environment in order to inform policy formulation and implementation

An attempt was made to accomplish these objectives by:

- Characterizing the vegetation cover in the study area
- Determining the extent of spatial and temporal land degradation threatening biodiversity.

- Assessing the impacts of management strategies on the spatial and temporal changes of the savannas.
- Assessing the direction and the levels of statistical significance of the observed changes.

1.4. Major hypothesis

Having systematically outlined the problem of land degradation in the area, this study hypothesizes that the spatial extent of degradation in Nkonkobe Local Municipality rangelands has increased significantly over the past three decades. This assertion is premised on the established observation that rangelands under communal management have been undergoing transformation since the inception of the land redistribution process (conversion of freehold farms to communal ownership) in 1994.

1.4.1. Specific hypothesis

Degradation increase in the communal rangelands of Nkonkobe Local Municipality is evident in the form of bush encroachment, increased bareness and soil erosion, abandonment of arable land, and substantial increase in unpalatable plant species.

1.5. Justification of the study

Since land degradation is a phenomenon that is manifested by observable development of bare soils, proliferation of woody plants, and decrease in vegetation vigour, it can therefore be monitored through measurements of land cover alteration over time. In this regard, remote sensing techniques of change detection have proven to be efficient and should be employed regularly. Although researchers have investigated vulnerability and responses to land degradation in Nkonkobe Local Municipality (Moyo et al., 2012; Duma, 2000; Buitenwerf et al., 2012), little research has been dedicated to measuring the extent to which degradation has occurred. This study attempted to bridge this gap by providing a time-series reconstruction of land degradation in the Nkonkobe Local Municipality. It is hoped that findings from this investigation will go a long way in enhancing our understanding of the drivers of degradation in this environment, more so, because it is one of the few studies that have so far been undertaken using remote sensing to quantify and characterize degradation in the Eastern Cape Province's communal savanna rangelands. Since more focus has been on qualitative measures and perceptions (Bai et al., 2008), the lack of up-to-date quantitative information is a hindrance to policy support, resource conservation and environmental integrity. The study therefore produced reliable degradation maps in communal areas, seeking to counteract the problem of data paucity at regional and local scales and it is hoped that the results of this research will assist the local government and communities in formulating environmentally friendly policies and sustainable land use and land management strategies.

1.6. Limitations

Although the objectives of the investigation were accomplished, there were constraints.

- Initially, the goal was to map the vegetation of the area at a species level, but this could not be achieved because of the spatial resolution of Landsat data.
- Gullies and rills were not captured because they occurred at a sub-pixel level, and to counteract this hindrance, gullies and rills were generalized as bare ground.
- Though the methods and the data were cost effective, unavailability of funds contributed to the above-mentioned limitations

CHAPTER 2

2. Literature review

This chapter entails exhaustive assessment of historical and recent research on rangeland degradation. The discussion focuses mainly on the causes of land degradation and the efforts that have been undertaken so far to counteract savanna rangeland degradation. The last part of the chapter (Section 2.5) then provides a review of GIS and Remote Sensing studies that have been undertaken to assess land degradation in Eastern Cape, particularly in Nkonkobe Local Municipality, and other areas in South Africa.

2.1. Importance of savanna rangelands

Utilization of savanna rangeland resources involves diverse economic activities including conservation and tourism, commercial livestock farming, and communal and smallholder livestock systems. Savanna rangelands in South Africa largely comprise grassland, arid savanna, semi-arid savanna, thicket, Nama-Karoo, succulent Karoo, desert and fynbos (Naidoo et al., 2013), and they occur across a wide range of conditions, their distribution being determined by soil and climatic conditions (Ford, 2002). These ecosystems are found mostly in the inland areas of Kwazulu Natal and Eastern Cape and mostly grazed by cattle, sheep, and goats (Palmer and Ainslie, 2006), with communal grazing systems and commercial ranching dominating the land use management schemes (Kgosikoma et al., 2013). The inhabitants of these regions are indirectly dependent upon these savannas for the production of meat, milk, and other traditional uses of livestock (Palmer and Ainslie, 2006). Although these products are not produced primarily for commercial systems; they contribute significantly to the economy and food security of these regions. However, the benefits derived by rural livelihoods from savanna rangelands are still undervalued in formal economic assessment and marginalized in policy making (Vetter, 2013).

2.2. Savanna rangeland degradation and its causes

Degradation of drylands, climate change, and loss of biodiversity are clear indications that natural processes are not well understood (Cowie et al., 2011). Society at large including laypersons need to be informed of the socioeconomic and environmental repercussions that are incurred due to the failure to counteract land degradation. Savanna degradation in some areas affects not just pastoralism but many other environmental land use activities that benefit society (Ahmad et al., 2012; Eldridge, 2011). Land degradation differs from place to place with respect to spatial and temporal variation of vegetation and land exploitation practices (Ahmad et al., 2012). Worldwide land degradation is seen as a result of a complex interaction of various environmental, climatic, historical, political, and socioeconomic factors. Research has confirmed the occurrence of savanna deterioration in many parts of the world including; Asia (Han et al., 2008; Harris, 2010), Australia (Dong et al., 2011; Bai et al., 2008), North America (Heitschmidt, 2004; Chamber and Pellant, 2008; Guevara et al., 2013;), South America (Fernandez and Busso, 1999, Dregne, 2002), Europe (Lorent et al., 2009), and many parts of Africa (Hoffman and Ashwell, 2001; Stringer and Reed, 2007, Miehe et al., 2010; Naidoo et al., 2013). Loss of land productivity in Sub-Saharan Africa is estimated to be almost 1% every year (Kiage, 2013). One of the major threats to ecological sustainability of savannas is the ongoing conversion of rangelands to other land uses such as croplands and residences (Heitschmidt et al., 2004).

Several authors have argued that heavy grazing by domestic livestock is the main cause for savanna rangeland degradation (Snyman, 2004; Snyman and Du Preez, 2005; Palmer and Ainslie, 2006; Du Preez et al., 2011), and some postulate that the effects of climate change contribute greatly to land degradation (Scogings et al., 1999; Vetter, 2009; Naidoo et al., 2013); while Meadows and Hoffman, (2003) assert that change does not often imply degradation because it occurs as a result of natural variability, so that the dynamics of vegetation cover should be seen as reactions to a wide range of environmental inputs, management being one of them. Intrinsic land properties such as biophysical factors including soil properties, climatic characteristics, topography, and vegetation do interact amongst themselves to exacerbate land degradation without human influence. Therefore, savanna rangeland degradation can result from natural processes, anthropological factors, or from both.

2.2.1. Natural causes

Topographic and geological factors such as slopes and soil susceptibility to wind and water erosion have a significant influence to savanna rangeland degradation. High rainfall on bare soils is likely to cause soil erosion (Morgan, 2009). Soil properties such as texture, structure, roughness, organic matter content, and soil moisture determine susceptibility of soil to erodibility. For instance, vegetation is easily established in moist soils, while drier soils tend to hinder vegetation growth (Ravi et al., 2010). Availability of forage in savannas is largely determined by soil types and rainfall patterns (O’ Farrell et al., 2010). Savannas with low annual rainfall, steep slopes, and high temperatures are the most vulnerable to extreme levels of degradation (Palmer and Ainslie, 2006). Research shows that areas with steep slopes in

South Africa, mostly located in Kwazulu Natal and Eastern Cape, exhibit the highest rate of degradation (Hoffman and Todd, 2000). In many places around the world, land degradation is expected to worsen ecosystem conditions and productivity due to climate change through frequent occurrence of extreme droughts and decline in annual rainfall (Vogt et al., 2011). Degradation in drylands is intensified by climate change and degradation itself can exacerbate climate change by exhausting carbon stocks in vegetation and soils, thus giving rise to atmospheric carbon dioxide, because the amount of carbon in the soil is very crucial to ecosystem services and to processes such as plant reproduction, as it also plays an important role in enhancing resilience to climate variability and climate change (Cowie et al., 2011).

Meadows and Hoffman (2003) point out that bare soil development and decrease of perennial vegetation cover in some situations result from severe climatic events such as drought. Droughts are typically short term and incurred damage may be followed by recovery, however, in some cases droughts can cause irreversible alterations to the ecosystem (Vetter, 2009). Frequent occurrence of droughts and low rainfall can trigger loss of vegetation cover, and in areas subdued by high grazing pressure drought can increase degradation. When drought is followed by heavy rains, the result is often soil erosion through removal of topsoil and nutrients (Stringer and Reed, 2007). Although natural processes are often triggered by human activities to cause degradation, natural processes can also act independently and interactively among themselves to exacerbate degradation (Kiage, 2013). Therefore, the natural setting of an environment needs to be factored in when investigating the causes of land degradation in a particular area. Mhangara et al., (2012) applied GIS and Remote Sensing to investigate spatial patterns of soil loss in the Keiskamma catchment and revealed that high rates of soil erosion occur on highly erodible soils and in areas with steep slopes.

2.2.2. Anthropogenic factors

Vetter (2013) argues that most degraded savanna rangelands are not necessarily the result of communal grazing, but a combination of high human densities and their various impacts. Human pressure on land resources is one of the driving forces behind the problem of land deterioration (Young, 1994). Human population increase demands expansion of residential areas and development of public infrastructure, and this threatens soil and vegetation and render savanna rangelands vulnerable to bare soil increase and invasion by alien plants (Zietsman, 2011).

In communal areas, human population has increased such that grazing land is being lost to housing (Scogings et al., 1999). Kiage (2013) reports pressure on savanna resources turns to overexploitation through overgrazing and deforestation, and in some areas; vacant land is scarcely available whilst the number of people dependent on savanna resources increases rapidly every year. Land shortage and poverty tend to exert pressure on the available land resources and this eventually results in poor and unsustainable land management practices (Young, 1994). The rate of population growth has been a setback to traditional farming systems which involved abandoning certain areas to permit natural recovery and this has resulted in soil erosion (Kiage, 2013). Javed et al., (2012) used GIS and remote sensing to assess land degradation in India, Rajasthan, and the investigation revealed that anthropogenic activities and population pressure contribute to land degradation.

2.2.3. Land redistribution and other political factors

Political instability and socio-economic problems in Africa have triggered migration of people from one country to another, thus creating a large number of refugees. In South Africa, colonization left the rural black citizens in small areas of land that are easily distinguished from the extensive private farms that belong to white farmers (Anderson and Hoffman, 2007). Zietsman (2011) reports that the escalating savanna exploitation in South Africa is a consequence of cultural changes, redistribution of people and human population increase. Meadows and Hoffman (2003) point out that the situation in Zimbabwe is a clear demonstration of how crucial land reform and redistribution is towards the subject of land degradation.

The land reform programme has only focused on redistributing land and failed to ensure that the rural communities have sufficient resources to sustain and maintain savannas (Palmer and Ainslie, 2006). The initiatives undertaken to sustain communal savannas thus far have not done any improvements because of their failure to take into consideration the ecological, social and economic complexities of these systems (Allsopp, 2013). The government sectors responsible for land redistribution and land reform have come to a realization that the idea that land redistribution would encourage rural pastoralists to practice commercial farming has not emerged as expected (Allsopp, 2013). There is a range of management techniques that scientists and extension officers can choose from, but they need additional training, equipment, finance and time for range managers to use them. In conclusion, inappropriate formulation and implementation of policies has been a setback to savanna rangeland sustainability.

2.2.4. *Management of savanna rangelands and policy formulation in South Africa*

Although the dependency of humans on agricultural resources features as one of the root causes of land degradation, savanna management emerges as the chief determinant of the rate, severity, and extent of degradation (Meadows and Hoffman, 2003). One of the major causes of land degradation is the exploitation of land without any management strategy). The current land tenure and land use management in South Africa stems from political and socioeconomic history (Meadows and Hoffman, 2003). Savanna management systems in South Africa are distinguished from one another by management strategies, animal diversity, and products (Smet and Ward, 2005). In areas where land is exploited for only one ecosystem service, other services are usually deemed less important (O'Farrell et al., 2010). Communal areas largely consist of diverse livestock, comprising browsers and grazers (Palmer and Ainslie, 2006; Kiage, 2012).

Rural graziers aim at keeping animals rather than maximizing productivity. On the other end, management strategies utilized by producers are often skewed towards achieving production goals, neglecting other issues such as biodiversity conservation (O'Connor et al., 2010). In some rural communities smallholder farmers feel that the rules rather tend to restrict their activities (Mokhahlane, 2009). While communal savanna rangeland management is mainly based on traditional systems with livestock owners having no formal education, commercial savannas are monitored by educated people with tertiary training.

In some areas, savanna management has almost been abandoned due to the dominance of the government welfare grants which have replaced the income generated through savanna rangeland resources (Rutherford and Powrie, 2011). As a result of poor management, livestock numbers grow unnoticed in communal areas, while in the long run livestock numbers exceed the capacity of the rangeland (Smet and Ward, 2005). Stocking rates in communal areas have been almost twice those recommended by the government (Anderson and Hoffman, 2007; Hoffman and Todd, 2000). Municipalities are affected by lack of proficiency and insufficient funds to employ effective management of communal rangelands on their own (Puttick et al., 2011).

The current policy for development and sustainable management of communal savanna rangelands is still lacking coherence and it does not address the situation in communal areas (Vetter, 2013). Adoption of mitigation measures and models developed elsewhere rather than on the unique local situation cannot efficiently address the problem of degradation. Strategies and projects aiming at counteracting this problem in communal areas need to first acquaint themselves with the management schemes employed by the communities, and then work towards enhancing those strategies (Kiage, 2013). Allsopp (2013) points out that graziers in communal areas respond to environmental variability through adaptive management, and this approach has been practiced in the Eastern Cape where livestock owners implement grazing strategies based on the ecosystem condition (Bennett and Barrett, 2007; Bennett et al., 2010).

In some rural communities livestock owners have become aware of land degradation through monitoring forage availability and livestock production and health, and this contradicts the notion that communal farmers do not exercise grazing management at all. This supports the statement made by Vetter (2013) that the grazing management plans based on rotational and erecting fences do not address the people's objectives and constraints. Thus, an ongoing interactive engagement needs to be established between rural land managers, scientists, and policy makers (Stringer and Reed, 2007). Management strategies that are devised with respect to the multi-functionality of savanna rangelands, taking into account sustainable food production, biodiversity conservation, water, and job creation, have the capacity to improve both ecological processes and ecosystem services, thus ensuring resilience and sustainability of the land (O'Farrell et al., 2010).

2.2.5. Overgrazing

Overgrazing occurs when livestock numbers become excessive and a high density of animals are grazed in the same area and grazing pressure exceeds the carrying capacity of the land (Rinehart, 2006), leading to loss of vegetation cover, replacement of palatable vegetation by unpalatable plants, and soil erosion. Footpaths created by human and animal hoofs develop into rills and gullies, thus increasing soil bareness and worsening soil erosion. A large number of animals can exert pressure on the available vegetation, but the manner in which the land is exploited is very crucial (Kiage, 2013). Thus, overgrazing is not exclusively determined by the number of animals in an area, but the time spent by the animals repetitively grazing an area is very crucial because continuous grazing allows animals to consume the most palatable plants, and consequently the palatable plants do not get enough time to regrow before they are grazed again (Rinehart, 2006).

The communal savanna rangelands of South Africa are heavily overstocked and evidently overgrazed (Hofman and Todd, 2000; Palmer and Ainslie, 2006). High grazing pressure during drought periods increases plant mortality, reduces the possibility of natural recovery, and renders the land susceptible to soil erosion and degradation (Vetter and Bond, 2012). Rowntree et al., (2004) evaluated two case studies (Duma, 2000; Kakembo, 2001) to examine the notion that communal grazing systems degrade savana condition, and concluded that the overgrazing hypothesis must be treated with vigilance. Studies have shown that plant species richness in heavily utilised communal savannas can be higher than in conservation and commercial areas (O'Connor et al., 2010; Rutherford and Powrie, 2011). Rutherford et al., (2012) argue that heavy utilization of communal savannas does not necessarily influence loss of biodiversity, rather the issue of loss of plant cover through intense land use is questionable whether it contributes to the decrease in ecosystem productivity. Heavy utilization of communal savanna rangelands in the future is less likely to negatively affect plant biodiversity than contributing to the change of individual plant species and transforming woody savanna to shrubland (Rutherford and Powrie, 2011).

2.3. Degradation processes

Basic knowledge, understanding, and unambiguous definition of the problem of degradation is essential to the selection of variables and indicators of degradation. Due to environmental shifts, land use and land cover change has been the crux of environmental research globally. Generally the term 'land use' refers to human activity of the land and includes a range of activities such as cultivation, grazing, settlements, recreational areas, infrastructure, industrial places, while land cover refers to the biophysical or natural features of the land. Land cover change usually occurs in two different forms, namely; land cover conversion and land cover modification (Hudak and Wessman, 1998). Land cover conversion is a complete shift from one land cover class to another (e.g. conversion of grazing areas into croplands or vice versa). This type of change is abrupt in impact and easily delineated, while land cover modification is more subtle involving a gradual alteration of characteristics within a particular land cover class (e.g. degradation of a grassland by overgrazing) (Turner et al., 1994).

Loss of vegetative cover and change in species composition are most likely the first discernible forms of savanna degradation (Meadows and Hoffman, 2003). Decrease in palatable species, and encroachment of undesired forbs and shrubs leads to decline in soil quality (Oluwole and Sikhalazo, 2008). Vegetation is an important indicator of physical or chemical degradation of an ecosystem. Vegetative cover has been a subject of investigation, indicating early signs of land use and land cover change (Mansour et al., 2012). Ground and surface water resources have also experienced negative changes including a disappearance of surface water and a decline in underground aquifers (Dube and Pickup, 2001). Savanna rangeland degradation indices including; decline in basal cover of perennial grasses, changes in species composition from palatable to unpalatable species, increase in density of woody shrubs, drying up of water resources and increase in soil erosion, can occur concurrently in the same area . However, delineation of variables and indicators of degradation needs interactive participation between researchers and local communities (Stringer and Reed, 2007). The following section provides an overview of indicators of degradation as identified from literature.

2.3.1. Bush encroachment

One of the important components of land cover modification and savanna deterioration in South Africa is the phenomenon known as bush encroachment. Bush encroachment occurs when woody plant species in grasslands and savannas advance gradually beyond accepted limits (Meadows and Hoffman, 2003; Wigley et al., 2009). Manjoro et al., (2012) define bush encroachment as an increase in density, cover, extent, biomass and species of woody vegetation on land previously inhabited by other vegetation or land use. Bush encroachment is an important indicator of land degradation and loss of biodiversity which has become a global concern (Moleele et al., 2002; Oldeland et al., 2010; Ratajczak et al., 2012). Classically, bush encroachment is understood as a phenomenon that is likely to occur in savanna areas (Meadows and Hoffman, 2003). Despite the differences amongst rangeland systems, several research findings have shown that bush encroachment occurs in both communal (De Bruyn, 1998; Puttick et al., 2011;) and private lend tenure systems (Buitenwerf et al., 2012; Wigley et al., 2009), and this indicates that it is more than just land use practice that accounts for woody plant proliferation in savannas. In South Africa, occurrence of woody plant proliferation has been confirmed in the savanna rangelands of Kwazulu Natal (Wigley et al., 2009; Bangamwabo, 2009), Northern Cape (Smet and Ward, 2005), North West (Mampholo, 2006), Limpopo (Munyati et al., 2011), and Eastern Cape (O'Connor and Crow, 1999; Manjoro et al., 2012).

Bush encroachment may cover an area with trees to store carbon while loss in vegetative cover may diminish carbon sinks. In areas where ranching is mainly browsing than grazing, bush encroachment is not considered a threat (Zietsman, 2011). In countries such as Botswana and Namibia including South Africa, thorny bush encroachment is considered a constraint by rural communities (Stringer and Reed, 2007; Bennett et al., 2010). The idea that bush encroachment is a degradation process must be considered vigilantly because when a broader perspective is applied to this phenomenon, considering other aspects of land use besides pastoralism, bush encroachment may have positive effects (Eldridge et al., 2011).

2.3.2. *Bareness and soil degradation*

Another indicator of overutilization and degradation of vegetation in rangelands is bare ground development (Ngcofe, 2009; Dube and Monde, 2011). Ighodaro et al., 2013 indicate that processes and practices that expose soil to wind and rainfall render the soil susceptible to erosion. The susceptibility of soil to erosion is dependent upon several interrelated elements including climate, soil moisture, soil properties, topography, land cover and management (Ravi et al., 2010). Bare soil reduces water infiltration, thus rendering the soil vulnerable to high run off rates, washing away of soil particles, and gully erosion (Smet and Ward, 2005; Dube and Monde, 2011). Semi-arid regions are often characterized by development of gullies and badland (Keay-Bright and Boardman, 2009). The greatest proportion of degraded land in the whole of Africa is due to soil erosion (Ezeaku and Davidson, 2008).

In South Africa, this problem is most severe in the Limpopo, Kwazulu Natal and Eastern Cape provinces (Palmer and Ainslie, 2006), and drastically higher in communal areas (Hoffman and Todd, 2000). Land managers in communal areas rely more in the inherent properties of their soils and landscapes because they do not have capital to supplement land (Ezeaku and Davidson, 2008). So the young people of these areas migrate to urban areas to seek income through employment, leaving old man, women, and children in the villages, and this has led to loss of land management knowledge and marginalization of vulnerable rural communities (Ezeaku and Davidson, 2008).

The grasslands and savannas of Nkonkobe Local Municipality are amongst the areas affected by bare soil development and soil erosion in the Eastern Cape Province (Duma, 2000; Dube and Monde, 2011; Ighodaro et al., 2013). Dube and Monde (2011) report that there’s an extensive proportion of bare soil that is vulnerable to high rates of runoff in the communal areas of Nkonkobe Local Municipality. Mhangara et al., (2012) used GIS and Remote Sensing to investigate soil erosion in the Keiskamma catchment and made an observation that high rate of soil degradation occur mostly in communal areas where high grazing pressure and woodcutting greatly reduce vegetation.

2.4. Land degradation monitoring

Characterizing the environment by evaluating and describing its resources is different from monitoring which comes with a temporal aspect with the objective to assess spatial events and changes in relation to management (Gintzburger and Saidi, 2009). Monitoring and assessment of land degradation requires a model or a system that takes into account the information needs of diverse groups including local, regional, national and global policy makers, scientists, rangeland managers and all who benefit from these ecosystems (Vogt et al., 2011). Monitoring of land provides information that facilitates policy formulation and decision making, informing farmers and environmentalists about efficiency and deficiency of different management practices and strategies (Beunemann et al., 2011; Schwilch et al., 2011; Vogt et al., 2011). Land degradation monitoring can be done using different approaches, each with its defined objectives. One approach is to monitor a land that is already undergoing a certain stage of deterioration, or alternative approach is to monitor the land for measuring degradation vulnerability.

2.4.1. Historical and recent savanna health condition assessment efforts

Strategies and efforts from various scientific disciplines have been employed in attempting to combat the problem of land degradation, and these include; ecological investigations, assessment of soil properties, interpretation of satellite images through remote sensing and Geographic Information Systems, and perceptions and community interviews. Nonetheless, modern day research has shown that even the best possible scientific explanation has its own shortfalls (Stringer and Reed, 2007). Beunemann et al., (2011) and Schwilch et al., (2011) argue that the monitoring efforts made by UNCCD (United Nations Convention to Combat Desertification) to counteract land degradation have so far been inadequate. The argument is that endeavors that marginalize geospatial techniques often provide geographically partial, potentially unstable, inaccurate, and misleading results, thus presenting themselves as unreliable to land managers and decision makers.

GLASOD (Global Assessment of Human Induced Soil Degradation) produced the first global map of soil degradation (Oldeman, 1994), and it has been utilized by UNCCD (Schwilch et al., 2011). Vogt et al., (2011) made an observation that GLASOD is limited to soil degradation assessment leaving out the other components of land resource. LADA (Land Degradation Assessment in Dry lands), a project that succeeded GLASOD (Vogt et al., (2011), is a land degradation assessment initiative undertaken at local, national and global scales to identify areas with severe land degradation (Nachtergaele and Licona-Manzur, 2009). LADA was initiated by UNEP (United Nationas Environment Programme) and FAO (Food and Agriculture Organisation) in 2001 to assess land degradation status, drivers, and impacts (Schwilch et al., 2011). Vogt et al., (2011) notes that as much as LADA is a good starting point towards integrated assessment, it has identified degradation in humid areas better than in arid areas.

2.4.2. Monitoring and assessment of savanna condition in South Africa

The earliest investigations of savanna rangeland deterioration in South Africa took place at the beginning of the 20th century, with researchers reporting that the degradation trends evident at that time were results of overgrazing and soil erosion (Acocks, 1988; Milton and Dean, 1995; Palmer and Bennett, 2013). The first savanna condition assessment technique in Southern Africa was formulated based on the decreaser-increaser species approach. Decreaser species decrease in abundance under heavy utilization of the land, while increasers are plant species that increase in abundance under intense grazing (Reed and Dougil, 2010). Rutherford and Powrie (2011) argue that the increaser-decreaser model needs to be revisited considering evidence of its inconsistency.

The first land degradation map of South Africa was produced in 1953 by Acocks (Zietsman, 2011), who predicted that there would be an incremental progressive trend signifying deterioration in the condition of South African veld, especially in grassland areas with communal grazing lands in Ciskei, being reported three decades later as severely degraded by soil erosion and overgrazing (Acocks, 1988). Studies on savanna condition, degradation assessment, and rehabilitation have been research priorities in South Africa since the beginning of the land redistribution and restitution process (Milton and Dean, 1995; Cousins, 1996; De Bruyn, 1998; Scogings et al., 1999; Rohde et al., 1999; Wessels et al., 2004; Kakembo, 2001; Bennett and Barrett, 2007; Puttick et al., 2011; Palmer and Bennett, 2013). Assessment of degradation trends and how research findings are interpreted remains an unresolved controversial issue. If savanna condition would reflect biodiversity condition as well as resource condition it would be a suitable indicator (O'Connor et al., 2010). When Hoffman and Todd (2000) conducted a national review of degradation, the investigation was not informed by objective measurements and empirical observations, but the findings of the assessment were largely based on people's perceptions. Monitoring, mapping, and assessing vegetation by species using conventional field-based techniques allow only small areas to be covered. There have been numerous efforts done to monitor range condition, yet very little helpful information accumulated. There has been little empirical research undertaken to relate land degradation to the amount of time the land has been under communal management (Palmer and Bennett, 2013).

Although studies have managed to identify and distinguish degraded areas from non-degraded areas, there is limited information classifying the different levels of rangeland degradation on large spatial extents (Mansour et al., 2012). A disregard of bush encroachment, loss of vegetative cover, and bare soil increase in savanna rangelands has the potential to far reachingly degrade the ecosystem within a short period of time. Mapping degradation at national level begins with assessing and monitoring land cover change at regional or local level. Regular monitoring is the most appropriate approach by which savanna degradation information can be captured, and the need for regular use of remote sensing and GIS techniques is undeniable.

2.5. Remote sensing and GIS in savanna rangeland monitoring

Geospatial technology has played a major role in the analysis of geographical phenomena. Since the advent of satellite remote sensing, environmental studies have been making use of information derived from satellite imagery to improve planning and to keep track of environmental changes. Today, the usage of satellite imagery provides quick answers to questions such as in this case; where are the savannas? What dynamic changes have shaped the land? To what extent have these changes occurred? Because land degradation is an environmental problem that is spatial in nature, trends can be spatially and temporally assessed by monitoring land cover to verify if the observed changes are indeed components of land degradation (Bangamwabo, 2009). Assessing spatiotemporal trends of land degradation helps in quantifying and measuring the rate at which the land is degraded. This information serves as a basis for prediction of future changes, and it also keeps the local communities alert of the effectiveness and defectiveness of their land management systems. Whether one is assessing, investigating, or monitoring land degradation, remote sensing and GIS techniques provide a useful platform in determining areas most and least degraded. Remote sensing and GIS techniques are also capable of determining spatial patterns of the detected changes, the rate of the land degradation, and spatial dispersal of land degradation in relation to other land cover types (Bangamwabo, 2009).

Various multispectral and hyperspectral images and aerial photographs have been used to discriminate different vegetation types from other land use types in degraded areas. One of the few investigations that used geospatial technology to investigate land degradation in the Eastern Cape is the study undertaken by Manjoro et al., (2012). Manjoro et al., (2012) applied NDVI analysis and unsupervised classification on spot imagery to assess spatial and temporal patterns of soil erosion and woody encroachment in a catchment in Peddie (±50km South East of Alice). Although the investigation was successful, other factors that sustain ecosystem functioning including; biodiversity and water resources were not addressed. The 10 year period that was investigated in the study was relatively short as some changes are not necessarily an indication of degradation, but occur because of natural variability.

Buitenwerf et al., (2012) integrated object-based image analysis with a fire regime experiment to analyze changes in woody cover in two private lend tenure systems (Honeydale Research Farm and Kruger National Park). Buitenwerf et al, (2012) used aerial photographs to determine how the contemporary tree cover density in Honeydale Research Farm compares to a pre-clearing (before 1980) state. The aerial photographs were classified in eCognition (a remote sensing software), and produced map-outputs with accuracies of 86% and 84% for 1973 and 2007 respectively (Buitenwerf et al., 2012). The results of the investigation showed that tree density increased significantly between 1973 and 2007 in Honeydale Research Farm. The study was successful, however, the investigation was limited to private land tenure systems, and the assessment focused exclusively on bush encroachment leaving out other land cover changes associated with land degradation.

Mhangara et al., (2012) used GIS modelling and object-oriented mapping to assess the spatial patterns of soil loss in the Keiskamma catchment, Eastern Cape, South Africa. A portion of the Keiskamma catchment falls within Nkonkobe Local Municipality. The results of the investigation revealed that the rates of soil loss in the catchment were above sustainable tolerance limits. The investigation also revealed that areas with high rates of soil loss were associated with the rural communities. The study was successful in determining the spatial patterns of soil loss. However, because the study was focused solely on assessing the spatial patterns of soil loss, temporal changes of land cover and land use that could have influenced soil erosion were not investigated.

Ngcofe, (2009) used Landsat imagery, combining remote sensing and GIS with community interviews to measure and assess the spatial characteristics and nature of land degradation in Qoqodala, Eastern Cape. The findings of the study revealed occurrence of bare ground increase and encroachment of indigenous vegetation by *Euryops* species. Since the study used community interviews and unsupervised classification to map land degradation, there is limited evidence of the observed changes because the method is more based upon people's perceptions and computer algorithms, than physical reality.

Munyati et al., (2011) assessed and monitored bush encroachment in two rangeland sites in Makopane, South Africa, using multi-temporal Spot data. Hybrid pixel based image classification techniques were used to discriminate areas affected by noticeable encroachment, and those affected by low encroachment, and no encroachment. The investigation was successful in detecting bush encroachment in the study area, however the research was limited to bush encroachment, omitting the other indicators of land degradation, such as; soil degradation and bare soil development, surface water depletion and expansion of the surrounding residential areas.

These investigations demonstrate that remote sensing and GIS can be effectively used to quantify land cover changes and monitor long term co-extensive trends in land degradation. The idea of authorizing "individual case studies" in the land degradation debate will produce far reaching effects only if geospatial technology is employed as much as conventional methods are employed. More spatio-temporal research that focuses on quantitative assessment of the various land cover changes that are associated with land degradation is required. This will enhance the people's ability to understand land degradation and its trends, and resolve the lacking empirical aspects in the current methodological framework.

CHAPTER 3

3. Methodology

The methodology (**Figure 1**) used in this study consists of a hybrid approach in which Remote Sensing and GIS techniques are conjunctively used to monitor degradation in the savannas of Nkonkobe Local Municipality.

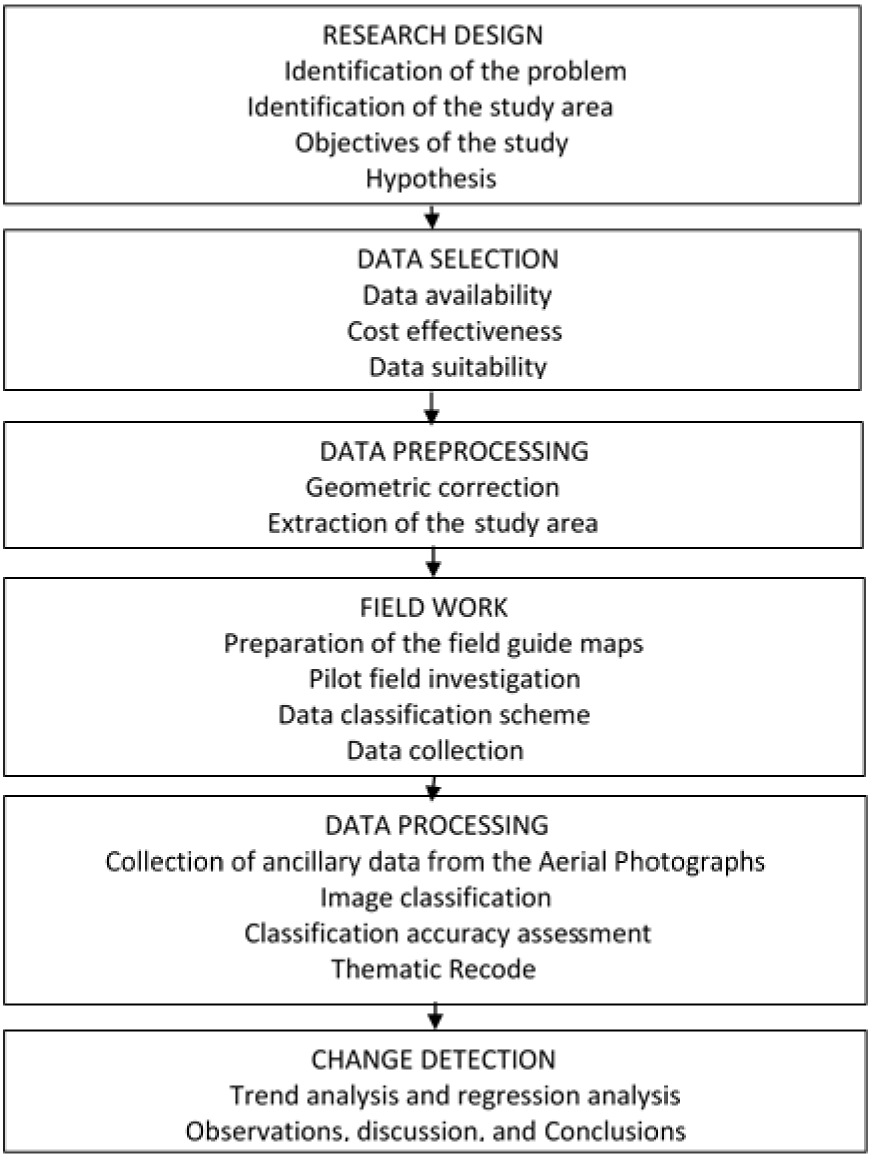


Figure 1: The sequence of how results were obtained in the study

3.1. Study area

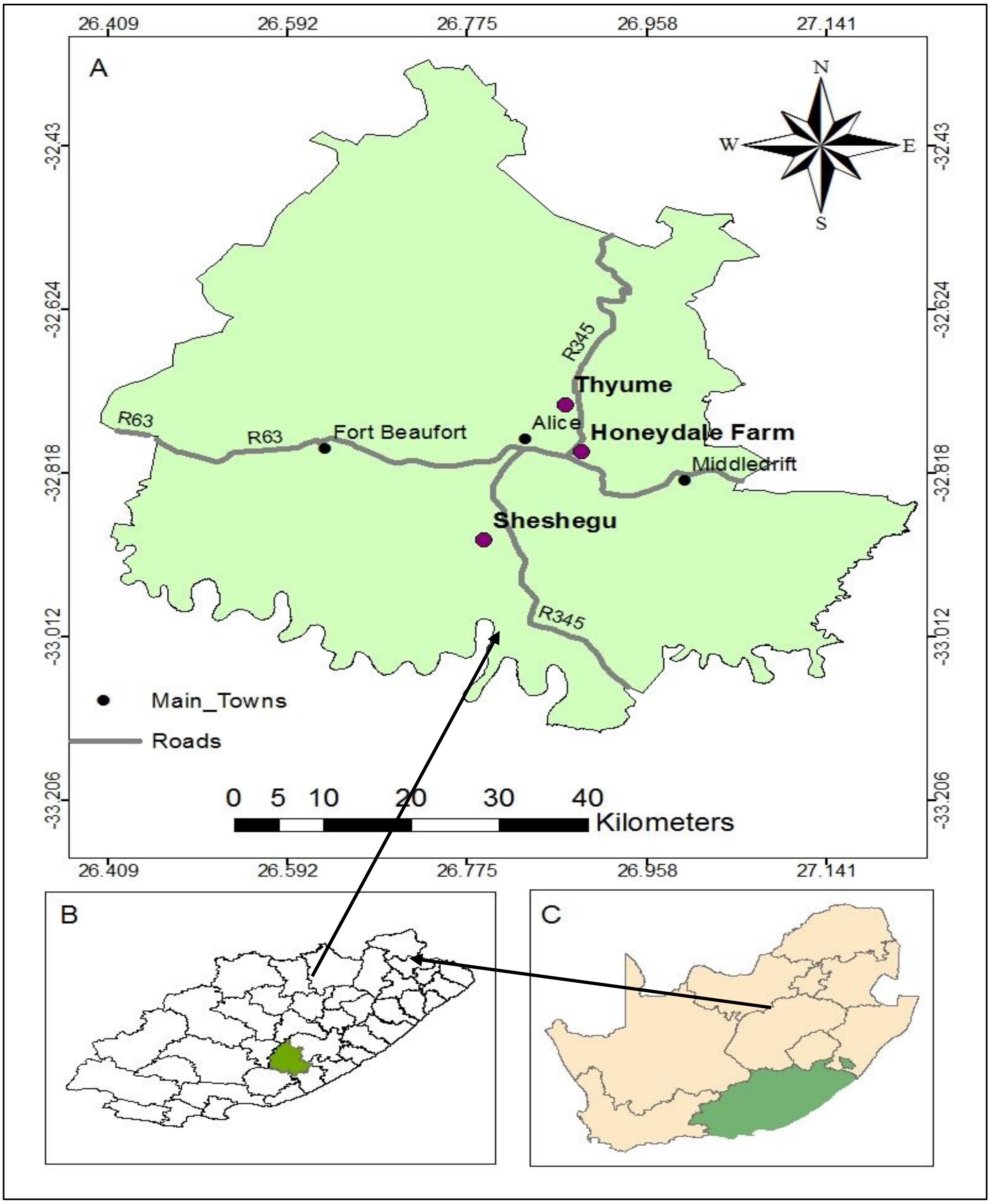


Figure 2: Nkonkobe Local Municipality (A), Eastern Cape (B), South Africa (C)

Nkonkobe Local Municipality (**Figure 2**) is situated between 32º 47' and 26º 50' east of the Karoo in Eastern Cape Province, South Africa. Nkonkobe Local Municipality is the second largest local municipality in the Eastern Cape province of South Africa. This municipality consists of small towns, farms, and villages, which fall under the Amathole District

Municipality. According to census 2011, Nkonkobe Local Municipality has a total population of 127115 of which 60% is black Africans who are rural dwellers. The area is dominated by rural dwellers that rely heavily on social grants. The study sites are situated at 80km inlands from the Eastern Cape coastline in a town called Alice.

3.1.1. Study sites

A number of study sites was investigated to reconstruct changes in vegetation distribution and to ascertain the extent of degradation in the savannas of Nkonkobe Local Municipality. These sampling sites include: Honeydale research farm, Sheshegu, and Thyume (**Figure 2**). These areas were purposely selected because they are degraded because of unsustainable land management practices (Dube and Monde, 2011; Ighodaro et al., 2013; Bennett and Barrett, 2007). Honeydale Research Farm is 4 km south east of Alice at an elevation of 517m above sea level. Honeydale Research Farm represents is a commercial farming system sharing a boundary with Thyume’s Dyamala location. Management practices in this farm include; stocking rates and rotational grazing of livestock in fenced camps (De Bruyn, 1998). Tree density inside these camps is controlled by fire and browsing by goats. The soil is classified as silty loam of the Glenrosa form. Honeydale Farm was used as a control site for comparative analysis of commercial and communal savannas. Thyume savanna is under communal ownership, about 5km east of Alice town. In Thyume, savannas belonging to three villages; Dyamala, Rwarwa, and Upper Gqumahashe, were selected. Thyume has been invaded by Acacia Karroo. (De Bruyn, 1998). There is no systematic range management scheme in Thyume and animals graze without any form of rotation. Sheshegu is a small rural area, 14km south west of Alice, consisting of six villages; Mpozisa, Skolweni, Balurha, Lower Sheshegu, Fingo, and Komkhulu. The area is dominated by mudstone and sandstones, and is characterised by low rainfall and poor quality soils. The vegetation in Sheshegu is savanna type and it is exclusively used for livestock grazing and browsing. According to Ighodaro et al., (2013), soil erosion has been the major degradation form adversely affecting communal farmers in Sheshegu.

3.1.2. Climate

The climate of the study area is semi-arid with mean annual rainfall ranging from 580mm to 700mm per annum. Rain is typically high in summer and winters are dry with frequent frosts http://www.nkonkobe.gov.za/?q=system/files/filedepot/2/Draft%20IDP%202014%20_%2015.pdf

3.1.3. Geology and soils

The geology of Nkonkobe Local Municipality falls under the Beaufort sediments that are characterized by the sills and dykes of the Karoo dolerite intrusions. These sediments consist of shales, mudstones, and sandstones. The area is dominated by shallow, poorly developed, and rocky, nutrient poor silts, nutrient rich red clays, and loamy soils. (http://www.nkonkobe.gov.za/?q=system/files/filedepot/2/Draft%20IDP%202014%20_%2015.pdf).

3.1.4. Topography

The northern part of Nkonkobe Local Municipality is characterized by high mountain ranges with the highest peak, Hogsback, at 1700 m to 2000 m above sea level. The southern parts have a regular flat surface with some areas situated at less than 200m above sea level (http://www.nkonkobe.gov.za/?q=system/files/filedepot/2/Draft%20IDP%202014%20_%2015.pdf).

3.1.5. Vegetation

The vegetation in the study area is classified as the False Thornveld of the Bhisho Thornveld (Mucina and Rutheford, 2011) with open savanna characterised by grasses such as Digitaria eriantha, Cymbopogon plurinodis, and Sporobolus species, and bush types of plants including Acacia Karroo, Scutia myrtina, Poycantha species and other bush clumps. The grasses of this area are suitable for grazing livestock but vulnerable to transformation due to overgrazing.

3.2. Data acquisition

Landsat imagery was used to map changes in vegetation between 1984 and 2014, and aerial photographs as complimentary sources of ground reference data to guide supervised classification of satellite images. These data sets were identified on the basis of the following selection criteria: cost, data availability, spectral and spatial resolution of the sensor, cloud cover, and frequency of use, temporal coverage and average classification accuracy of the sensor in vegetation mapping. Four Landsat TM, ETM+, and OLI (Thematic Mapper and Enhanced Thematic Mapper plus) images were acquired from the United States Geological Survey (USGS) Landsat archives. Landsat TM images were selected partly because they are freely available, and also because they provide optimum temporal coverage and spectral and spatial resolution for vegetation mapping. Dry season images of June, July, and August were preferred to facilitate acquisition of scenes with minimal distortions, and this was done to avoid misinterpretation since images of the same season have a high comparability (**Table 1**).

Table 1: Specifications of Landsat imagery (TM/ ETM+/ OLI TIRS*) used in the study.

Band	Wavelength Micrometres	Spatial Resolution(meters)	Use
1 Blue-Green	0.45 – 0.52	30 m	Bathymetry and coastal mapping, distinguishing soil and vegetation
2 **Blue	0.45 – 0.51	30 m	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
2 Green	0.52 – 0.61	30 m	Green vegetation mapping, useful when assessing vegetation vigour
3 Red	0.63 – 0.69	30 m	Soil and vegetation discrimination, monitoring vegetation health
4 Near IR	0.76 – 0.90	30 m	Identifying vegetation types, emphasizes biomass content, detecting water bodies, soil moisture
5 **Near IR	0.85 - 0.88	30 m	Emphasizes biomass content and shorelines
LANDSAT OLI/ TIRS **			

Source: http://www.landsat.usgs.gov

Given the suitability characteristics of the Landsat bands; bands 2, band 3, band 4, and band 5 were used to classify the images. Band combinations 321 and 432 were used to interpret the Landsat TM and ETM+ images, and band combination 543 was used to interpret the Landsat OTI/TIRS images. All the images had less than 10% cloud cover and were of excellent acquisition quality (**Table 2**). Acquisition quality is expressed as a single digit number, based on the errors encountered during the archiving of the image and visible artefacts in the data when manually inspected.

Table 2: Acquisition dates and quality characteristics of the Landsat imagery

Satellite/Sensor	Acquisition date	Cloud cover	Acquisition quality
Landsat 5 TM	22 June 1984	0%	9
Landsat 5 TM	07 July 1995	8.26%	9
Landsat 7 ETM+	15 July 2004	0.04%	9
Landsat 8 0LI/TIRS	12 August 2014	0.03	9
Acquisition quality: 9 = excellent, 7-8 = good, 5-6 = fair, 1-2= extremely poor, 0=missing			

Source: https://lta.cr.usgs.gov/landsat_dictionary.html#acquisition_quality

3.2.1. Properties of the digital and analogue aerial photographs.

Aerial photographs are very useful sources of geographic data because they possess a high level of spatial detail. The aerial photographs used in this study were captured in RGB (true colour) and panchromatic, with a ground sample distance (pixel resolution) of 0.5m and 5m for recent and historical aerial photographs respectively (http://www.ngi.gov.za/index.php/what-we-do/aerial-photography-and-imagery).

Table 3: Characteristics of the digital and analogue aerial photographs as supplied by NGI.

Description (Type)	Date of acquisition	Resolution/ Scale
RGB / True colour	2012 (exact date not provided)	0.5 meters
Panchromatic	21 October 2002	1:30 000
	18 November 2002	1:30 000
Panchromatic	03 June 1996	1:50 000
Panchromatic	02 May 1985	1:30 000

Acquisition dates between the aerial photographs and the Landsat imagery did not match perfectly; however, they closely corresponded with fairly acceptable differences allowing the objectives of the study to be carried out. The most recent aerial photographs were used in conjunction with 2014 Google Earth images as sources of ground truth.

3.3. Image preprocessing

Pre-processing procedures applied on imagery depend upon the processing level at which data is provided by the source. Whether it is necessary to apply atmospheric correction depends upon the quality of the data, the information desired, and the methods used to extract the information. In this case, all images were acquired during the dry season with less than 10% cloud coverage. As explained in Section 3.1.1, acquisition quality of the images was excellent, and the area of interest was not affected by clouds. Therefore, since atmospheric correction has little effects on classification accuracy, it was omitted to avoid interfering with spectral information.

3.3.1. Geometric correction

The 2014 Landsat image was geo-referenced using the 2012 aerial photograph (**Table 3**) as a reference image, and registered to UTM WGS84 zone 35S. The historical Landsat imagery (1984, 1995, and 2004) were georeferenced and spatially registered to the 2014 Landsat image.

The historical aerial photographs (1985, 1996, and 2002) were georeferenced and spatially registered to the 2012 aerial photograph (**Table 3**). Further assessment of spatial correspondence between the images was performed using the "Linked viewer" and the "Swipe" tools in ERDAS IMAGINE (Hamandawana, 2009). The study sites were extracted from the images in ERDAS IMAGINE using shapefiles of the study sites, with the sites covering; 34.8862 km^2, 25 km^2, and 6.314 km^2; for Sheshegu, Thyume, and Honeydale Farm respectively.

3.4. Field work

Field data was collected over the dry season and corresponded with the acquisition period of the Landsat imagery. Field investigation was undertaken in May and June 2015 to compile data for land cover classification and image interpretation. This involved an on-site verification and extraction of information that optimally captures and characterizes conditions and parameters associated with surface features. Expert knowledge of the study sites and a two day preliminary exploration of each site were applied to aid data collection. Equipments that were used in the field include; a digital camera, two Garmin Global Position System (GPS) devices, field guide maps, measuring tape, and barricade tape.

3.4.1. Preparation of field guide maps from unsupervised classification

To model the field survey, guide maps were produced using unsupervised classification. Unsupervised classification is useful when the user is unable to collect training data, and sometimes it can precede supervised classification, operating as an initial step. However, the approach of choice is determined by the nature of the data being analysed, the analysis tools available, and the objective of the analysis (Lillesand et al., 2004). These limitations prompted consideration of supervised classification in lieu of unsupervised classification in order to facilitate objective and reliable identification and delineation of different information classes. Unsupervised classification was performed as a preliminary step to guide the field work. Unsupervised classification was carried out in Erdas Imagine using the Iterative Self Organising Data Analysis (ISODATA) algorithm. The August 2014 Landsat OLI image was classified into 13 classes (**Table 4**) for each study site on the basis of expert knowledge and the preliminary exploration of the area. After performing unsupervised classification, three sampling locations were selected for each class.

3.4.2. Land cover classification guide

Land Cover classification guide used for field surveys was based on Di Gregorio, (2005) and Thomspson, (1996)'s land cover classification systems combined and modified on the basis of field observations. The land cover classification guide used in this study was formulated such that it captures as much detail as possible. Land cover and land use types were first identified and then further categorized with respect to their distribution in that specific area. The study adopted Di Gregiorio (2005)'s *spatial distribution classification* (also known as macropattern). Spatial distribution classification characterizes the spatial arrangement of specific structural vegetation types. Mapping vegetation at species level is partly achievable when using Landsat imagery because of the spatial resolution of Landsat as plants occur at densities below 30mx30m in most situations. However, attempts were made where it was feasible to capture data at species level (e.g. *Acacia Karoo*).

Table 4: Land cover classification guide used for field data compilation.

Class name	Description
Clear water	Deep clear water with little or no suspended rock or soil material.
Turbid water	Muddy water with suspended soil particles and other sedimentary materials
Open grassland	Areas of grassland with <10% tree and/or shrub canopy cover.
Overgrazed grassland	Grassland with patches of bare ground.
Open Mixed bush	Almost equal occurrence of different multi-stemmed pant species, with 2-20% canopy cover, and 3-4m tall.
Closed Mixed bush	Almost equal percentages of different multi-stemmed plant species, with 20-80% canopy cover, and 3-4m tall.
Dense shrub	Plants with persistent woody stems and without any defined main stem, being <3m tall. Covers 20-80% of the smallest mappable area
Open shrub	Scattered shrubs with a matrix of grassland, <3m tall, with 2-20% canopy cover.
Dense *Acacia Karoo*	>80% occurrence of *Acacia Karroo* within a minimum mappable area.
Sparse *Acacia Karoo*	20-80% occurrence of *Acacia Karroo* within a minimum mappable area.
Olea capensis	>80% occurrence of Olea capensis within a minimum mappable area
Bare ground	Bare soil/non vegetated areas or <10% vegetated. Includes built up area, residential areas and manmade structures.
Built up areas	Areas in which people reside on a permanent or near permanent basis, includes buildings and other man-made structures.

3.4.3. Field data collection

Distribution of cover types across the sites was noted during the preliminary field investigation course through visual assessment. A total of 32 training sites in Sheshegu, 31 in Thyume, and 28 in Honeydale; were delineated, recorded and photographed. There were three to five training samples for each land cover type, and data was collected in quadrats with a minimum size of 30m x 30m (Appendix II). This was purposely done because the size of the smallest feature that Landsat ETM records is 30 m x 30 m. Location of each training site was recorded from the centre of the quadrat using a Garmin GPS with a rated accuracy of ±4 meters. The boundaries of the quadrats were marked out with a barricade tape (Figure 3) and the area of each training site was measured using a measuring tape. Cover type in each training location was identified by recording individual species within the quadrats and class names were assigned based on percentage composition of species within the quadrats (Hamandawana, 2002). In densely vegetated areas where more than one plant species occurred and no individual species dominated the sample, cover type was classified as mixed bush. The tables in Appendix II provide descriptions of different cover types that were recorded during the field survey. Figure 3 illustrates how the boundaries of the sampling locations were marked out during field data compilation.

3.5. Image classification

The land use and land cover types mapped in this study were properly defined after running supervised classification experimental assessments, where similar and related classes were merged and unnecessary detail removed. This was done to minimize misclassification and misinterpretation. In the final analysis after merging and regrouping some of the classes, each study site was classified into six to eight information classes depending on the land cover diversity of that particular site (**Table 5**).

Table 5: Land cover types mapped during the image classification process

Study site	**Information classes (cover types)**
Honeydale	*Water, Open grassland, Acacia Karroo, Shrubs, Mixed Bush, Bare ground*
Thyume	*Water, Open grassland, Acacia Karroo, Shrubs, Mixed Bush, Bare ground, Arable land, Built up area*
Sheshegu	*Water, Open grassland, Acacia Karroo, Shrubs, Mixed bush, Bare ground* *Arable land, Built up area*

3.5.1. Supervised classification

The main goal of classifying an image is to categorize all pixels in an image into land cover classes or themes (Lillesand et al., 2004). Classically, spectral oriented techniques for land cover mapping have formed the backbone of multispectral imagery classification (Lillesand et al., 2004). In this study, pixel-based supervised classification was used to produce detailed multi-temporal land cover maps of all the study sites. Classifying an image using this procedure means that the analyst supervises the pixel categorization process by assigning parameters to each of the desired output classes on the basis of knowledge of representative sections of the sampling universe or, availability of a sufficient number of known pixels (Lillesand et al., 2004). The corresponding locations of these pixels in the image (training sites) are assigned attributes to describe each class of interest. Each pixel in the image is then classified into the feature class it resembles the most. The level of classification accuracy depends upon the distribution of the sites throughout the image and the number and quality of training sites (Lillesand et al., 2004; Perumal and Bhaskaran, 2010). The collection of training data on the basis of field compiled ground truth facilitates confident capturing of differences in the spectral reflectance of different features.

3.5.2. Classification of the 2014 Landsat imagery

Reference data compiled during the field survey was used as input data for supervised classification. A total of three samples were collected for each information class, and ancillary data was acquired from aerial photographs and Google Earth. Information acquired from the aerial photographs and Google Earth was useful in increasing the number of training samples, and thus increasing the probability of the classification being accurate. Spectral signatures were extracted from the Landsat imagery in Erdas Imagine using the coordinates of the information classes recorded during the field survey. 60% of the reference data for each information class were used for signature extraction, and the remaining 40% reserved for classification accuracy assessment depending on the number of sampling points for each information class.

The three algorithms (Mahalanobis-distance, Minimum-distance, and Maximum likelihood classification) were compared to identify a classifier that produced the best results. The Maximum likelihood classifier computes the probability of a pixel belonging to a particular category; and after calculating the probability in each category, the pixel would be assigned to the most likely class or be labelled unknown if the probability values are below a threshold specified by the interpreter . The general procedure firstly determines; the number of land cover types within the area, the training pixels are selected for each cover type, the training statistics is then used to estimate the mean vector and covariance matrix of each class, then finally; each pixel in the image is assigned to the class it resembles the most or labelled unknown. In minimum distance classification, every pixel is classified by calculating the distance between the pixel whose value is unknown and each of the category means. After calculating the distances between the unknown pixel and each of the class means, the unknown pixel is assigned to the closest class. The Mahalanobis distance classifier is similar to Minimum distance, however it is slightly different because it uses the covariant matrix. Variance and covariance are included so that clusters that are highly varied lead to similarly varied classes (https://wiki.hexagongeospatial.com/index.php?title=Classification_Decision_Rules).

After running supervised classification using the three classifiers, the resulting maps were firstly assessed through visual inspection for easily identifiable misclassifications. The Maximum likelihood classifier produced good results, however, its shortcoming is that it produced maps in which there were few extra water bodies which did not correspond with ground truth. The Minimum distance classifier produced results that looked accurate from a visual assessment point of view; however, several classes were misclassified, and this includes open grassland being misclassified as bare ground and vice versa, mixed bush misclassified as *Acacia Karroo*, and open grassland misclassified as shrubs. The Mahalanobis distance procedure produced similar results as the Maximum likelihood procedure. In the final analysis after these observations and after running site specific accuracy assessment, the Maximum likelihood procedure was selected. However, there were still misclassified pixels that needed to be reclassified before the maps could be used for further analysis (i.e. water). In this regard, thematic recode was employed to reclassify all the misclassified pixels. Recoding involves assignment of new values to one or more classes, and it is used to; reduce the number of classes, combine classes, and to assign different class values to existing classes. Thematic recode was performed to assign correct class values to those pixels that were initially misclassified as water.

Misclassification of built-up area was anticipated because of the high spectral variability of residential areas. Arable lands were also misclassified as bare ground, and in some cases misclassified as *Acacia Karroo* and shrub because of similarities in spectral properties between agricultural crops, *Acacia Karroo* and shrub. To solve this error, the study adopted image segmentation in which the respective pixels were extracted and reallocated to appropriate classes by using thematic recode. This technique uses ground truth to categorize the data and correct class labels are assigned by the analyst instead of relying on computer automation that categorizes pixels using statistical probabilities (Hamandawana, 2009). To perform this procedure, the AOI (area of interest) tool in Erdas Imagine was used to mark out boundaries of arable land and built-up area. Built-up area and arable land were extracted with ease from the maps, because the boundaries were easily discernible from the aerial photographs. After extracting and isolating built-up area and arable land from the maps, they were then reclassified and categorized as separate information classes through thematic recode, and overlaid back to the correctly classified maps (**Figure 3**).

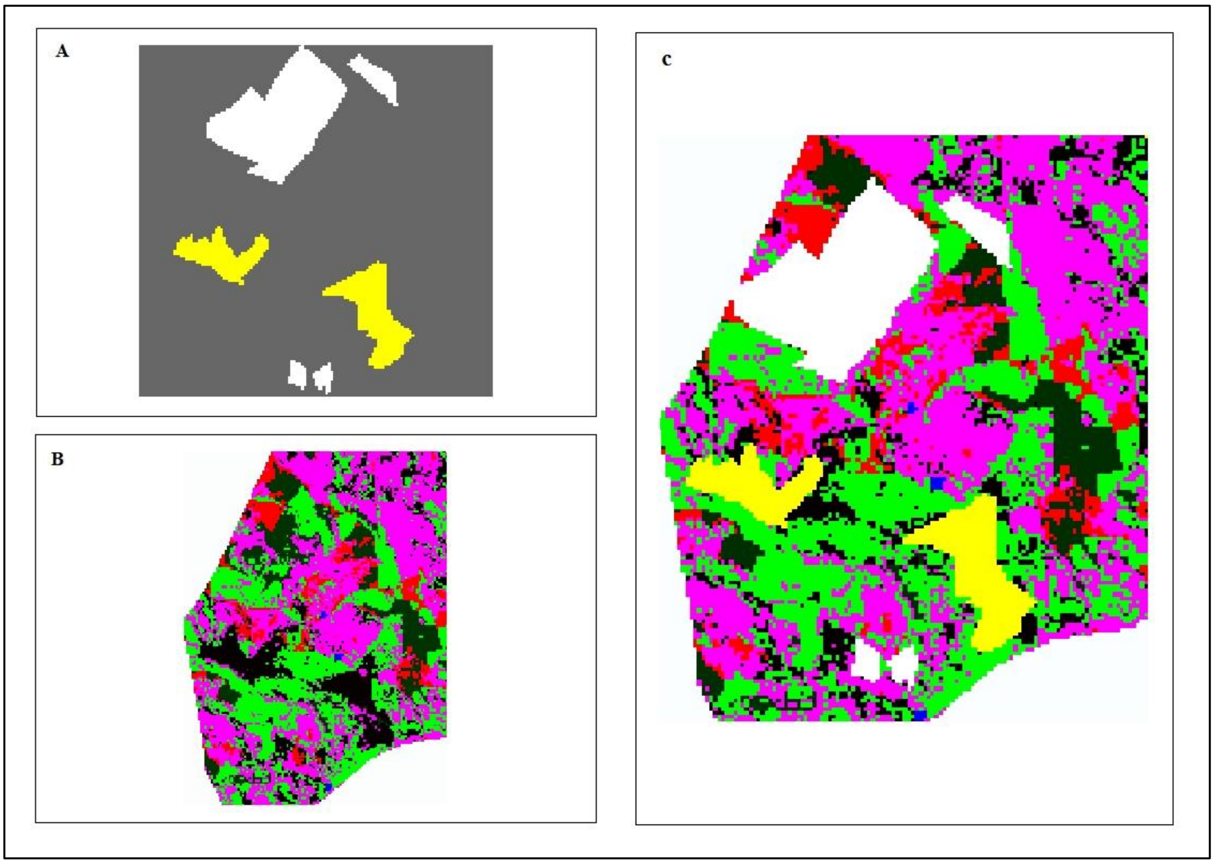


Figure 3: Reclassification of arable lands and built-up area using thematic overlay

Note: **A** = Arable land and Built-up area, **B** = All the information classes, **C** = Overlay output

3.5.3. Classification of the 1984, 1995, and 2004 Landsat images.

It is almost impossible to conduct field surveys for land cover information of historical years. Since ground truth of the historical past is not directly accessible, reference data to guide supervised classification of historical Landsat data was acquired indirectly through aerial photographs. Spectral signatures of the information classes were extracted by displaying the Landsat images and the aerial photographs in "Linked viewers" (**Figure 4**) and the aerial photographs used as a guide to identify pixels that correspond with specific cover types. Signatures were then extracted on the basis of correspondence between specific locations in the aerial photographs and coinciding pixels in the Landsat imagery. Training data was collected from locations where the cover types are most clearly visible on the aerial photographs. Although the aerial photographs and the Landsat data did not correspond in terms of the acquisition dates, the gap between the dates was not a major constraint as explained in Section 3.1.2.

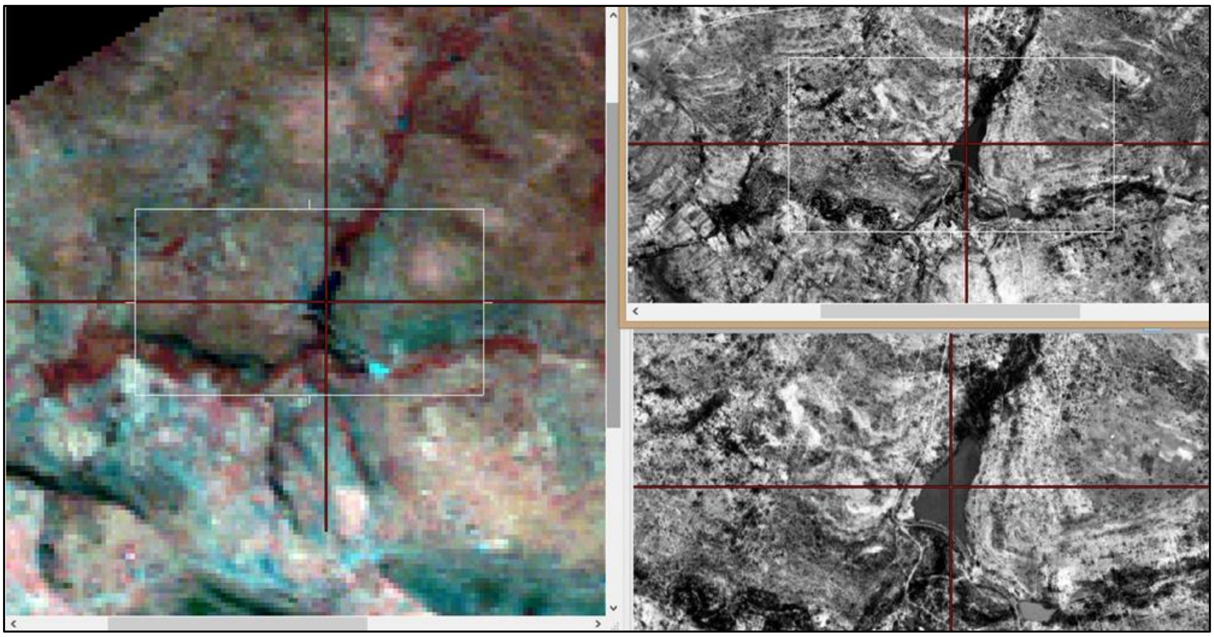


Figure 4: Extracting signatures using aerial photographs as source for reference data

Note: On the left is the Landsat image opened concurrently with the aerial photographs (Top right and bottom right) in Erdas IMAGINE's linked views.

Acacia Karroo could not be confidently identified in some of the 1984 images as the trees were more scattered and fewer than in the more recent images. Consequently *Acacia Karroo* was omitted in the 1984 maps for all the study sites, and also in the 1995 map of Honeydale Farm. Mixed bush on steep slopes was misclassified as water due to the low spectral reflectance of shadows. Thematic recode was performed to reclassify all the misclassified pixels.

3.6. Classification accuracy assessment

Thematic maps produced with image classification do not often come out 100% accurate, and the common errors associated with classification imprecision include; spectral mixing, improper assignment of pixels, and errors in spatial registration. An interpreter may confuse a classification error with change (Foody, 2002). In remote sensing, classification accuracy typically refers to the degree of precision of an image classification in relation to ground reality. Classification accuracy assessment is the process of comparing a classification with ground truth data to examine the precision of the classification in relation to the real world. Initially accuracy assessment was carried out by performing a general visual judgement of the derived map (Foody, 2002). However, this procedure has been criticized because of its dependence on subjective conclusions. A map may give a good impression when assessed visually; but, there are other factors that need to be considered, and these include; quantitative accuracy and spatial proximity of information classes. Another method is the non-site specific approach in which a comparison is performed between the areas assigned to different categories in the map and their extent in some reference data. The problem is that this approach does not assess accuracy at specific locations. Given these limitations, this study employed a site-specific approach in which exhaustive evaluation of correspondence between the map output and ground truth is performed at specific locations. This procedure calculates classification accuracy by compiling error matrices in which the accuracy of each information class is presented in terms of percentages, and commission and omission errors in the classification. Commission error, also known as user's accuracy, occurs when pixels that belong to a certain category are incorrectly assigned to other categories. Omission error, also referred to as producer's accuracy, occurs when pixels that belong to a certain category are excluded from that category. This information is then used to calculate overall accuracy of the classification. Overall classification accuracy is established by counting the number of correctly classified pixels against the total number of pixels in the entire error matrix. Results of classification accuracy assessment are presented in Chapter 4.

3.7. Change detection and statistical analysis

The study employed simple linear trend analysis and regression analysis to examine the results of image interpretation. Simple linear trend analysis was performed in Microsoft Excel to assess the direction of land use and land cover change in each site. Cover change was measured against time, in which the former was considered the response variable and the latter the independent variable. Time was selected as the independent variable because land use and land cover change over time in response to evolving rainfall patterns, biophysical conditions, human activity and human population. The coefficient of determination (R^2) was also calculated to assess the strength of the land use and land cover temporal changes. Linear regression analysis was also performed in Microsoft Excel to determine the levels of statistical significance of the observed changes. The F statistic values obtained from the image interpretation results were then compared with critical values calculated from the tables of F distribution to test significance at $\alpha=0.05$, and $\alpha=0.01$. The results of the statistical analysis are presented in Chapter 4.

CHAPTER 4

4. Results.

The results of image classification are presented in a form of thematic maps that depict the spatial distribution of cover types, graphs that capture trends, and tables that show magnitudes and significance of land use and land cover change.

4.1. Accuracy assessment of supervised classification and results

Accuracy assessment of individual information classes was performed before built up areas and arable lands were overlaid to the maps. Built-up areas and arable lands were classified separately as explained in Section 3.4.2, and therefore not included in the classification accuracy assessment. After supervised classification was performed using 60% of the reference data, the remaining 40% of the data was used to guide accuracy assessment.

Table 6: Accuracy assessment of results from the Maximum likelihood classifier: Honeydale

Class name	Reference totals	Classified totals	Correctly classified	Producer's accuracy (%)	User's accuracy (%)
Water	3	2	2	66.67	100
Bare ground	3	3	3	100	100
Open grassland	3	3	3	100	100
Mixed bush	3	4	3	100	75
Overgrazed grassland	3	3	3	100	100
Acacia Karroo	3	3	3	100	100
Shrub	3	3	3	100	100
Global accuracy = 95.24% K = 0.9444					

Table 7: Accuracy assessment of results from the Minimum-distance classifier: Honeydale

Class name	Reference totals	Classified totals	Correctly classified	Producer's accuracy (%)	User's accuracy (%)
Water	3	3	3	100	100
Bare ground	3	4	3	100	75
Open grassland	3	2	2	66.67	100
Mixed bush	3	3	3	100	100
Overgrazed grassland	3	4	3	100	75
Acacia Karroo	3	3	3	100	100
Shrub	3	2	2	66.67	100
Global accuracy = 90.48% K = 0.8889					

Table 8: Accuracy assessment of results from the Mahalanobis-distance classifier: Honeydale

Class name	Reference totals	Classified totals	Correctly classified	Producer's accuracy (%)	User's accuracy (%)
Water	3	2	2	66.67	100
Bare ground	3	3	3	100	100
Open grassland	3	2	2	100	100
Mixed bush	3	4	3	100	75
Overgrazed grassland	3	3	3	100	100
Acacia Karroo	3	3	3	100	100
Shrub	3	3	3	100	100
Global accuracy = 95.24% K = 0.9444					

The maps for Honeydale were produced at an accuracy of; 95.24% (**Table 6**), 90.48% (**Table 7**), and 95.24% (**Table 8**) for Maximum likelihood, Minimum distance, and Mahalanobis-distance respectively.

Table 9: Accuracy assessment of results from the Maximum likelihood classifier: Thyume

Class name	Reference totals	Classified totals	Correctly classified	Producer's accuracy (%)	User's accuracy (%)
Water	4	3	3	75	100
Bare ground	5	5	5	100	100
Open grassland	5	5	5	100	100
Mixed bush	5	5	4	80	80
Acacia Karroo	5	5	4	80	80
Shrub	5	6	5	100	83.33
Global accuracy = 89.66% K = 0.8755					

Table 10: Accuracy assessment of results from the Minimum-distance classifier: Thyume

Class name	Reference totals	Classified totals	Correctly classified	Producer's accuracy (%)	User's accuracy (%)
Water	4	4	4	100	100
Bare ground	5	5	5	100	100
Open grassland	5	5	5	100	100
Mixed bush	5	2	2	40	100
Acacia Karroo	5	7	4	80	57.14
Shrub	5	6	5	100	83.33
Global accuracy = 86.21% K = 0.8343					

Table 11: Accuracy assessment of results from the Mahalanobis-distance classifier: Thyume

Class name	Reference totals	Classified totals	Correctly classified	Producer's accuracy (%)	User's accuracy (%)
Water	4	3	3	75	100
Bare ground	5	5	5	100	100
Open grassland	5	5	5	100	100
Mixed bush	5	5	4	80	80
Acacia Karroo	5	5	4	80	80
Shrub	5	6	5	100	83.33
Global accuracy = 89.66% K = 0.8755					

The Landsat image for Thyume was classified at an accuracy of 89.66% (**Table 9**), 86.21% (**Table 10**), and 89.66% (**Table 11**) for Maximum likelihood, Minimum-distance, and Mahalanobis-distance respectively.

Table 12: Accuracy assessment of results from the Maximum likelihood classifier: Sheshegu

Class name	Reference totals	Classified totals	Correctly classified	Producer's accuracy (%)	User's accuracy (%)
Water	3	3	3	100	100
Bare ground	4	4	4	100	100
Open grassland	4	4	4	100	100
Mixed bush	4	3	3	75	100
Acacia Karroo	4	4	4	100	100
Shrub	4	5	4	100	80
Global accuracy = 95.65% K = 0.9477					

Table 13: Accuracy assessment of results from the Minimum-distance classifier: Sheshegu

Class name	Reference totals	Classified totals	Correctly classified	Producer's accuracy (%)	User's accuracy (%)
Water	3	3	3	100	100
Bare ground	4	4	4	100	100
Open grassland	4	4	4	100	100
Mixed bush	4	3	3	75	100
Acacia Karroo	4	5	4	100	80
Shrub	4	4	3	75	75
Global accuracy = 91.30% K = 0.8955					

Table 14: Accuracy assessment of results from the Mahalanobis-distance classifier: Sheshegu

Class name	Reference totals	Classified totals	Correctly classified	Producer's accuracy (%)	User's accuracy (%)
Water	3	3	3	100	100
Bare ground	4	4	4	100	100
Open grassland	4	4	4	100	100
Mixed bush	4	3	3	75	100
Acacia Karroo	4	4	4	100	100
Shrub	4	5	4	100	80
Global accuracy = 95.65%	K = 0.9477				

The maps for Sheshegu were produced at an accuracy of 95.65% (**Table 12**), 91.30% (**Table 13**), and 95.65% (**Table 14**) for Maximum likelihood, Minimum-distance, and Mahalanobis-distance respectively.

The maps were visually interpreted for further for further assessment of classification accuracy. Although Maximum likelihood classification and Mahalanobis-distance classification produced the maps at equal degrees of accuracy, Maximum likelihood less and easily discernible errors than the Mahalanobis-distance classifier. Therefore, in the final analysis, the study used mas that were produced through Maximum likelihood classification.

4.2. Spatio-temporal mapping of land cover in Honeydale Farm: 1984-2014

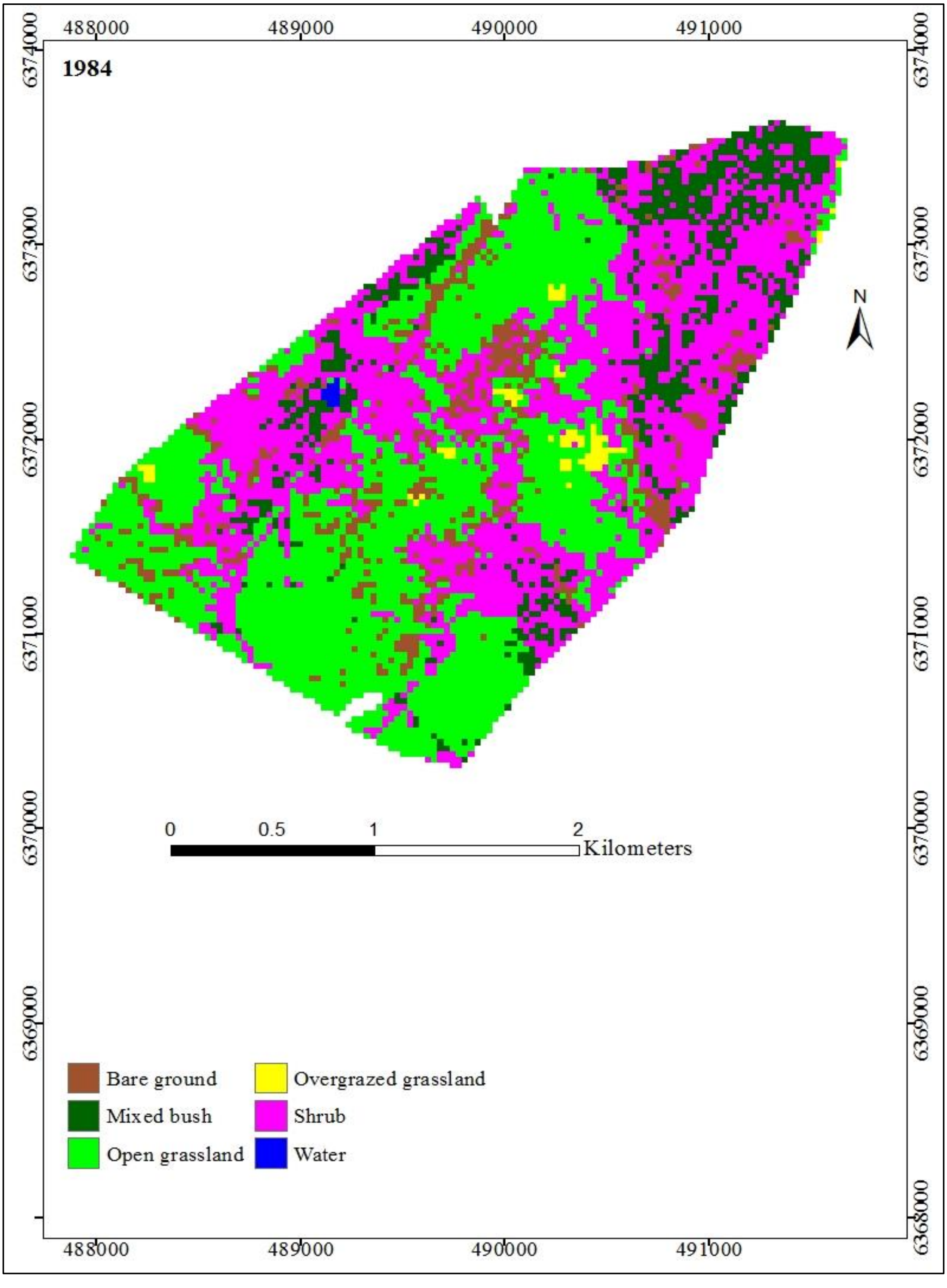


Figure 5: Land cover map of Honeydale: 1984

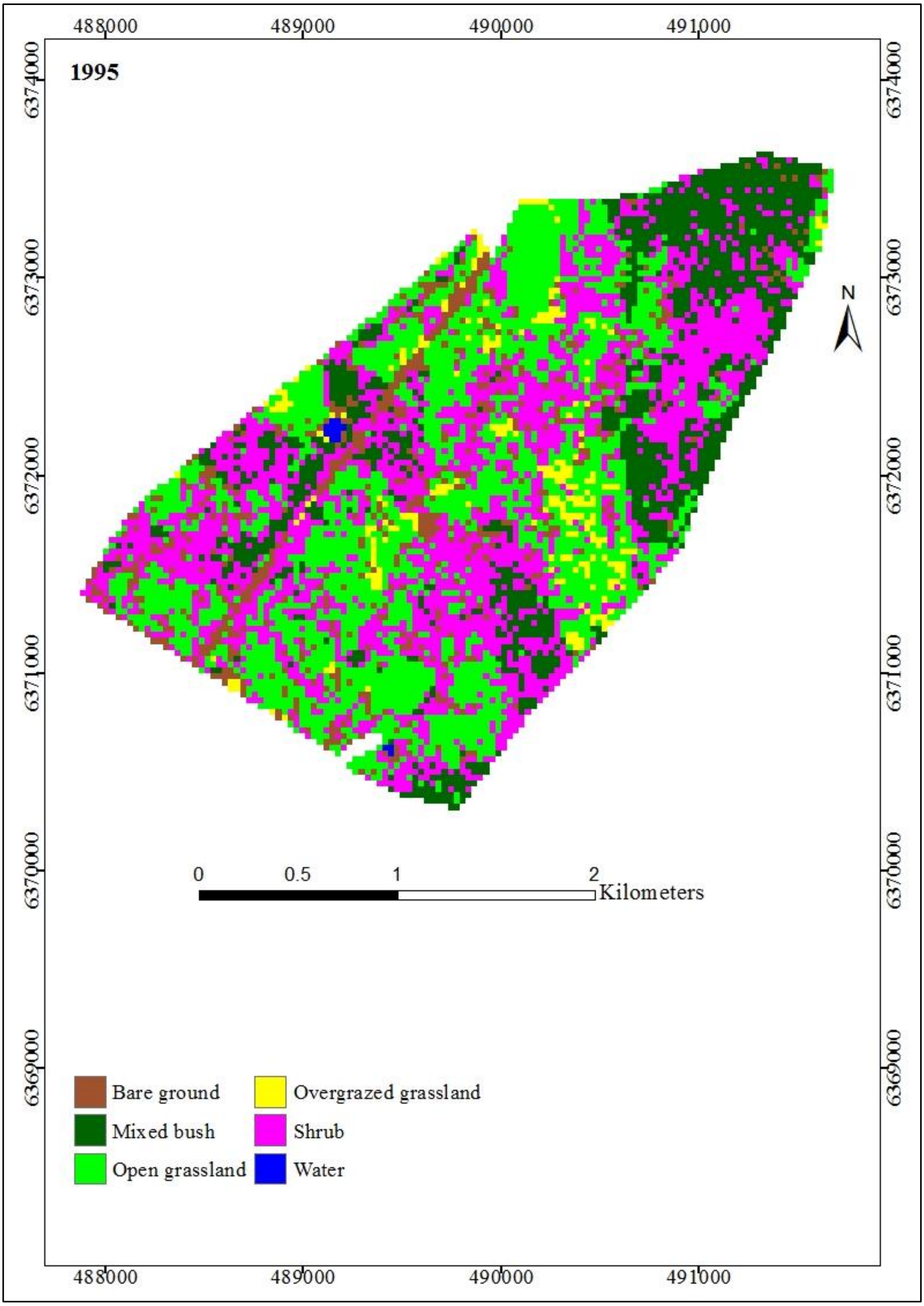


Figure 6: Land cover map of Honeydale Farm: 1995

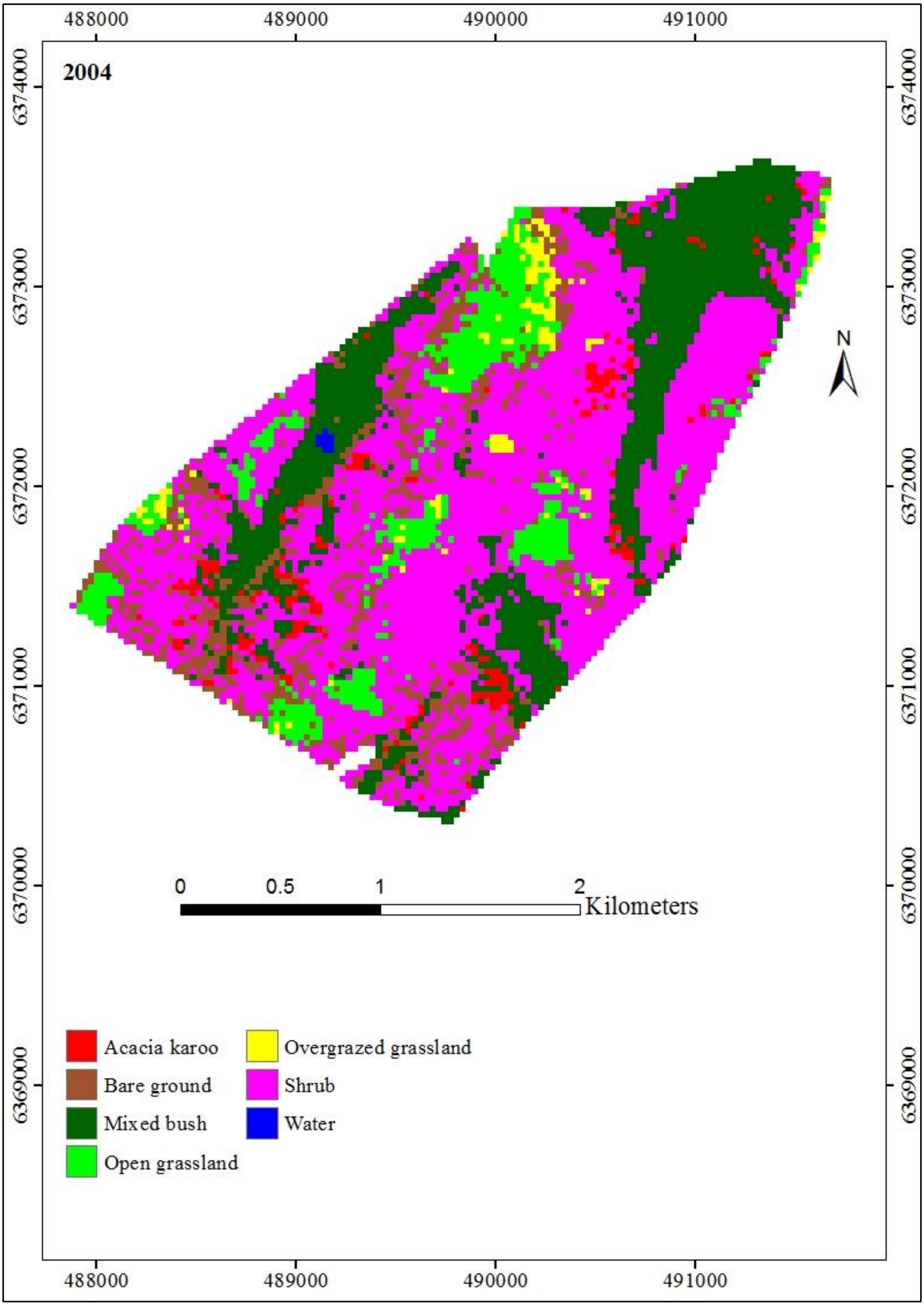


Figure 7: Land cover map of Honeydale: 2004

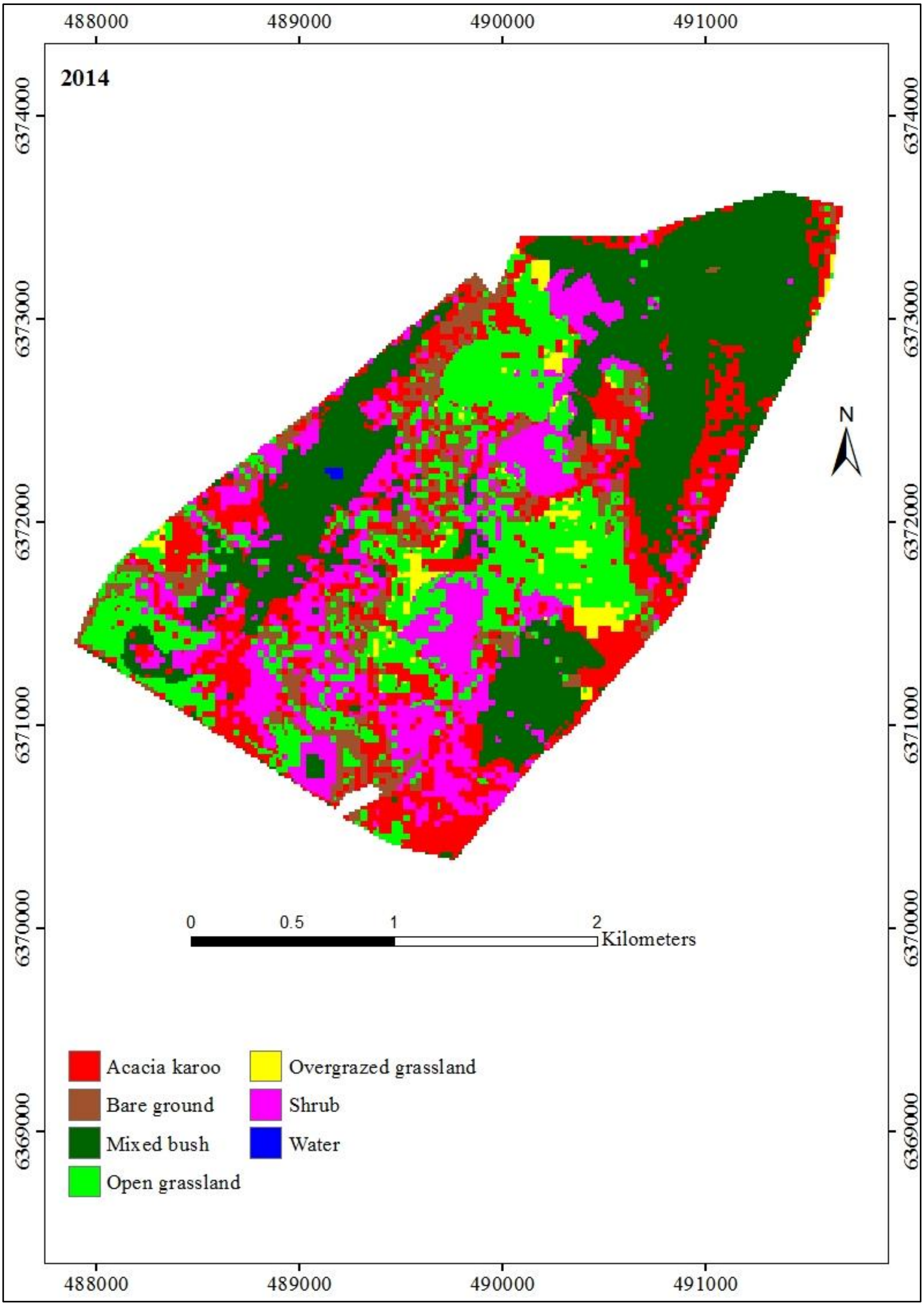


Figure 8: Land cover map of Honeydale Farm: 2014

4.2.1. General trends in Honeydale: 1984-2014

Land cover type	**Area (Percentage/year)**			
	1984	**1995**	**2004**	**2014**
Water	0.15	0.19	0.12	0.07
Open grassland	41.19	35.30	9.56	19.61
Acacia Karroo	0.00	0.00	3.21	21.50
Overgrazed grassland	1.08	3.45	2.08	2.17
Mixed bush	11.19	18.39	23.67	30.90
Shrub	37.32	33.53	49.56	17.81
Bare ground	9.07	9.14	11.80	7.94
Total	100	100	100	100

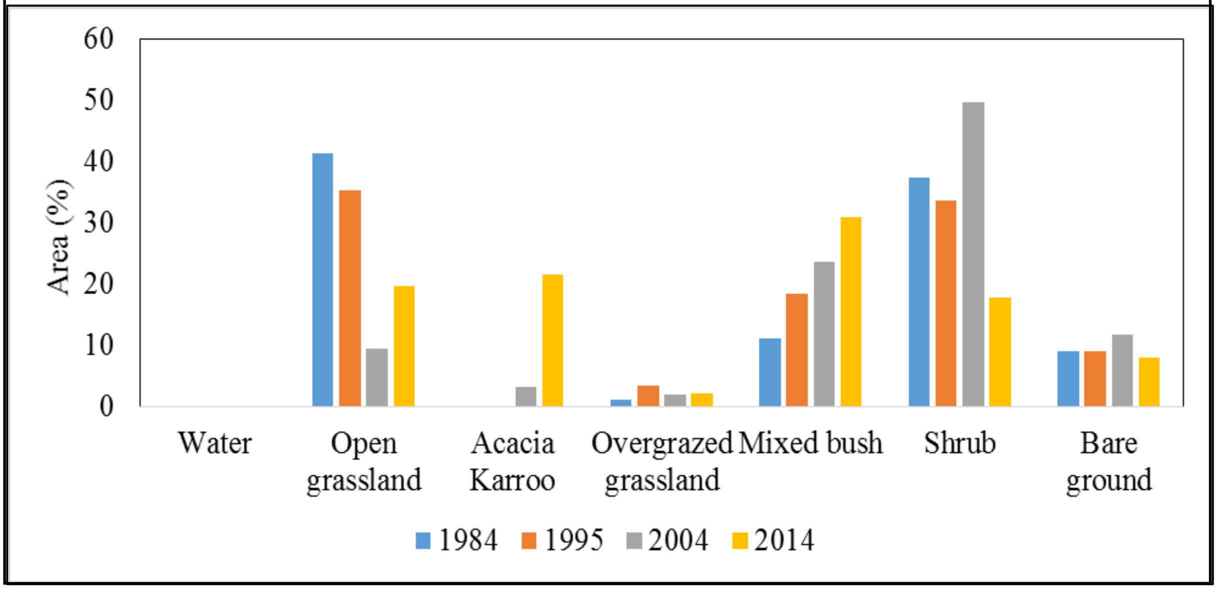


Figure 9: Percent proportions land cover types in Honeydale: 1984-2014

In terms of cover composition, Honeydale was predominantly open grassland (41%) in the 1980s with a considerable amount of shrub (37%). The area has now transformed into mixed bush (30%) accompanied by an exponential increase in *Acacia Karroo* which now covers almost 22% of the area, whilst open grassland covers 19% (**Figure 9**).

4.2.2. Specific trends in the distribution of land cover types in Honeydale: 1984-2014

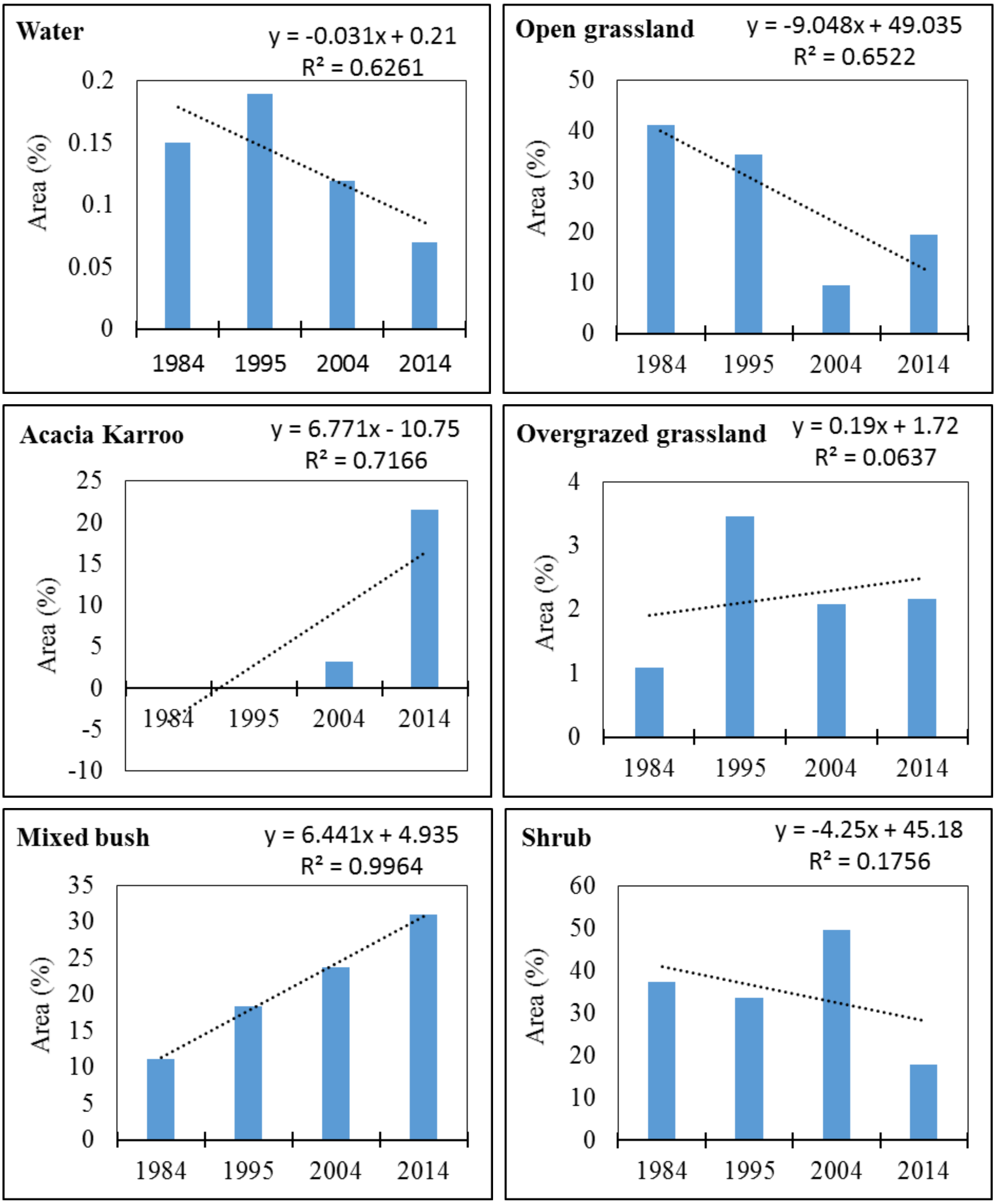


Figure 10: Area extents of land cover types in Honeydale: 1984-2014

Note: It is unique to Honeydale Farm that open grassland fluctuated between 1984 and 2014 (**Figure 10**).

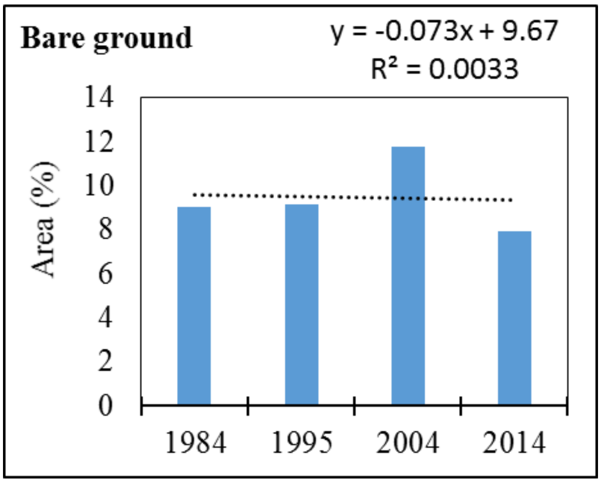


Figure 10 continued.

Note: Another important thing to point out is the increase of bare ground and the substantial decline of grassland in 2004 (**Figure 10**). These land cover changes occurred because there was a major drought period in 2004 (Mniki, 2009).

Table 15: Percentage changes of land cover types in Honeydale: 1984-2014

Land cover type	**Percentage increase/decrease**			
	1984-1995	**1995-2004**	**2004-2014**	**1984-2014**
Water	0.04	-0.07	-0.05	-0.08
Open grassland	-5.89	-25.74	10.05	-21.58
Acacia Karroo	0	3.21	18.20	21.50
Overgrazed grassland	2.37	-1.37	0.10	1.09
Mixed bush	7.20	5.28	7.23	19.71
Shrub	-3.79	16.04	-31.76	-19.50
Bare ground	0.07	2.66	-3.86	-1.13

Table 16: Land cover trend analysis and significance test for Honeydale: 1984-2014

Land cover type	**Trend equation**	**R^2**	**F**
Water	$y = -0.031x + 0.21$	0.6261	2.89
Open grassland	$y = -9.048x + 49.035$	0.6522	3.53
Acacia Karroo	$y = 6.771x - 10.75$	0.7166	4.74
Overgrazed grassland	$y = 0.19x + 1.72$	0.0637	0.18
Mixed bush	$y = 6.441x + 4.935$	0.9964	1387.03**
Shrub	$y = -4.25x + 45.18$	0.1756	0.44
Bare ground	$y = -0.073x + 9.67$	0.003	0.01

F-critical values at 3df = 6.59*, 16.69** Significant at $\alpha = 0.05$* Significant at $\alpha = 0.01$**

Table 17: Land cover trend analysis and significance test for Honeydale: 1995-2014

Land cover type	Trend equation	R^2	F
Water	y = -0.06x + 0.2467	0.9908	62.02**
Open grassland	y = -7.845x + 37.18	0.3657	0.50
Acacia Karroo	y = 10.75x - 13.263	0.8591	7.30
Overgrazed grassland	y = -0.64x + 3.8467	0.6975	2.02
Mixed bush	y = 6.255x + 11.81	0.992	282.98**
Shrub	y = -7.86x + 49.353	0.2451	0.37
Bare ground	y = -0.6x + 10.827	0.0922	0.12
F-critical values at 2df = 9.55*, 30.82** Significant at α = 0.05* Significant at α = 0.01**			

(i) Surface water (measured as area in hectares) slightly increased initially (1984-1995), and this was followed by a gradual decline between 1995 and 2014. Although surface water covers the smallest area (just below 1%) in comparison to the other land cover types in Honeydale Farm, water declined by a considerable amount of 53% relative to the initial amount of water in 1984, decreasing from 0.15% in 1984 to 0.07% in 2014 (**Figure 9**). The decrease in surface water was statistically significant at α = 0.01, F= 62.02 (between 1995 and 2014) (**Table 17**).

(ii) Open grassland decreased drastically between 1995 and 2004 and this occurred at the same period when shrub, mixed bush, and *Acacia Karroo* increased. In the entire 30 years, open grassland declined by 53% as compared to the amount of open grassland in 1984. Open grassland covered 41% of the total Honeydale Farm area in 1984, and decreased to 19% in 2014 (**Figure 9**).

(iii) *Acacia Karroo* was mappable only between 2004 and 2014 for reasons already explained in Section 3.4.3. *Acacia Karoo* went from being one of the least found cover types in 2004, with surface water and overgrazed grassland, to being the second prevalent cover type in 2014 after mixed bush. *Acacia Karroo* increased by 18.20% (**Table 15**) between 2004 and 2014, covering 3.21% of the area in 2004 and 21.50% in 2014 (**Figure 9**).

(iv) In spite of the fluctuation in overgrazed grassland, overgrazed grassland increased by 1% during the 30 year period and this may be due to the decrease in open grassland. When open grassland decreases, overgrazing occurs because animals exert pressure on the available grass, thus creating patches of bare soil as animals spend more time grazing in the same area.

(v) Mixed bush increased almost at a constant rate over the entire 30 year period (at an average increase of 6.57% per 10 years). Mixed bush increased by 20%, from just 11% in 1984 to 31% in 2014 (**Figure 9**).). The increase in mixed bush was statistically significant at $\alpha = 0.01$, $F = 1387.03$ (**Table 16**).

(vi) Although shrub fluctuated over the entire 30 years, shrub decreased by 19.50% (**Table 15)** between 1984 and 2004, and this is due to the fact that some shrubs grow into trees. Shrub increased only between 1995 and 2004, the same period when open grassland decreased considerably (**Figure 9**).

(vii) Though bare ground increased by 3% between 1995 and 2004, the overall direction of change in bare ground between 1984 and 2014 was a decrease by 1.13% (**Table 15**).

4.3. Spatio-temporal mapping of land cover in Thyume: 1984-2014

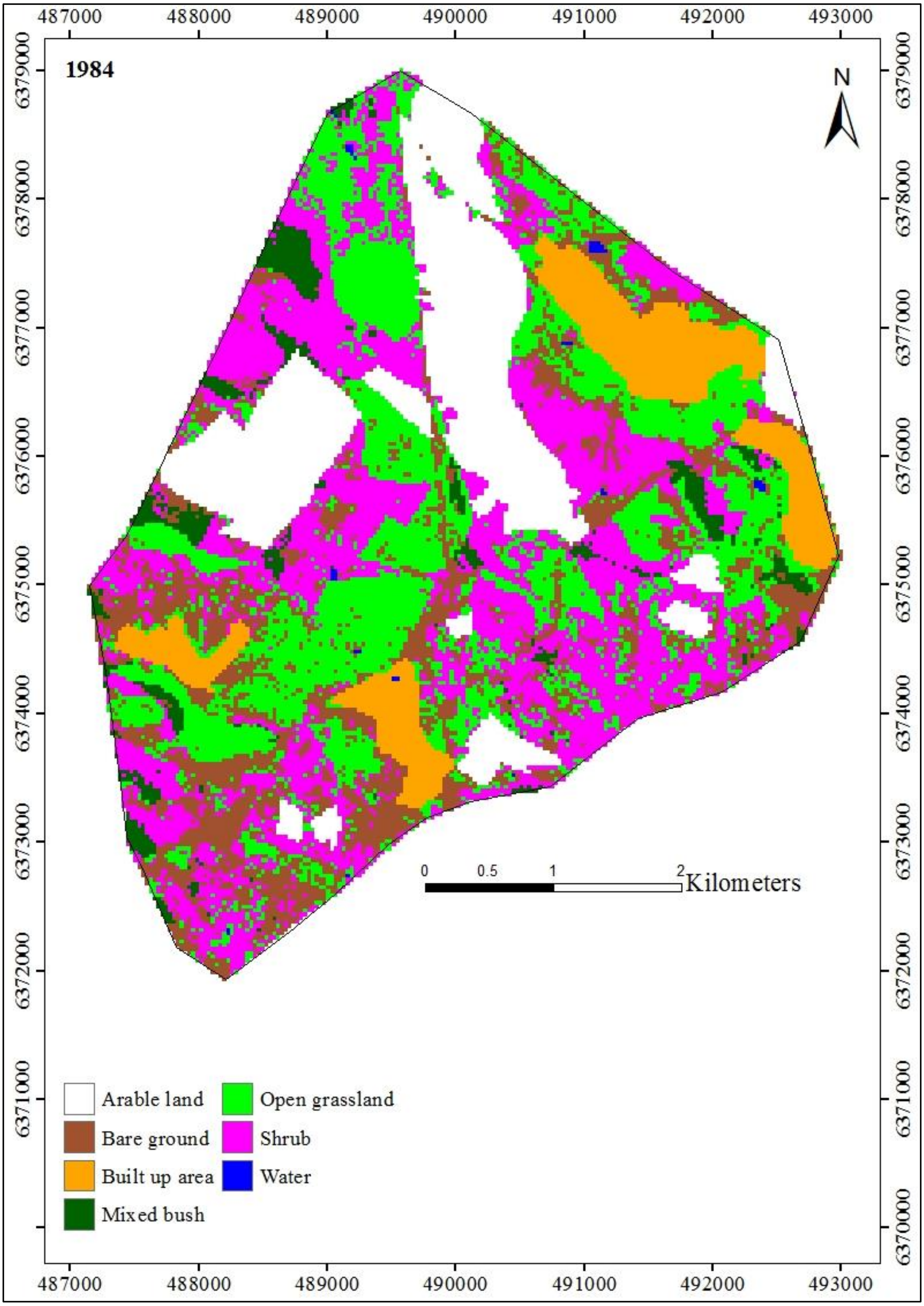


Figure 11: Land use and land cover map of Thyume: 1984

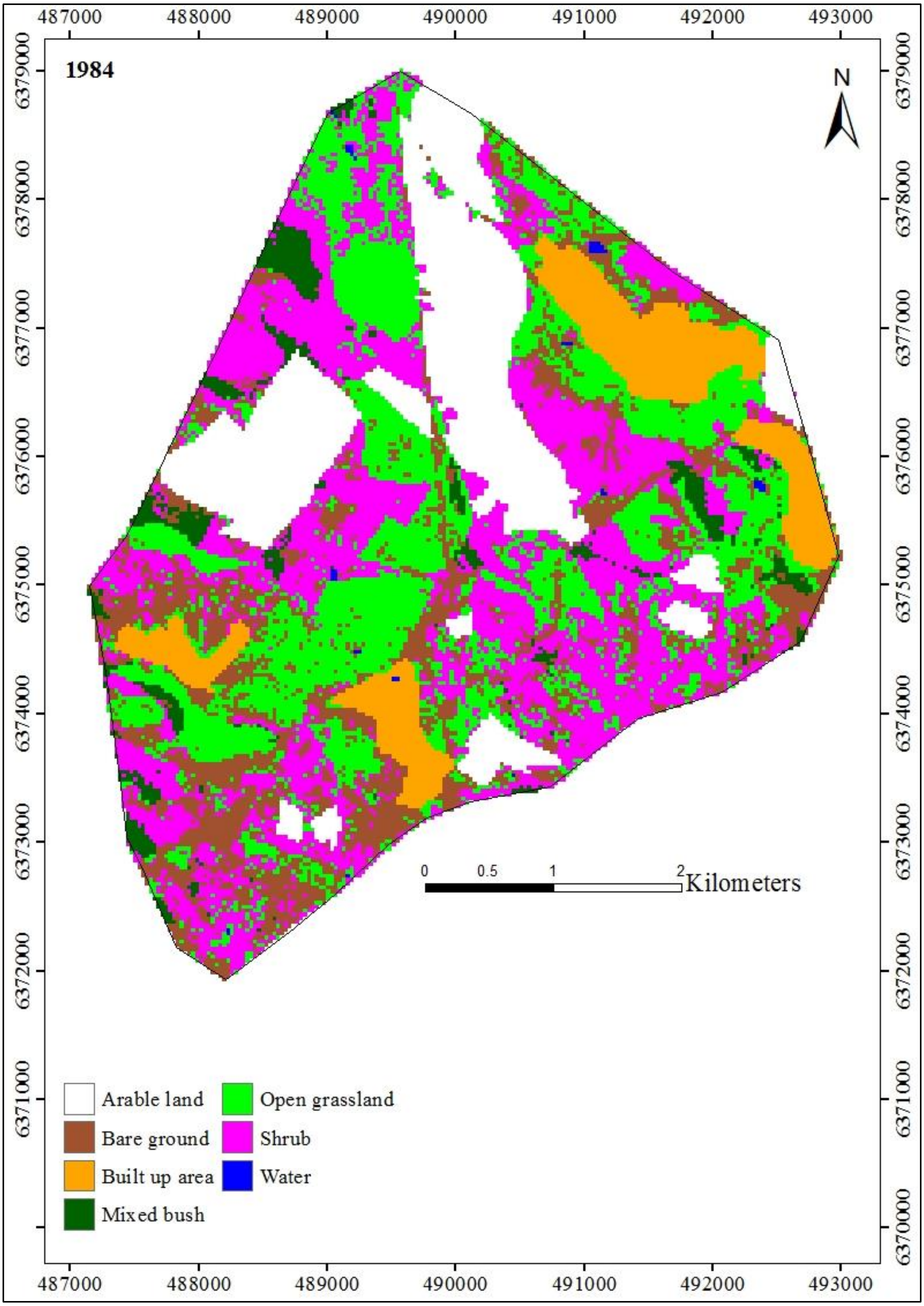


Figure 12: Land use and land cover map of Thyume: 1995

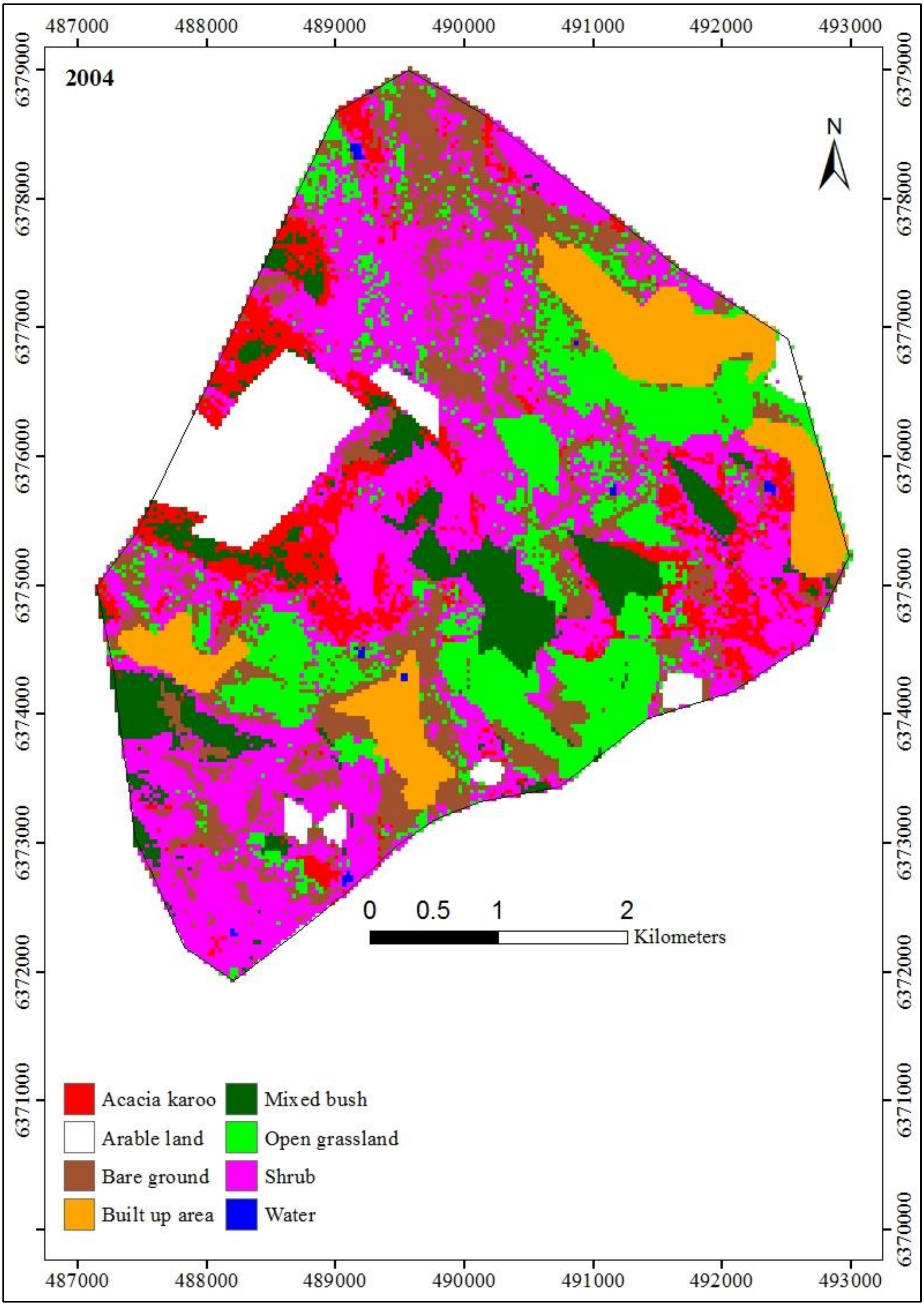


Figure 13: Land use and land cover map of Thyume: 2004

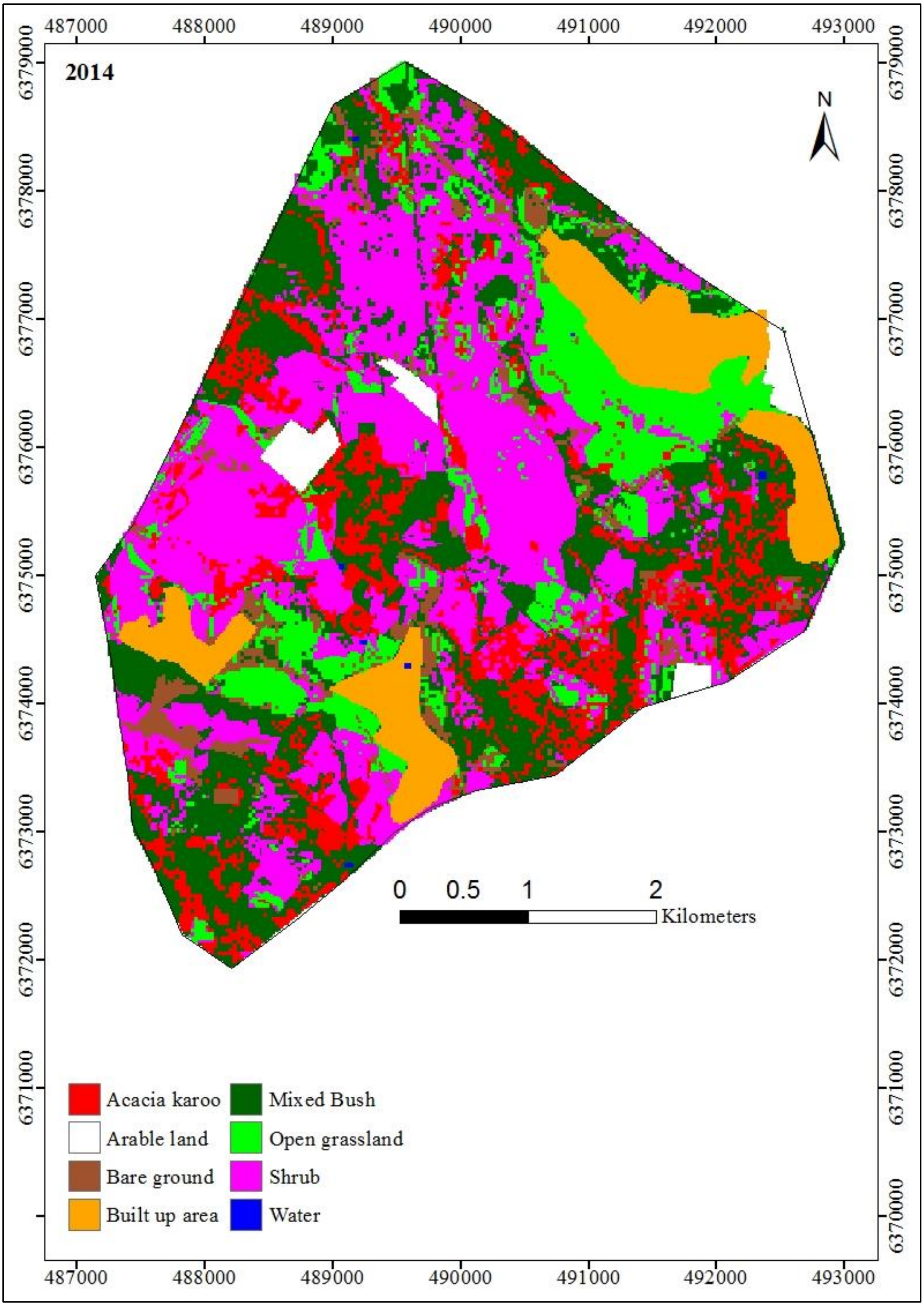


Figure 14: Land use and land cover map of Thyume: 2014

4.3.1. General trends in Thyume: 1984-2014

Land use/ land cover type	Area (Percentage/year)			
	1984	1995	2004	2014
Water	0.17	0.28	0.18	0.06
Open grassland	25.81	28.13	16.40	12.01
Bare ground	17.15	10.64	16.75	5.22
Shrub	27.26	33.93	32.91	31.47
Mixed bush	3.86	6.03	8.08	25.51
Acacia Karroo	0.00	4.78	9.63	14.18
Arable land	17.29	7.50	7.28	2.04
Built up area	8.46	8.71	8.77	9.51
Total	100	100	100	100

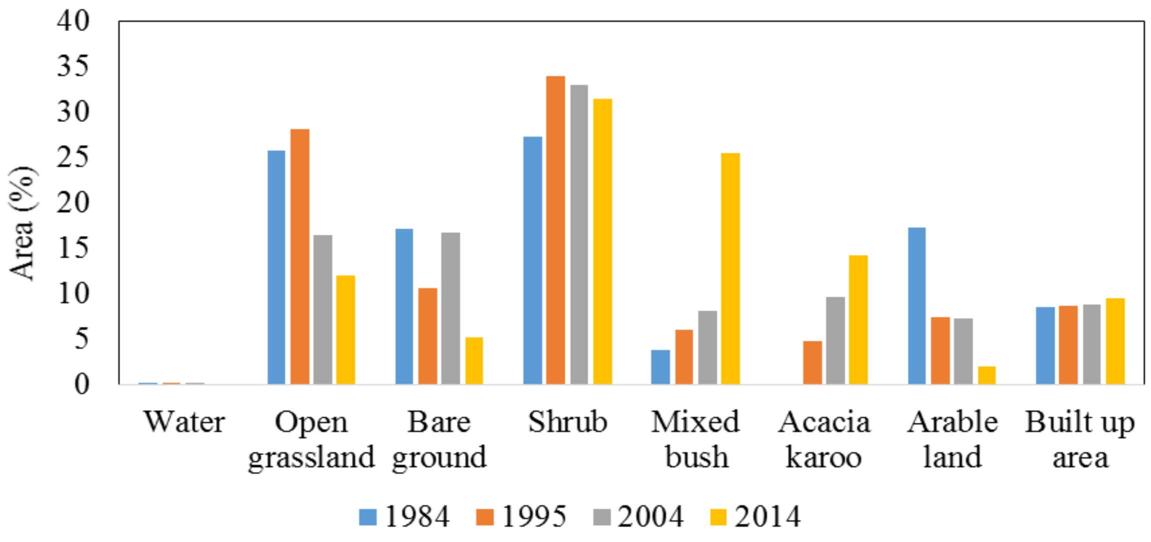


Figure 15: Percent proportions of land cover types in Thyume: 1984-2014

Although water covers a marginal amount of the area (below 1%), water decreased by a threefold (from 0.17% to 0.06%) between 1984 and 2014. Initially, 17% of the area was covered by arable land which by 2014 constituted only 2% of the area. Open grassland was the second most extensive land cover type, constituting 26% of the area in 1984, and decreased to 12% in 2014. The most extensive land cover types in 2014 after Shrub (31%) were mixed bush (26%) and *Acacia Karroo* (14%) (**Figure 15**).

4.3.2. Specific trends in the distribution of land use and land cover in Thyume: 1984-2014

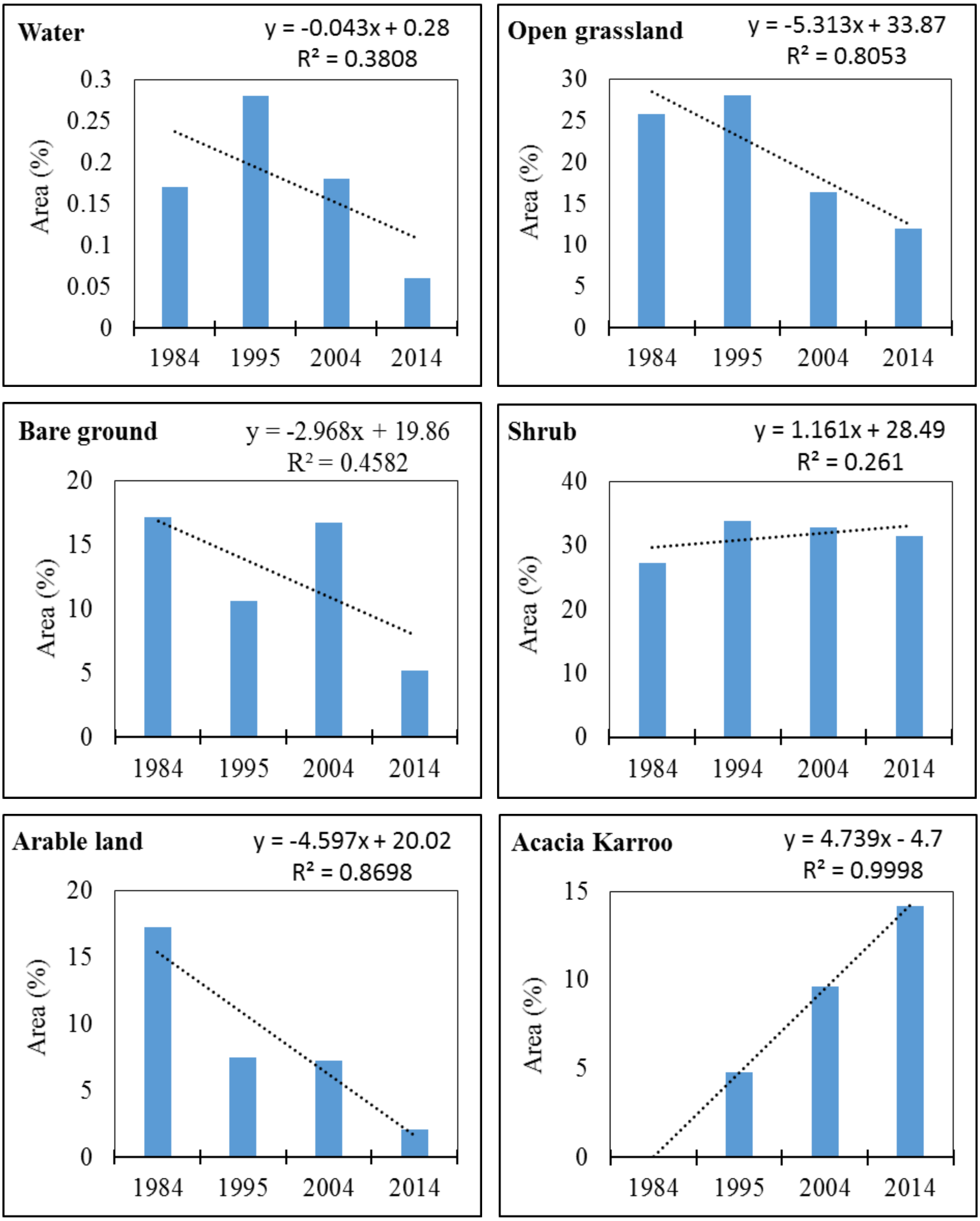


Figure 16: Area extents of land cover types in Thyume: 1984-2014

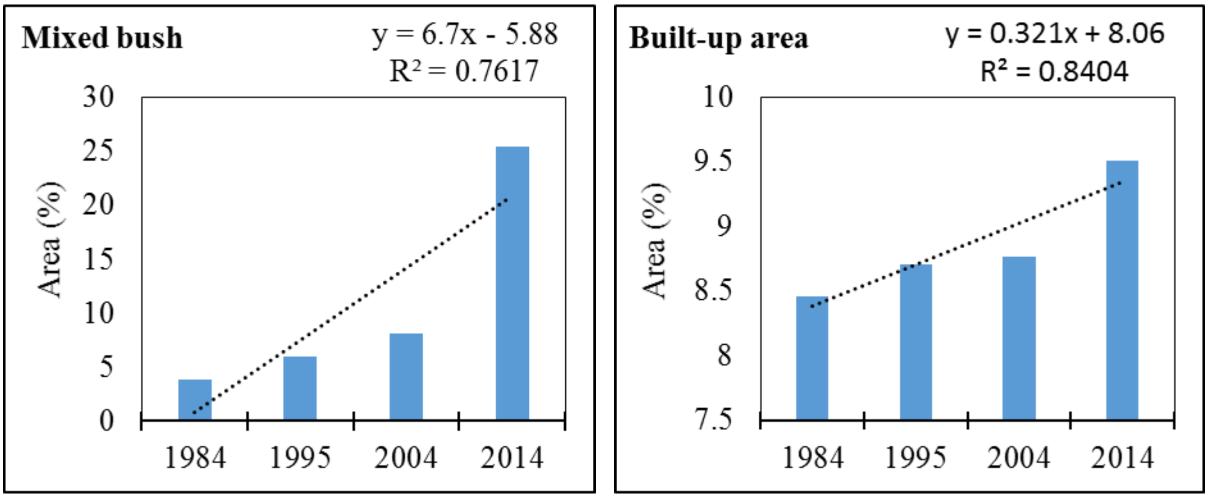


Figure 16 continued.

Table 18: Percentage changes of land use and land cover types in Thyume: 1984-2014

Land use/ land cover type	Percentage increase/decrease			
	1984-1995	1995-2004	2004-2014	1984-2014
Water	0.11	-0.10	-0.12	-0.11
Open grassland	2.33	-11.74	-4.38	-13.79
Bare ground	-6.51	6.11	-11.53	-11.93
Shrub	6.67	-1.02	-1.45	4.20
Mixed bush	2.17	2.05	17.43	21.65
Acacia Karroo	4.78	4.85	4.55	14.18
Arable land	-9.80	-0.22	-5.24	15.26
Built-up area	0.25	0.07	0.74	1.05

Table 19: Land cover trend analysis and significance test for Thyume: 1984-2014

LULC type	Trend equation	R^2	F
Water	$y = -0.043x + 0.28$	0.3808	1.08
Open grassland	$y = -5.313x + 33.87$	0.8053	6.87*
Acacia Karroo	$y = 4.739x - 4.7$	0.9998	1257.60**
Bare ground	$y = -2.968x + 19.86$	0.4582	1.83
Shrub	$y = 1.161x + 28.49$	0.261	0.71
Mixed bush	$y = 6.7x - 5.88$	0.7617	6.12
Arable land	$y = -4.597x + 20.02$	0.8698	16.89*
Built-up area	$y = 0.321x + 8.06$	0.8404	10.50**

F-critical values at 3df = 6.59*, 16.69** Significant at $\alpha = 0.05$* Significant at $\alpha = 0.01$**

Table 20: Land cover trend analysis and significance test for Thyume: 1995-2014

LULC type	Trend equation	R^2	F
Water	y = -0.11x + 0.3933	0.9973	2054.08**
Open grassland	y = -8.06x + 34.967	0.9354	11.44*
Acacia Karroo	y = 4.7x + 0.13	0.9997	419.22**
Bare ground	y = -2.71x + 16.29	0.2207	0.33
Shrub	y = -1.23x + 35.23	0.9904	102.92**
Mixed bush	y = 9.74x - 6.2733	0.828	5.68
Arable land	y = -2.73x + 11.067	0.7802	4.12
Built-up area	y = 0.4x + 8.1967	0.8059	4.86
F-critical value at 2df = 9.55*, 30.82** Significant at α = 0.05* Significant at α = 0.01**			

(i) Surface water increased by 0.11% in the first 9 years of the 30 year period, after which surface water declined by 0.22% between 1995 and 2014 (**Table 18**). Although water covered the smallest area in comparison to other land cover types, the amount of water in the area was three times less in 2014 in comparison to the amount of water in 1984 (**Figure 16**). Though water increased between 1984 and 1995, the steady decline of water between 1995 and 2014 was statistically significant at α = 0.01, F = 2054.08 (**Table 20)**

(ii) Whilst open grassland increased by 2.3% between 1984 and 1995, bare ground decreased by 6.51%. However, open grassland decreased considerably over the entire 30 year period, with open grassland covering 25.81% of the area in 1984 and 12.01% in 2014 (**Figure 15**). The observed trend in open grassland was statistically significant at α = 0.05, F = 6.87 (**Table 19**). The substantial decline in open grassland coincided with the gradual increase in *Acacia Karroo* and mixed bush, and the slight increase in built-up area (**Figure 16**)

(iii) Although the observed trends in bare ground were not statistically significant, it is worth noting that bare ground decreased by 11.93% (**Table 18**) over the entire 30 year period

(iv) Shrubs contribute indirectly to bush encroachment because they grow and transform into trees. Shrub increased by 6.67% between 1984 and 1995 (**Table 18**), after which it decreased continually, with a statistically significant decrease (α = 0.01, F = 102.92) (**Table 20**).

(v) Mixed bush increased by 22% between 1984 and 2014; constituting 4% of the area in 1984 and 26% in 2014. Mixed bush increased most extensively during the 10 year period between 2004 and 2014 over which it increased by 17% (see **Table 16**).

(vi) The fact that *Acacia Karroo* clumps were not mappable for 1984 gives an indication that this species covered an insignificant portion of the total area. *Acacia Karroo* covered 4.78% of the total area in 1995, increasing at a constant rate of 5% over every 10 years (**Table 18**), and *Acacia Karroo* constituted just above 14.18% of the area in 2014 (**Figure 15**). Much of the shrub found in the area is *Acacia Karroo*, which grows and transforms into trees. In the overall 30 year period, *Acacia Karroo* increased by 14.18%, and it was the second most spreading cover type in Thyume after mixed bush (**Table 18**). The increase in *Acacia Karroo* was statistically significant at $\alpha = 0.01$, $F = 1257.60$ (**Table 19**).

(vii) The most declining cover type in Thyume was arable land. Arable land went from being the third most extensive LULC (land use and land cover) type in Thyume to being the second least in 2014. It is worth noting that arable land decreased as the amount of surface water decreased in the area. A considerable decrease in arable land occurred at the same time when open grassland and shrub increased (1984-1995). Between 1984 and 1995 arable land decreased by 10%, whilst it declined by 15% between 1984 and 2004, constituting 17% of the area in 1984 and just 2% in 2014 (**Figure 15**). In Thyume arable land declined by 15.26% over the entire 30 year period, and this trend was statistically significant at $\alpha = 0.01$, $F = 16.89$ (**Table 19**).

(viii) Built-up area was mapped by digitizing boundaries of the residential areas. Therefore, changes in built-up area were mapped in terms of area increase/ decrease rather than through mapping of individual buildings. The highest expansion rate of built-up area occurred between 2004 and 2014 (**Table 18**). Built-up area increased by 1.05% between 1984 and 2014, and the observed trend was statistically significant at $\alpha = 0.05$, $F = 10.50$ (**Table 19**).

4.4. Spatio-temporal mapping of land cover in Sheshegu: 1984-2014

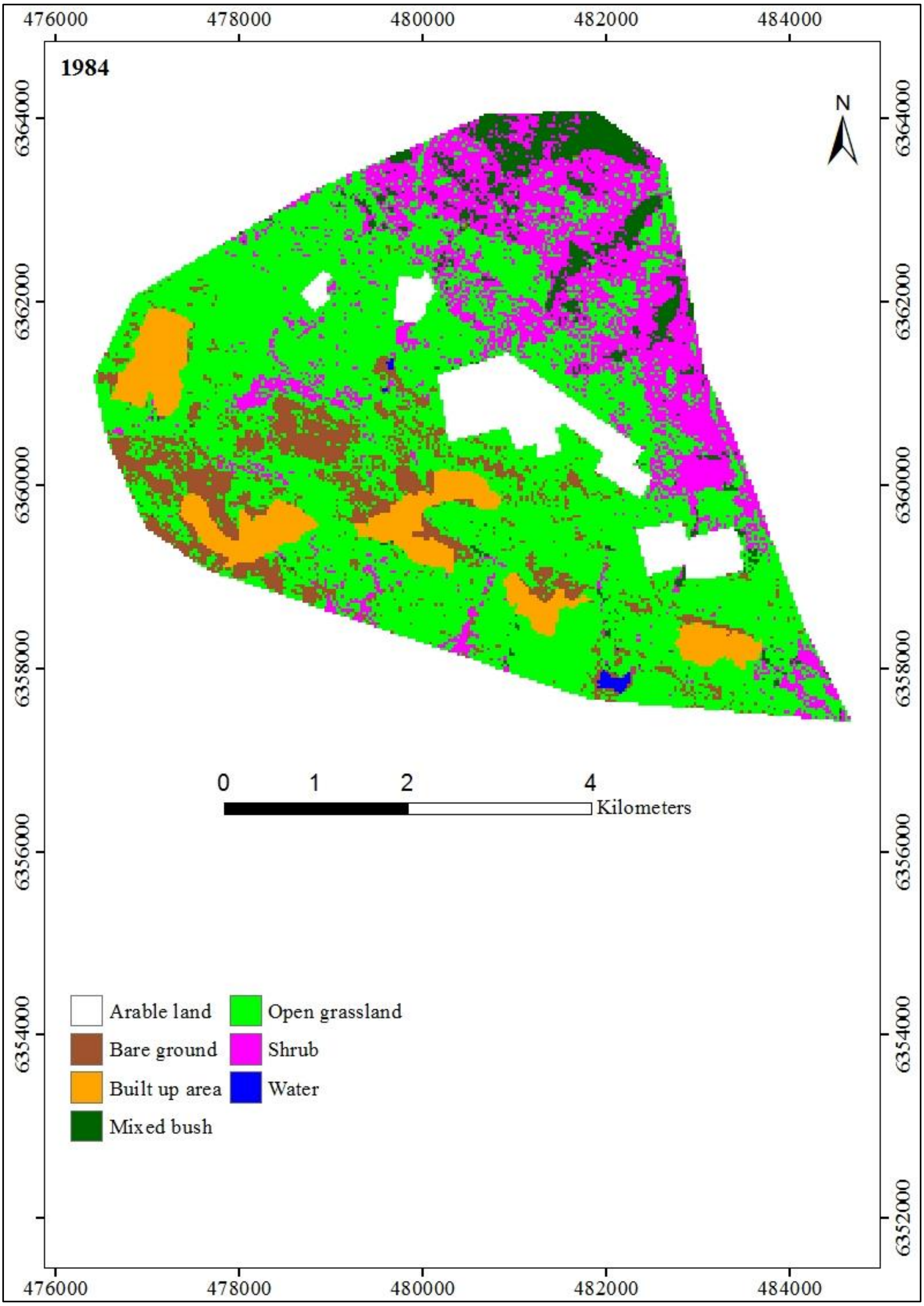


Figure 17: Land use and land cover map of Sheshegu: 1984

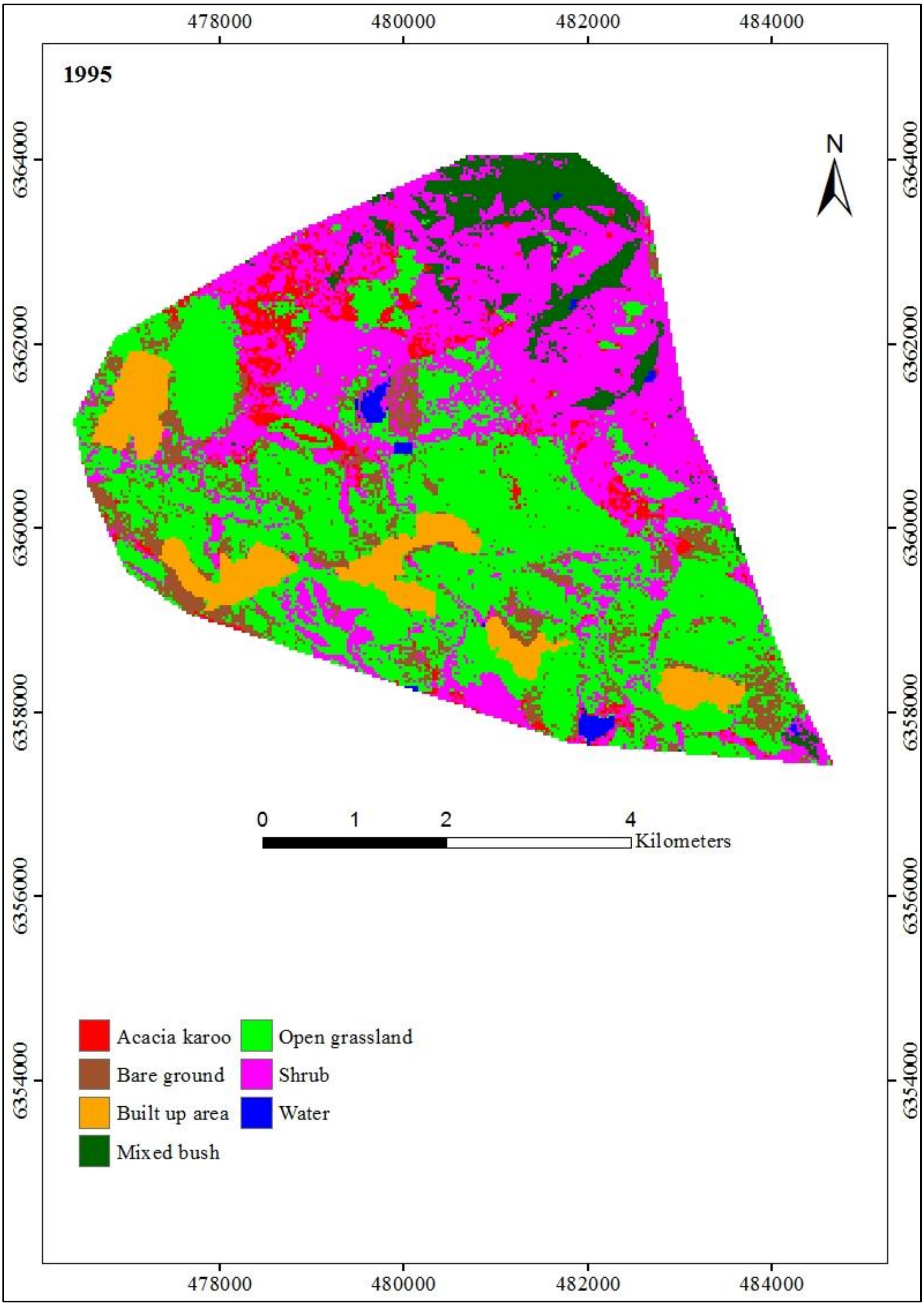


Figure 18: Land use and land cover map of Sheshegu: 1995

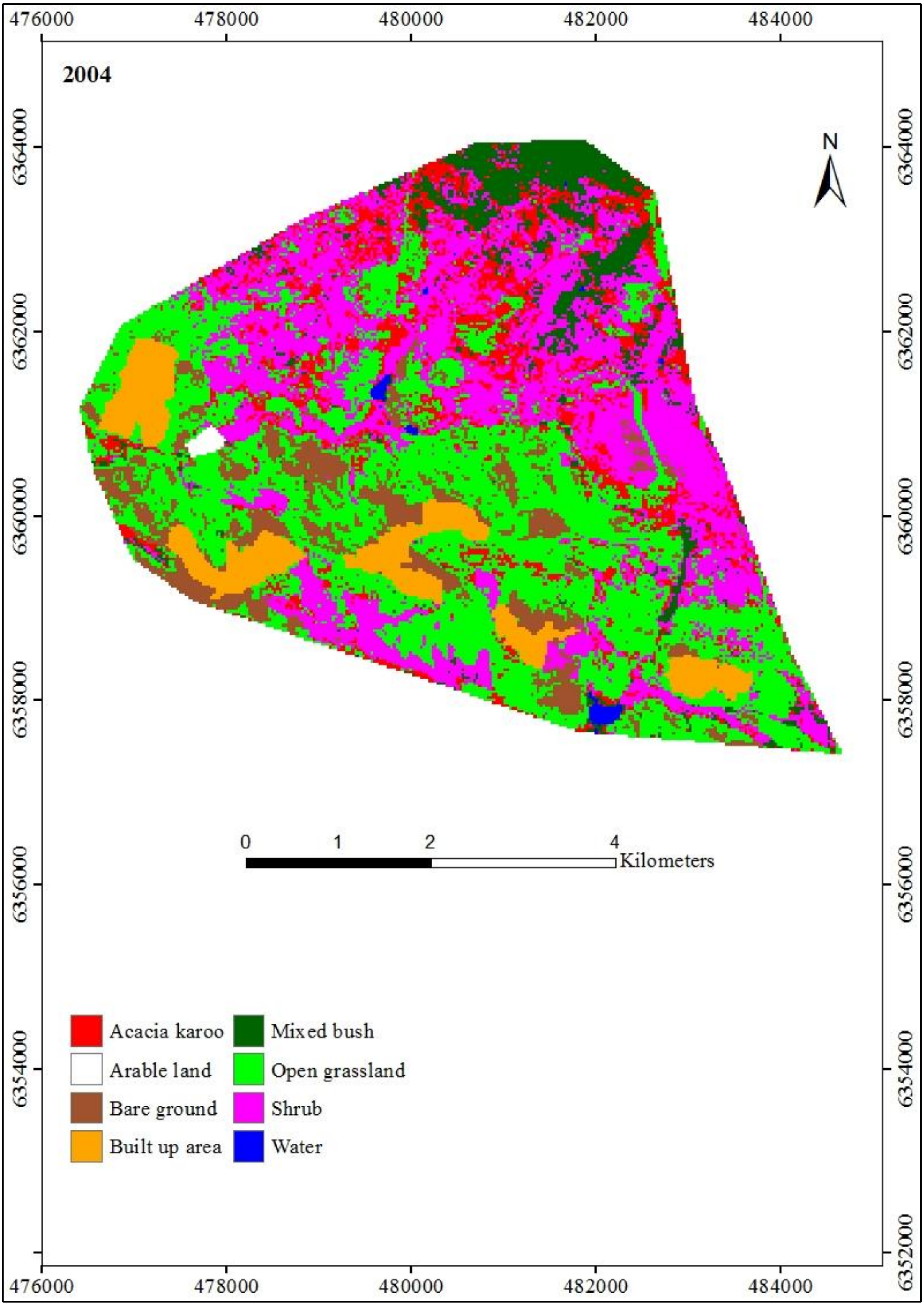


Figure 19: Land use and land cover map of Sheshegu: 2004

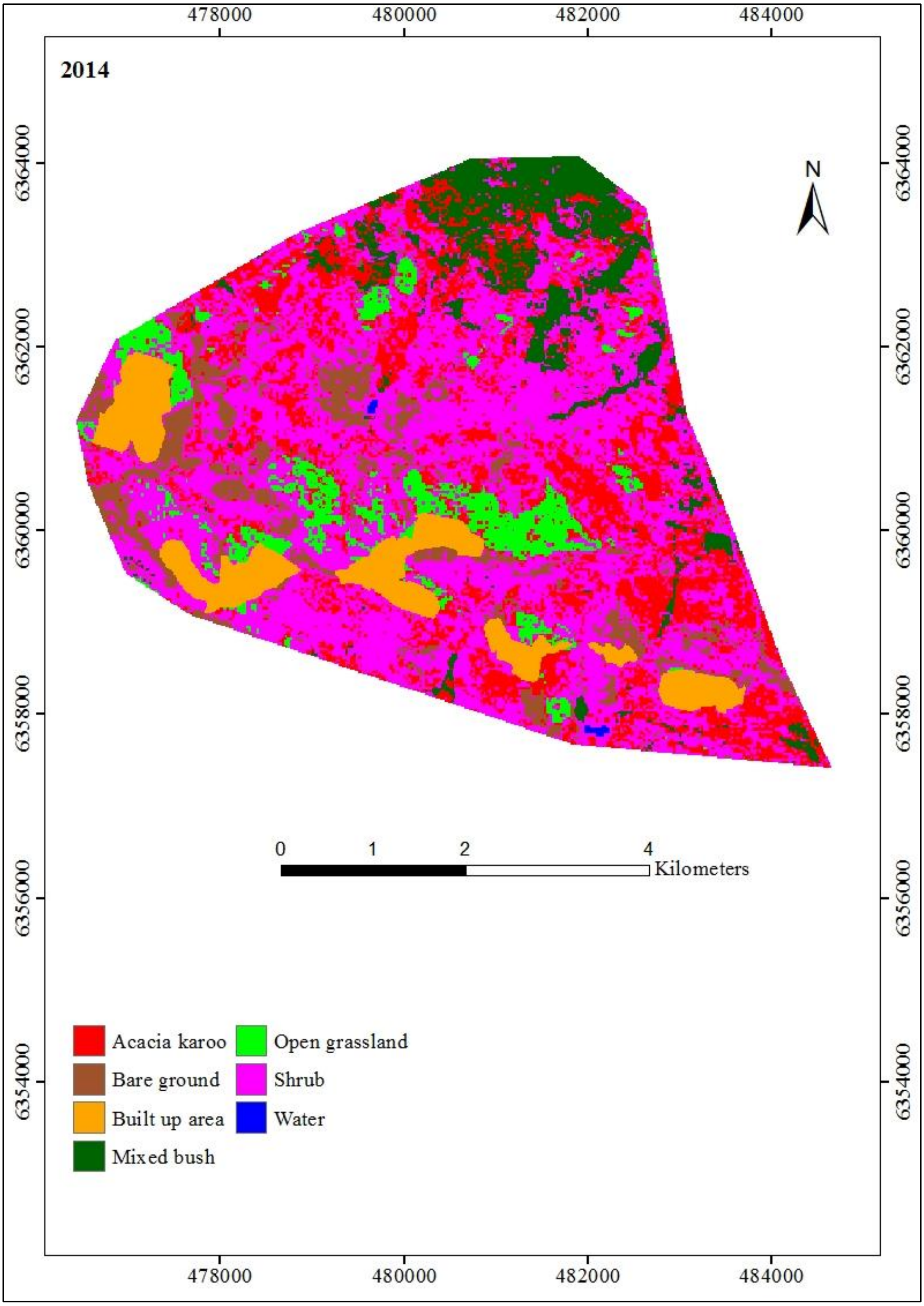


Figure 20: Land use and land cover map of Sheshegu: 2014

4.4.1. General trends in Sheshegu: 1984-2014

Land use/ land cover type	**Area (Percentage /year**			
	1984	**1995**	**2004**	**2014**
Water	0.19	0.74	0.40	0.10
Open grassland	53.91	39.77	34.45	6.45
Bare ground	9.40	8.48	9.63	8.33
Shrub	18.09	32.82	28.78	45.27
Mixed bush	4.95	6.43	7.28	8.99
Acacia Karroo	0.00	4.85	12.29	22.85
Arable land	6.55	0.00	0.26	0.00
Built-up area	6.91	6.91	6.91	7.60
Unclassified	0.00	0.00	0.00	0.41
Total	100	100	100	100

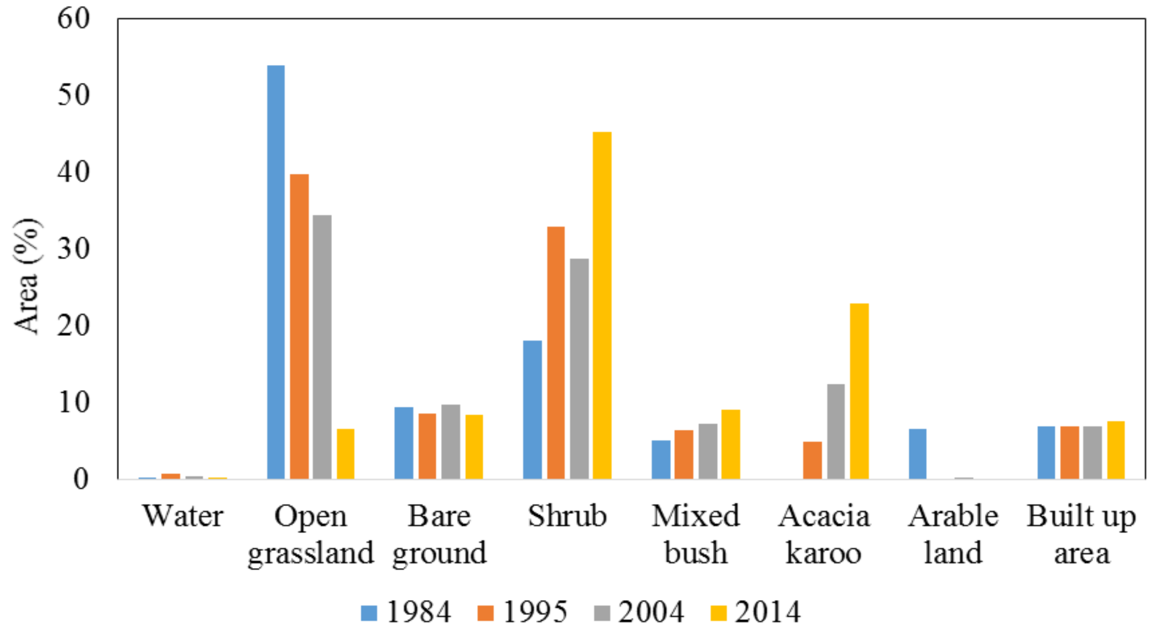


Figure 21: Percent proportions of land cover types in Sheshegu: 1984-2014

As shown in **Figure 21**; Sheshegu was predominantly open grassland (54%) in 1984, and open grassland decreased to 7% in 2014. In 2014, the area was dominated by shrubs (42/%), *Acacia Karroo* (23%), and mixed bush (9%).

4.4.2. Specific trends in the distribution of land use and land cover in Sheshegu: 1984-2014

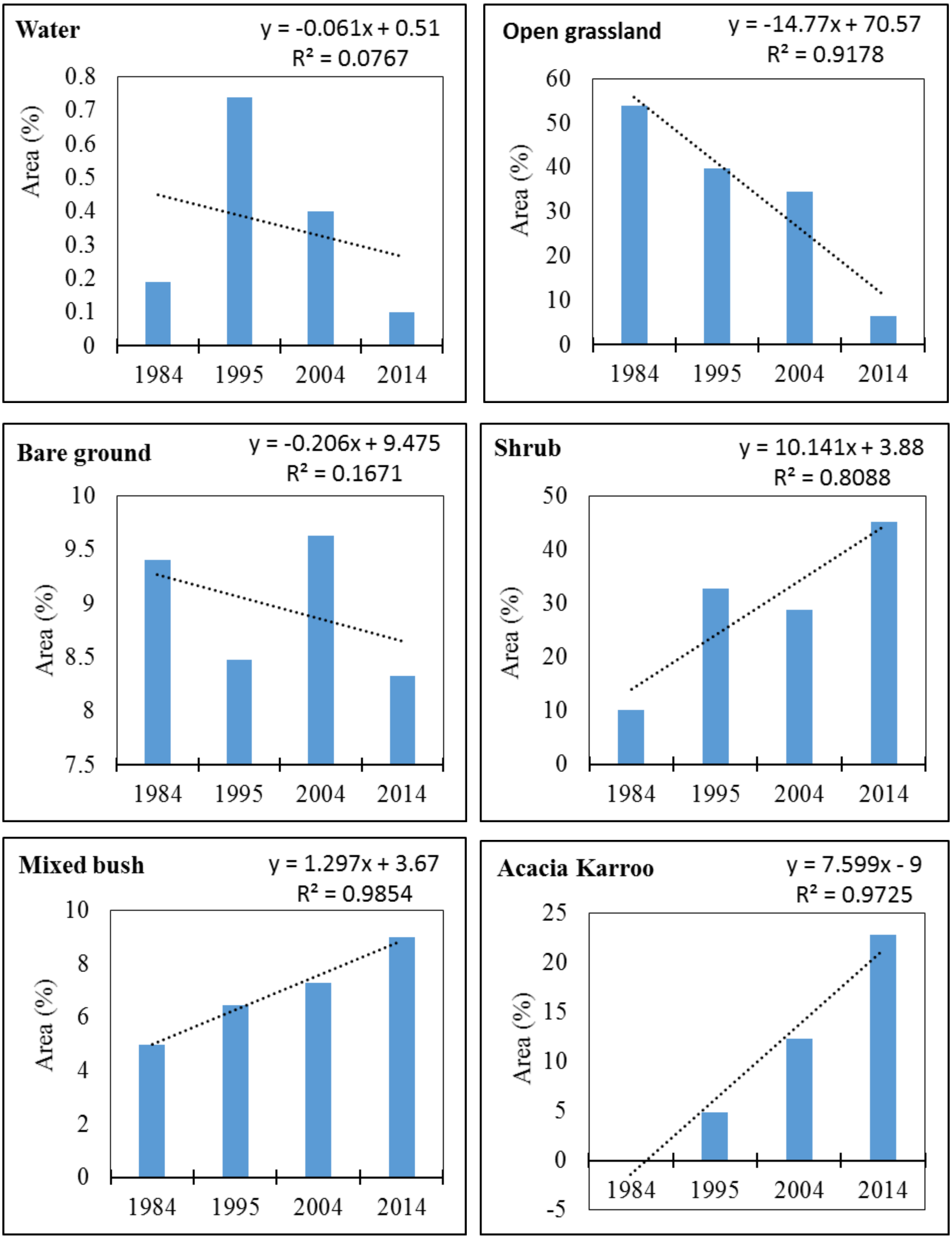
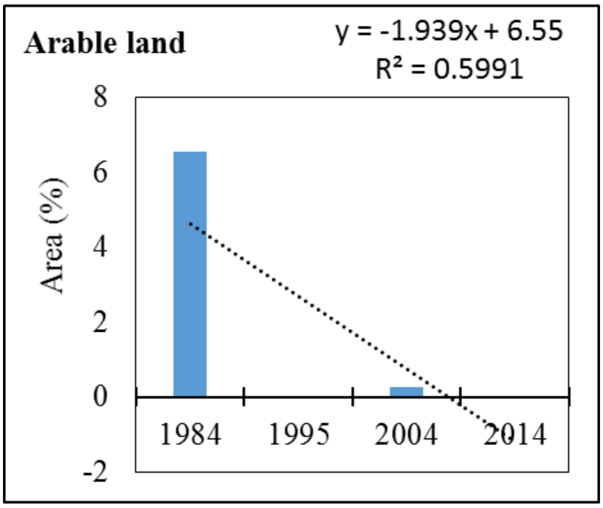


Figure 22: Area extents of land cover types in Sheshegu: 1984-2014



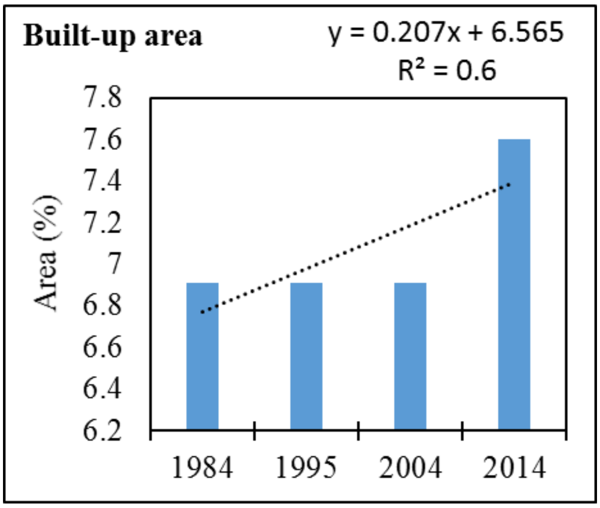


Figure 22 continued

Table 21: Percentage changes of land use and land cover types in Sheshegu: 1984-2014

Land use/ land cover type	Percentage increase/decrease			
	1984-1995	1995-2004	2004-2014	1984-2014
Water	0.55	-0.34	-0.30	-0.08
Open grassland	-14.14	-5.32	-28.00	-47.45
Bare ground	-0.92	1.15	-1.31	-1.08
Shrub	14.73	-4.04	16.49	27.18
Mixed bush	1.48	0.85	1.71	4.04
Acacia Karroo	4.85	7.43	10.56	22.85
Arable land	-6.55	0.26	-0.26	-6.55
Built-up area	0.00	0.00	0.68	0.68

Table 22: Land cover trend analysis and significance test for Sheshegu: 1984-2014

LULC type	Trend equation	R^2	F
Water	$y = -0.061x + 0.51$	0.0767	0.13
Open grassland	$y = -14.77x + 70.57$	0.9178	22.90**
Acacia Karroo	$y = 7.599x - 9$	0.9725	53.80**
Bare ground	$y = -0.206x + 9.475$	0.1671	0.46
Shrub	$y = 10.141x + 3.88$	0.8088	10.17*
Mixed bush	$y = 1.297x + 3.67$	0.9854	182.07**
Arable land	$y = -1.939x + 6.55$	0.5991	3.44
Built-up area	$y = 0.207x + 6.565$	0.6000	2.89

F-critical value at 3df = 6.59*, 16.69** Significant at $\alpha = 0.05$* Significant at $\alpha = 0.01$**

Table 23: Land cover trend analysis and significance test for Sheshegu: 1995-2014

LULC type	Trend equation	R^2	F
Water	y = -0.32x + 1.0533	0.9987	225.83**
Open grassland	y = -16.66x + 60.21	0.8662	7.78
Acacia Karroo	y = 9x - 4.67	0.9901	207.17**
Bare ground	y = -0.075x + 8.9633	0.0111	0.02
Shrub	y = 6.21x + 23.193	0.5241	1.24
Mixed bush	y = 1.28x + 5.0067	0.9637	37.81**
Arable land	y = 0.0867	0.0000	0.00
Built-up area	y = 0.345x + 6.45	0.7500	3.46
F-critical value at 2df = 9.55*, 30.82** Significant at α = 0.05* Significant at α = 0.01**			

(i) Water increased by a relatively considerable magnitude (0.55%) between 1984 and 1995. Between 1995 and 2014 water experienced a steady decline, from 0.74% in 1995 to 0.10% in 2014. Although water increased between 1984 and 1995, water was less in 2014 (0.10%) as compared to the amount of water in 1984 (0.19%) (**Figure 21**). The decrease in water was statistically significant at α = 0.01, F = 225.83 (**Table 21**).

(ii) Open grassland declined considerably between 1984 and 2014, because open grassland covered 53% of Sheshegu in 1984 and was the most extensive land cover type, and declined to 6% in 2014. The highest rate of decrease occurred during the 10 year period between 2004 and 2014 in which open grassland declined by 27%. Open grassland decreased as shrub, mixed bush, and *Acacia Karroo* increased in Sheshegu (**Table 21**). The decline in open grassland was statistically significant at α = 0.01, F = 22.90 (**Table 22**).

(iii) There were variations in the magnitude of bare ground between 1984 and 2014, however bare ground declined by 1% over the entire 30 year period, with bare ground covering 9% of the area in 1984, and 8% in 2014. When open grassland decreased drastically between 1995 and 2014, bare ground increased (**Table 17**).

(iv) Shrub increased by 27% of the total over the entire 30 years, and a portion of this upsurge could be ascribed to abandonment of arable land. Shrub declined by 4%, as arable land, mixed bush, *Acacia Karroo*, and bare ground increased between 1995 and 2004 (see **Table 17**). The increase in shrub was statistically significant at α = 0.05, F = 10.17 (**Table 22**).

(v) Mixed bush covered 5% of the area in 1984, increasing at a subtle rate over the 30 year period, and constituted 9% of the area in 2014 (**Figure 21**). The proliferation of mixed bush was statistically significant at $\alpha = 0.01$, $F = 182.07$ (**Table 22).**

(vi) *Acacia Karroo* intensified exponentially in comparison to the other cover types. *Acacia Karroo* increased from 4.8% in 1995 to 22.85% in 2014 (**Figure 21**), with an overall increase of 23% between 1984 and 2014 (**Table 21**). The increase in *Acacia Karroo* was statistically significant at $\alpha = 0.01$, $F = 53.80$ (**Table 22**).

(vii) Arable land constituted 6.5% of the area in 1984, and with gradual abandonment of agricultural activity, in 2014 there was 0% active arable land in the area (**Figure 21**).

(viii) The magnitude of the area covered by built-up area was constant between1984, 1995, and 2004, after which it increased by 1% (**Figure 21**).

At this point, observations that can be pointed out by doing a site-to-site comparison include the following:

a) Water slightly increased in all the sites between 1984 and 1995, after which it gradually decreased to levels below the quantity of water in 1984.

b) All the sites were predominantly open grassland in 1984, however, open grassland deteriorated considerably over the entire 30 year period.

c) In 2014 both savanna systems (communal and private) were dominated by shrub, whilst mixed bush and *Acacia Karroo* increased between 1984 and 2014.

d) In all the sites bush encroachment increased at a higher rate in comparison to the other forms of land cover change.

e) Abandonment of arable increased considerably in the communal savannas over the past 30 years, especially in Sheshegu where there was zero amount of arable land in 2014.

CHAPTER 5

5. Discussion

This section presents a detailed explanation and assessment of the land cover trends observed in the study sites and a site-to-site comparison of land cover trends.

5.1. Assessment of land use and land cover trends in the study sites.

This section provides a comprehensive discussion of the statistically significant land use and land cover changes. The results of the investigation are then compared with findings of other studies of similar nature.

5.1.1. The direction of land cover change in Honeydale

As indicated in the previous chapter, Honeydale exhibited a steady shift over the 30 year period; from being an open grassland to being densely populated by woody vegetation in the form of mixed bush and *Acacia Karroo*. The findings of the study are consistent with the findings of Buitenwerf et al., (2012) who discovered that tree density increased significantly in Honeydale Farm between 1973 and 2007.

5.1.2. The direction of land use and land cover change in Thyume

Thyume underwent considerable land use and land cover changes in the past 30 years, and these include; decrease in surface water, decline in open grassland, and invasion by *Acacia Karroo*, bush encroachment, and abandonment of arable land. In the 1980s, Thyume was covered by extensive open grasslands which gradually declined with time. The decrease in open grassland coincided with the gradual increase of mixed bush and invasion by *Acacia Karroo*. The increasing dominance by mixed bush and *Acacia Karroo*, and the steady decrease in open grassland can be explained by the fact that shrub has, over the 30 year period, always covered the largest portion of the area as compared to the other cover types (**Figure 15**).

One of the factors that have contributed to the steady increase of *Acacia Karroo* in this area is the abandonment of arable land. Areas that were arable lands in the mid-1980s and 1990s (**Figure 11** and **Figure 12**) were covered by shrubs and *Acacia Karroo* in 2014 (**Figure 14**). Abandonment of arable land in rural areas could result from several factors, including; inherent properties of soils and lack of capital to supplement land, relinquishment of traditional land management schemes, and decrease in surface water. Manyevere et al., (2014) reported that lack of able-bodied farmers, shortage of labour, and low literacy levels among the youth in Nkonkobe Local Municipality influence abandonment of arable land.

5.1.3. The direction of land use and land cover change in Sheshegu

As in Honeydale and Thyume, surface water in Sheshegu increased between 1984 and 1995, and gradually decreased thereafter. Whilst open grassland exhibited a substantial decline, *Acacia Karroo*, mixed bush, and shrub increased extensively.

Although abandonment of arable land was statistically insignificant, it may perhaps be observed that; between 1984 and 2014, the magnitude of cover change due to abandonment of arable land was 6.55%. It is also worth mentioning that; in 2014, the abandoned arable lands of this area were covered by shrub, *Acacia Karroo* (**Figure 17**, **Figure 19**, and **Figure 20**), and rills that result from eroded bare ground (**Appendix IIc**). According to Ighodaro et al., (2013), the occurrence of soil erosion in Sheshegu has negative effects on crop production. Ighodaro et al., (2013) also reported that migration of young people to urban areas and the average age (52 years old) of farmers in Sheshegu are a big challenge to agricultural activity. Manyevere et al., (2014) reported that; apart from soil degradation, abandonment of arable in Nkonkobe Local Municipality is partly influenced by low rainfall, and lack of security, shortage of fertilizer and seed, and lack of farm machinery.

5.2. Comparative observations of land cover trends in Honeydale, Thyume, and Sheshegu.

Decline in surface water was statistically significant in all the study sites. Annual rainfall between 1984 and 2014 does not give any indication of correlation with surface water.

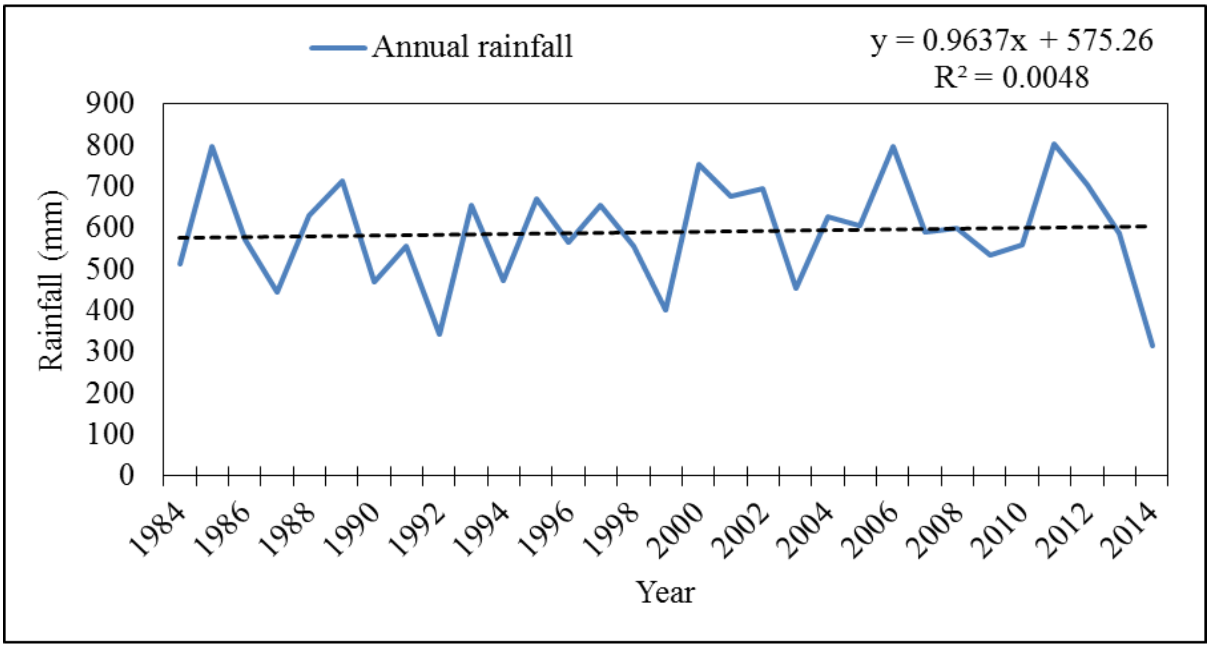


Figure 23: Distribution of annual rainfall in Nkonkobe Local Municipality: 1984-2014

Though there was no persistent decrease of annual rainfall during this period, there were periods of droughts, including; 1992, 1997, 2004, and 2009 (www.weathersa.co.za). During these periods, water flow in rivers became very low, water dams were dry in some areas, and crop harvest decreased considerably (Mniki, 2009). Frequent occurrence of drought can cause permanent changes to the ecosystem (Vetter, 2009). The decrease in surface water could also be attributed to the advent of "tap water" in rural areas. Management of surface water (small dams) became a secondary matter immediately when tap water was introduced in rural areas. The rural communities relied on both ground and surface water before the introduction of taps. Water quantity is very crucial in an ecosystem because it is one of the factors that determine the adequacy and potential of the ecosystem to provide goods and services. Drying up of surface water threatens livestock farming and biodiversity.

Though decrease in open grassland occurred in all the sites, open grassland decreased significantly only in the communal areas. Similarly, *Acacia Karroo* increased in both the communal savannas and the private farm. *Acacia Karroo* is a very adaptive species, and it can grow under a variety of climatic, soil, and topographic conditions. *Acacia Karroo* can be a hindrance to agricultural productivity because it competes for space, water, and nutrients with grasses (http://www.worldagroforestry.org/treedb/AFTPDFS/Acacia_karroo.PDF), thus inhibiting livestock farming as grazers prefer grass. *Acacia Karroo* becomes invasive in overgrazed areas (http://www.plantzafrica.com/plantab/acaciakar.htm). Therefore, the decrease in the palatable, sweet grasses of Thyume and Sheshegu, and the occurrence of overgrazed grasses in Honeydale could be due to the invasion by *Acacia Karroo*.

It is also worth observing that though open grassland decreased consistently in the communal areas, there was a 10% increase of grass cover in Honeydale Farm between 2004 and 2014. The 10% increase of open grassland in Honeydale Farm between 2004 and 2014 coincided with the 41% decrease in shrub and the 4% decrease in bare ground (**Figure 9**). Shrub decreased in the same period (2004-2014) when Dube et al., (2011) applied *Bromacil* to control *Acacia Karroo* in Honeydale.

With regards to bare ground, there was more evidence of soil erosion in Sheshegu than in Thyume and Honeydale because there were more rills (Appendix II). Whilst bare ground decreased considerably in Thyume, it changed trivially and insignificantly in Sheshegu. These findings are congruent with those reported in Ighodaro et al., (2013)'s investigation.

In terms of bush encroachment, the findings of this investigation were consistent with the findings of Wigley et al., (2009) that bush encroachment occurs across both South Africa's communal and private savanna systems. In 2014, woody vegetation covered 52.4% of

Honeydale, 39.69% of Thyume, and 31.13% of Sheshegu. The highest rate of bush encroachment over the entire 30 year period occurred in the private savanna (i.e. Honeydale). The amount by which woody vegetation increased in Honeydale between 1984 and 2014 sums up to 41.2%, whilst it increased by 35.83% and 26.89% in Thyume and Sheshegu respectively, and this includes mixed bush and *Acacia Karroo*. Woody vegetation increased more severely in Honeydale farm because; unlike Sheshegu and Thyume, Honeydale is not an open access system. Generally, in open access systems woody vegetation is regulated by wood cutting and uncontrolled burning and harvesting of medicinal plants. In Honeydale, woody vegetation is regulated through occasional fires and goat browsing (De Bruyn, 1998).

The findings of the study (abandonment of arable lands in the communal areas, higher tree density increase in the private area) suggest that the management strategies employed in both the private and the communal savannas have an influence on the observed changes. However, changes including; decrease in surface water and bush encroachment generally, indicate that there are other influential factors besides the management strategies. On the other hand, the frequent occurrence of droughts in the area needs careful consideration. The results of this investigation can also be measured against the socioeconomic status of the study sites and the natural setting of the area for a more comprehensive analysis of the environmental situation. The use of Remote Sensing in the investigation was time efficient and cost effective, and successfully providing empirical insights on the land use and land cover changes in Nkonkobe Local Municipality communal savanna rangelands.

CHAPTER 6.

6. Conclusions and recommendations

This study concludes by giving a coherent synopsis of the temporal and spatial trends by highlighting the major findings of the investigation. In this Chapter, the objectives of the inquiry itemized in Chapter One are compared with the findings to evaluate the techniques by which they were achieved. The outcomes of the analysis are reviewed to check whether the results are consistent with the hypotheses.

6.1. Conclusions

The major objective of this research was to map spatial and temporal savanna degradation in Thyume, Sheshegu, and Honeydale. This was achieved by mapping trends and quantifying changes in land cover between 1984 and 2014. Mappable land cover types were identified and environmental change indicators related to degradation were investigated, and these include; bush encroachment, abandonment of arable land, loss of biodiversity, invasive plant species, expansion of built-up area, and depletion of surface water. All the LULC changes that occurred in the communal areas were statistically significant. The management strategies used in both land tenure systems had an influence on the spatial temporal changes that occurred in the study sites. In Honeydale, bush encroachment increased more severely than in the communal areas because there is limited access to the land. Fires are applied occasionally in Honeydale, whereas the communal areas are burnt regularly without any methods. Lack of expertise, low literacy levels, lack of able-bodied farmers and shortage of labour in the communal areas emerge as some of the reasons for abandonment of arable land. The mapping techniques employed to accomplish the aims and objectives of this investigation were efficient. The degree of accuracy and the post-classification refinement techniques with which the maps were produced demonstrate that this method can be replicated in other studies of the same nature.

The major hypothesis of this investigation was that land degradation has increased in Nkonkobe Local Municipality communal savannas over the past 3 decades. As indicated in Chapter Two, the trends observed in the selected sample sites are typically unfavorable to a range ecosystem. In the specific hypothesis, bare ground increase was listed as one of the degradation indicators confronting the study area. However, changes in bare ground were not threatening, except in Sheshegu where most bare areas were rills.

The land cover changes measured through this investigation suggest an environmental shift that threatens biodiversity and agricultural activity. The rate at which surface water and open grassland declined will sooner or later render the land unsuitable for grazing livestock. The frequent occurrence of drought in this area can cause permanent ecosystem changes (Vogt et al., 2011); including drying up of water bodies, deterioration of soil quality through soil erosion (Mniki, 2009), and a continued replacement of open grasslands by drought tolerant species like *Acacia Karroo*. Another important discovery from this study is the abandonment of arable land suggesting relinquishment of agricultural activity, which could threaten food security and general livelihood.

6.2. Recommendations

The findings of this study can be used to enhance the understanding of the causes of land cover change and the driving factors behind land degradation. It is also hoped that the direction to which these savannas are changing will prompt formulation and implementation of effective policies. Given the limitations of the data used in this study, it is hoped that as multispectral remote sensing improves and more data becomes available, there will be more investigations of this nature, and thus more detailed findings. The study did, nonetheless, demonstrate that Remote Sensing and GIS can be used, time efficiently and cost effectively, to monitor communal savanna rangelands.

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APPENDICES

Appendix (I): Specifications of the Landsat datasets used in the study

Landsat Scene identifier	Spacecraft Identifier	Acquisition Date	WRS Path	WRS Row	Sensor Anomalies	Level of Processing
LT51700831984174XXX02	LANDSAT5	22 June 1948	170	083	N	Level 1
LT51700831995188JSA00	LANDSAT5	07 July 1995	170	83	N	Level 1
LT51700832004197JSA00	LANDSAT5	02 July 2004	170	83	N	Level 1
LC81700832014224LGN00	LANDSAT 8	12 August 2014	170	083	N	Level 1

N=No sensor anomalies exist

Appendix (IIa): Data collected in Honeydale during the field survey.

Class#	**Coordinates** (UTM Meters)		**Elevation (**metres above sea level)	**Plant species/ descriptive characteristics**	**General class**
	X	**Y**			
1	489482	6370618	531	Water dam	Water
1	489171.90	6372235.98	555	Water dam	Water
2	488539	6371051	528	*Acacia Karroo*	*Acacia Karroo*
2	490691	6371693	548	*Acacia Karroo*	*Acacia Karroo*
2	488511.48	6371291.77	530	*Acacia Karroo*	*Acacia Karroo*
3	490288.86	6371703.50	568	*Cymbopogon plurinodis, Digitaria eriantha*	Open grassland
3	489962	6372675	609	*Cymbopogon plurinodis, Termite mound, Digitaria eriantha*	Open grassland
3	488029.37	6371501.84	552	*Cymbopogon plurinodis, Digitaria eriantha*	Open grassland
4	491290	6372671	610	*Cussonia spicata, Aloe, Acacia Karroo, Olea capensis, Maytenus capitata*	Dense mixed bush
4	489277	6371089	567	*Rhoicissus lucida, Scutia myrtina, Maytenus, Cussonia spicata, Maytenus capitata, Ehretia rigida, Coddia rudis, Acacia Karroo*	Dense mixed bush
4	488996	6372192	556	*Grewia occidentalis, Acacia Karroo, Maytenus heterophylla, Olea capensis, Rhus lucida*	Dense mixed bush

Class#	Coordinates (UTM Meters) X	Y	Elevation (metres above sea level)	Plant species/ descriptive characteristics	General class
5	490206	6371163	581	*Acacia Karroo, Olea capensis*	Olea Capensis
5	488852	6371655	538	*Acacia Karroo, Olea capensis, Scutia myrtina*	Olea Capensis
5	491351	6373570	625	*Olea capensis, Acacia Karroo, Cussonia spicata*	Olea Capensis
6	490455.31	6373059.65	600	*Acacia Karroo, Maytenus heterophylla, Coddia rudis*	Shrubs
6	490308.79	6371533.75	579	*Scutia myrtina, Maytenus heterophylla, Coddia rudis, Acacia Karroo*	Shrubs
6	490034.62	6372464.88	603	*Coddia rudis, Maytenus capitata, Acacia Karoo, Scutia myrtina*	Shrubs
7	489715.32	6372948.71	600	Silt, Sandstone	Bare ground
7	488520.00	6372066.00	560	Silt, Sandstone	Bare ground
7	491026.36	6373243.09	596	Silt, Sandstone	Bare ground
8	490621.30	6371618.51	551	Bare soil, *Digitaria eriantha*	Overgrazed grassland
8	490055.70	6372258.02	592	Bare soil, *Digitaria eriantha*	Overgrazed grassland
8	489800.15	6372519.28	598	Bare soil, *Digitaria eriantha*	Overgrazed grassland
9	489883	6370840	555	*Scutia myrtina, Acacia Karroo, Aloe, Maytenus heterophylla*	Open mixed bush
9	488555	6371913	555	*Acacia Karroo, Olea capensis, Maytenus capitata, Scutia myrtina*	Open mixed bush
9	489221	6371802	563	*Scutia myrtina, Olea capensis,*	Sparse mixed bush

Appendix (IIb): Data collected in Thyume during the field survey

Class#	Coordinates (UTM meters)		Elevation (metres above sea level)	Plant species/ Descriptive characteristics	General class
	X	Y			
1.	489182	6378383	646	Water dam	Water
2.	488246	6372306	570	Water dam	Water
2.	489122	6372733	570	Water dam	Water
2.	489075	6375069	631	Water dam	Water
3.	488786	6372952	589	*Acacia Karroo*	*Acacia Karroo*
3.	490811	6373713	612	*Acacia Karroo*	*Acacia Karroo*
3.	489904	6377392	680	*Acacia Karroo*	*Acacia Karroo*
4.	489294	6373415	602	*Sediments, bare soil, acacia Karroo*	Bare soil
4.	487892	6373710	578	*Sediments, acacia Karroo*	Bare soil
4.	489819	6375577	687	*Sediments, rills, acacia Karoo*	Bare soil
5.	488474	6374150	666	*Digitaria eriantha*	Open grassland
5.	491694	6376176	704	*Digitaria eriantha*	Open grassland
5.	488554	6372466	575	*Digitaria eriantha*	Open grassland
6.	488596	6375268	611	*Aloe, Acacia Karroo, Scutia myrtina, Cussonia paniculata, Opuntia ficus-indicus, Olea capensis*	Mixed Bush
6.	490967	6375213	697	*Scutia myrtina, Acacia Karroo, Maytenus heterophylla, Grewia occidentalis, Melia azedarach*	Mixed bush
6	492477	6375039	670	*Acacia Karroo, Aloe, Opuntia ficus-indica, Scutia myrtina, Maytenus*	Mixed bush

Class#	**Coordinates** (UTM meters) **X**	**Y**	**Elevation (**metres above sea level)	**Plant species/ Descriptive characteristics**	**General class**
7.	492308	6374285	620	*Acacia Karroo, Digitaria eriantha, Coddia rudis*	Sparse *Acacia Karroo*
7.	489222	6373205	592	*Acacia Karroo, Scutia myrtina, Aloe*	Sparse *Acacia Karroo*
7.	489495	6377819	671	*Acacia Karroo, Digitaria eriantha*	Sparse *Acacia Karroo*
8.	487764	6375400	593	*Scutia myrtina, Coddia rudis, Aloe, Maytenus Capitata*	Shrub
8.	488589	6373783	659	*Coddia rudis, Scutia myrtina, Aloe, Acacia Karoo*	Shrub
8.	488052	6372868	617	*Coddia rudis, Acacia Karroo, Maytenus capitata, Scutia myrtina*	Shrub
9.	488826	6376858	706	*Scutia myrtina, Acacia Karroo, Maytenus heterophylla*	Open mixed bush
9.	490608	6374411	671	*Scutia myrtina, Acacia Karroo, Maytenus heterophylla, Olea capensis*	Open mixed bush
9.	488908	6377543	673	*Acacia Karroo, Scutia myrtina, Olea capensis, Maytenus heterophylla*	Open mixed bush
10.	489545	6374038	668	Residential area	Built-up area
10.	487717	6374507	649	Residential area	Built-up area
10.	492742	6375380	703	Residential area	Built-up area

Appendix (IIc): Data collected in Sheshegu during the field survey

Class#	**Coordinates** (UTM meters)		**Elevation** (meters above sea level**)**	**Plant species/ Descriptive characteristics**	**General class**
	X	**Y**			
1.	482107	6357798	437	Water dam	Clear water
1.	479647	6361287	474	Water dam	Clear water
1.	481846	6362397	531	Water dam	Clear water
2.	479995	6360875	476	Water dam	Turbid water
2.	482693	6361638	527	Water dam	Turbid water
2.	480155	6362385	494	Water dam	Turbid water
3.	477680	6360911	434	*Acacia Karroo*	*Acacia Karroo*
3.	481755	6360519	518	*Acacia Karoo*	*Acacia Karroo*
3.	479038	6362316	480	*Acacia Karroo*	*Acacia Karroo*
4.	480678	6362021	528	*Acacia Karoo, Digitaria eriantha*	Sparse *Acacia Karroo*
4.	482541	6361237	521	*Acacia Karoo Digitaria eriantha*	Sparse *Acacia Karroo*
4.	481481	6360958	499	*Acacia Karoo, Digitaria eriantha*	Sparse *Acacia Karroo*
5.	482870	6359561	518	*Sandstones, bare soil, Rills, Acacia Karoo*	Bare ground
5.	478456	6360928	441	*Sandstones, bare soil, Rills, Acacia Karoo*	Bare ground
5.	481885	6359460	525	*Sandstones, bare soil, Acacia Karoo*	Bare ground
6.	477122	6362055	468	*Digitaria eriantha*	Open grassland
6.	480014	6362653	514	*Cynodon dactylon*	Open grassland
6.	481917	6359877	555	*Digitaria eriantha*	Open grassland

Class#	**Coordinates** (UTM meters) **X**	**Y**	**Elevation** (meters above sea level**)**	**Plant species/ Descriptive characteristics**	**General class**
7.	480572	6362328	517	*Euphorbia triangularis, Aloe, Acacia Karroo, Scutia myrtina, Cussonia paniculata, Opuntia, Maytenus heterophylla, Maytenus capitata*	Mixed Bush
7.	482744	6361875	536	*Scutia myrtina, Acacia Karroo, Opuntia ficus-indica, Aloe, Euphorbia triangularis, Cussonia paniculata,*	Mixed bush
7.	481506	6362190	527	*Acacia Karoo, Aloe, Opuntia ficus-indica, Scutia myrtina, Cussonia spicata, Maytenus heterophylla, Euphorbia triangularis*	Mixed bush
8.	480134	6358838	514	*Opuntia, Coddia rudis, Acacia Karroo*	Shrub
8.	478051	6362222	494	*Cordia rudis, Scutia myrtina*	Shrub
8.	483512	6359619	557	*Cordia rudis, Scutia myrtina, Maytenus heterophylla, Maytenus capitata*	Shrub
9.	482901	6360665	545	*Aloe, Scutia myrtina, Maytenus heterophylla, Acacia, Karroo*	Open mixed bush
9.	482018	6363337	558	*Euphorbia triangularis, Scutia myrtina, Acacia Karroo, Maytenus heterophylla, Opuntia*	Open mixed bush
9.	481133	6362760	541	*Aloe, Scutia myrtina, Maytenus heterophylla, Acacia, Karroo*	Sparse mixed bush
10.	479777	6359456	557	Residential area	Built-up area
10.	483093	6358258	505	Residential area	Built-up area
10.	477313	6361747	477	Residential area	Built-up area

Appendix (IIIa): Extents of LULC type in Honeydale: 1984-2014

Land cover types	Area (hectares/year)			
	1984	**1995**	**2004**	**2014**
Water	0.99	1.26	0.81	0.45
Open grassland	268.17	229.84	62.22	126.14
Acacia Karroo	0	0	20.92	138.33
Overgrazed grassland	7.03	22.45	13.53	13.99
Mixed bush	72.86	119.75	154.10	198.77
Shrub	243.00	218.30	322.72	114.57
Bare ground	59.06	59.51	76.82	51.10
Unclassified	0	0	0	7.78
Total	651.12	651.12	651.12	651.12

Appendix (IIIb): Extents of LULC types in Thyume: 1984-2014

Land use/ land cover type	**Area (hectares/year)**			
	1984	**1995**	**2004**	**2014**
Water	4.24	6.85	4.42	1.51
Open grassland	633.44	690.61	402.52	293.24
Bare ground	420.91	261.22	411.18	127.36
Shrub	669.24	832.00	807.92	768.09
Mixed bush	94.68	148.06	198.37	622.62
Acacia Karroo	0	117.22	236.34	346.13
Arable land	424.52	184.04	178.63	49.70
Built up area	207.66	213.70	215.33	232.22
Unclassified	0	0	0	13.83
Total	2454.70	2454.70	2454.70	2454.70

Appendix (IIIc): Extents of LULC types in Sheshegu: 1984-2014

Land use/ land cover type	**Area (hectares/year)**			
	1984	**1995**	**2004**	**2014**
Water	6.40	25.51	13.79	3.60
Open grassland	1860.66	1372.75	1189.16	222.78
Bare ground	324.61	292.69	332.54	287.37
Shrub	624.51	1132.8	993.40	1562.59
Mixed bush	170.87	221.81	251.21	310.18
Acacia Karroo	0	167.44	424.07	788.71
Arable land	225.96	0	8.83	0
Built up area	238.59	238.59	238.59	262.19
Unclassified	0	0	0	14.18
Total	3451.62	3451.62	3451.62	3451.62