AN ASSESSMENT OF VEGETATION CONDITION OF SMALL, EPHEMERAL WETLAND ECOSYSTEMS IN A CONSERVED AND NON-CONSERVED AREA OF THE NELSON MANDELA BAY METROPOLE

By

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DECLARATION

I, Mandla Evidence Dlamini (s212466593) hereby declare that this dissertation titled ***"An assessment of vegetation condition of small, ephemeral wetland ecosystems in a conserved and non-conserved area the Nelson Mandela Bay Metropole***" represents the original work of the author and has not previously been submitted for any qualification to another university. Any work taken from other authors or organizations is acknowledged within the text and references list.

Signature …………………. Date……………………

Mandla Dlamini

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ABSTRACT

Wetlands in South Africa are increasingly coming under threat from agriculture and urban development and rapidly disappearing, especially small, ephemeral wetlands. In response to the many threats to wetlands, South Africa has seen an increased interest in wetland research, which has introduced many methods to help standardize the approach to research, management and conservation of wetlands. Remote sensing can be a powerful tool to monitor changes in wetland vegetation and degradation leading to losses in wetlands. However, research into wetland ecosystems has focused on large systems (> 8 ha). Small wetlands (< 2 ha), by contrast, are often overlooked and unprotected due to the lack of detailed inventories at a scale that is appropriate for their inclusion. The main aim of this study was to determine if remote sensing (RS) and Geographical Information System (GIS) techniques could detect changes in small, ephemeral wetlands within areas under different management regimes in the Nelson Mandela Bay Metropole (NMBM) at different time intervals. Further, to explore the potential of hyperspectral remote sensing for the discrimination between plant species and to see if differences could be detected in the same species within two areas different management regimes.

Four SPOT satellite images taken within a 6-year period (2006-2012) were analysed to detect land cover land changes. Supervised classification to classify land cover classes and post-classification change detection was used. Proportions of dense vegetation were higher in the conservation area and bare surface was higher outside that conservation area in the metropolitan open space area.

Statistical tests were performed to compare the spectral responses of the four individual wetland sites using Normalized Difference Vegetation Index (NDVI) and red edge position (REP) .REP results for conserved sites showed significant differences ($P < 0.05$), as opposed to non-conserved ones. By implication, wetland vegetation that is in less degraded condition can be spectrally discriminated, than the one that is most degraded. Field spectroscopy and multi-temporal imagery can be useful in studying small wetlands

Key words: wetlands, remote sensing, vegetation condition, red edge position, normalized difference vegetation index

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CFR	Cape Floristic Region
CSIR	Council for Scientific and Industrial Research
DWAF	Department of Water and Forestry
ERTS	Earth Resources Technology Satellite
GCC	Global Climate Change
GIS	Geographical Information System
GPS	Geographical Positioning System
HGM	Hydrogeomorphic
HRV	High Resolution Visible
ISODATA	Iterative Self organising Data
KIA	Kappa Index Agreement
LAI	Leaf Area Index
Landsat ETM	Landsat Enhances Thematic Mapper
Landsat MSS	Landsat Multispectral Scanner
Landsat TM	Landsat Thematic Mapper
Lin-Inter	Linear Interpolation
MIR	Mid- Infrared
MLC	Maximum Likelihood Classifier
MMC	Migrating Means Clustering Classifier
NCWS	National Wetland Classification System
NDVI	Normalized Difference Vegetation Index
NIR	Near- Infrared
NMBM	Nelson Mandela Bay Metropole
NMMOSS	Nelson Mandela Metropolitan Open Space Systems
PCC	Post Classification Comparison
PSR	Portable Spectroradiometer
R	Red
REP	Red Edge Position
RS	Remote Sensing
SANBI	South African National Biodiversity Institute
SANSA	South African National Agency
SPOT	System Pour I' de la Terre
SSE	Sum of the Square Error
SWI	Short Wave Infrared
Tukey HSD	Tukey Honest Significance Different
VI	Vegetation Indices

CHAPTER 1: INTRODUCTION

1.1 Background

Wetlands are not easily defined due to their variability and broad diversity; hence, many definitions have been developed both nationally and internationally. The Classification System (Ollis *et al*., 2013, page 6) defines wetlands as *"areas of marsh, peatland or water whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt including areas of marine water with the depth of which at low tides does not exceed ten metres*". The legislated definition of wetlands in South Africa under the National Water Act 36 of 1998 was taken from Cowardin *et al*., (1979) in the United States. They define wetlands as *"lands transitional between terrestrial and aquatic ecosystems and the water table is usually at or near the surface or the land is periodically covered with shallow water whereby under normal circumstances supports or would support vegetation adapted to life in saturated soils*."

South African wetlands are one of the most threatened and under-managed habitat types (Assessment, 2005). Several studies have revealed that over 50% of South African wetland ecosystems have been destroyed (Barbier 1993; Kotze and Breen 1994; Kotze *et al.*, 1995; Organization for Economic Co-operation Development (OECD) 1996; Lindley 2003). Threats such as dam construction, agriculture, water abstraction, drainage, invasion of alien species and pollution all threaten and degrade our sensitive wetland ecosystems (Kotze and Breen, 1994; Lindley, 1998; Lindley, 2003). Dam construction and water abstraction alter and modify wetlands, which can reduce water level and change hydrological cycles (e.g. perennial wetlands could become seasonal to intermittent). This in turn can force changes in vegetation species composition, distribution patterns, and condition (Dugan, 1993). According to World Wildlife Fund (WWF), 2004; Breen and Begg, 1989, dams and water abstraction reduce the amount of available water necessary to support wetlands and river ecosystems. South Africa is a water scarce country receiving an average of less than 500 mm of rainfall per year (WWF, 2004 and Breen and Begg, 1989). Invasion of alien species can also threaten wetland ecosystems by the uptake of considerably more water than indigenous plants, which then modifies the hydrological cycle and changes the character of the wetland (Kotze *et al*., 1995). Concerns about changes in the size and quality of many of the world's wetland systems have been growing, as more wetlands are being converted into agricultural land or for urban use and affected by natural factors such as climate change (Munyati, 2000). Climate change is expected to exacerbate the loss and degradation of many wetland ecosystems (Assessment, 2005). Increasing temperatures can affect the relationship between rainfall and flows to surface and groundwater (IPCC, 2007). This changes flow regimes of rivers and wetlands (Palmer *et al*., 2008). The loss and degradation of wetland ecosystems reduces their ability to provide ecosystem services to communities and to support biodiversity (Moser *et al*., 1996). A number of authors and organisations have outlined these services (Costanza *et al*., 1989; Hammer and Bastian 1989; Finlayson and Moser 1991; Richardson 1994; Emerton, 1999; Mitsch and Gosselink, 2000; RAMSAR, 2002; Appleton, 2003; Assessment, 2005; Zedler and Kercher 2005; Brauman *et al*., 2007; Mbereko et al., 2007; Kotze *et al*., 2008 and Working for Wetlands, 2008). The importance of wetlands is due to the fact that they occupy a transition zone between purely aquatic and terrestrial ecosystems (Mwita *et al*., 2013). The aquatic and terrestrial zone of a wetland provides food and shelter to animals adapted on wetlands (Richardson, 1994, Zedler and Kercher, 2005, Working for Wetlands, 2008). In many parts of the world, wetlands are used as sites for tourism and recreation for example bird watching (Assessment, 2005, Zedler and Kercher, 2005 and Working for Wetlands, 2008). Wetlands are also used as valuable lands for cultivators and pastoralists providing a source of arable land for grazing (Emerton *et al*., 1999; Mitsch and Gosselink, 2000; Assessment, 2005; Zedler and Kercher, 2005; Mbereko *et al*., 2007; Working for wetlands 2008). Wetlands provide areas for consumptive uses, which includes production of fish for human, support great diversity of plant species used for traditional crafts across many rural areas (Mitsch and Gosselink 2000; Assessment 2005; Working for Wetlands 2008). In addition, wetlands can act as natural filters that help to purify water by trapping pollutants improving water quality, recedes floods and recharge aquifers (Hammer and Bastian, 1989; Finlayson and Moser, 1991; RAMSAR, 2002; Appleton, 2003).

In order to conserve and manage wetland systems, it is important to monitor changes that have occurred over time. Remote sensing (RS) has been used to monitor different attributes including changes in land cover of large wetland systems. Therefore, the aim of this study was to determine if RS and Geographical Information Systems (GIS) techniques are effective and applicable to monitor small, ephemeral wetlands and to subsequently use these techniques to detect changes in vegetation cover of four wetland ecosystems exposed to two different management systems over a specific period.

1.2 Problem Statement

The use of Geographical Information Systems (GIS) and remote sensing (RS) techniques for delineating different habitats/areas, detecting or predicting changes in those habitats and long-term monitoring has increased over the years (Morain 1991, Munyati 2000, Ozesmi and Bauer 2002). A majority of research studies in wetlands have been done on large systems (Rebelo *et al*., 2009; Mwita, 2010) predominantly in the Western Cape and KwaZulu Natal, however, it has been lacking in the Eastern Cape (Malan 2010). The focus of this study was to use GIS and RS in the delineation, detection and classification of small (<2 ha), ephemeral wetland systems in the Hopewell Conservancy (conserved) and Nelson Mandela Metropolitan open space systems (under-managed), and determine the viability of these techniques for broad-scale use, given relatively small habitat boundaries. Public open spaces are more susceptible to human induced pressures and more difficult to manage and monitor than private and publicly held conservation areas. In public open space, for instance there is a tendency for over grazing leading to degradation and over trampling. In comparison, conserved areas when, well managed tend to have much less pressure in terms of land use practises, hence retaining healthier ecosystem function. In this study, multi-temporal imagery was used to assess the wetland vegetation condition in conserved and non-conserved areas over a specific period, 2006 to 2012. Multi-temporal imagery has been widely used to monitor vegetation, but unfortunately, it has limited capability for accurate identification of vegetation species (Schmidt and Skidmore, 2003). Therefore, this study also investigated the potential of hyperspectral remote sensing (using field spectrometry) for vegetation species discrimination at field level within the differently managed areas of the NMBM.

1.3 Research aim and objectives

Aim: To discriminate general vegetation condition and dominant plant species of small, ephemeral wetlands in a conserved and non-conserved area of the NMBM using multi-temporal imagery and field spectroscopy.

Specific Objectives

- To compare wetland vegetation condition within conserved and non- conserved areas.
- To assess the temporal and spatial changes in wetland vegetation condition.
- To determine the spectral characteristics of the dominant wetland vegetation species using field spectroscopy.

1.4 Research questions

The Hopewell Conservancy adjacent to the Nelson Mandela Metropolitan Open Space Systems (NM MOSS) was used for farming purposes before and then it was fenced in 2009. Within the NM MOSS outside Hopewell, there are no activities currently evident other than cattle grazing by local subsistence farmers. Grazing practises are not directly managed or monitored due to budgetary and capacity constraints within the environmental section of the municipality (pers. Comm.). Within the Hopewell Conservancy there is managed grazing of wild game and cattle. Against this background, the following research questions were posed:

- What are the differences in vegetation condition in the conserved and non-conserved wetland areas?
- What are the spatial and temporal changes and differences in vegetation condition in the managed and under-managed wetland areas?
- How different are the vegetation spectral signatures between wetland areas subject to different management regimes?

1.5 Thesis outline

Chapter 1*: General background, introduction, and study area*

In chapter 1, the background, aim, objectives and research problem of the study are introduced where the research questions are posed.

Chapter 2*: Description of the study area*

This chapter presents background to the study area. Information on the geographical location, climate, geology, soils, surface and groundwater as well as vegetation are described.

Chapter 3*: Theoretical background*

This chapter deals with the definitions, types of wetlands, and their landscape settings in a South African context. This information is reviewed and explained. Ecosystem services that wetlands provide are discussed along with the importance of wetlands in the context of anthropogenic activities and climate change. This chapter also examines the use of remote sensing techniques (e.g. multispectral and hyperspectral) and GIS in assessing wetland vegetation.

Chapter 4*: Methodology*

This chapter provides information on the methods and materials used to achieve the aim and objectives of the study (see Chapter 1). Wetland delineation and identification, image acquisition and rectification, image classification, change detection, NDVI, accuracy assessment and field data collection are described. Statistical analyses and justification of which methods were chosen are discussed.

Chapter 5*: Results*

This chapter explains the results of the analyses performed on the data obtained from this research study. These results are presented in various formats including tables, graphs and maps describing the differences in vegetation condition of wetland systems between two areas of different management regimes.

Chapter 6*: Discussion and recommendations*

Discussion of results, recommendations for future research and conclusion of the overall research project are provided.

CHAPTER 2: THEORETICAL BACKGROUND

2.1 Introduction

Assessing the land cover changes that have occurred over time in wetland ecosystem require investigation and understanding of various concepts. As this is a multidisciplinary topic, both the general importance of wetlands and the use of RS and GIS tools to detect, assess and monitor wetlands will be reviewed. The study of wetlands is multifaceted and cross disciplinary involving, ecology, hydrology, geology and geography in the broadest sense. Remote sensing and GIS techniques are a complex set of tools that use maps, satellite images and specialized computer programs and algorithms in order to detect changes in various variables in terrestrial and aquatic systems (Klemas, 2009).

Wetlands are important and sensitive ecosystems, and the effects of anthropogenic activities can be detrimental (Frenken, 2005). In response to the need to protect South Africa's wetlands, government departments including Department of Environmental Affairs (DEA) and Department of Water and Sanitation (DWS) launched the Working for Wetlands programme (SANBI, 2007). The programme focuses mainly on protection, rehabilitation and sustainable use of wetlands. One of the activities of the programme was to eradicate invasive plants and to raise awareness of wetlands among workers, landowners and public (SANBI, 2007). The Working for Wetlands programme targeted 91 South African wetlands for rehabilitation in 2007 and 2008, employing nearly 2000 previously disadvantaged individuals.

Wetland ecosystems have shown to be important in terms of ecology, ecosystem services, hydrology, biogeochemistry and habitat. However, there has been a lot of literature that has shown that wetlands are increasingly under threat from anthropogenic impacts (Barbier 1993, Kotze and Breen 1994, Kotze *et al*., 1995, IPCC, 1996; OECD 1996; Sahagian and Melack, 1998, Patterson, 1999; Lindley, 2003; Christensen *et al*., 2007). There has been an effort put into place in identifying, understanding and managing wetlands (Ewart-Smith *et al*., 2006; Ollis *et al*., 2013). Further research into how they can function ecologically and in providing a variety of ecosystem services has been done (Macfarlane *et al*., 2007; Ellery *et al*., 2009).

Traditional methods and techniques of monitoring wetlands involve going out into the field and collecting data, which is important in building knowledge of the biodiversity and functioning of these systems. However, because of a large number of wetlands it is not possible to visit each within a limited time (Schael *et al*., In Press).Other tools, methods and techniques such as RS and GIS are required to adequately monitor, manage and study wetland ecosystems. Pairing direct field knowledge of wetland systems with RS/GIS tools and techniques can expand our ability to identify, delineate and monitor the health of these systems and preserve their integrity, therefore their provision of ecosystem services.

2.2 Types of wetlands

The Ramsar Convention classifies wetland types into three main categories (Kabii, 1998). Coastal, Estuarine and Inland wetlands. Each wetland type has features and functions unique to their type and place within the landscape. Similarly, South African wetlands have been classified into three main categories: marine, estuarine and inland wetlands. The Classification System by Ollis *et al* (2013) for South African wetlands uses levels that help to define and differentiate wetland types (Table 2.1).

Table 2.1: Six levels for differentiating South African wetlands (adapted from SANBI, 2009 and Ollis *et al.,* 2013).

Level	Description
Level 1	In this level, a distinction is made between Marine, Estuarine and Inland systems using the level of connectivity to the sea.
Level 2	This deals with a combination of biophysical attributes within landscapes that operate at abroad scale rather than specific attributes such as soil or vegetation.
Level 3	No subsystems are recognised for Marine systems, but Estuarine systems are grouped to their periodicity of connection to the ocean because such processes directly affect wetland's biotic characteristics. In terms of inland systems, a distinction is made between four landscapes units on basis of the broad scale topographic position within which a wetland is situated.
Level 4	The system classifies the hydrogeomorphic (HGM) units, which are landform, hydrological and hydrodynamics characteristics.
Level 5	At this level tidal regime is considered for Marine and Estuarine systems, while hydrological regime and inundation depth is considered for Inland systems.
Level 6	This level requires fieldwork/ surveys to characterise wetland types whereby six descriptors are being considered, but depending on the availability of the information. These are geology, natural versus artificial, vegetation cover type, substratum, salinity and alkalinity/acidity.

The focus of this study is on inland wetland systems, which are defined as aquatic ecosystem with no existing connection to the ocean (Ollis *et al*., 2013). Inland wetlands can be placed into hierarchical classification structure presented in Table 2.1 from level 1 to 4 using desktop methods such GIS where it can provide a clear picture of the extent, distribution and diversity of these wetlands. Classification structure can be further extended to level 5 and 6 which require site visits/ fieldwork. Fieldwork is important for ground referencing but can be expensive and time consuming. Remote sensing could be used to systematically and frequently acquire information for large features and maintains permanent record at the time of acquisition (National Academy of Sciences, NAS, 1997). This helps in determining the status and trends on how wetlands have changed therefore the need and effectiveness of wetland conservation strategies.

2.3 Functioning of wetland systems

Most wetland ecosystems fall within three categories of primary functioning: hydrological, biogeochemical and habitat (Finlayson and van de Valk 1995a; Rogers 1995; Mulamoottil *et al*., 1996; Shine and de Klemm, 1999; United States Environmental Protection Agency, 2002a; Clarkson *et al*., 2003). Hydrological functions include water storage for both long and short term, and maintenance of water tables (Barbier, 1993). Such activities reduce the amplitude of flooding peaks, maintain base flow rates by buffering flow distributions and maintain the hydrophilic community and habitat (Dunne *et al*., 1998). Biogeochemical functions include the transformation and cycling of mineral elements, retention and removal of dissolved substances from surface waters and accumulation of organic and inorganic peats (Jansson *et al*., 1998). Wetlands can act as buffering systems whereby they can weaken flood effects by prolonging water flow and retarding runoff during times of peak flow (Kotze, 2010).

The habitat function includes the provisioning of food and the place of stay for waterfowl and other animals depended on wetlands (Sahagian and Melack, 1996; Smith, 2003; Ramsar Convention Bureau, 2008).

2.4 Ecosystem services and their importance in South Africa

A number of authors referred to Chapter 1, Section 1.1 have identified ecosystem services that wetlands provide (Costanza et al., 1989, Richardson, 1994; Barbier *et al*., 1997; Mitsch and Gosselink, 2000; Assessment, 2005; Zedler and Kercher, 2005; Kotze *et al*., 2008 and Working for Wetlands, 2008). For instance, in South Africa many peri-urban and informal rural communities have no access to reticulated sanitation and clean water, wetland systems can improve water quality (De Steven and Toner, 2004). Wetlands can act as natural filters to help purify water by trapping pollutants such as suspended sediment, excess nutrients (nitrogen and phosphorus), toxicants e.g. pesticides and excess heavy metals, pathogenic bacteria and viruses (Mitsch and Gosselink 1986), therefore, they can supply clean water essential for human health (Daily, 1997; Kotze 2000; De Steven and Toner, 2004). Some wetlands can act like sponges storing water during the rainy season and then slowly releasing it during dry season to provide continuous flow into rivers (Mitsch and Gosselink, 2000).

Other benefits include food, subsistence agriculture, traditional crafts, cultural significance and recreational uses. Wetlands can be a food source, such as the harvesting of fish for subsistence and commercial use (Kyler, 1991). In Kosi Bay 40 Tonnes of fish is caught for family consumption with the surplus being sold at local markets (WESSA, 2003b). Wetlands, especially temporarily and seasonally waterlogged areas may provide very valuable grazing lands for domestic animals and wild life. Some wetland plants, particularly sedges, are used to make traditional sleeping mats in many rural areas (Wildlife and Environment Society of South Africa, WESSA, 2003b). In KwaZulu Natal, sleeping mats (amacansi in isiZulu) are one of the customary gifts that the bride gives to the groom's family during the wedding. Wetlands are recognised as having a cultural significance for different population groups, for example, they can act as places for baptisms and for cleansing ceremonies (WESSA, 2003b). Wetland ecosystems can provide opportunities for recreation, and have aesthetic experience/value (Pennington, 2010, Barbier *et al*., 1995). Examples of recreational activities in wetlands are fishing, sport hunting, bird watching, and photography and water sports important for tourism. Tourism is one of the leading income generating industries globally (Vendana and Surabhi, 2011). It is important to protect and use wetlands in a sustainable manner because further destruction will threaten any ecosystem services that they can provide. Further destruction will threaten cultural wealth of the country; considering also that tourism is a cultural aspect of wetlands that can boost local economies (WESSA, 2003b).

One of the ecosystem services highlighted in the previous section is the importance of wetlands in improving water quality and of acting as a natural reservoir to store water, releases it later during dry seasons and to keep rivers flowing (Daily, 1997; Kotze, 2000; De Steven and Toner, 2004). The Eastern Cape, for example, is the poorest province, with a higher unemployment rate than the national average and a large rural population (Municipal Demarcation board, 2006).Consequently, many people in rural settings who are usually without water and sanitation services rely on natural resources including direct use of water from wetlands and streams for consumption and domestic use. According to the Council for Scientific and Industrial Research (CSIR) (2004), 50% of the households in the Eastern Cape did not have access to treated water and 66% of them did not have sewage treatment facilities.

2.5 Effects of anthropogenic activities on wetland ecosystems

Even though wetlands have been demonstrated to be important for their provision of ecosystem services, they are being degraded. Degradation of wetlands by these activities can result in reduced provision of ecosystem services that wetlands provide (Kotze and Breen 1994). As highlighted earlier, an estimated 50% of South African wetland ecosystems have been destroyed (Barbier 1993, Kotze *et al*., 1995, Kotze and Breen, 1994; Lindley, 2003; OECD, 1996). Most of the wetland ecosystems have been lost through anthropogenic activities such as water abstraction, agricultural practices and pollution (Frenken, 2005). Dams and water abstraction can reduce the amount of water available to support wetlands and river systems, which alter water flowing downstream (Davies and Day, 1998). Farming practices which take a lot of water for irrigation purposes can cause changes in the catchment soil and vegetation conditions, and this can lead to the disturbance of how precipitation is routed to wetland catchments, thus leading to wetland water budget or cycle being interrupted (Voldseth *et al*., 2007). Grazing and trampling of wetlands plants by cattle is a particularly important disturbance factor that can encourage biological diversity (White, 1979; Sousa, 1984; Hobbs and Huenneke, 1992), however, it should be minimal and managed. A study by Marty (2005) in California (USA) in ephemeral pool grasslands indicated that when cattle are moved to grazed grasslands, diversity declines and non-native species abundance increases. Another disadvantage is that, if grazing is not managed correctly since it can negatively affect some biodiversity in some ecosystems (Milchumas and Lauenroth, 1993; Perevolotsky and Seligman, 1998), since plants can be uprooted during grazing (Braack and Walters, 2003), diminish overall ground cover and lead to soil erosion (Middleton *et al*., 2006). The advantage of cattle grazing is that it maybe particularly effective at reducing grass cover because cattle selectively forage on grasses (Kie and Boroski, 1996) and help maintain a more open canopy (Weiss 1999). Some species require short, open grasslands (ten Hurkel and van der Muelan, 1995) for example some imperilled butterfly like *Pyronia tithonus*, *Coenonympha pamphulus*, *Ochlodes venata* and *Aphantopus hyperantus* species require sheep and rabbit grazing to maintain suitably short grasses (Oates, 1995). In addition to dam and water abstraction and agricultural practices, wetlands are impacted by the impoundment and water transfer schemes which alter the flow regime of wetlands therefore reduce amount of water to support wetland and river ecosystems.

(Department of Water Affairs, 1986). Discharge of wastes and irrigation return flows from agriculture cause pollution to wetlands through sanilisation and eutrophication (Department of Water Affairs, 1986). Invasion of alien species is also one of the effects with negative impacts on wetlands (Vitousek *et al*., 1996; OTA, 1993). Alien species tend to use more water through transpiration than the indigenous plants and this can lead to a reduction in the natural flow of streams, therefore changing the character of wetlands (Meffe and Carroll, 1996).

It is of importance to mitigate the effects of anthropogenic activities which can improve the resiliency of wetland ecosystems in order to continue providing crucial ecosystem services under changed climatic conditions (Ferrati *et al*., 2005; Kusler *et al*., 1999). Natural events may exacerbate the losses of wetland ecosystems, therefore it is highly important that people recognise the significance of these systems because of the ecosystem services they provide (Scholes and Biggs 2004; Assessment, 2005). Measures need to be put in place to mitigate, ameliorate and rehabilitate the anthropogenic activities effects on wetlands so that they can continue function and provide their ecosystem services.

2.6 Effect of climate change on wetland ecosystems

Wetlands especially temporary ones can be affected by climate change, whereby they are most at risk in an enhanced drought due to increasing temperatures and altered rainfall patterns. This changes their structure and functioning, therefore the goods and services they provide to humans (Christensen *et al*.,2007). An increase in water could destabilise the system as some fauna and flora need specific water temperatures (Poff *et al.*, 2002). Migration of species will also be affected since waterways connecting wetlands will also be lost due to warming (Mitsch *et al*., 2009). Another effect of climate change is the exacerbation of global warming by degradation, removal of wetlands because of their role in the water cycle and their ability to store carbon (Sahagian and Melack, 1998; Patterson, 1999; IPCC, 1996). Carbon storage would be lost, as well as the carbon stored up in the wetlands would be released. Globally, wetlands cover 4-5% of the Earth's land area; they hold approximately 20% of the land's carbon (Roulet, 2000). According to Clair *et al*., (1997), wetland responses to climate are still poorly understood and are not included in global models of the effects of climate change. Therefore those that still exist, it is uncertain if they will continue to function as hydrological buffers during extreme events or providing other vital ecological, social and economic services.

2.7 Use of Remote Sensing and GIS in Wetland Studies

Remote sensing (RS) is the collection and interpretation of information about the earth's surface without being in physical contact with it (Congalton and Green, 1999). RS techniques include data imagery acquisition, interpretation, classification and accuracy assessment and groundtruthing. RS techniques can be integrated with GIS during image processing, interpretation and data analysis. GIS is useful for editing of imagery, for example geo-referencing, cross tabulation, merging and combining of different data formats. Geographical Information system (GIS) is thus defined as a computer system for capturing, storing, querying, analysing and displaying geospatial data (Chang, 2006).

Due to the numerous threats to wetland ecosystems, knowledge of the locations, characteristics and changes of the wetland plants and animals must be available to establish the protection and management policies. GIS and Remote Sensing is becoming an important tool for natural resource research and management. GIS and RS technologies have been shown to be useful in the assessment of changes in vegetation (Woodwell *et al*., 1984; Marble 1984; Iverson and Perry 1985). Data acquired by satellite sensors have become available and have been used in many environmental studies (Haack, 1982; Pillay, 2001; Ozesmi and Bauer, 2002; Adam *et al*., 2010). One of the advantages of remote sensing is that it systematically and frequently acquires information for areas that are difficult to access, and also provides a synoptic view of large features for many images and maintains a permanent record at the time of acquisition (NAS, 1997; Paul and Mascarenhas, 1981). Remote sensing and GIS are useful and valuable tools for use in developing countries to provide current and reliable information (Morain, 1991) as well as for studying the nature of wetlands and the potential of their restoration (Gottgens *et al*., 1998). In order to analyse the dynamic geographical phenomenon related to wetlands, it is important to take into account their changes in space and time whereby multi-imagery can be used (Jensen *et al.*,1996). Historically, aerial photography was the first remote sensing technique to be used for mapping wetland vegetation; however it is not feasible for monitoring wetland vegetation on a regional scale because it's costly, time consuming and it can only determine the vegetation extent, not health or species diversity (Ozesmi and Bauer, 2002, Adam *et al*., 2010). Remotely sensed images from multispectral and hyperspectral sensors are now currently used for mapping wetland vegetation at different levels by a range of airborne and space borne sensors (Adam *et al*., 2010). Satellite data is in a digital format and relatively easy to integrate into a geographic information system. Multispectral remote sensing can be used to monitor changes in vegetation cover, shoreline changes, watershed land cover and wetland losses and degradation (Klemas, 2001). A number of studies on the assessment of wetland vegetation and its spatial distribution were done using multispectral data such as Landsat TM (Harvey and Hill, 2001). Multispectral data can be used to monitor vegetation status, but with a limited capability for accurate identification of vegetation species (Harvey and Hill, 2001; McCarthy *et al*., 2005). Among other limitations is that it is difficult to distinguish between certain vegetation species and the lack of high spectral and spatial resolution of optical multispectral imagery, which limits the detection and mapping of vegetation types (Basham May *et al*., 1997; Harvey and Hill, 2001; Ringrose *et al*., 2003, and McCarthy *et al*., 2005). However, there is a growing interest in using hyperspectral data to map and discriminate wetland vegetation at species level (Schmidt and Skidmore, 2003). Multispectral remote sensing, however, cannot detect plant and animal species or water quality properties. Therefore, a different tool needs to be used to acquire more detailed and specific information. Hyperspectral remote sensing can be used to discriminate and map wetland vegetation at species level once sensors are field calibrated for specific species (Schmidt and Skidmore, 2003).

Satellite remote sensing is appropriate in inventorying and monitoring land use changes of wetland ecosystems and it can provide information on surrounding land uses and their changes over time (Ozesmi and Bauer, 2002). Many studies have been conducted to detect land cover changes using remote sensing and GIS tools. One such example is the study by Ngcofe (2009) for the assessment of nature and extent of land degradation in Wit-Kei catchment at Qoqodala in the Eastern Cape. RS and GIS techniques together with household interviews were used in determining the extent, spatial characteristics and nature of land degradation within the study area. Vegetation cover and bare ground change were the land degradation indicators assessed and monitored in the study. Landsat images for years, 1984, 1993, 1996, 2000 and 2002 were analysed where Tasselled Cap Analysis and Unsupervised ISODATA classification technique were used. The study showed an increase in degradation of vegetation cover and increase of bare ground. Analyses of slope showed the spatial characteristics of bare ground occurring on moderate to flat slopes while vegetation occurs on steep to very high steep slopes. Photographs captured during field visits showed rills and gullies occurring on bare ground. The interviewed respondents indicated that the decline in food production, increase in dongas, vast increase in *Euryops* and a decline in grassland were the indicators of degradation. GIS and RS techniques showed to have positive correlation with field and household surveys toward establishing the nature of land degradation. In the overall study, Landsat images proved to be useful for land degradation, however higher spatial resolution satellite images on small catchment was highly recommended by the author.

An assessment of potential wetland decline in the Western Cape was done using classification of Landsat TM and ETM multispectral images and GIS supported software, Idrisi 32 (Bayasgalan, 2008). Idrisi 32 was used to classify, delineate and determine wetlands in the region that is approximately 7000 km^2 for the years 1987, 1990, 2001, 2002. Three supervised image classification methods were used and accuracy assessment was done which showed an overall accuracy of 99.8% to 99.9%. The classified images were analysed for the number, size, occurrence, amount of permanent and temporary wetlands and the distances between wetlands in different seasons. The main objectives of the study were to characterise temporary and permanent wetlands and to assess their potential loss over the period of 19 years. The number of wetlands that could be identified varied within years and seasons; during winter there were 4136 wetlands identified in June 2002, 1819 wetlands in October 1990, 504 wetlands in January 1987 and 878 wetlands in February 2001. Both temporary and permanent wetlands were detected, but a relatively high number of permanent wetlands were detected as compared to small, temporary ones since it is not easy to detect them during dry periods. Therefore, the results showed an increased in the number of wetlands during winter and decrease during in summer. The mean distance between wetlands varied with greater distances in summer and shorter in winter. The study conducted by Bayasgalan (2008) concluded that remote sensing techniques could be useful tools in characterizing wetlands; however, the decline of wetlands in the Western Cape should be investigated using higher resolution images to accommodate small wetlands. Loss of these systems was determined to be caused agriculture and urban development. These activities drained, degraded and destroyed wetland systems which resulted in increased flooding risk, water scarcity and loss of ecological diversity and functioning of the wetlands. A study by Pillay (2001) investigated mapping wetlands using satellite imagery in the Midmar sub catchment of KwaZulu Natal. The aim of the investigation was to develop a methodology for the accurate and efficient delineation of wetland areas using satellite imagery. Summer and winter Landsat ETM+ satellite covering Midmar catchment were processed using various image classification techniques. Different classification techniques had different classification accuracies when compared to verified wetland dataset. The inaccuracies were attributed to a change in land cover since there was an overall loss of wetland areas. The study concluded that Landsat ETM+ satellite imagery was useful for detecting wetland areas during summer (Pillay, 2001).

Investigation of human and beaver induced wetland changes between 1953 and 1994 in the Chickahominy River, USA was done by Syphard and Garcis (2001) using remote sensing techniques. Anthropogenic activities have contributed directly to the loss of wetlands, mostly due to agriculture and urban land uses. Altered wetland hydrology and change in a landscape scale was indirectly impacted by urbanisation. A raster geographical information system was used to analyse the combined effects of the humans and beavers on wetland types and area in the river. Their results showed that, the majority of wetland loss was attributed to the construction of two large water supply reservoirs on the river and remaining loss of wetlands was due to urbanisation. About 23% of the wetland change was caused by beaver activity and 90% of the change in wetlands from 1953 to 1994 was due to the shifting between palustrine farmed wetlands and lacustrine littoral unconsolidated shore.

Detecting changes in a wetland, using multispectral and temporal Landsat in the Upper Noun Valley catchment in Cameroon by Ndzeidze (2008) is yet another study that demonstrates the utilization of RS and GIS techniques to determine the extent of change of the wetland area. The objective of this study was to use remote sensing and GIS technology to determine the extent of change of the wetland area and other land use and land cover classes in the upper catchment from 1973 to 2007. The Upper Noun catchment is an important wetland that lies within the western plateau of Cameroon where it supports wide range of wildlife. Four land cover classes were defined: wetland area, agropastoral landscape, montane forest and settlement. Data analysis revealed a considerable change in wetland area. The reservoir showed evidence of large fluctuations in the area since the construction of a dam in 1975. Within the reservoir area, acute siltation was also observed since 1988. Irrigated farmland showed downward trends from 1988 to 2002. Grazing areas showed a general drop while the mixed farming area increased from 1978 to 2002. The montane forest also decreased; however it recovered because of the successful implementation of the community forest management project. Settlement within the catchment expanded in an area because of a rapid transformation of most enclosures and open fields to larger villages and major settlements. The study thus demonstrated the use of RS and GIS to monitor human impacts within and around the Upper Noun catchment.

A final example of the use of RS in detecting changes in wetlands is from the Kafue Flats in Zambia (Munyati, 2000). A RS approach was used to assess change on the section of Kafue Flats floodplain wetland system which was under stress from reduced rainfall, damming and water abstraction by humans. During the dry seasons, when rainfall is normally low, the Kafue River is the primary source of water and agricultural practises. Water abstraction for sugar cane irrigation has placed adverse pressure on the functioning of the Kafue Flats wetland ecosystem (Munyati, 1997). Four images between 1984 and 1994 using Landsat Thematic Mapper (TM) were used. The images were analysed for change in each land cover category i.e. open water, sparse green vegetation and very sparse green vegetation. The results indicated spatial reduction in area of dense green vegetation in the upstream section of the wetland. RS techniques employed appeared to be applicable in monitoring southern Africa's inland wetland systems.

It is important to have a clear indication of the status of sensitive wetland ecosystems in order to conserve them. Multispectral remote sensing has shown great success in mapping the extent wetland vegetation, however it is difficult to analyse health or type vegetation because of its' spectral resolution. More research is therefore required to improve accuracy of mapping wetland vegetation at species level by using hyperspectral data.

2.8 Imagery

The basis of RS and GIS is the use of various types of imagery (aerial photos, maps, satellites, etc.) for data capture and analysis. Different types of visible and infrared satellite sensors are commonly used in wetland identification and classification. For the purpose of this study, System Pour I' Observation de la Terre (SPOT) and Landsat Thematic Mapper (TM) are outlined in Tables 2.2 and 2.3 respectively.

SPOT was first launched by the French government in 1986. SPOT 2 was launched in 1990, SPOT 3 in 1993 and SPOT 4 and SPOT 5 in 1998 and 2002 which has a middle infrared band in addition to other bands (Lillesand and Kiefer, 2004). SPOT was the first earth resource satellite to have a pointable optics which increases the opportunity for imaging an area. SPOT has a stereoscopic imaging capability as well (Jensen, 2005). High Resolution Visible (HRV) found on SPOT has green, red and near infrared spectral bands with 20 m spatial resolution.

Landsat Thematic Mapper (TM) was first launched in 1982 with improved spectral, radiometric, temporal and spatial resolution over Landsat Multispectral Scanner (Lillesand and Kiefer, 1994; Lillesand and Kiefer, 2004). Landsat MSS was launched in 1972, originally, it was known as Earth Resources Technology Satellite (ERTS). Landsat MSS has been regarded as useful for spectral discrimination of large vegetated wetlands (Jensen, 1996). The improvements on Landsat TM made it more useful to identify wetland and other land cover types. Landsat TM bands can be beneficial for distinguishing and obtaining data associated with biophysical attributes such as vegetation, clouds, temperature, land type, rocks and minerals. Table 2.3 illustrates and describes the various bands and their uses. Landsat TM procedures can provide greater accuracies in terms of observing changes in wetlands than other remote satellites such as SPOT because of its greater spectral resolution (Bolstad and Lillesand, 1992). It has a potential for detecting moisture content and is useful in wetland monitoring work for both vegetation and soil moisture discrimination (Lillesand and Kiefer, 1994).

Table 2.2: SPOT satellite sensor description (adapted from Lillesand and Kiefer, 2004).

	SPOT 5	SPOT 4	SPOT 1,2 & 3
Launch date	04 May 2002	24 Mar 1998	22 Feb 1986, 22 Jan 1990, 26 Sep 1993
Spectral bands	2 panchromatic bands(5m) combined to generate a 2.5 m product	1 panchromatic band (10m)	1 panchromatic band (10m)
	3 multispectral bands (10m)	3 multispectral bands(20m)	2 multispectral bands (20m)
	1 shortwave infrared band (20m)	1 shortwave infrared band (20m)	
Spectral range	B1 (green) 0.50 - 0.59µm	B1 (Green) 0.50 - 0.59µm	B1 (Green) 0.50 - 0.59µm
	B2 (Red) 0.61 - 0.68µm	B2 (Red) 0.61 - 0.68µm	B2 (Red) 0.61 - 0.68µm
	B3 (NIR) 0.78 - 0.89µm	B3 (NIR) 0.78 - 0.89µm	B3 (NIR) 0.78 - 0.89µm
	B4 (SWIR) 1.58 - 1.75µm	B4 (SWIR) 1.58 - 1.75µm	
Average revisit over 26 day orbital cycle	2 to 3 days	2 to 3 days	2 to 3 days

Table 2. 3: **Landsat TM spectral bands (adapted from Gao, 2008).**

Band	Wavelength (µm)	Spectral Region	Sensitivity of landscape features
1	0.52 – 0.52	Blue	Provides increased penetration of water bodies of land use, soil and vegetation characteristics.
2	0.52 – 0.60	Green	Corresponds to the green reflectance of healthy vegetation.
3	0.63 – 0.69	Red	This band is important for detecting chlorophyll absorption of healthy green vegetation.
4	0.76 – 0.90	Near Infrared	It is responsible for detecting the amount of vegetation biomass in a scene.
5	1.55 – 1.75	Mid infrared	Indication of the amount of water in plants and distinguishing of smoke from clouds is done by this band.
6	10.4 – 12.5	Thermal	This band measures the amount of infrared radiant flux (heat) emitted from surfaces. It is used to locate geothermal activity.
7	2.08 – 2.35	Mid infrared	Discriminates among various rock formations.

2.8.1 Image pre-processing and data merging

The aim of image pre-processing is to correct distorted or degraded image data and to create an accurate presentation of the original scene. It is often referred as image pre-processing operations because there is a precedent for further manipulation and analysis of the image to extract specific information. There are common steps that are done in the image data before further analyses can take place such as image classification, vegetation indices and change detection (Wright *et al*., 2000). Firstly, geometric correction, which involves calibration of data to remove geometric errors such as clouds (Gao, 2008)and secondly is georeferencing whereby images are reprojected from one coordinate system to another represented by eastings and northings (Gao, 2008). After geometric correction and georeferencing then data merging can take place. Data merging is a process whereby images are re-projected from one coordinate system to another (Gao, 2008). Data merging is used in order to combine image data for a given geographic areas with other geographically referenced data sets for the same area. The aim for data merging is to combine the remote sensing data with other sources of information in the context of GIS.

2.9 Analysis of image

Remote sensing data can be analysed by means of vegetation indices and image classification. Spectral vegetation indices (VI) are mathematical combination of different spectral bands mostly in the visible (red) and near infrared regions of the electromagnetic spectrum (Vina *et al*., 2011). The purpose of VI is to enhance the information contained in the spectral reflectance data such as leaf area index (Moulin and Guerif, 1999). VI are formed when a number of spectral values are combined, which produce a single value indicating the biomass and growth of vegetation within a pixels, spectral values are multiplied, added or divided during combination (Campbell, 2006). Healthy vegetation is indicated by high values of VI pixels (Campbell 2006). Among existing vegetation indices, the Normalized Difference Vegetation Index (NDVI) is the most often used and is an operation global based vegetation index. Its ratio properties enable a large proportion of noise caused by changing sun angles, topography and clouds to be cancelled out (Huete *at al*., 1999). NDVI uses vegetation indices derived from satellite images to represent the level of greenness of plant species, which in turn can reflect their health or photosynthetic activity (Kovacs *at al*., 2005, Townsend *et al*., 1991). NDVI has been widely used to estimate changes in plant greenness (Zhang *et al*., 2003). Values of this index are calculated from the reflected solar radiation in the Near Infrared (NIR) and Red (R) wavelength bands, 700 to 1100 nm and 600 to 700 nm respectively. A value close to zero represents no vegetation/ unhealthy vegetation whereas values close to one indicate high density of green leaves/ healthy vegetation (Bartholy and Pongracz, 2005 ; Seto and Fragkias, 2007). NDVI can be determined using the following formula:

$$NDVI= \frac{(R_{NIR}-R_{RED})}{(R_{NIR}+R_{RED})}$$

Knowledge about trends in the wetland vegetation and its status is important for conservation and wise use of wetland’s resources. According to Huete and Jackson, (1988) and Huete *et al*., (2002), NDVI is known to have deficits of saturation when atmospheric and soil backgrounds vary. The saturation problem has been overcome by using broad bands from hyperspectral remote sensing (Mutanga and Skidmore 2004).

Image classification is defined as a procedure where by all pixels are automatically categorised into land cover classes or clusters. This involves the analysis of multispectral image data and the application of statistically bases decision rules for determining the land cover identity of each pixel in an image. Image classification can be supervised, unsupervised or object-orientated based.

2.9.1 Unsupervised classification

This type of classification does not require user to have foreknowledge of the classes, and mainly uses a clustering algorithm to classify an image data (Jensen, 2005). Unsupervised procedure can be used to determine the number and location of unimodal spectral classes. One of the most commonly used unsupervised classifications is the Migrating Means Clustering classifier (MMC). This method is based on labelling each pixel from one cluster centre to another in a way that the Sum of the Square Error (SSE) measure of the preceding section is reduced (Jensen, 2005). The advantage of this type of classification is that it can be less time consuming as it eliminates the training. Its disadvantage is that clusters may not correspond to desired information classes that the investigator wants (Ozesmi and Bauer, 2002).

2.9.2 Supervised classification

Supervised classification has been described as the process of assigning pixels or the basic units of an image to classes (Palaniswami *et al*., 2006; Lillesand and Kiefer, 2004). It is likely to assemble groups of identical pixels found in the remotely sensed data into classes that match the informational categories of interest to the user, by comparing pixels to one another and to those of known identity. The advantage of supervised classification is that the user has an ability to specify desired information classes, therefore often preferred over unsupervised classification, because land classes are chosen prior. The disadvantage of supervised classification is that desired classes may not correspond to spectrally unique or homogeneous classes and the training data acquisition can be time consuming (Ozesmi and Bauer, 2002).

2.9.3 Object orientated classification

Object orientated image analysis approach is the approach to image analysis combining spectral and spatial information. Not only spectral information is used, but the texture and content information as well (Benz *et al*., 2004). Some advantages of object-orientated classification include the following: It is suitable for medium to high resolution satellite imagery and involves segmenting an image into objects (Baatz *et al*., 2004). Object orientated classification also has geographical features such as shape, length and topological entities. The latter includes the adjacency relationships of objects (Baatz *et al*., 2004).

2.10 Change detection procedures

According Singh (1989) and Lillesand and Kiefer *et al* (2000) change detection involves the use of multi-temporal data sets to discriminate area of land cover change between dates of imaging. Examples of changes can range from short-term scenes such as snow cover or floodwater to long-term scenes such as desertification or urban sprawl. Change detection procedures should involve data acquisition by the same or similar sensor and be recorded using the same spatial resolution, viewing geometry, spectral bands, radiometric resolution and time of day. Change detection process may be strongly influenced by various environmental factors that might change between image dates. Environmental effects such as wetland level, tidal stage, wind, soil moisture condition can be also important (Inglis-Smith, 2006).

2.10.1 Post classification

Post classification comparison classifies multi-temporal images into thematic maps then implements comparison of the classified images pixel to pixel (Lu *et al*., 2004). Its advantage is that it minimizes impacts of atmospheric, sensor and environmental differences between multi-temporal images and provides a complete matrix of change information (Gao, 2008). The disadvantage of post classification is that it is subject to misclassifications and inaccuracy of registering two maps. This causes the inaccuracy of the classification process, which eventually degrades change analysis outcome (Gao, 2008). Another disadvantage is that it requires a great amount of time to create classification products and the final accuracy depends on the quality of classified image for each date (Lu *et al*., 2004).

2.11 Accuracy assessment

Accuracy assessment is the degree of closeness of results to the values accepted as true (Campbell, 2006). It is important in order to increase the quality of map information by identifying and correcting the sources of errors (Congalton and Green, 1999). Analysts often need to compare various techniques and algorithms to test which is the best (Congalton and Green, 1999). Error matrix is one of the standard forms of accuracy assessment that does identification, measurement of error maps and comparison of a site on a map against reference information for the same site (Congalton and Green, 1999). Reference data assumed to be correct if the image classification corresponds closely with the given standard. An error matrix is a square array of numbers set out in rows and columns, which express the number of sample units i.e. pixels, clusters of pixels or polygons assigned to a particular category in one classification relative to the labels assigned to a particular category in another classification (Congalton, 1991). The columns usually represent the reference data while the rows indicate the classification generated from the remotely sensed data (Congalton, 1991). Computed summary statistics for the error matrix include overall map accuracy proportion correct by classes (user and producer accuracy) and errors of omission and commission. Producer's accuracy is often called omission error where correct number of pixels in a category is divided by total number of category i.e. column total. In this type of error, the producer of the classification is interested in how a certain area can be classified (Congalton, 1991, Story and Congalton, 1986). The user's accuracy is called the error of commission where the number of correct pixel in a category is divided by the total of category i.e. row total. It is an indicative of the probability that a pixel on the map or image actually represents that category on the ground (Congalton, 1991; Story and Congalton, 1986). The overall accuracy is performed by dividing the total correct (sum of the major diagonal) by the total number in the error matrix (Congalton 1991). Additional statistics usually include a Kappa coefficient that adjusts the overall proportion correct for the possibility of chance agreement (Congalton and Green, 1999).

Table 2. 4: **An example of the accuracy assessment (adapted from Story and Congalton 1986; Congalton, 1991; Congalton and Green, 1999).**

REFERENCE DATA						
	A	**B**	**C**	**D**	**Row Total**	**Land Cover Categories**
A	64	5	23	24	**116**	Dense Vegetation
B	7	80	9	13	**109**	Transformed vegetation
C	1	12	84	17	**114**	Degraded vegetation
D	3	19	4	96	**122**	Bare surface
Column Total	**75**	**116**	**120**	**150**	**461**	

Producer's Accuracy	User's Accuracy	Overall Accuracy
64/75= 85.3%	64/116 = 55.2 %	324/461=70.1%
80/116 = 69%	80/109 = 73.4%	
84/120 = 70%	84/225 = 37.3 %	
96/150 =64%	96/122 = 79%	

Table 2.4 represents an example of the accuracy assessment. The red numbers represent the sum of the major diagonal, while the green number represents a total number in the error matrix. The overall accuracy is performed by dividing the total correct (sum of the major diagonal) by the total number in the error matrix**.**

2.12 Hyperspectral remote sensing

Hyper from hyperspectral means above or in excess. In the field of remote sensing, spectroscopy is the branch of physics that has to do with production, transmission, measurement and interpretation of electromagnetic spectra (Schmidt, 2003; Swain and Davis, 1981). It is rare to perform mathematical analysis of waveforms on remote sensing applications instead spectrographic devices such as airborne scanner or laboratory spectrometers are used (Suits, 1983). Spectrometer is an optical instrument used to measure apparent electromagnetic radiation emanating from a target in one or more fixed wavelength bands or subsequently through a range of wavelengths (Swain and Davis, 1981). Spectrometers are used in the field, laboratories and in aircrafts. Imaging spectroscopy is a technique for obtaining a spectrum in each position of a large array of spatial positions in order for spectral wavelength to be used and make recognisable image (Schmidt, 2003).

2.12.1 Hyperspectral remote sensing and vegetation

Hyperspectral remote sensing has been used to delineate and classify wetland vegetation characteristics at species level (Schmidt and Skidmore, 2003). Reflection, absorption or transmission expected to happen when light solar radiation interacts with leaves. All vegetation species consist of basic components that affect spectral response which include chlorophyll and other light absorbing pigments such as proteins waxes and structural biochemical molecules such as lignin and cellulose (Kokaly *et al*., 2003). It is therefore difficult to separate vegetation species due to the components mentioned (Price, 1992; Rosso, 2005). To differentiate spectra of vegetation species, leaf optical properties are used which are related to biochemical and biophysical status of plants. Pigment concentration, biochemical composition, water content, leaf thickness, leaf surface and internal structure are the factors that leaf optical properties depend on (Kumar *et al*., 2001). Vegetation usually has a high reflectance, transmittance, and water absorption in the near infrared region (Kumar *et al*., 2001; Rosso, 2005). Factors affecting the spectral reflectance among wetland vegetation are the biochemical and biophysical components of plant's leaves and canopy such as chlorophyll *a* and *b*, carotene and xanthophylls (Kumar *et al*., 2001). Wetland species differ in chlorophyll and biomass reflectance as a function of plant species and hydrologic regime (Anderson, 1995). Leaf water content as one of the factors that affects spectral behaviour of the wetland species determines the absorption of the infrared region (Datt, 1999). Leaf area index (LAI) is another factor that influences canopy spectral reflectance of wetland vegetation. Canopies with higher LAI reflect more than the canopies with medium or low LAI. In higher LAI, little radiation reaches the mature leaves under vegetation canopies (Abdel-Rahman and Ahmed 2008, Tejera *et al*., 2007).

2.12.2 Red edge

Red edge is the point of the maximum slope in vegetation reflectance spectra between red absorption and NIR reflection (Mutanga, 2004). Physiological changes in vegetation studies have been indicated by using red edge (Curran, 1995). According to Wamunyima (2005), red edge position occurs within 680 nm to 750nm of wavelength range. The spectral range of green vegetation falls into four regions of electromagnetic spectrum (Table 2.5); more details are shown in Figure 1.1. In order to calculate red edge three parameters are used which are red edge position, amplitude and slope (Mutanga and Skidmore, 2004). The amplitude is the first derivative value at the maximum slope position within 680nm to 750 nm range (Cho and Skidmore, 2006). Red edge position (REP) is determined or changes due to factors like plant health, LAI, chlorophyll, seasonal patterns and phenological state (Mutanga and Skidmore, 2004). Different techniques are used to extract the red edge position, which are linear interpolation, inverted Gaussian, linear extrapolation, maximum first derivative and Lagrangian (Dawson and Curran, 1998; Cho and Skidmore, 2006). These techniques are used to discriminate biophysical and biochemical properties for example nitrogen content and leaf area index (Mutanga, 2004, Mutanga and Skidmore, 2004; Cho and Skidmore, 2006).

Table 2.5: **Four regions of electromagnetic spectrum (Adapted from Kumar *et al*., 2001).**

Wavelength (nm)	Description	Spectral reflection of vegetation
400 - 700	Visible	Low reflectance and transmittance due to chlorophyll and carotene absorption
680 - 750	Red edge	The reflection is strongly correlated with plant biochemical and biophysical parameters
700 - 1300	NIR	High reflectance and transmittance, very low absorption
1300 - 2500	MID/SWIR	Lower reflectance due to strong water absorption and minor absorption of biochemical content

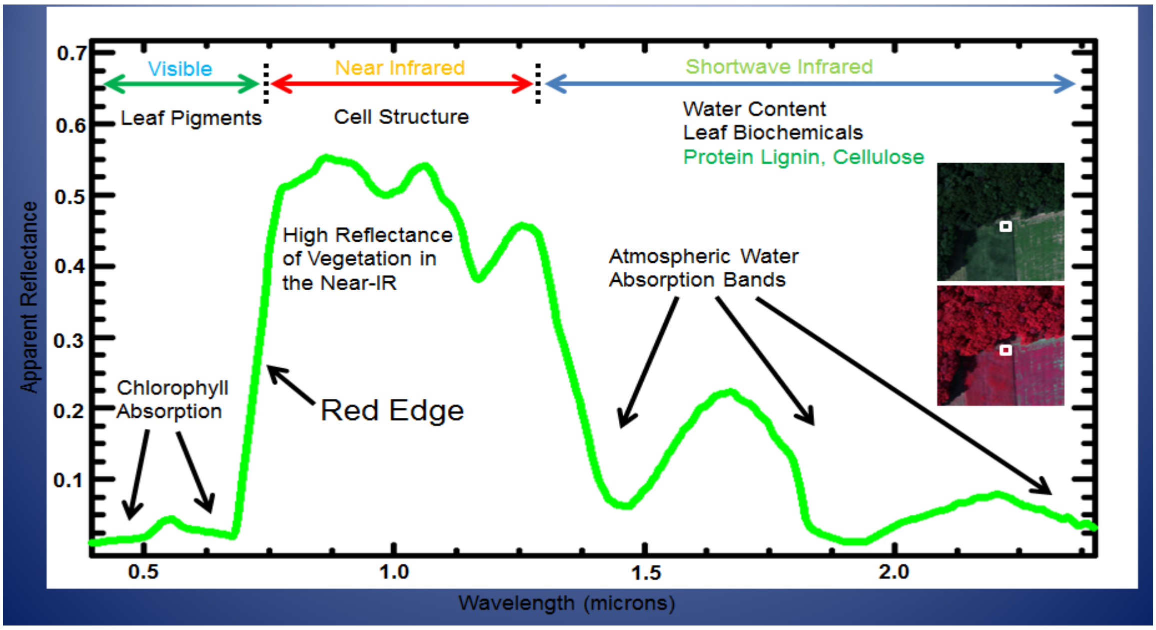

Figure 2.1: **The vegetation spectrum (image taken from www.markelowitz.com).**

2.13 Conclusion

Wetlands are important for their intrinsic and instrumental value; however, they are being threatened and degraded. It is therefore of importance to have an up to date information of their status in order to initiate restoration and monitoring programmes. Traditionally, mapping and monitoring wetland vegetation requires intensive fieldwork and visual estimation of percentage for each species. This is labour intensive, costly and time consuming and sometimes inapplicable in inaccessible areas (Lee and Lunneta, 1995). Remote sensing offers a practical, less time consuming and less costly way to discriminate and estimate biochemical and biophysical parameters of wetland species. At the same time offering a repeat coverage where archive data is being stored for change detection purposes (Ozesmi and Bauer, 2002). Archive data can be easily integrated and merged with GIS for further analyses (Shaikh *et al.*, 2001; Ozesmi and Bauer, 2002). For this advantage, SPOT 5 imagery was used in the present study to identify land cover classes over a specific time interval and hyperspectral data to further discriminate wetland vegetation at species level.

CHAPTER 3: STUDY AREA

3.1 Background and general description of the study area

The study was conducted in the Hopewell Nature Conservancy, which was initially a series of farms (Goodman Matsha *pers. comm*; Stewart, 2008). It was owned by the Dakian and Judith Issroff Trust, which was then bought by the Issroff family during 1940's. From the mid 1960's onwards the poor quality of the soils, lack of water for irrigation and problems of personal security and stock theft made the land untenable for farming. Therefore, all farming operations were terminated and the area was fenced in 2009. Dr Issroff made a number of attempts through personal research and the appointment of consultants to find a productive ways to utilise the land holdings. A conservation-based development (Hopewell Conservation project) was then proposed that hoped to have environmental benefits including the removal of alien species, eradication of illegal activities (e.g. mining, & dumping), rehabilitation of degraded areas that were illegally mined, and the implementation of management practices such as fire management. Just outside the boundaries of the Hopewell Conservancy is the Nelson Mandela Municipal Open Space System (NM MOSS), which is managed by the local municipality. The Hopewell Conservation area (25^0 27' E and $34^0$27'S) is approximately 3000 ha and is located within the NMBM approximately 22 km northwest from the city of Port Elizabeth in the Eastern Cape Province (Figure 3.1). The Hopewell Conservation management area encompasses the Hopewell Planning domain (green shaded area, Figure 3.1) and the properties immediately adjacent to it on either side of Stanford Road until the NM MOSS boundary (grey shaded area, Figure 2), where they have fence lines. To the north and northeast are two townships KwaNobuhle and Booysen's Park and to the south is the suburb of Greenbushes. Both sides of the Hopewell Conservation area experience grazing, at different levels of management. The NM MOSS is generally unregulated and consists predominately of cattle grazing from the local communities. The Hopewell conservation area is stocked with game (ungulates) and some cattle, which has some regulation.

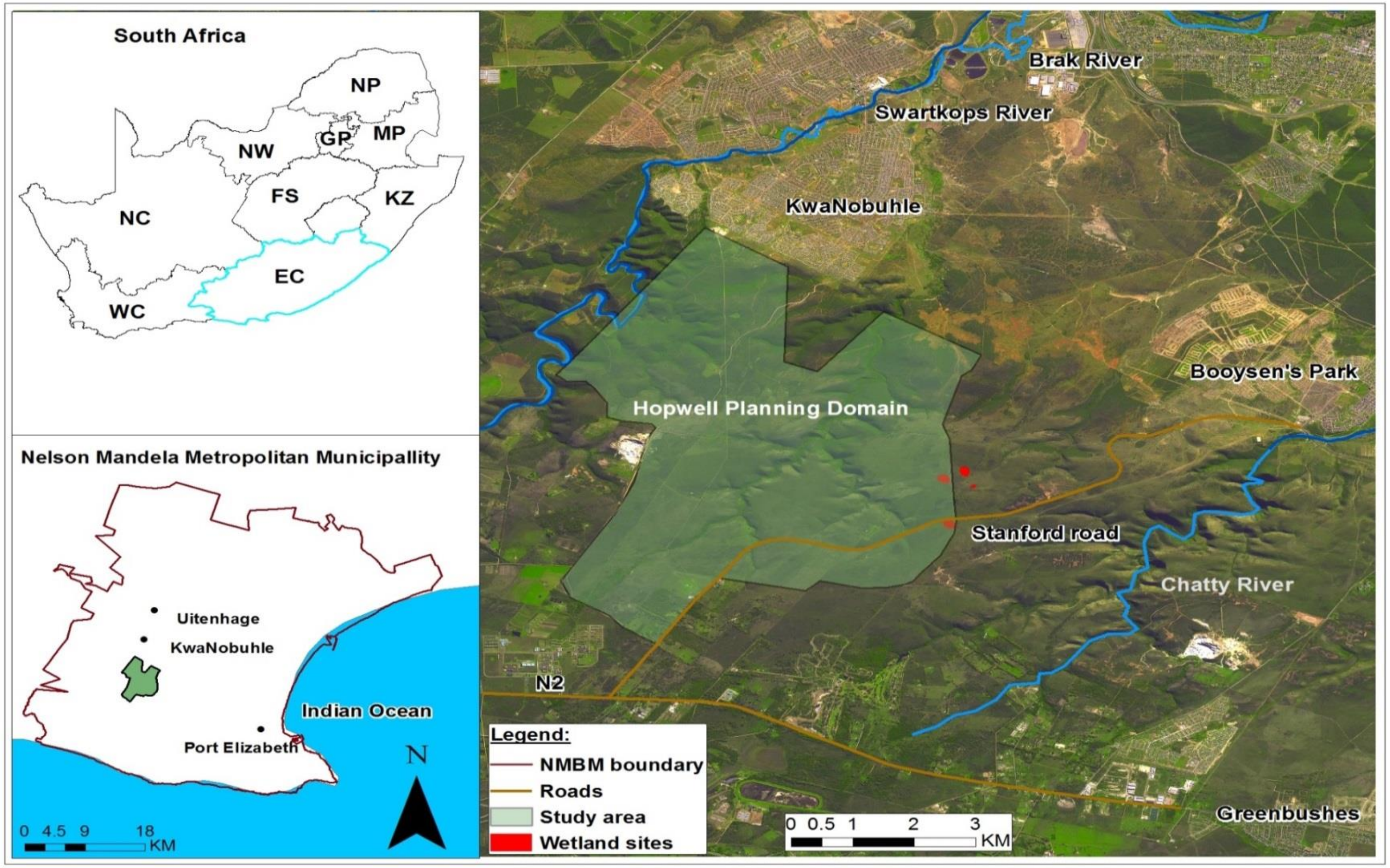

Figure 3.1: The location of the study area Hopewell Conservancy in Port Elizabeth, Eastern Cape, South Africa.

3.2 Climate

The climate of the NMBM is complex, as the NMBM is located at the confluence of several climatic regimes, ranging from temperate to subtropical (Stewart, 2008). The area has warm temperate climate and the temperature ranges are not extreme. The mean summer temperature ranges between 21°C to 35°C while the winter mean temperature ranges between 8°C and14°C. Port Elizabeth receives rainfall throughout the year ranging from 440 mm to 820 mm with an average annual rainfall of about 614 mm (Stewart, 2008). June and August are the rainfall peaks with means between 60 and 65 mm (Table 3.1).

Table 3.1: **Average Monthly Temperatures and Rainfall for Port Elizabeth (Port Elizabeth Weather Service Data).**

Months	Average Monthly Temperatures (1980-2012)		Average Monthly Rainfall (mm)
	Min °C	Max °C	
January	17.6	25.6	37.2
February	17.9	25.9	38.2
March	16.5	24.8	51.1
April	14.0	23.3	45.0
May	11.4	22.1	46.5
June	8.7	20.4	62.3
July	8.2	20.1	47.0
August	9.5	20.0	64.8
September	11.1	20.3	44.4
October	13.0	21.2	61.3
November	14.6	22.6	53.9
December	16.2	24.3	43.9

3.3 Geology and soils

Geology and soil characteristics of the study area were reviewed from Stewart, (2008). Hopewell is characterised by the soil of the Peninsula formation, Nardouw subgroup, Bokkeveld group and to a lesser extent the Uitenhage and the Nanaga Formations. The southern portion of the area comprises of a thin aelioniate and sand deposits (Nanaga

Formation) overlying quartizitic sandstones of the Table Mountain Group (Peninsula Formation). The central part of the area is underlain by moderately folded sandstones of the Table Mountain Group, specifically the Baviaanskloof, Skurweberg and Goudin Formations from the south to north. The bedrock in the northern part of Hopewell consists of shale and siltstone rock of the Bokkeveld Group. The Peninsula Formation consists of coarse-grained sandstone becoming quartzitic in places. The Nardouw subgroup is represented by the Goudini, Skuwerberg and Baviaanskloof sandstone formations. The Bokkeveld group is represented by Ceres subgroup, which consists of dark grey shales with intervening sandstone units. The Uitenhage group is represented by Enon Conglomerate. The geology of the four study wetland sites were characterised by the soils of the Skuwerberg and Goudini Formations (Figure 3.2).

3.4 Surface and ground water

The study area is dominated by a plateau (Stewart, 2008), which is broken by incised valley that runs in a general south to north direction. Brak River that is a tributary of Swartkops River flows adjacent to the western boundary of the Hopewell. A number of small streams are found in the area including the upper reaches of Chatty River. Depression wetlands are also found within the study areas, which become inundated with water from time to time following good rains. Hopewell is classified as a minor to poor fractured rock aquifer with a median range of 0.1 to 0.5 l/s, fresh to moderately saline groundwater quality (500 to 1000 mg/l Total Dissolved solids) (DWAF, 1998). The central to southern portion where the 4 study sites are located is underlain by sandstones of the Table Mountain Group, which is considered to have a better groundwater supply. This is good for groundwater development perspective during dry seasons.

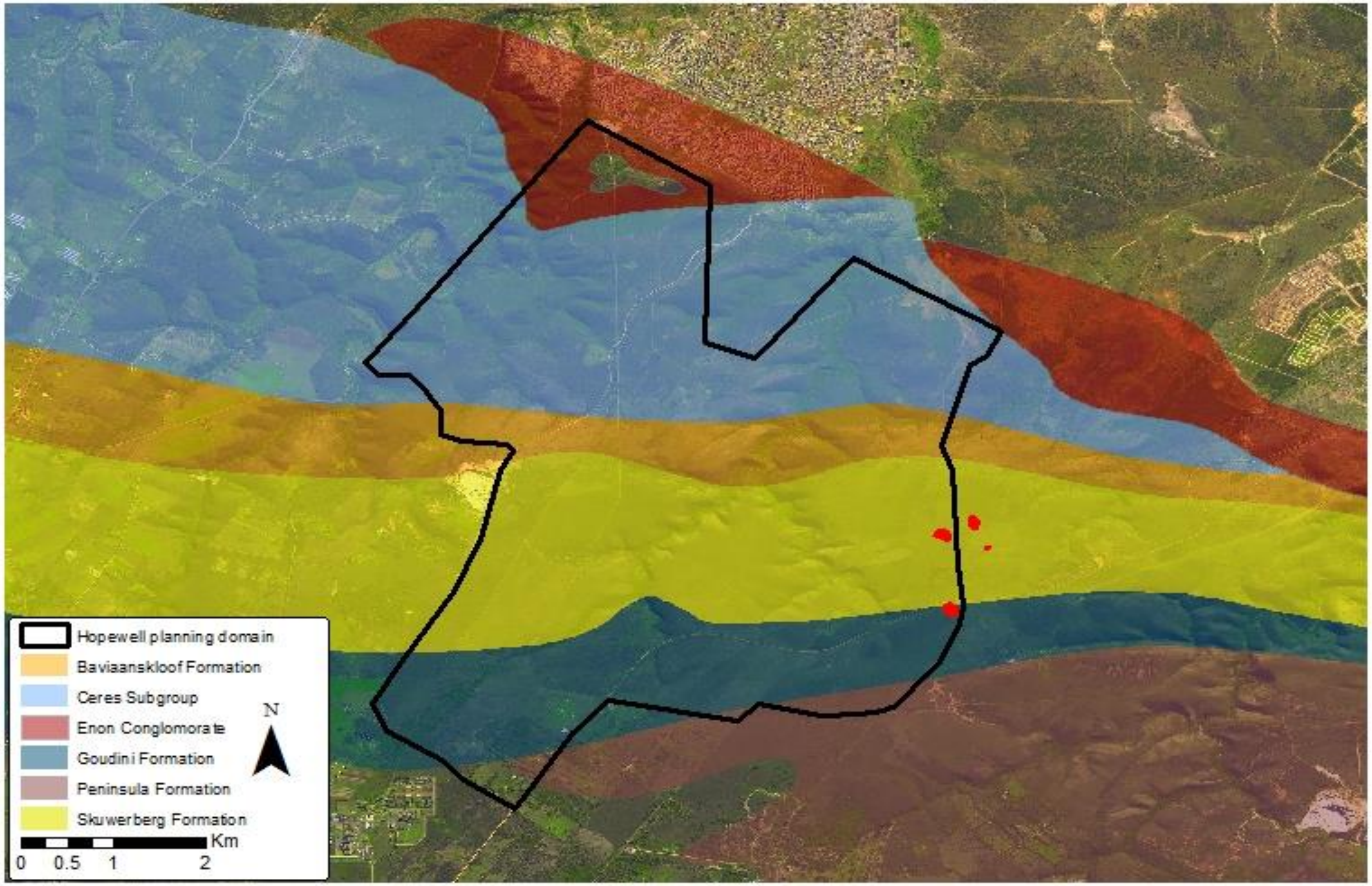

Figure 3.2: The geology of the Hopewell Nature Conservancy (NMBM)

3.5 Vegetation

NMBM is situated within two recognised centres of diversity and endemism for plant (Goldblatt and Manning, 2002) and animal groups called the Cape Floristic Region (CFR) and Albany Centre of Endemism. NMBM area is well known as an ecological hotspot with five of South Africa's seven floristic biomes i.e. Fynbos, Subtropical Thicket, Nama Karoo, Forest and Grassland (Low and Rebelo, 1998). The biodiversity of the NMBM is characterised by coastal fynbos, inland fynbos and subtropical thicket vegetation that are regarded as a conservation priority because of the land use pressures (Cowling *et al*., 1999).

The Hopewell conservation area incorporates three of the five Eastern Cape biomes, Algoa Grassy Fynbos, Groot Valley Thicket and Sundays Valley Thicket (Vlok and Euston-Brown, 2003 and Stewart, 2005). The distribution of vegetation with Hopewell is presented in Figure 3.3. Some of this vegetation is in good health, but other parts have been severely impacted by human activities such as illegal grazing, sand mining, off road vehicle racing and are infestation by invasive alien plants (SRK Consulting, 2007).

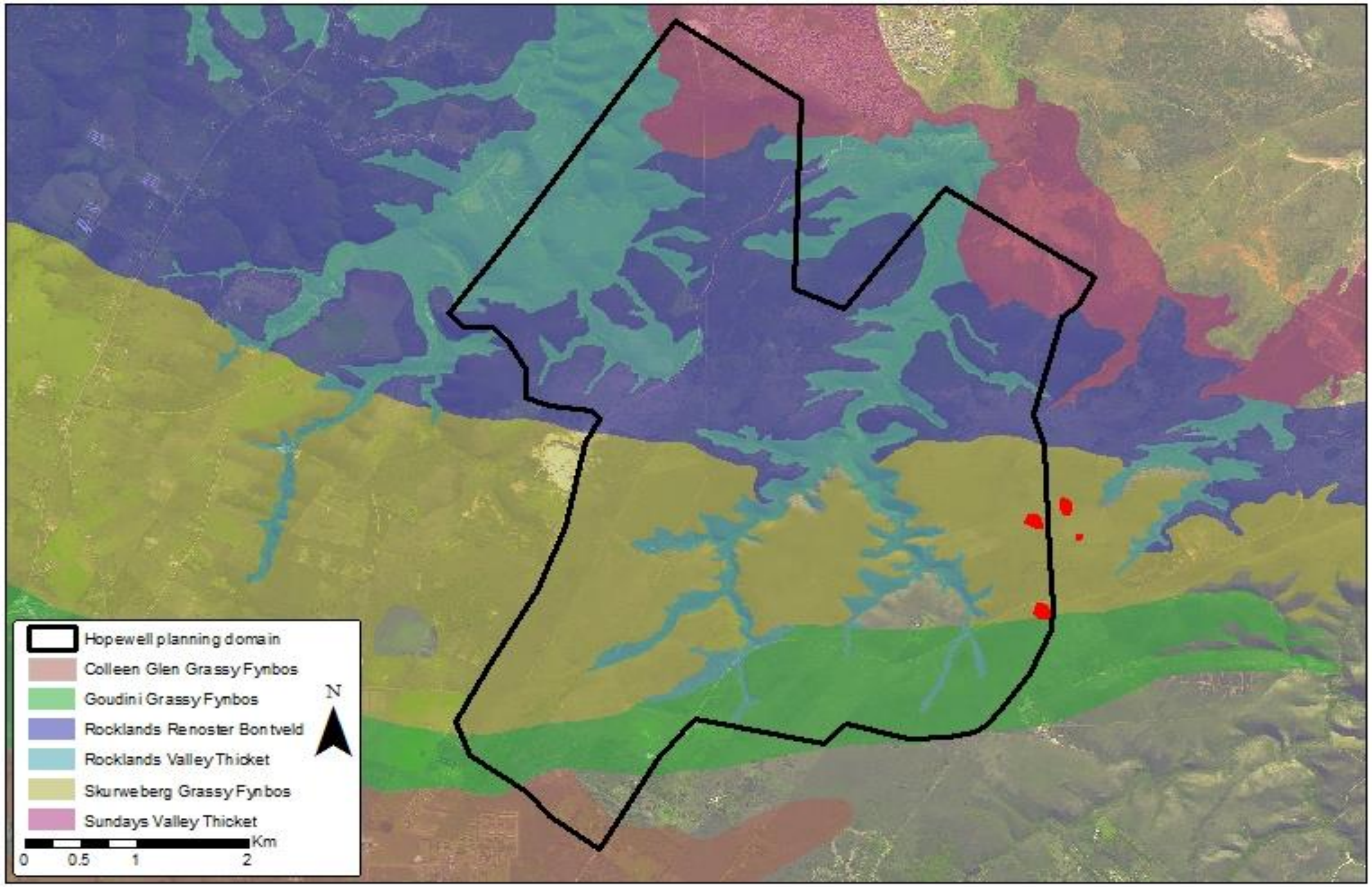

Figure 3.3: The distribution of vegetation types within Hopewell Nature Conservancy planning domain (NMBM).

Chapter 4: MATERIALS AND METHODS

4.1 Introduction

Changes in wetland land cover classes were assessed using SPOT. Fieldwork was conducted to select and delineate wetland sites and to determine dominant wetland plant species. Field spectroscopy for spectral reflectance of dominant wetland vegetation species was also done to determine their differences between two areas of different management regimes. The types of data, data sources and equipment used is summarised in Table 4.1. Figure 4.1 illustrates methods and techniques used to address the aims and objectives of the study.

Table 4.1: **Data and equipment used in this study.**

Data and equipment	Source
SPOT 5images for 2006, 2008, 2010 and 2012	South African National Space Agency
Port Elizabeth rainfall data	South African Weather Services
SANBI shapefiles: wetlands and rivers	SANBI
Hand held trimble Global Positioning System (GPS) navigation device	
Spectral Evolution Portable Spectroradiometer (PSR) 3500	
Image processing software: GIS (ArcGIS 10.2), remote sensing (IDRISI Kilimanjaro)	
Statistical package (STATISTICA 12)	

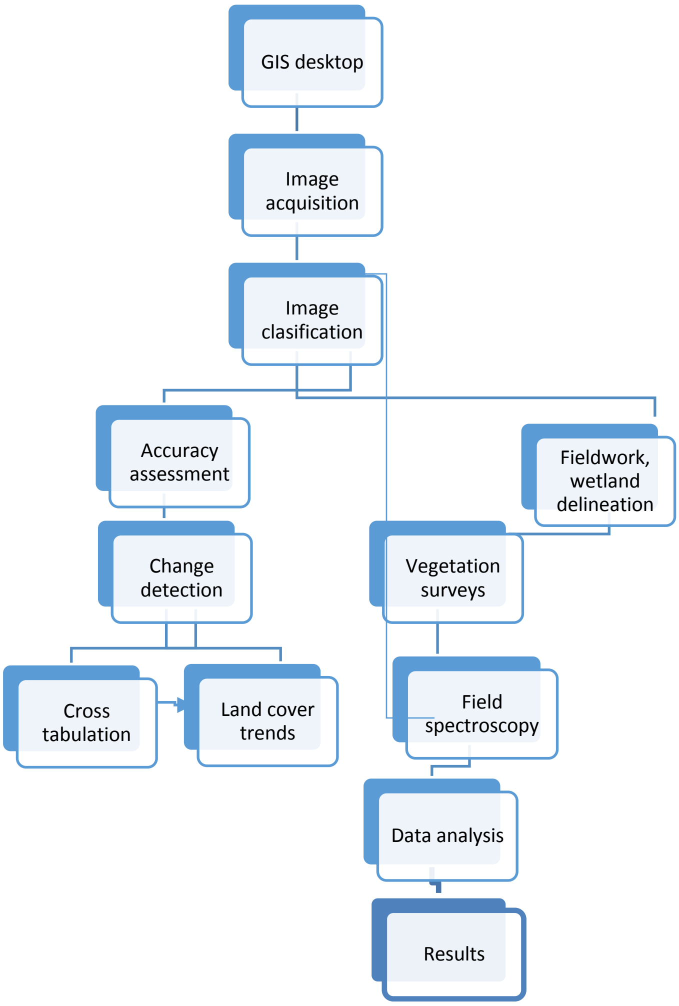

Figure 4.1: **Flow chart illustrating the methodology of the study.**

4.2 Selection of wetland ecosystem study sites

Hopewell Conservancy wetlands were selected to compare with wetlands in the NM MOSS, each with different protection and management regimes. These wetlands were selected because of their close proximity to one another. In this way differences between them could more confidently be determined because of management and land use of the wetlands as opposed to natural difference due to climate, geology or vegetation (as discussed in Chapter 3). This was to establish effects of land use activities on the wetland ecosystems in the NM MOSS since they are more susceptible to human induced activities such as overgrazing, relative to conserved area (Hopewell Conservancy). Four wetland sites, two within the recently conserved area 910 and 944) and two in non-conserved area (945 and 947) were selected, see Figure 4.3.

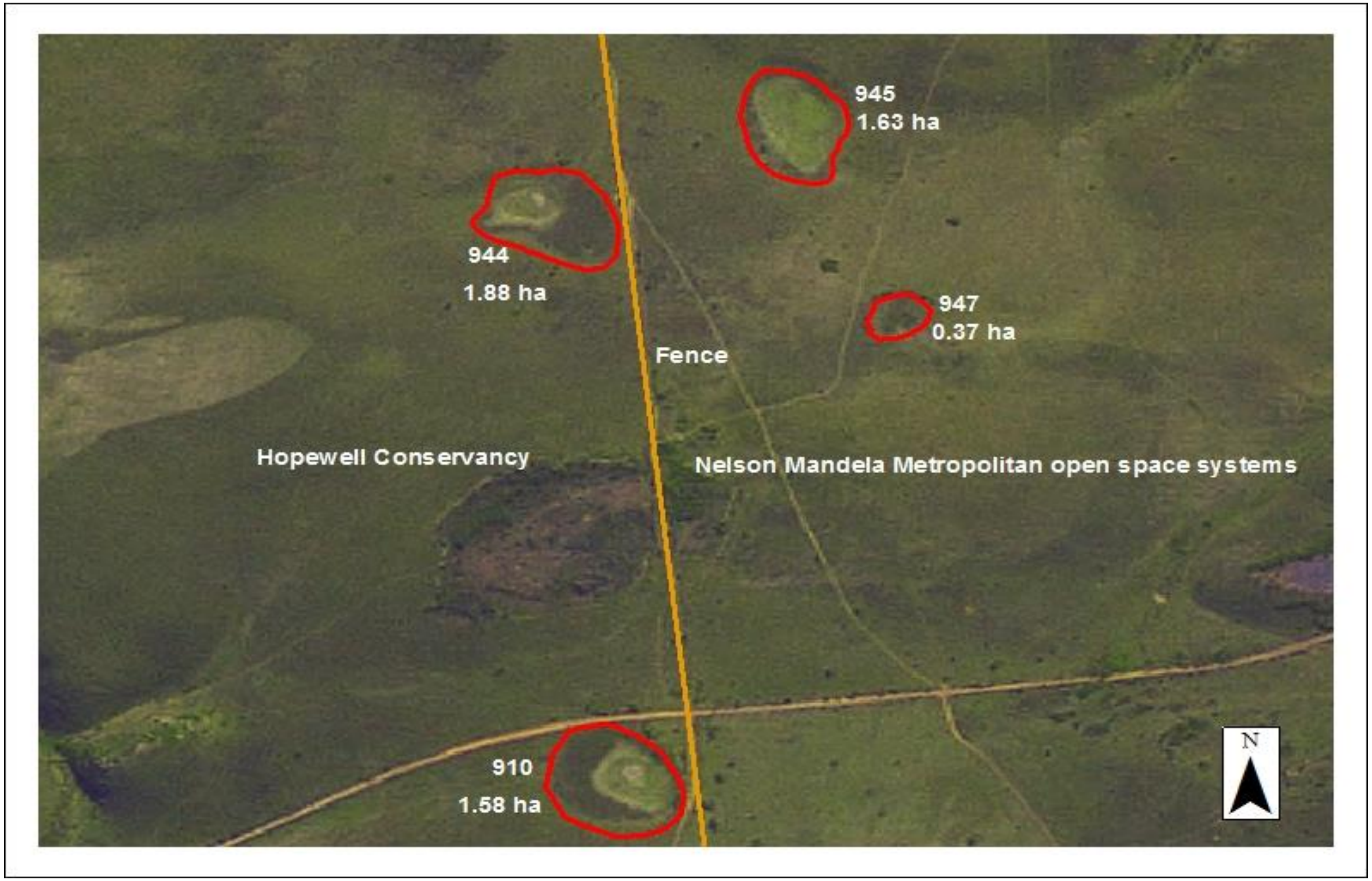

Figure 4.2: **SPOT 5 imagery (2010) and wetland polygons for conserved and non-conserved area showing wetlands within conserved and non- conserved area (SANSA). The Seville orange line shows the fence separating the conserved and non-conserved area.**

4.3 Wetland delineation and identification

The National Wetland Classification System (SANBI, 2009; Ollis *et al.*, 2013) was applied to classify and delineate wetlands completed to Level 4 (see, Table 2.1).The study used ESRI's ArcGIS 10.2 software to delineate small ephemeral wetland types in the Hopewell Nature Reserve and in the NMBM open space outside the reserve. NMBM and Hopewell boundary shapefiles were added onto the Arcmap. Wetlands were digitised in a vector format as discrete polygon units using ancillary data obtained from the NMBM. Aerial photos obtained from the Municipality, as well as existing shape files of the SANBI national wetlands database, rivers and two-metre contours were overlaid onto the map as guidelines for identifying wetlands. After overlaying ancillary data onto the map new polygon shapefiles were created in order to digitise the wetlands observed. A 500m by 500m grid was also created to ensure proper scanning over aerial photos from west to east. Wetlands were digitised at a scale of 1: 2000. In order to ground truth the Levels 3- 4 and complete the classification of sites to Levels 5 and 6, site visits were done and wetlands identified on the desktop exercise were delineated using GPS navigation facility. All GPS coordinates for the four sites were used to create shapefiles (polygons) in ArcGIS 10.1. Polygons created were then masked with SPOT images for the years 2006, 2008, 2010 and 2012 using Extract mask module in ArcGIS 10.2.

4.4 Image acquisition

Landsat Thematic Mapper (TM) has a huge data archive dating back to 1982. However, given its resolution, spanning only about 10 pixels per wetland, it was too coarse for the present study. It was therefore considered unsuitable. SPOT 5 imagery for years 2006, 2008, 2010 and 2012, which has a resolution of 10 metres pan sharpened to 2.5 metres was then used (Table 4.2). The downside of SPOT 5 is that the imagery is available only from 2006; consequently, long-term vegetation changes cannot be analysed. Selecting data from peak rainfall months is suggested as they provide high degree of discrimination between healthy and degraded vegetation conditions (Tanser, 1997), however there were limited scenes to choose wet and dry periods; therefore imagery used in this study was selected based on availability. The images had near anniversary dates and were captured between March and April of each selected year. Using imagery from one season minimizes the effects of seasonal phenological differences on the results of change detection (Jensen, 2005). SPOT 5 has 10 m spatial resolution and four bands, B1 (Green 0.50 to 0.59 µm), B2 (Red 0.62 to 0.68 µm), B3 (Near Infrared 0.79 to 0.89 µm), B4 (Shortwave infrared 1.58 to 1.75 µm). Bands 2 and 3 were used for vegetation analysis. Average monthly rainfall for March 2006 and April 2008, 2010 and 2012 are presented in Table 4.3. Images were analysed using IDRISI Kilimanjaro.

Table 4.2: **Available SPOT 5 satellite imagery for the present study.**

Year	Date of acquisition	Bands	Band wavelength (µm)	Resolution
2006	08/03/2006	B1-Green	0.50 to 0.59	10m
2008	14/04/2008	B2-Red	0.62 to 0.68	
2010	25/04/2010	B3-NIR	0.79 to 0.89	
2012	17/04/2012			

Table 4.3: **Average monthly rainfall (mm) corresponding to SPOT imagery used in Table 4.1.**

Months	2006	2008	2010	2012
February	27.5	25.6	14.0	92.8
March	27.2	29.6	48.2	108.8
April	60.0	49.0	34.8	13.0

4.5 Image rectification and classification

SPOT 5 images were obtained from South African National Space Agency (SANSA) in a Tagged Image File Format (TIFF) files with D-WGS–1984 projections, which made it possible to export them to IDRISI Kilimanjaro and GIS processing software. Images were already orthorectified by the provider. Images were re-projected using projections and transformation toolset on ArcGIS 10.1. After re-projection they were exported to IDRISI Kilimanjaro for further analyses. False colour composites (bands 3, 2 and 1) for different years, 2006, 2008, 2010 and 2012 were created for better identification of land cover classes; water, dense vegetation, sparse vegetation and bare surface. Training classes were created for each land cover class based on field survey data and recent aerial photos.

Signatures describing statistical characteristics of each land cover class were extracted using MAKESIG module. Under the supervised classification option, Maximum Likelihood Classifier (MLC) was used under MAXLIKE module in IDRISI to assess the likelihood of each pixel belonging to a specific land cover class. MLC is the most commonly used technique as it assigns pixels in the image to the class that it has the maximum likelihood of belonging to (Lillesand *et al*., 2000, Ndzeidze, 2004, Jensen, 2005). It has a sound theory and preferred algorithm especially in land cover and land use monitoring approaches (Palaniswami *et al*., 2006 and Lillesand and Kiefer, 2004). It is available in any commercial image processing software, hence mostly used technique (Palaniswami *et al*., 2006; Lillesand and Kiefer, 2004; Gao, 2008).

According to Jensen, (2005), no image classification technique is superior to another. Even though object orientated classification has more advantages over pixel based-based classification (Baatz *et al*., 2004), pixel based classification was used as software packages for object orientated classification such as eCognition and ERDAS IMAGINE were not available.

4.6 Accuracy Assessment

Accuracy assessment determines the quality of the information derived from remotely sensed data (Congalton and Green, 1999). Accuracy assessment was conducted for all classified images using ERRMAT module on IDRISI Kilimanjaro. Land cover classes (water, dense vegetation, sparse vegetation, and bare surface) were identified in the field and recent aerial photographs. Coordinates for land cover classes collected during field surveys were converted into shapefiles. Shapefiles created were then overlaid on the reference image and a new image was classified based on the selected coordinates. New classified images per wetland were produced based on the reference images. The reference and classified images were used to create error matrices per wetland. The overall accuracy was then calculated for each image. An error of commission represents pixels that belong to another class but labelled as belonging to the class, whilst error of omission represents pixels that were assigned to the incorrect class. The Kappa coefficient is an overall index which combines both errors of commission and omission. It demonstrates a measure of reliability of the classification. Kappa coefficient was automatically calculated on the accuracy assessment using ERRMAT in IDRISI. According to Landis and Koch (1977), Kappa ranges between 0 and 1. The Kappa can be broken into three groupings for interpretation. Table 4.4 presents KIA statistic and strength of agreement.

Table 4.4: **KIA statistic and strength of agreement (Presented after Landis and Koch 1977).**

KIA	Strength of Agreement
< 0.00	Poor
0.21 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost perfect - Perfect

4.7 Change Detection

Change detection algorithms in remote sensing are used to monitor long term effects from changes in climate as well as short term effects such vegetation succession and geomorphological processes (Story and Congalton, 1986). It is also used to monitor anthropogenic effects within a landscape such as deforestation, urbanization and human induced climate changes (Story and Congalton, 1986). In this study post-classification change detection was used. This technique was selected because it has an advantage to reduce the impacts of sensor and environmental differences between multi-temporal images (Gao, 2009). It is also provides a complete matrix of change directions (Gao, 2008).

Supervised classification (MLC) results were used to determine the difference in wetland systems from 2006, 2008, 2010 and 2012 in terms of their land cover classes. Post-classification change detection was carried out through cross tabulation module in IDRISI Kilimanjaro presenting “from-to” results (2006-2012). Complete matrices of amounts of conversion from a particular land cover class to another were generated using this facility.

4.8 Field data collection

4.8.1 Vegetation surveys

Vegetation surveys were conducted in different seasons to evaluate relative abundance, cover for each plant species, and assess dominant plant species in different quadrats. Two perpendicular transects were demarcated with measuring tapes from the edge of the terrestrial zone, across the wetland to the opposite terrestrial zone edge. One tape across the longest point and other across the shorter side and then a 1 square meter (m^2) quadrat was used every 3 meters (m) along each transect to assess vegetation cover and species. Specimens of plants not identified in the field were tagged, coded and returned to the laboratory for identification. Vegetation surveys were done at sites 910, 944 and 947. The field data were then used, along with georeferenced aerial photos, to create reference images for groundtruthing the image classification of land cover. Although multispectral remote sensing has been widely used to classify overall vegetation cover, it has a limited capability for accurate identification of vegetation species. Field spectroscopy was then conducted.

4.8.2 Field Spectrometry

In order to determine the spectral differences between the dominant vegetation species within conserved and non-conserved wetlands, a Spectral Evolution Spectroradiometer PSR-3500 was used. Canopy spectral measurements were recorded under sunny and cloudless conditions on the 6th and 7th of September 2013, between 10h30 and 13h00, and 10h00 and 11h00 respectively. Hyperspectral canopy reflectance measurements were acquired using the hand-held spectroradiometer. This spectrometer has a large number of narrow contiguous bands between 350 nm and 2500 nm in the electromagnetic spectrum, which allows the detection of fine details of vegetation species (Schmidt and Skidmore, 2003). Field points were selected using purposive or judgemental sampling technique. A Global Positioning System (GPS), Trimble Juno SB GPS navigation device was used to record coordinates where canopy spectral measurements for dominant species were taken. It provides photo capture, cellular data transmission and high yield GPS receiver with 2 to 5 meter positioning accuracy. Geographic coordinates were converted to shapefiles (points) and located on georeferenced aerial photos using ArcGIS, see Figures 4.8 and 4.9. There were a number of plant species present within each wetland, but only 10 were identified as dominant within the sites. These 10 plant species were selected based on their percentage cover within each site, and were from the three main common groups, namely: grasses (*Sporobolus africana, Stenotaphrum secundatum, Thamnochortus lucens, Merxmuellera disticha and Cynodon dactylon)*, sedges (*Eleocharis* spp.*, Cyperus* spp.*, Isolepis sepulcralis and Schoenoplectus decipiens*) and reeds (*Typha capensis*) (Table 4.4). Three spectral measurements within each point (Table 4.3) were collected, and the species name, viewing height and GPS coordinates recorded. Viewing height was determined by the height of a dominant species. If the plant species was tall then the viewing height was between 60 cm and 1 m and if the vegetation was short, like *Cynodon dactylon,* then viewing height was 30 cm.

Table 4.5: **Wetland ID's, wetland plant species and number of points collected per species.**

Wetland ID	Species name	No of points
910	*Sporobolus africana*	9
	Thamnochortus lucens	5
	Cyperus spp.	2
	Schoenoplectus decipiens	3
	Cynodon dactylon	2
944	*Sporobolus africana*	4
	Merxmuellera disticha	1
	Eleocharis limosa	3
	Typha capensis	5
945	*Sporobolus africanus*	5
	Schoenoplectus decipiens	5
947	*Sporobolus africana*	4
	Isolepis *sepulcralis*	4
	Cyperus spp.	4

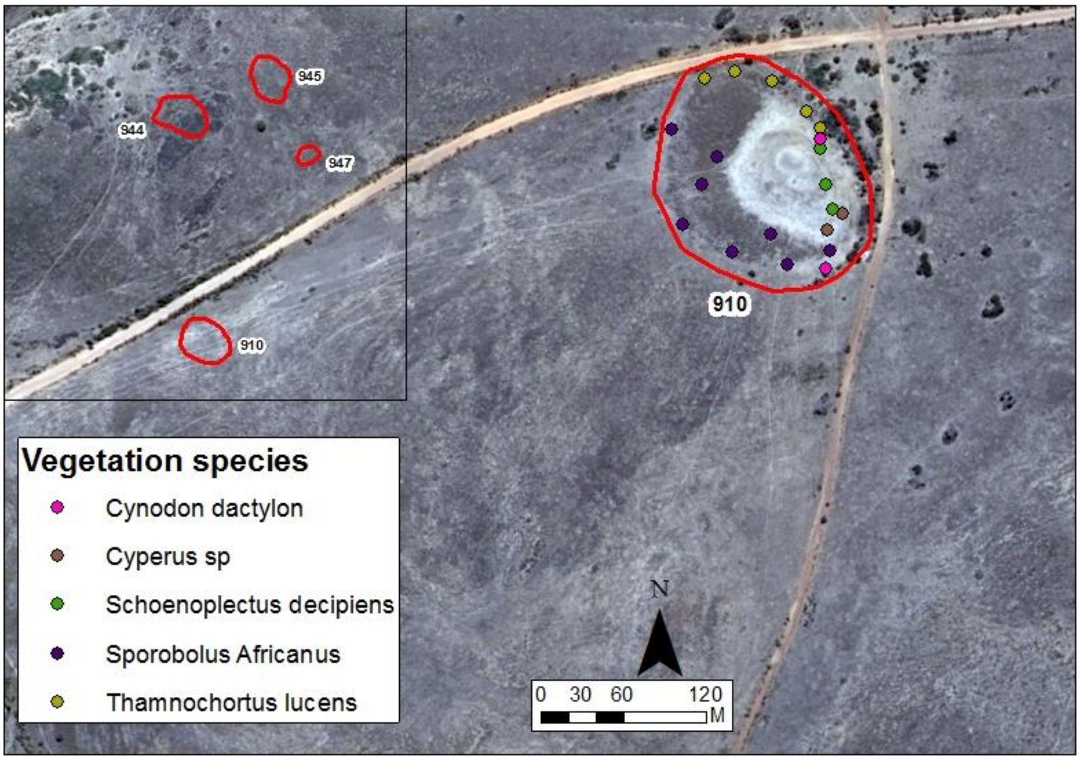

Figure 4.3: **Points representing dominant vegetation species found in wetland site 910.**

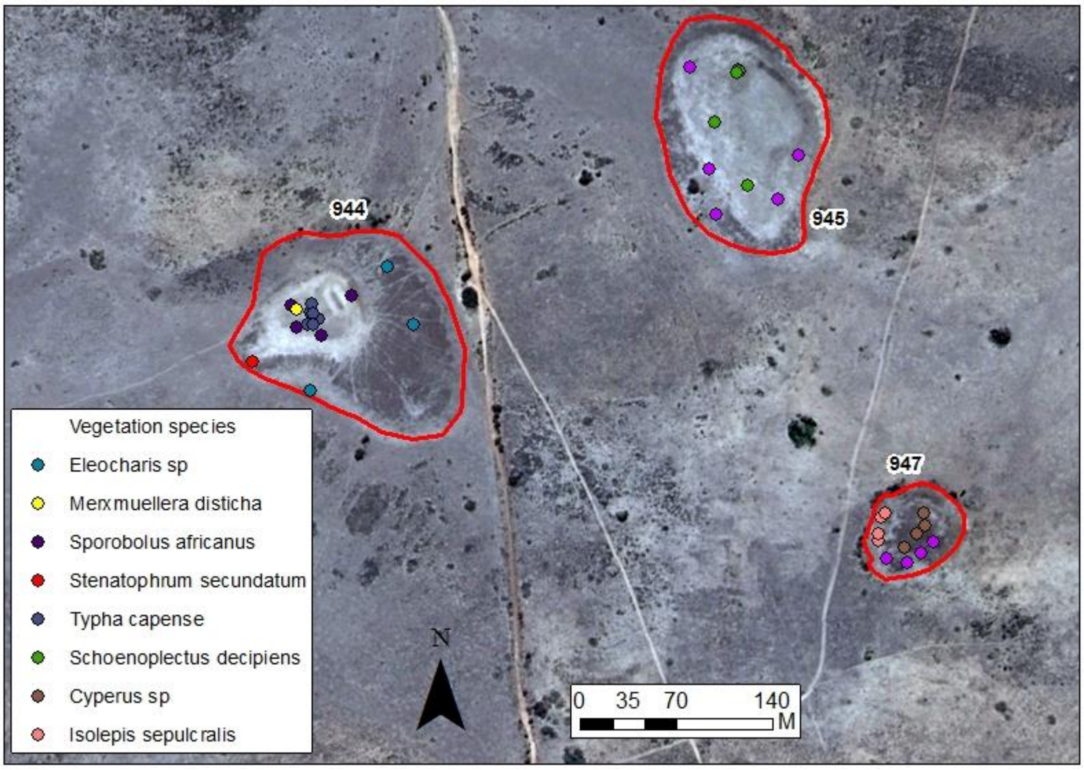

Figure 4.4: Points representing dominant vegetation species in sites 944, 945 and 947.

4.9 Analysis of vegetation indices

4.9.1 Normalised Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) is broadly used to identify the health and vigour of vegetation as well as estimating green biomass (Singh 1989). In order to determine possible changes in wetlands of the conserved and non- conserved area, NDVI was used in this research study. This vegetation index use Near Infrared (NIR) and red bands of multispectral image. The equation used to calculate NDVI is:

$$NDVI = \frac{(R_{NIR} - R_{RED})}{(R_{NIR} + R_{RED})}$$

Values are generally between 0.0 and 1.0. High values (closer to 1.0) of NDVI indicate healthy vegetation while low values (closer to 0.0) indicate unhealthy vegetation (Seto and Fragkias, 2007). Hyperspectral remote sensing has opened new perspectives for developing indices using narrow bands within the visible, NIR and SWIR (350- 2500) rather than using bands focusing on the red and NIR broad bands (Mutanga and Skidmore, 2004). This was to overcome the NDVI saturation problem, which is common in environments like wetlands referred to in chapter 2, section 2.8.6. NDVI was then calculated using NIR and red region of the spectrum from the data collected in the field using a spectroradiometer. NDVI was calculated at 670 nm and 800 nm. These regions are based on the contrast between the maximum absorption in the red band due to chlorophyll pigments and the maximum reflection in the near infrared caused by leaf structure (Haboudane *et al*., 2004).

4.9.2 Red edge position

The Red edge position (REP) (680nm to 750 nm), as shown in Figure 2.1, is defined as a rise in the vegetation reflectance from the red part of the visible spectrum to the near infrared part (Clevers *et al*., 2002). Many techniques for determining red edge position have been used in a number of studies for several reasons referred to in section 2.12.2 of the literature review chapter. In the present study, "linear four point interpolation" (Lin inter) technique developed by Baret *et al*., (1987) was used. The Lin inter technique assumes that the reflectance curve at the red edge can be simplified to a straight line centred near the mid-point between the reflectance in the NIR at about 780nm and the minimum reflectance of the chlorophyll absorption at 670nm (Guyot and Baret, 1988). The technique uses four wavelength bands (670, 700, 740 and 780) and the REP is determined by using a two-step calculation procedure.

Calculation of the reflectance at the inflexion point (R_{re}) is represented as:

$$R_{re} = \frac{(R_{670}+R_{780})}{2}$$

Calculation of the REP is represented as:

$$REP = 700 + 40 \frac{(R_{re}+R_{700})}{(R_{740}+R_{700})}$$

Where R_{re} is the inflexion point and R is the reflectance

700 and 40 are constants resulting from interpolation or wavelength interval between 700nm and 740 nm

REP was used in this study to estimate chlorophyll content in vegetation species and to support NDVI results; therefore, the health status of the dominant vegetation species was determined.

4.10 Data analysis

Tabular outputs obtained from accuracy assessment (error matrix), from cross tabulation were organised, and analysed using Microsoft Excel spreadsheet. Spectral data for the respective dominant vegetation species data collected in the field in *SED* (Spectral Energy Distribution) file format were converted to text (Tab delimited) using PSR- 3500 software. It was then viewed and organised in the Microsoft Excel spreadsheet. These data were then analysed using STATISTICA 12 software. The statistical tests were performed to compare the spectral responses of 4 wetlands within different management levels. Statistical analyses were performed per site and for all common vegetation species found in 4 wetland sites. A two-step procedure was applied to adequately discriminate vegetation species using REP and NDVI values. Firstly, One-way ANOVA and Student's T-tests were performed to establish whether there was a significance differences in means of each values. Secondly, if a significant difference was found, a Tukey honest significant different (HSD) was performed to indicate which species had significant differences between their means. Tukey HSD calculates a new pairwise alpha to keep the familywise alpha value at 0.05.

CHAPTER 5: RESULTS

5.1 Introduction

The vegetation condition of the four selected wetland sites, two in the NM MOSS area (945 and 947) and two within the Hopewell Conservancy (910 and 944) were compared. This was done in order to see if there were differences in vegetation cover and health between areas with different management regimes. The results are presented in separate sections to represent the different methods that were used to address the research aim and specific objectives of the study. Accuracy assessment of the classified images is presented first as a foundation of establishing the reliability of trends in wetland cover classes. Image classification and cross-classification using SPOT 5 will be presented to illustrate the distribution of the various land cover classes as well as changes over time. The hyperspectral analysis of individual dominant plant species will then be presented to examine if those plant species have significantly different spectral signatures and how those signatures might differ dependant on the health of the plant, demonstrating differences in management regimes.

5.2 Accuracy Assessment

To determine the accuracy of the classified images, an accuracy assessment was performed using ERRMAT module in IDRISI Kilimanjaro. This was to establish reality of the spatial and temporal trends in wetland vegetation condition through image classification. For this study, accuracy assessment is given by indicating overall accuracy together with the Kappa Index of Agreement (KIA) using the KIA statistic and strength of agreement referred to in Section 4.6 and Table 4.4. Overall KIA for the study sites and years showed a "substantial" rating of 0.63 and a "almost perfect" rating of 0.95 (Table 5.1). The overall KIA ratings for site 947 was "almost perfect" over all of the years analysed. The other sites accuracy scores varied from year to year between the two top rating categories." A summary for overall accuracy and KIA for all wetlands for 2006, 2008, 2010 and 2012 are shown in Table 5.2. Full overall error matrices for each year and each wetland site are presented in Appendix A.

5.1: A summary for overall accuracy and KIA for all wetlands for 2006, 2008, 2010 and 2012.

Wetland ID	2006		2008		2010		2012	
	Overall Accuracy	KIA	Overall Accuracy	KIA	Overall Accuracy	KIA	Overall Accuracy	KIA
910	0.82	0.75	0.78	0.72	0.72	0.64	0.80	0.75
944	0.96	0.95	0.72	0.65	0.90	0.82	0.71	0.63
945	0.87	0.78	0.86	0.82	0.72	0.63	0.80	0.72
947	0.90	0.84	0.87	0.83	0.86	0.82	0.90	0.95

5.3 Temporal cover changes within the wetlands

Images from 2006, 2008, 2010 and 2012 were classified into four land cover classes: water, dense vegetation, sparse vegetation and bare surface. Figures 5.1 and 5.2 illustrate the land cover classification for the conservation area sites, 910 and 944. The classified sites from the NM MOSS, 945 and 947 are illustrated in Figures 5.3 and 5.4. Using long term rainfall records, the average monthly rainfall peaked in March and April, therefore SPOT images used were captured between March and April for the years 2006, 2008, 2010 and 2012. In year 2008, April had a higher average monthly rainfall of 49 mm than all other years, whereas year 2012 had the lowest average of 13 mm. A visual inspection of the images showed year 2008 to have a higher proportion of dense vegetation cover in the Hopewell Conservancy sites than in the NM MOSS sites (Figures 5.1 and 5.2. In terms of visual interpretations, it was noted that bare surface covered a greater area in the NM MOSS sites.

ANOVA results also confirmed that there was a significant difference between NM MOSS sites (945 and 947) with a p-value of 0.003. However, there was no significant difference between two sites (910 and 944) in the conservancy area (p-value, 0.897) In supporting this, Tukey's multiple comparison test was performed and it showed that only NM MOSS sites had significant differences than Conservancy sites (Table 5.6). A quantification of these changes between different years is provided in Figures 5.5 to 5.8.

Table 5.2: **Tukey HSD results for bare surface land cover class, significant at p<0.05.**

Wetland ID	910	944	945	947
910		0.897		
944	0.897			
945	**0.003**	**0.010**		
947	**0.003**	**0.002**		

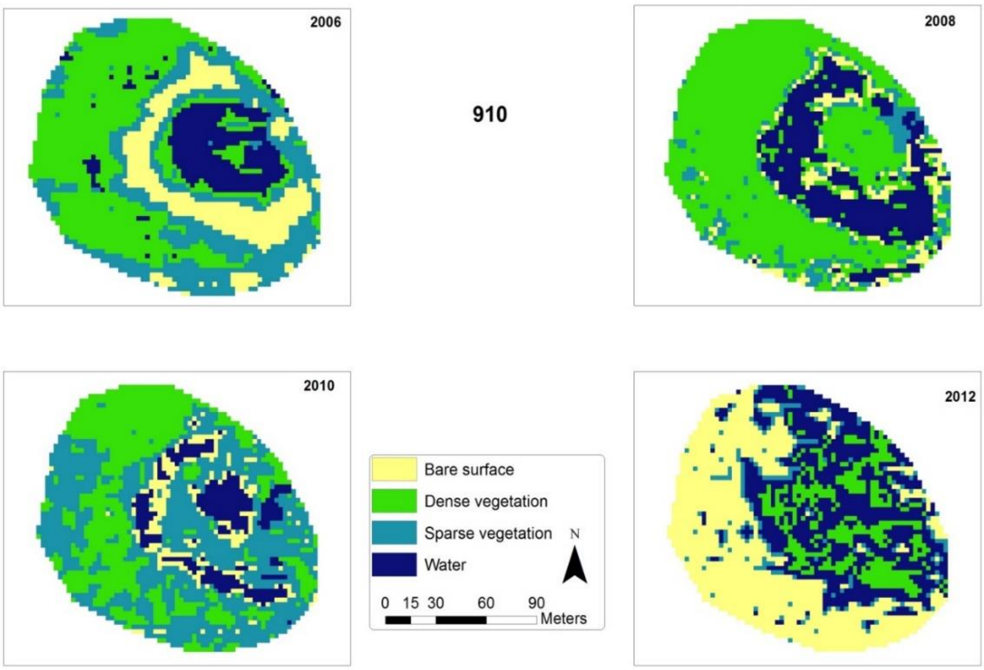

Figure 5.1: Supervised classification for 2006, 2008, 2010 and 2012 illustrating land cover classes for wetland site 910.

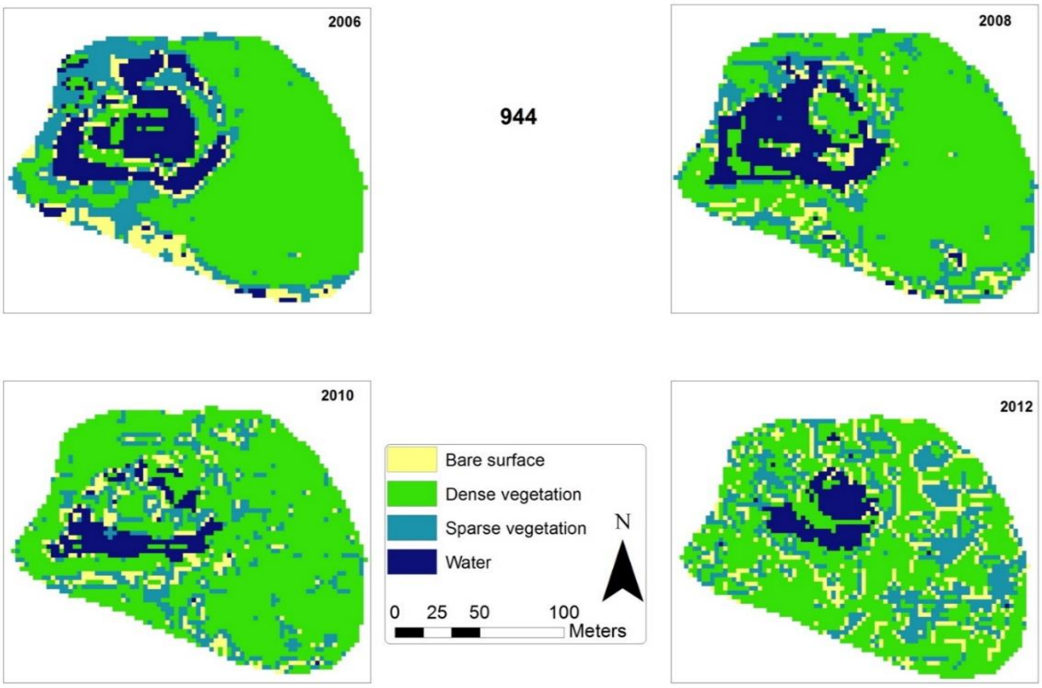

Figure 5.2: **Supervised classification for 2006, 2008, 2010 and 2012 illustrating land cover classes for wetland site 944.**

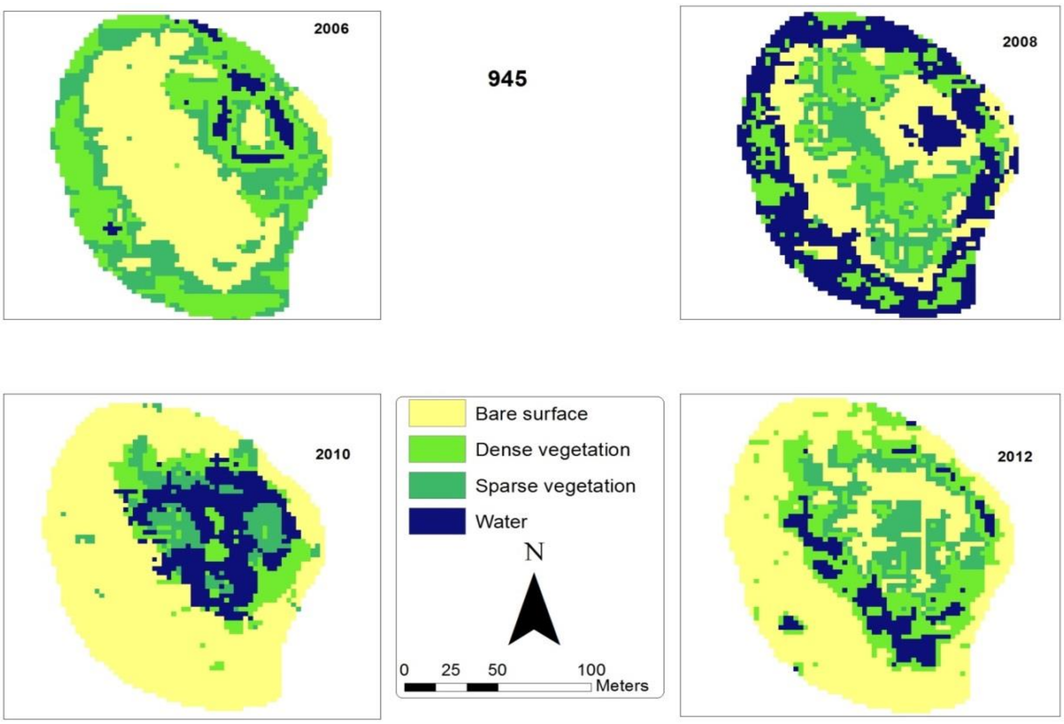

Figure 5.3: **Supervised classification for 2006, 2008, 2010 and 2012 illustrating land cover classes for wetland site 945.**

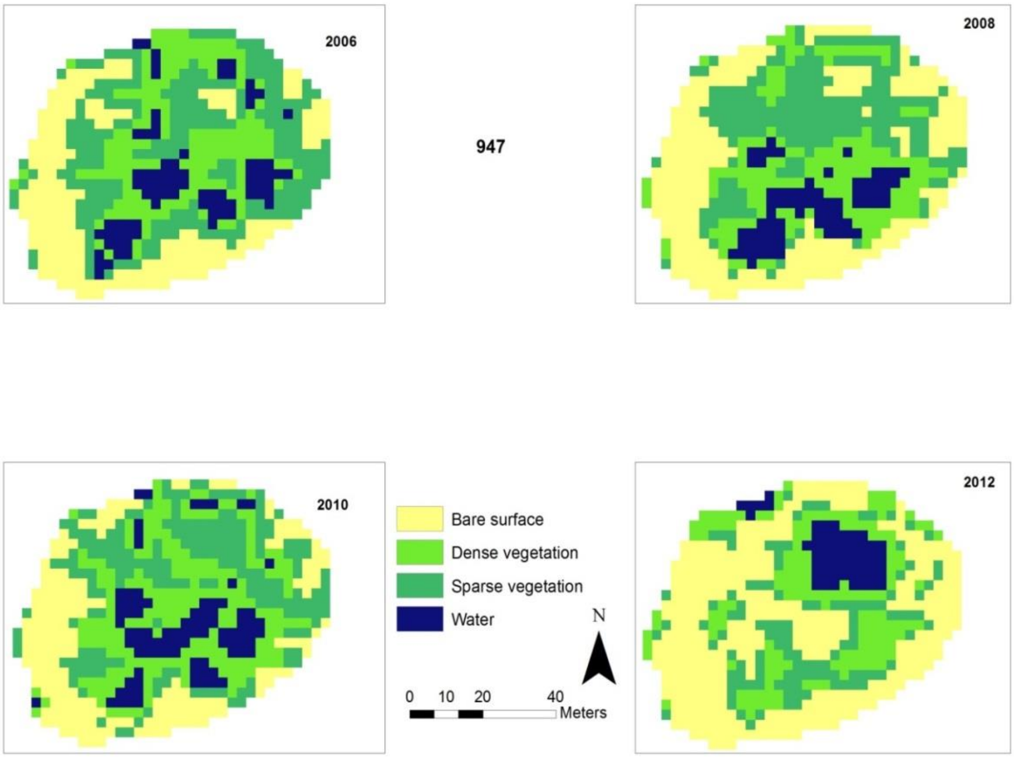

Figure 5.4: **Supervised classification for 2006, 2008, 2010 and 2012 illustrating land cover classes for wetland site 910.**

5.4 Land cover trends

Using cross-tabulation facility in Idrisi Kilimanjaro to analyse the distribution of land cover classes, changes in land cover classes were quantified and are presented in Figures 5.5 to 5.8. Rainfall patterns varied between the years. The year 2008 was during the drought period referred in Table 4.3. This could affect all the sites equally; however the greater proportion of bare surface in the NM MOSS sites than the Conservancy sites is noticeable (Figures 5.5 to 5.8). The trend in the Hopewell Conservancy sites showed land cover percentage of the bare surface area decreased between 2006 and 2012. At site 944 in 2006 bare surface area was 10 % with incremental decreases in subsequent years of 10, 12 and 5 % (Figures 5.1 and 5.4). The proportions of water and dense vegetation are noticeably greater in site 944 (Figures 5.1 and 5.4). In the NMB MOSS sites, the proportion of bare surface area at both sites is quite prominent in all years, but decreased in 2012 (Figures 5.7 and 5.8). For example in site 947, the bare surface was 41 % in 2006, 27% in 2008, 66% in

2010 and 36 % in 2012 of the total area (Figures 5.3 and 5.8). The prominence of bare surface in all years may be due to anthropogenic pressure.

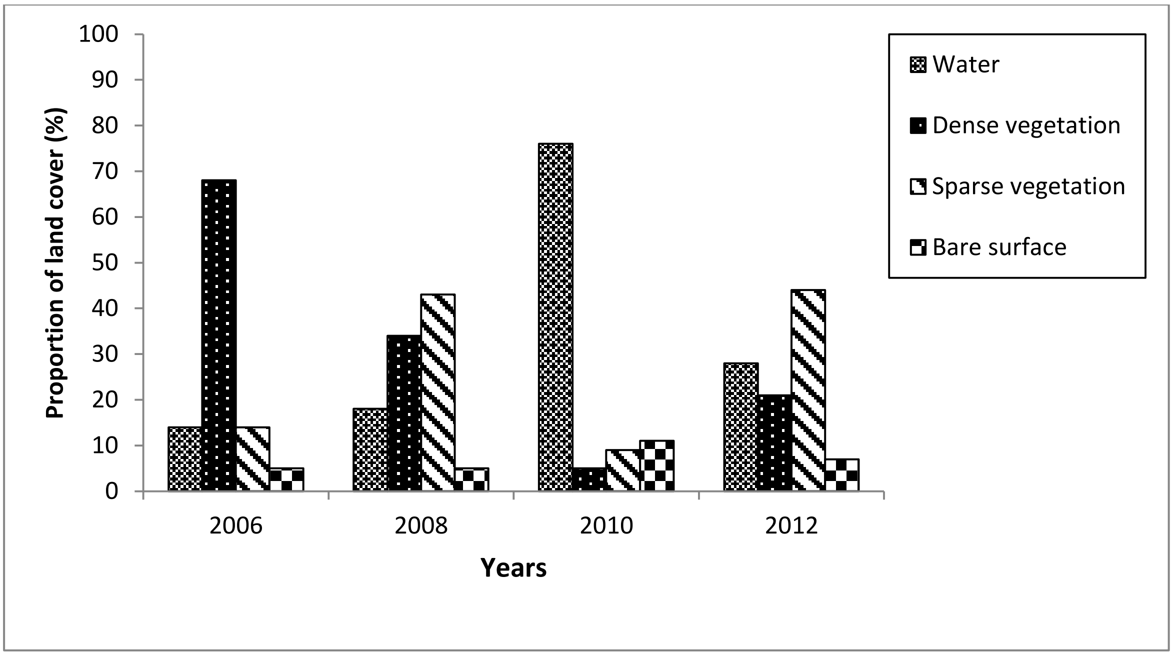

Figure 5.5: **Change in land cover classes for 910, conserved wetland site from 2006 to 2012.**

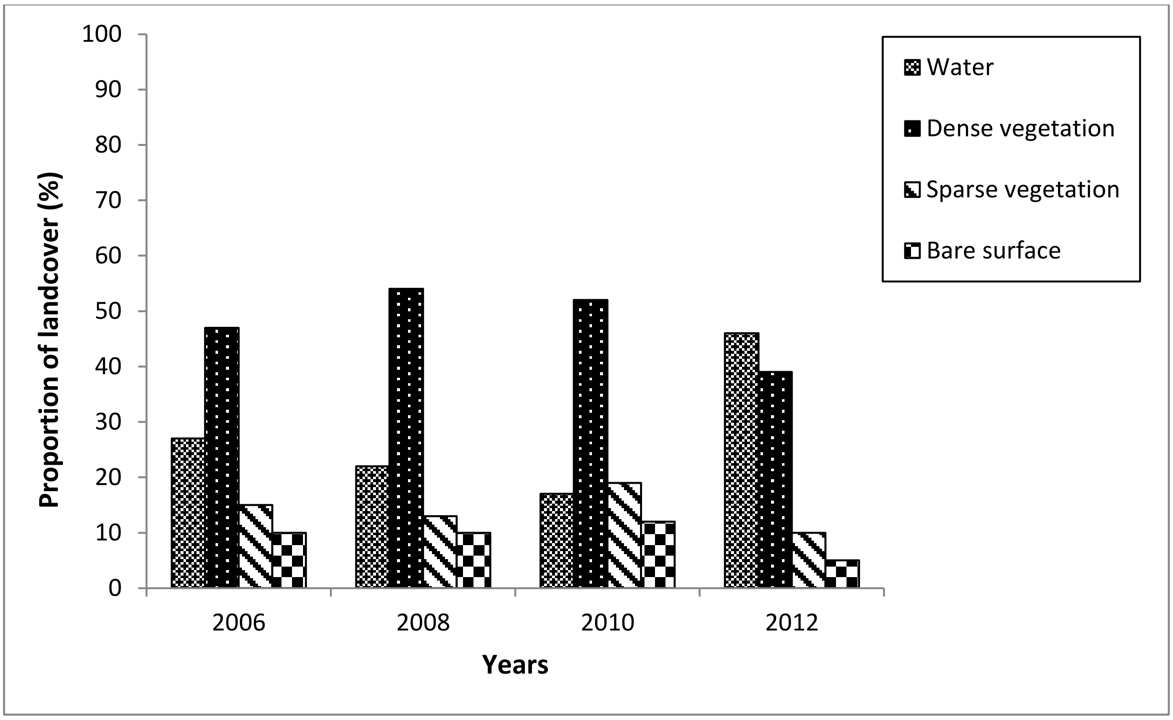

Figure 5.6: **Change in land cover classes for 944, conserved wetland site from 2006 to 2012.**

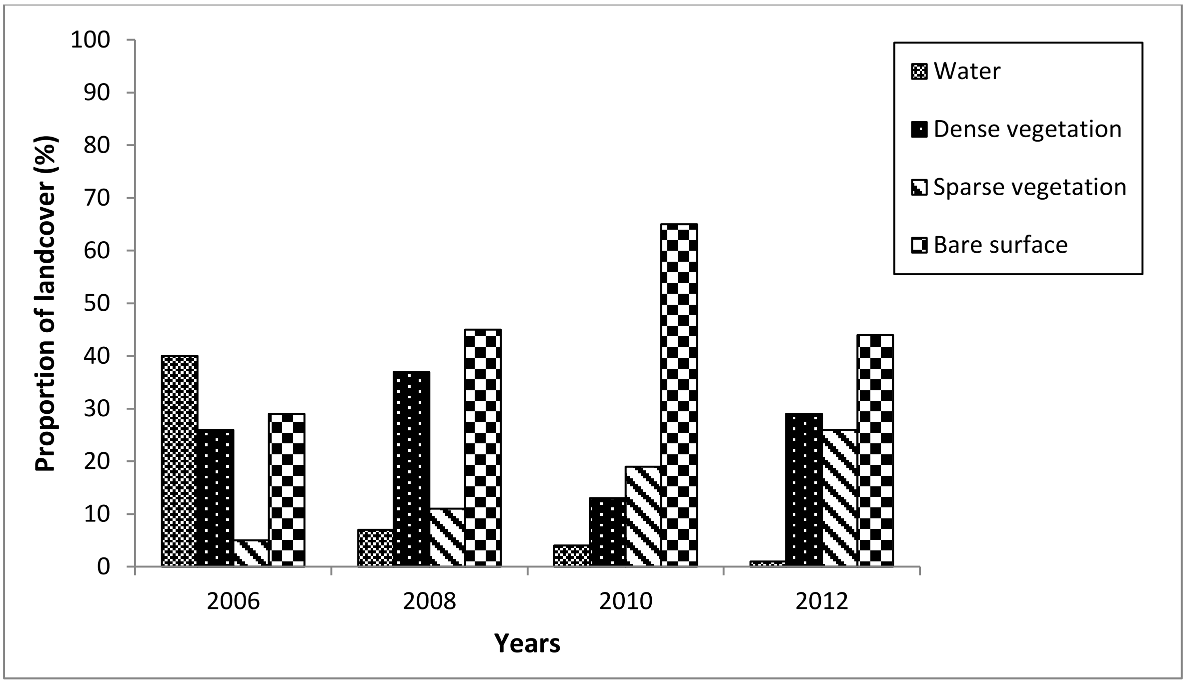

Figure 5.7: **Change in land cover classes for 945, non-conserved wetland site from 2006 to 2012.**

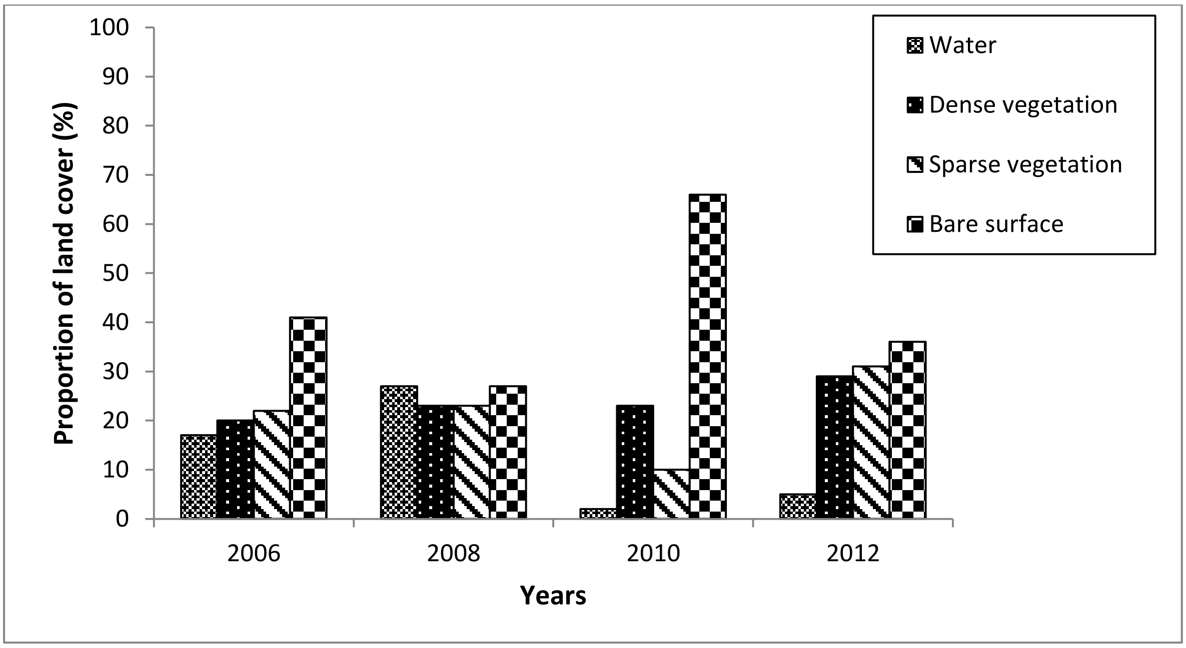

Figure 5.8: **Change in land cover classes for 947, non-conserved wetland site from 2006 to 2012.**

5.5 Cross-classification

Cross-classification comparison was performed to obtain change statistics; from one land cover to another over a specific period. This was done in order to assess and compare temporal and spatial conversion changes from one land cover type to another in vegetation between wetlands of different management regimes. Results for the wetlands in conserved area are presented in Tables 5.2 & 5.3, while the ones for NMB MOSS area are presented in Tables 5.4 and 5.5 showing a conversion from a particular land cover class to another land cover class, with their converted percentage area.

A large change from water to dense vegetation of 59% between 2006 and 2008 and great change of 64% from dense vegetation to bare surface between 2006 and 2012 is also noticeable (Table 5.6). In site 944, a large conversion from sparse vegetation to dense vegetation from 2008 to 2010 of 71% is visible and 61% of conversion from bare surface to dense vegetation is significant between 2010 and 2012 (Table 5.7).

At site 947, a major change is noticeable between 2006 and 2008 whereby sparse vegetation was converted to bare surface by 80% and more change of 53% from bare surface to sparse vegetation is conspicuous (Table 5.8). Between 2006 and 2008 for site 947 there is a considerable conversion of 43% from water to dense vegetation and a perceptible change of 38% from sparse vegetation to dense vegetation between 2008 and 2010 (Table 5.9).

Table 5.3: **Land cover changes of wetland site 910.**

From class	To class	Area (%)	Year
Water	Dense vegetation	59	2006-2008
	Sparse vegetation	14	
	Bare surface	9	
Dense vegetation	Water	22	2006-2012
	Sparse vegetation	8	
	Bare surface	64	
Sparse vegetation	Water	7	2008-2010
	Dense vegetation	29	
	Bare surface	2	
Bare surface	Water	47	2010-2012
	Dense vegetation	40	
	Sparse vegetation	4	

Table 5.4: **Land cover changes of wetland site 944.**

From class	To class	Area (%)	Year
Water	Dense vegetation	30	2006-2008
	Sparse vegetation	11	
	Bare surface	11	
Dense vegetation	Water	3	2006-2012
	Sparse vegetation	27	
	Bare surface	17	
Sparse vegetation	Water	2	2008-2010
	Dense vegetation	71	
	Bare surface	8	
Bare surface	Water	12	2010-2012
	Dense vegetation	61	
	Sparse vegetation	13	

Table 5.5: Land cover changes of wetland site 945.

From class	To class	Area (%)	Year
Water	Dense vegetation	14	2006-2008
	Sparse vegetation	1	
	Bare surface	35	
Dense vegetation	Water	2	2006-2012
	Sparse vegetation	37	
	Bare surface	29	
Sparse vegetation	Water	0	2008-2010
	Dense vegetation	0	
	Bare surface	80	
Bare surface	Water	23	2010-2012
	Dense vegetation	10	
	Sparse vegetation	53	

Table 5.6: Land cover changes of wetland site 947.

From class	To class	Area (%)	Year
Water	Dense vegetation	43	2006-2008
	Sparse vegetation	18	
	Bare surface	4	
Dense vegetation	Water	2	2006-2012
	Sparse vegetation	24	
	Bare surface	36	
Sparse vegetation	Water	0	2008-2010
	Dense vegetation	38	
	Bare surface	0	
Bare surface	Water	3	2010-2012
	Dense vegetation	7	
	Sparse vegetation	8	

5.6 Vegetation survey results

The dominant plant species, in terms of cover and occurrence were from four families, namely: Poaceae, Cyperaceae, Juncaceae, and Typhaceae. Not all families had representative species that were dominant at each site. The dominant families were: Asteraceae, Celestraceae, Apicaceae, Hypoxidaceae, Asparagaceae, Hydrocharitaceae, Lobelliaceae and Aponogetonaceae. The plant species common in all four wetland sites was in *Sporobolus africanus*. Although certain plant species were not dominant at sites, that does not mean they were absent. Quarterly surveys at sites 944 and 947 show shifts in species composition and dominants. Plant species that remained dominant over time were *S.africanus*, *Sporobolus fimbriatus*, *Paspalum distichum*, *Schoenoplectus decipiens*, *Eleocharis* sp. and *Typha capensis*. The reason for the dominance of these plant species over time can be attributed to the fact that they are primarily facultative wetland plant species with a mix of obligate wetland plants. Plant species like *Setaria lindenbergiana* was not dominant in most of seasons because it is found in terrestrial habitat. Site 910 was dominated by five species, two grasses, Poaceae (*C. dactylon* and *S. africana*) two sedges, Cyperaceae (*S. decipiens*, *Cyperus* sp.) and Juncaceae, *Juncus* sp. Figures 5.9, 5.10 and 5.11 represent the results of the dominant families identified and their zones demarcated in each wetland site surveyed. The dominant plant species found within each family are listed in Tables 5.9 and 5.10.

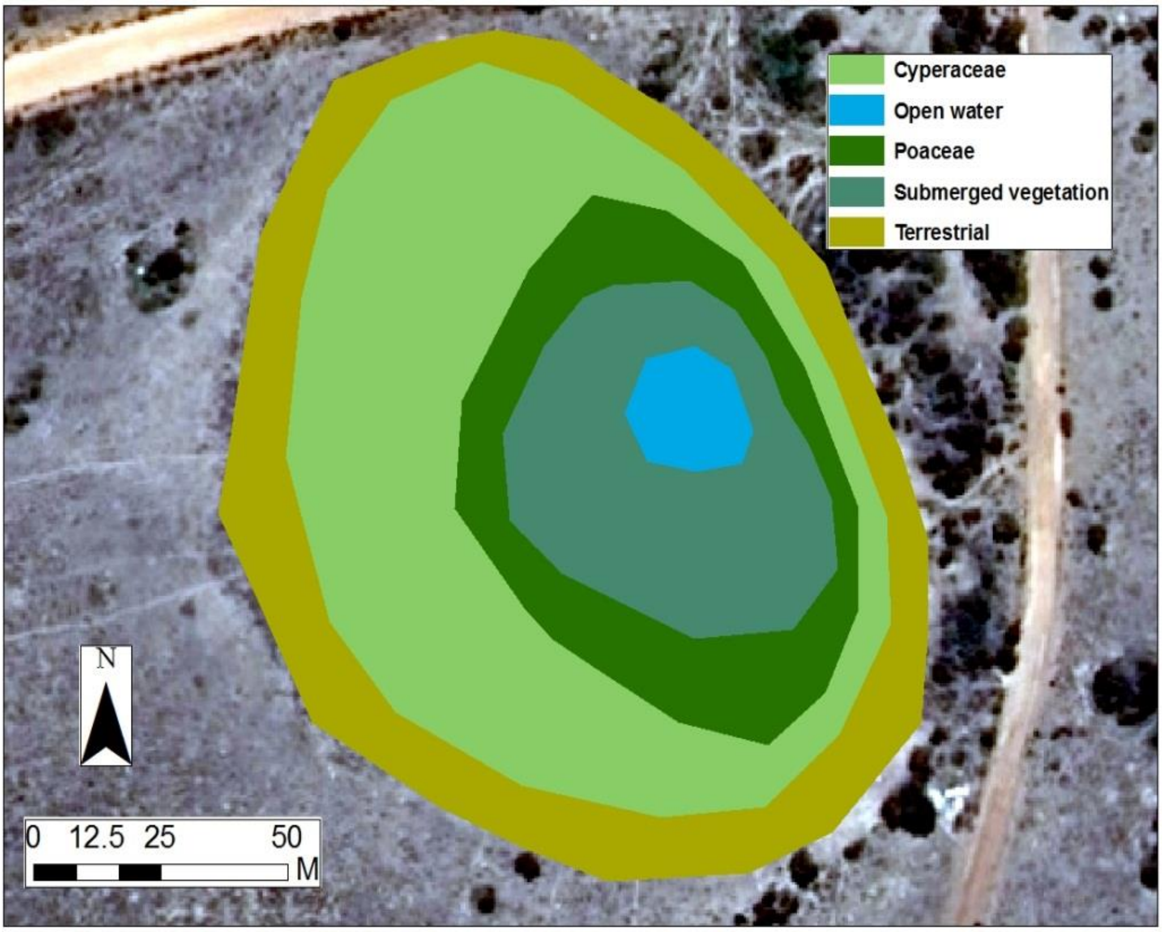

Figure 5.9: **Dominant vegetation cover from vegetation surveys conducted in summer, February 2013 overlaid on an aerial photograph of wetland site 910.**

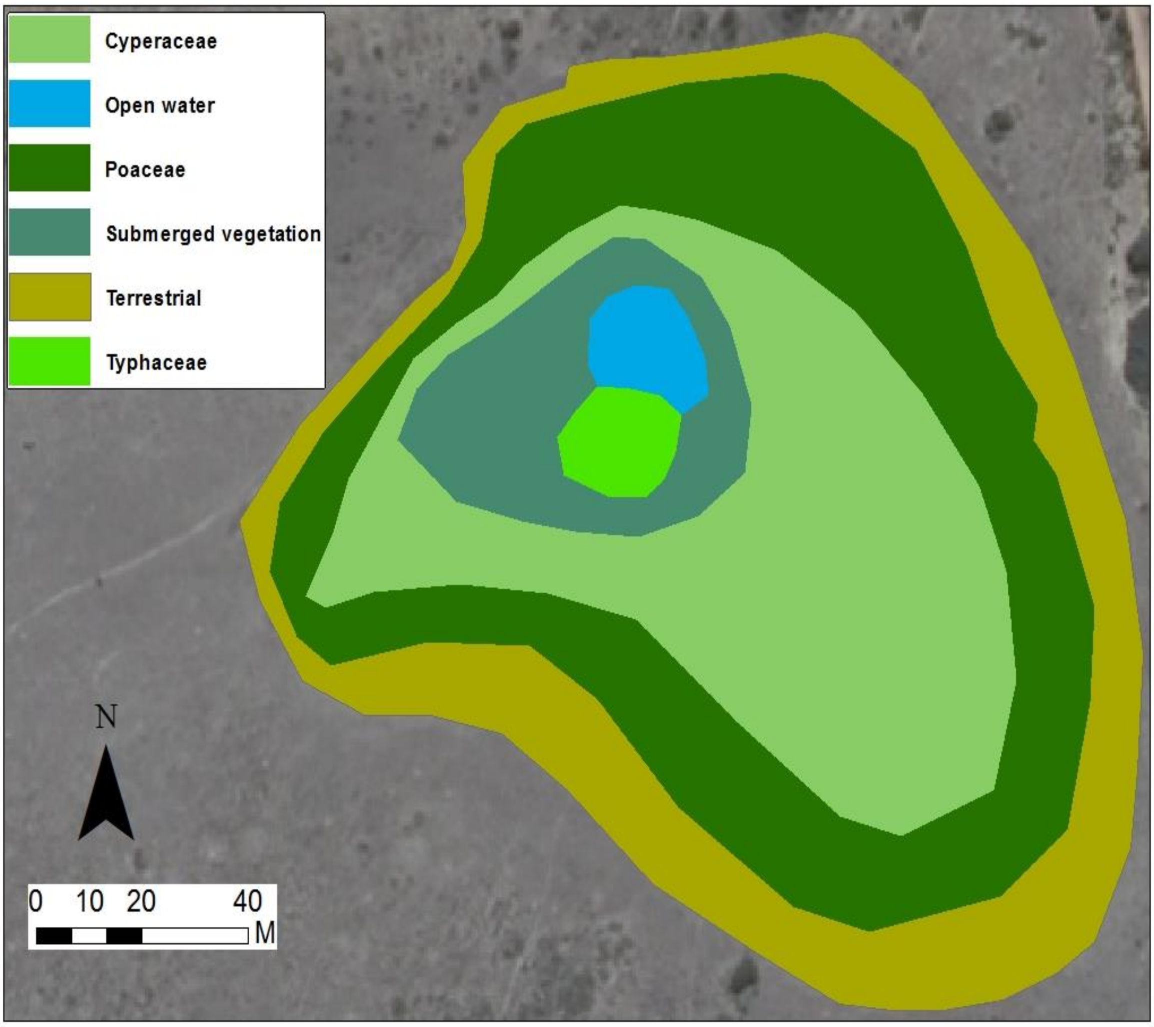

Figure 5.10: **Dominant vegetation cover from vegetation surveys conducted in different season from November 2012 to February 2014 overlaid on an aerial photograph on wetland site 944.**

Table 5.7: Dominant plant species, listed by family, identified in wetland site 944 between November 2012 and February 2014.

Date	Poaceae	Cyperaceae	Typhaceae
Nov-12	*Setaria lindenbergiana* *Sporobolus africana* *Sporobolus fimbriatus* *Themeda trianda* *Setaria sphacelata* *Bromus cartharticus*	*Schoenoplectus sp* *Isolepis setaca* *Isolepis fluitans* *Fuierena hirsute* *Eleocharis dregeana*	*Typha capensis*
Feb-13	*Setaria lindenbergiana* *Cynodon dactylon* *Paspalum distichum* *Leersia hexandra*	*Cyperus denudatus* *Eleocharis sp.*	*T. capensis*
May-13	*S. lindenbergiana* *Digitaria sanguinalis* *P. distichum* *L. hexandra*	*C. denudatus*	*T. capensis*
Jul-13	*P. distichum*	*E. dregeana* *Eleocharis sp*	*T. capensis*
Oct-13	*S. fimbriatus*	*Schoenoplectus sp.*	*T. capensis*
Feb-14	*Digitaria sp.* *P. distichum* *L. hexandra*		*T. capensis*

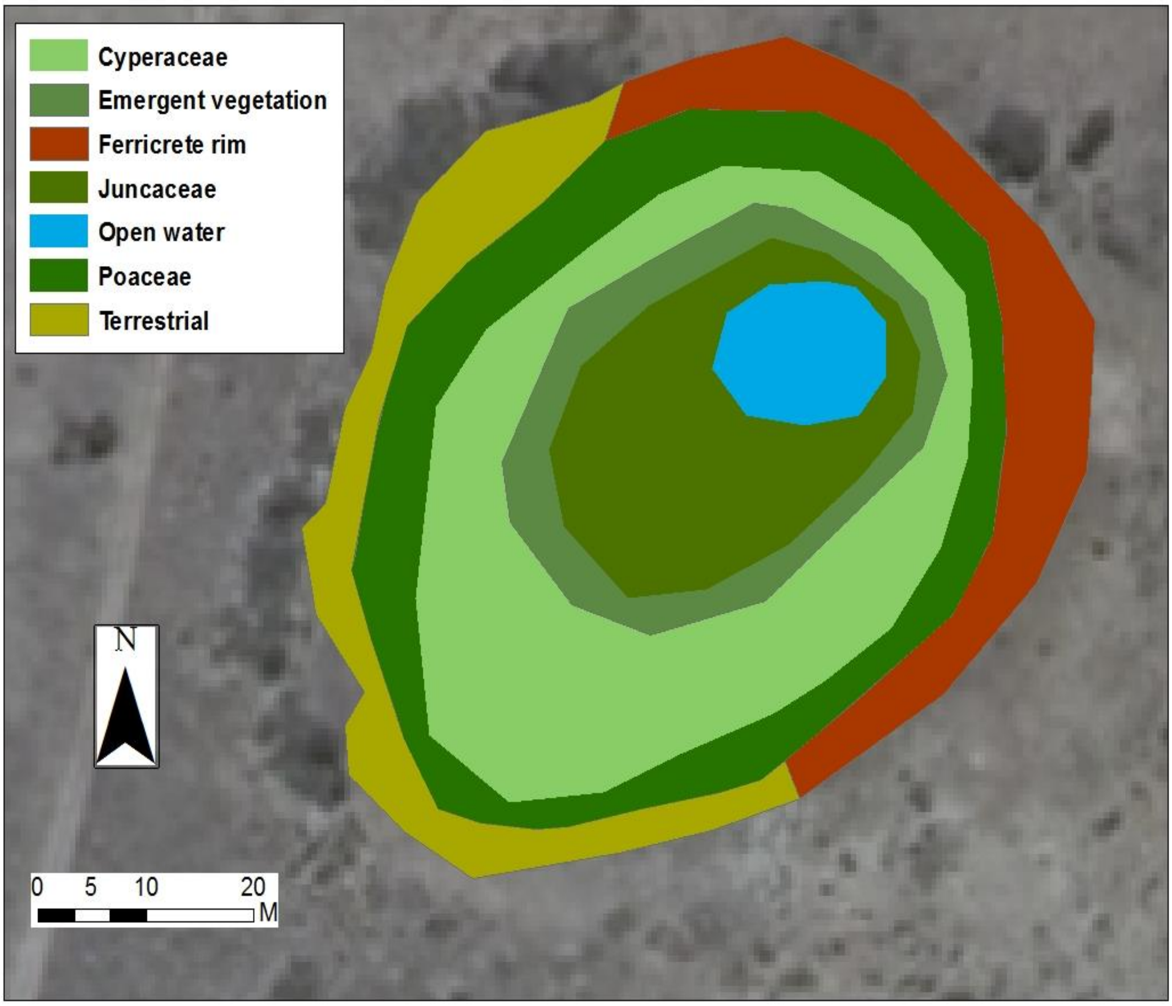

Figure 5.11: **Dominant vegetation cover from vegetation surveys conducted in different season from November 2012 to February 2014 overlaid on an aerial photograph on wetland site 947.**

Table 5.8: **Dominant plant species, listed by family, identified in wetland site 947 from Nov 2012 to Feb 2014.**

	Taxon (Family)		
Date	**Poaceae**	**Cyperaceae**	**Juncaceae**
Nov-12	*Paspalum* sp. *Andropogon* sp.	*Isolepis cernua* *Eleocharis* sp. *I. fluitans* *I. setaca* *S. decipiens*	*Juncus dregeana*
Feb-13	*S. fimbriatus* *S. africanus* *Digitaria ternate* *P. distichum*	*Carpha glomerata* *Eleocharis sp* *Schoenoplectus sp*	*T. capensis*
May-13	*Cynodon* sp. *S. africana* *P. distichum*	*I. fluitans*	*Juncus krassui* *Juncus* sp.
Jul-13	*Stenotaphrum* sp. *P. distichum* *S. fimbriatus* *S. africana*	*Cyperus* sp. *Schoenoplectus sp* *Eleocharis* sp.	
Oct-13	*Cynodon* sp. *P. distichum*	*Schoenoplectus sp.* *Cyperus sp.* *Isolepis sp.*	
Feb-14	*P. distichum* *L. hexandra*	*C.denudatus* *Schoenoplectus sp* *Cyperus* sp.	

5.7 Wetland vegetation spectral responses

Most wetland vegetation exhibit similar spectral reflectance curves when trying to discriminate them using traditional methods like visual interpretation. Both conserved and under-managed areas, showed similar trends in terms of spectral reflection responses (Figures 5.12 to 5.16). There is a low reflectance in visible part due to photosynthetic pigment absorptions in all plant species, however low peaks in green wavelength are observed in *C. dactylon, T. capensis* and *I. sepulcralis* (Figures 5.12, 5.13 and 5.16). These plant species were greener than all other species hence the peak in the green wavelength. In terms of the red edge position (REP), *C. dactylon, T. capensis* and *I. sepulcralis* had a steeply red edge, which could be related to the greenness of these plants (Figures 5.12, 5.13 and 5.16). Reflectance is highest in the near infrared region between 700 and 1300 nm due to lack of strongly absorbing materials in plants. However, the three above mentioned plant species reflected strongly than all other species.

Strong water absorption features are found around 1450 nm. Spectral reflectance curves for each plant species can be unique and used as a spectral signature. There are changes in reflectance that are related to the health of the plant, that when known can be used to assess the overall health of the wetland vegetation. In order to make these comparisons in terms of the health of plant species, their spectral signatures need to be determined first when healthy. It is also important to determine which plants can be clearly distinguished from others. Then we can use this baseline reflectance data to discriminate between plant types and also determine overall health.

The results of the spectral reflectance signatures of dominant plant species in each wetland site are shown in Figure 5.12 to 5.15. Each spectral curve represents a different plant species. *S. africana* was one of the dominant species in all four wetlands, showing that there is little difference between the curves from site to site, Figure 5.16. *S. africana* showed that there was a significant difference between all four sites, p-value =0.000, however after the application of Tukey HSD, only sites 945 and 947 showed significant differences (Table 5.15). It is also clear that some species in the conservation area, i.e. *T. capensis*, have a more distinct signature than other plant species (Figure 5.13), *C. dactylon* reflected strongly in the near infrared region, with a steeply rising red edge than all other plant species found in wetland site 910 (Figure 5.12). In the NMB MOSS sites, *S. decipiens* had a higher reflectance response than *S. africana* in wetland site 945 (Figure 5.14). *I. sepulcralis* in site 947 had a strong reflectance in the NIR with a steeply red edge than all other plant species (Figure 5.15).

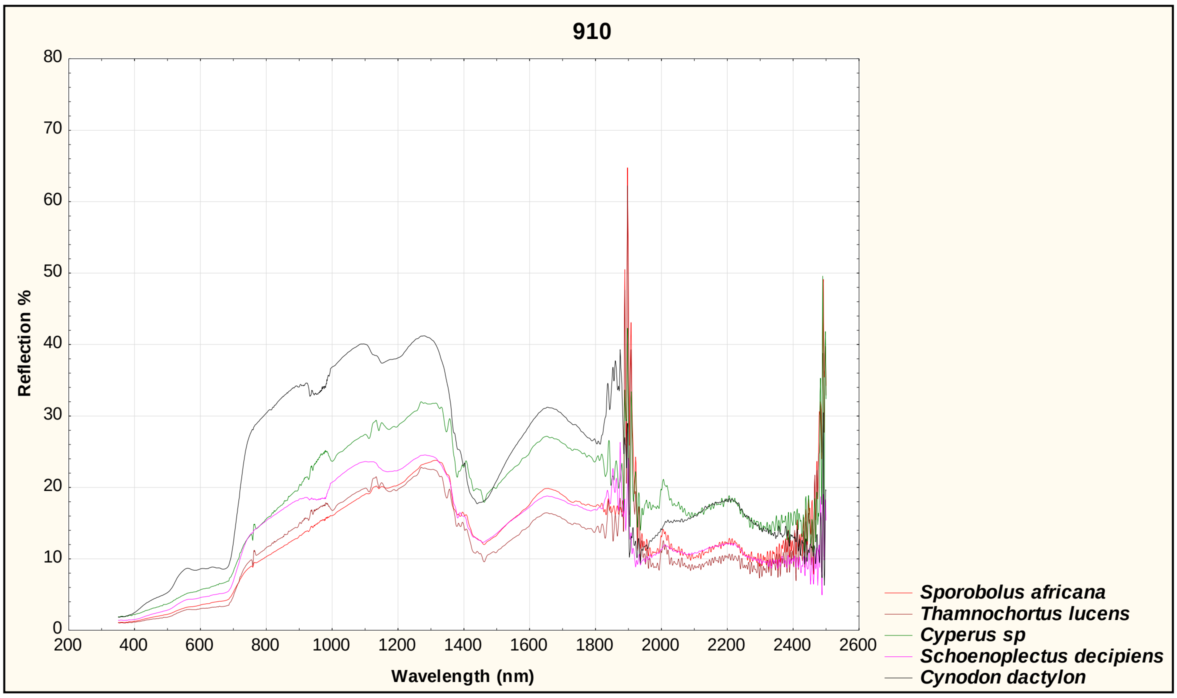

Figure 5.12: **Dominant plant species reflectance curves for the wetland site 910, conserved area.**

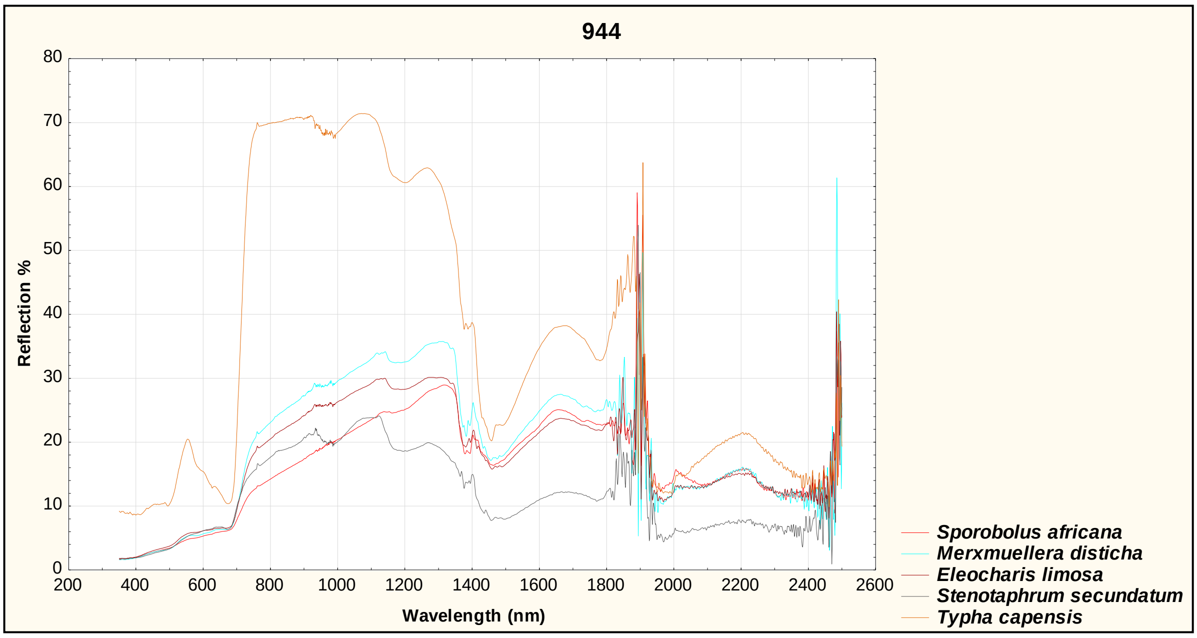

Figure 5.13: **Dominant plant species reflectance curves for wetland site 944, conserved area.**

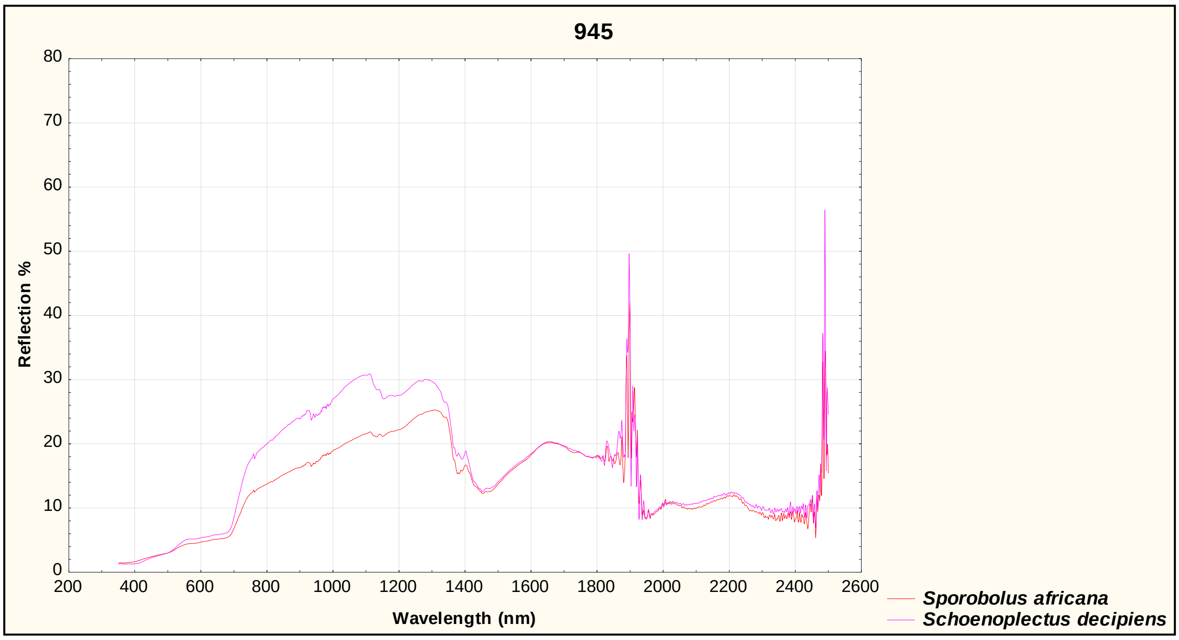

Figure 5.14: **Dominant plant species reflectance curves for wetland site 945, under-managed area.**

Figure 5.15: **Dominant plant species reflectance curves for the wetland site 947, under-managed area.**

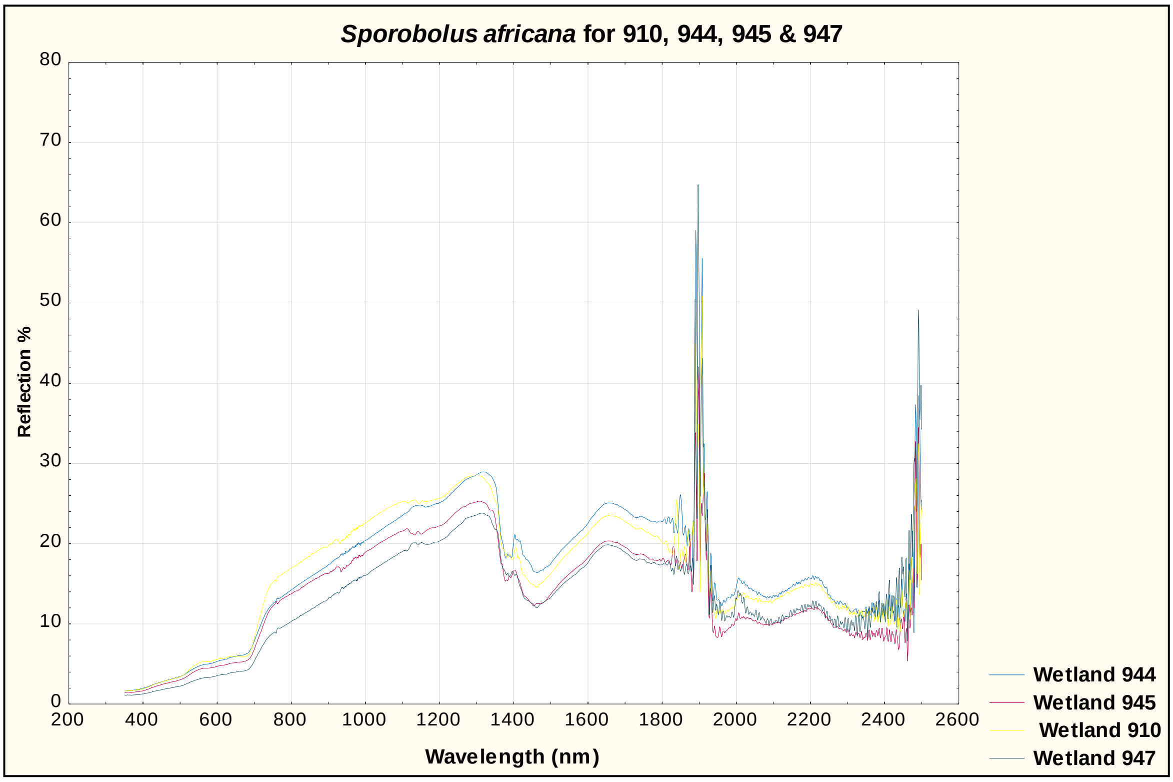

Figure 5.16: ***Sporobolus africana* reflectance curves for sites 910, 944, 945 and 947.**

5.8 Discriminating wetland vegetation using the Normalized Difference Vegetation Index and the red edge position

In order to discriminate wetland vegetation spectral responses, REP and NDVI values were analysed. REP and NDVI are indicators of chlorophyll concentration hence they were used to assess health of the dominant vegetation species of the conserved and under-managed areas. These results correspond to the above presented spectral reflectance curves in section 5.5. The higher the reflectance curve especially in the NIR region of the electromagnetic spectrum, the higher the NDVI, or REP value. The following box plots (Figure 5.19 to 5.25) show the spread of mean, standard error and confidence interval of each vegetation species and each wetland produced by NDVI and REP using the linear interpolation technique (Lin Inter).

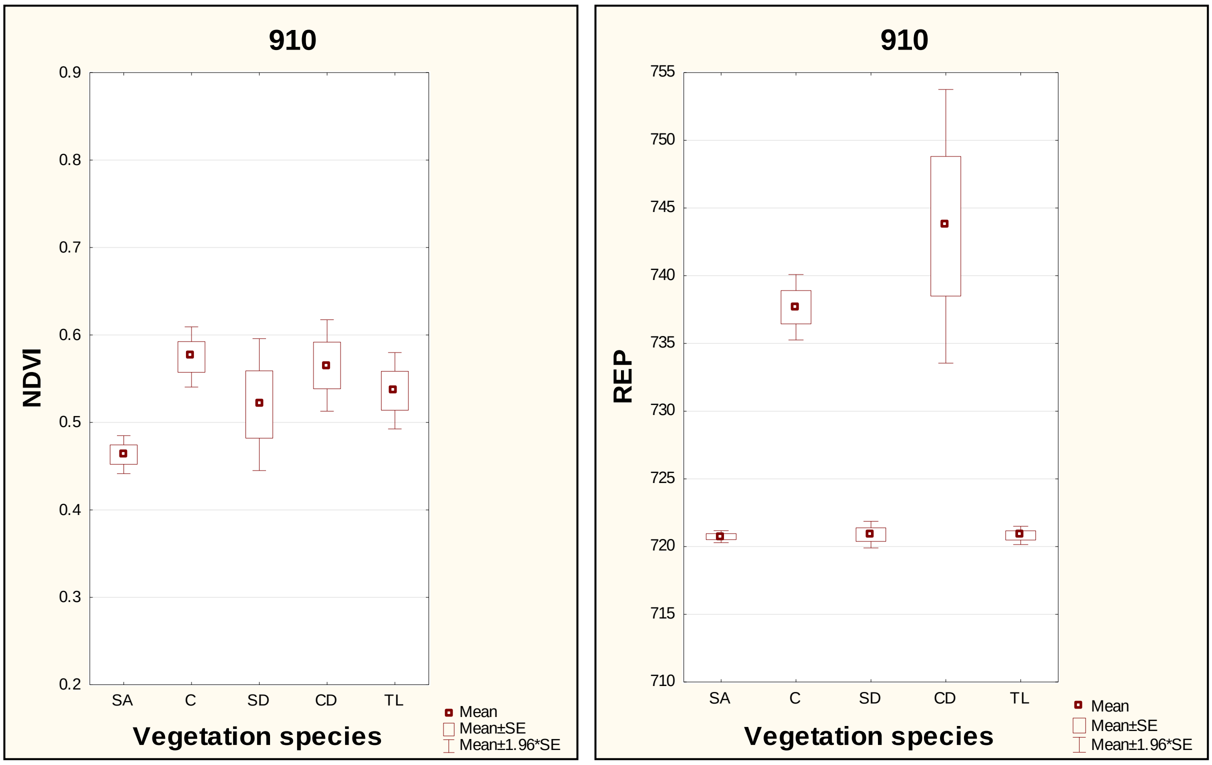

Figure 5.17: **Box plots for wetland site 910 showing the spread of mean, standard error and confidence interval of each vegetation species produced by REP and NDVI. SA = *Sporobolus africana*, C = *Cyperus* spp., SD = *Schoenoplectus decipiens*, CD = *Cynodon dactylon*, TL = *Thamnochortus lucens*.**

NDVI and REP results for wetland 910 species showed significant differences (p-values, 0.001 & 0.000). *C. dactylon* had the highest REP mean of 744 nm obtained using Lin Inter technique followed by *Cyperus* sp., *S. decipiens* , *T. lucens* and *Sporobolus africana*. NDVI results showed that *Cyperus* spp. and *Cynodon dactylon* had the highest NDVI mean value of 0.57 followed by *T. lucens*, *Schoenoplectus decipiens* and *S. africana.*

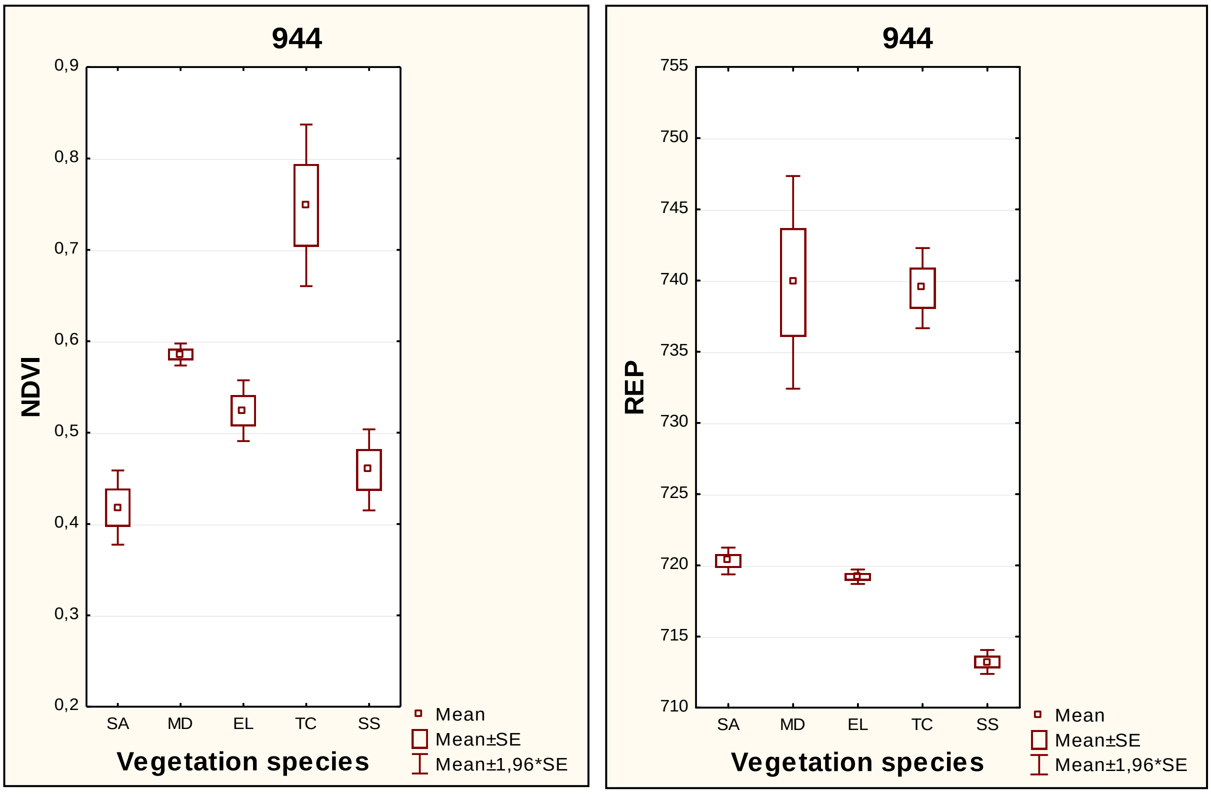

Figure 5.18: **Box plots for wetland site 944 showing the spread of mean, standard error and confidence interval of each vegetation species produced by REP and NDVI. SA = *Sporobolus africana*, MD = *Merxmuellera disticha*, EL = *Eleocharis limosa*, TC = *Typha capense*, SS = *Stenotaphrum secundatum*.**

NDVI and red edge position results for 944 wetland site showed a significant difference (p-values, 0.000 & 0.000). *M. disticha* and *T. capense* had the highest REP value of 740 nm, followed by *S. africana*, *E. limosa* and *Stenotaphrum secundatum*. In terms of NDVI, *T. capense* had the highest mean value followed by *M. disticha*, *E. limosa*, *S. secundatum* and *S. africana*.

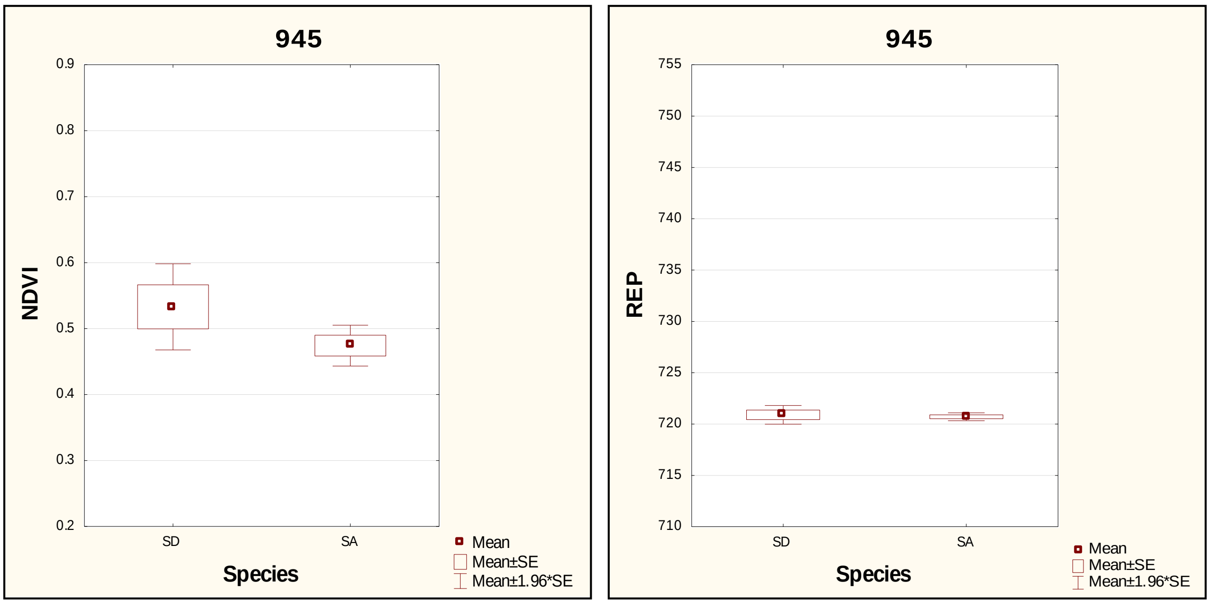

Figure 19: **Box plots for wetland site 945 showing the spread of mean, standard error and confidence interval of each vegetation species produced by REP and NDVI. SA = *Sporobolus africana* and SD = *Schoenoplectus decipiens*.**

There was no significant difference for the NDVI and slightly difference between *S. decipiens* and *S. africanus* for REP results in site 945 (p- values, 0.69 and 0.1). *S. decipiens* had a higher REP mean value of 720.90 nm than *S. africanus*. It also had a higher NDVI value 0.53 than *S. africanus*.

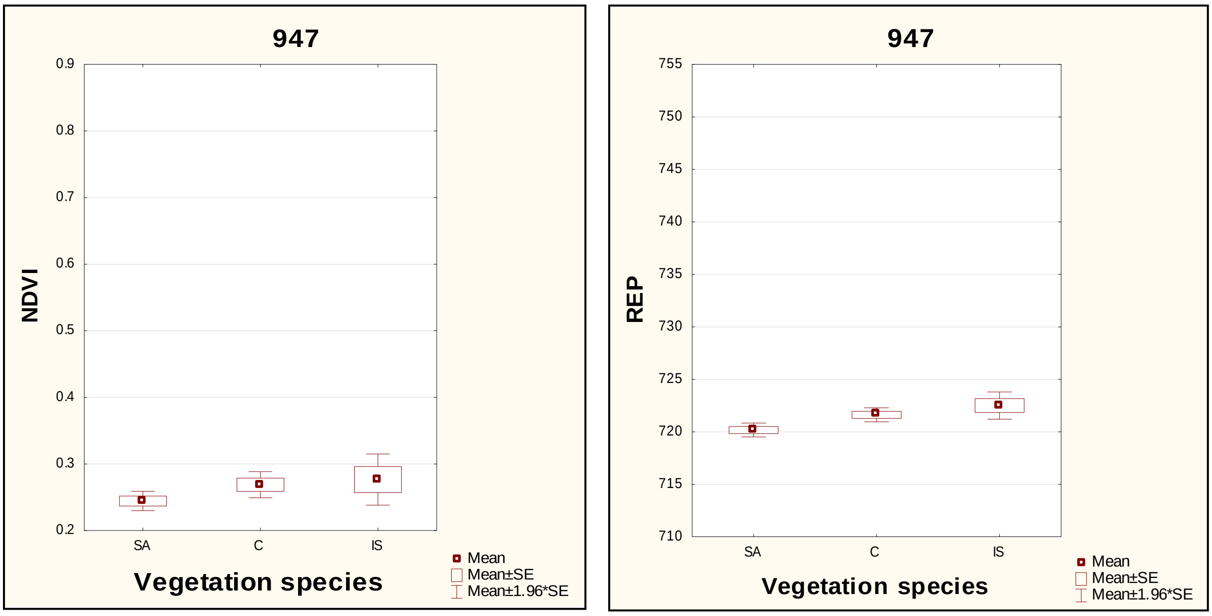

Figure 5.20: **Box plots for Wetland site 947 showing the spread of mean, standard error and confidence interval of each vegetation species produced by REP and NDVI. SA = *Sporobolus africana*, C = *Cyperus* spp., IS = *Isolepis sepulcralis*.**

NDVI showed a slight significant difference with a p-value of 0.134 whereas REP showed a significant difference between *I. sepulcralis*, *Cyperus* sp and *S. africanus* with a p-value of 0.02. *I. sepulcralis* had the highest NDVI and REP values between *Cyperus* sp and *S. africanus.*

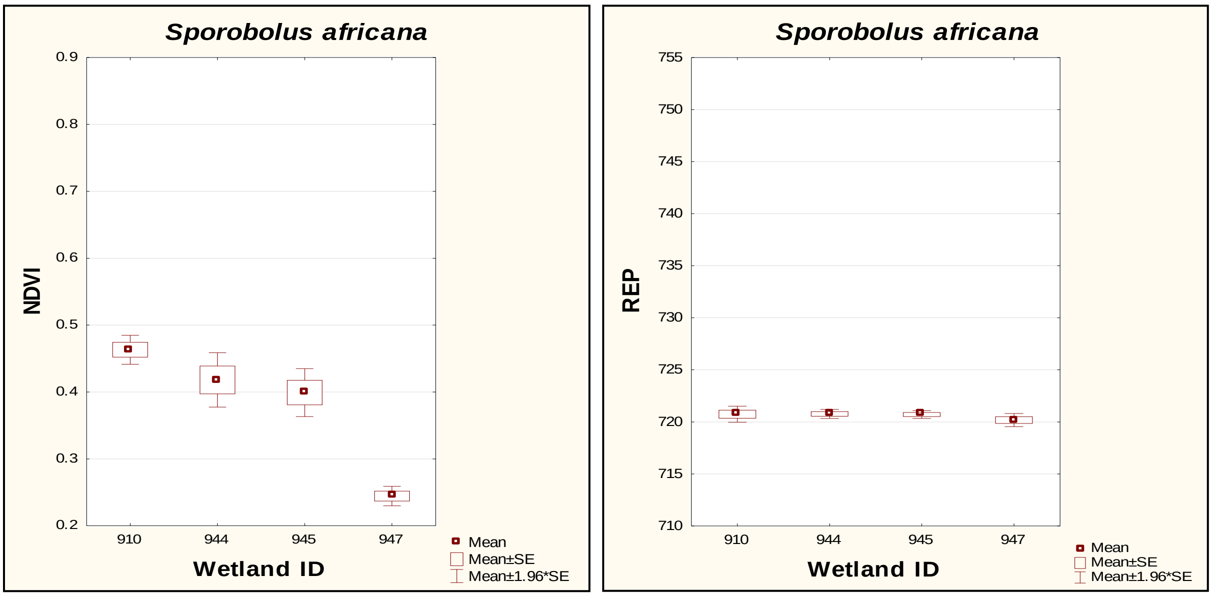

Figure 5.21: **Box plots for S.*africana* showing the spread of mean, standard error and confidence interval of each wetland site produced by REP and NDVI.**

S. africana, which is a common dominant species at all four sites, showed significant differences in all four wetland sites on the NDVI results, p-value of 0.000. However, REP showed no significant differences at all four sites, p-value of 0.339.

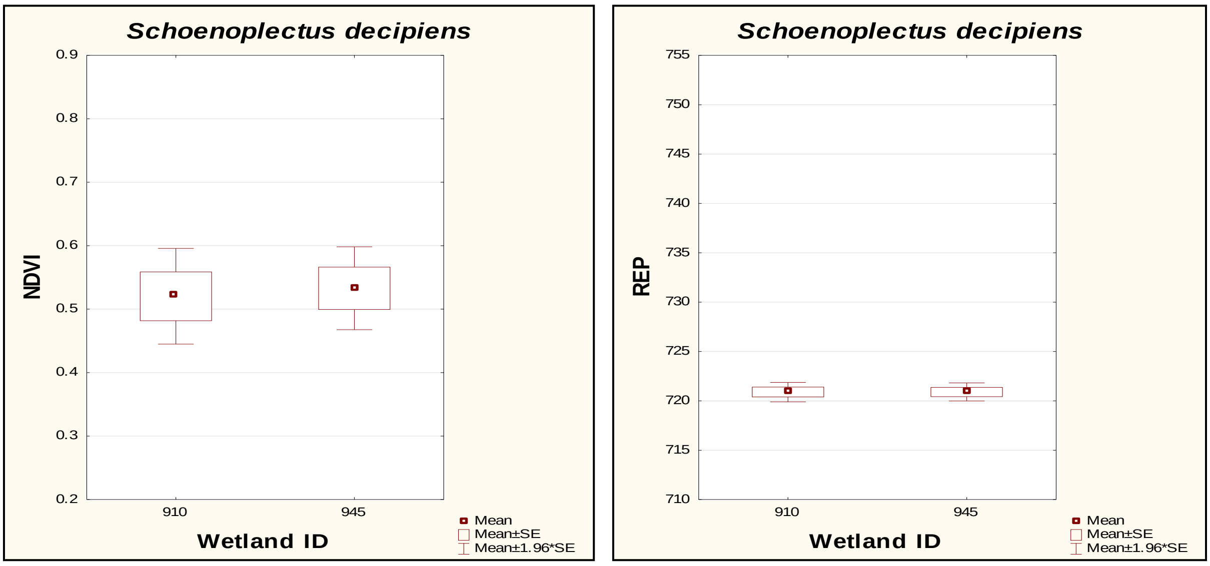

Figure 5.22: **Box plots for S.*decipiens* showing the spread of mean, standard error and confidence interval of wetland sites 910 and 945 produced by REP and NDVI.**

S. decipiens, which is a common species between wetland 910 and 945 showed no significant difference between two sites. NDVI showed p-value of 0.807 and t-value of -0.248 while REP showed a p value of 0.992 and t-value of -0.010.

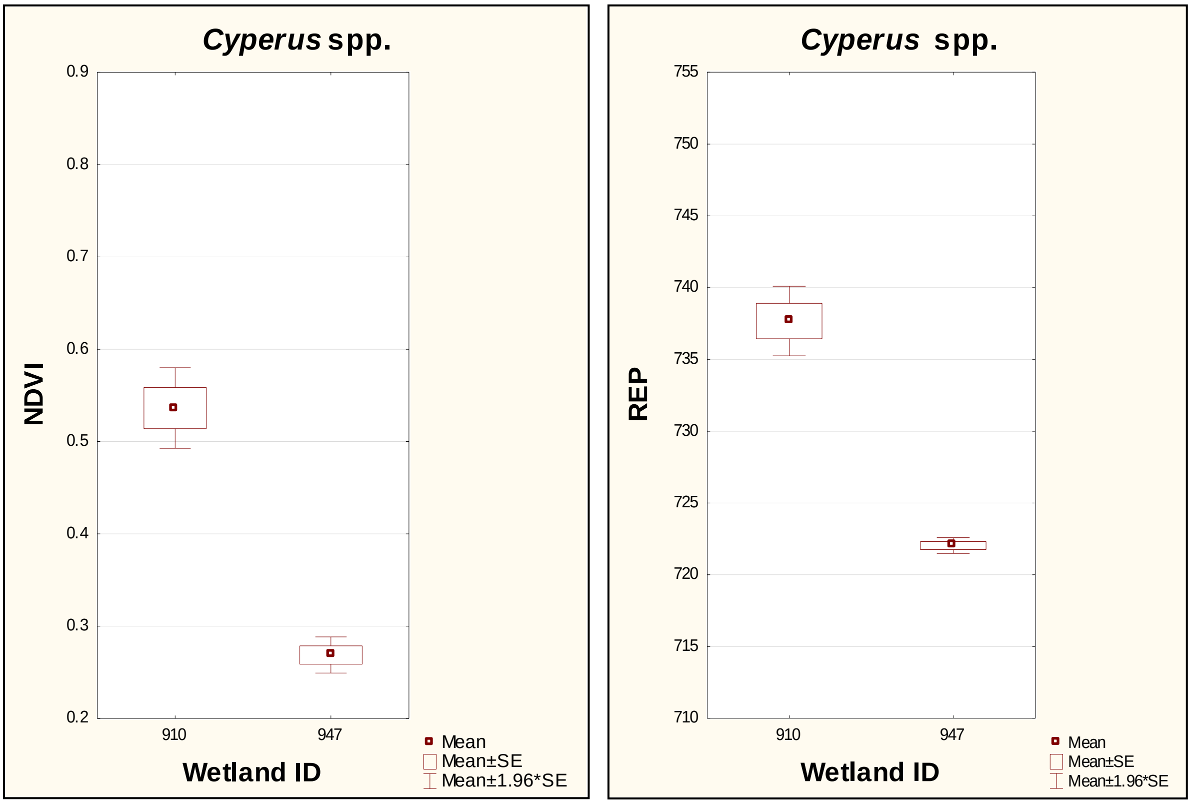

Figure 5.23: Box plots for *Cyperus* sp. showing the spread of mean, standard error and confidence interval of wetland sites 910 and 947 produced by REP and NDVI.

A dominant and common species, *Cyperus* sp. identified in wetland sites 910 and 947 showed a significant difference between two sites in NDVI and REP values with a p-value of 0.000. T-values for NDVI and REP were 8.743 and 9.449.

One-way ANOVA and Student's T-tests were conducted and they indicated that hyperspectral remote sensing data could be used to distinguish some wetland vegetation at species level. As mentioned in section 4.2.2, ten plant species were selected based on their percentage cover. These plant species were representatives of two major plant taxa of grasses and reeds (Poaceae) and sedges (Cyperacae). *S. africana* is a grass that was common at all 4 sites. *S. decipiens* and *Cyperus* sp, common sedges were dominant in sites 910, 945 and 947. Plant species common to all or most sites were tested using one-way ANOVA or Student's T-test to determine if the spectral reflectance of each plant species was the same between sites. Both NDVI and REP did not show any significant differences for *S. decipiens*.

Cyperus sp showed a significant difference for both NDVI and REP (p-value, 0.000). *S. africana* showed a significant difference only on the REP (p-value, 0.000).

Using four sites, two in the conservation area (910 and 944) and two in the open space (945 and 947), the REP and NDVI of the different plant species were compared (Figures 5.19, 5.20, 5.21 & 5.22). One-way ANOVA for both REP and NDVI showed that the reflectance spectra of most plant species were statistically different from one another (P< 0.05). However, one-way ANOVA did not show which specific pair of plant species were statistically different. Tukey's multiple comparison test showed that at site 910, *Cyperus* spp. and *T. lucens* were statistically different (P < 0.05), however the other species did not differ significantly (Tables 5.10 & 5.11). In site 944, *M.disticha, E.limosa and T.capense* were statistically different (P<0.05), however the other plant species did not differ differently (Tables 5.12 & 5.13). In site 947, *I. sepulcralis* was significantly different from the other plant species (P< 0.05). However, there was no significant difference between *S. africana* and *Cyperus* sp (Table 5.14). In terms of the common plant species, only NDVI showed a significant different between sites 945 and 947 for *S. africana,* sites 910 and 944 did not differ significantly (Table 5.15). Both NDVI and REP for *Cyperus* sp showed a significant differences between sites 910 and 944 (p-value of 0.000). Pairs of plant species that showed significant differences are highlighted in bold, significant at p <0.05.

Table 5.9: NDVI Tukey HSD results for wetland site 910, species codes are as follows: **SA = *Sporobolus africana*, C = *Cyperus* spp., SD = *Schoenoplectus decipiens*, CD = *Cynodon dactylon*, TL = *Thamnochortus lucens*.**

Veg species	SA	C	SD	CD	TL
SA					
C	**0.001**				
SD	0.351	0.502			
CD	0.062	0.999	0.837		
TL	**0.028**	0.649	0.988	0.944	

Table 5.10: REP Tukey HSD results for wetland site 910, species codes are as follows: **SA = *S. africana***, **C = *Cyperus*** sp, **SD = *S. decipiens***, **CD = *C. dactylon***, **TL = *T. lucens***.

Veg species	SA	C	SD	CD	TL
SA					
C	**0.012**				
SD	0.999	**0.012**			
CD	**0.012**	**0.043**	**0.012**		
TL	0.999	**0.000**	1.000	**0.012**	

Table 5.11: **NDVI Tukey HSD results for wetland site 944,** species codes are as follows**: SA = *S. africana***, **MD = *M. disticha***, **EL= *E. limosa,*** **TC= *T. capense,*** **SS= *S. secundatum.***

Veg species	SA	MD	EL	TC	SS
SA					
MD	**0.005**				
EL	**0.011**	0.648			
TC	**0.014**	**0.020**	**0.000**		
SS	0.874	0.174	0.603	**0.014**	

Table 5.12: **REP Tukey HSD results for wetland site 944,** species codes are as follows: **SA = *S. africana***, **MD = *M. disticha***, **EL= *E. limosa,*** **TC= *T. capense,*** **SS= *S. secundatum.***

Veg species	SA	MD	EL	TC	SS
SA					
MD	**0.013**				
EL	0.926	**0.000**			
TC	**0.013**	0.999	**0.013**		
SS	**0.010**	**0.000**	**0.050**	**0.013**	

Table 5.13: REP Tukey HSD results for site 947, species codes are as follows: **SA= *S. africana***, **C= *Cyperus*** sp, **IS= *I. sepulcralis*.**

Veg species	SA	C	IS
SA			
C	0.077		
IS	**0.001**	0.438	

Table 5.14: NDVI Tukey HSD results for *S. africanus* for all wetlands.

Wetland ID	910	944	945	947
910				
944	0.126			
945	**0.005**	0.832		
947	**0.002**		**0.002**	

5.9 Conclusion

In this chapter, vegetation condition between wetlands of different management regimes was assessed by looking at the changes in land cover classes and cross-classification in different years. Great proportions of water and dense vegetation land cover classes were observed in the conserved sites. Sites in the under-managed area exhibited a great proportion of bare surface land cover class. Furthermore, to discriminate wetland vegetation at species level using vegetation indices (red edge position and NDVI) derived from field hyperspectral data was covered in this chapter. Statistical analyses showed the significant differences of plant species in conserved sites, 910 and 944 when using NDVI and REP variables. Only one site in the NMB MOSS area that is 947 which showed significant difference and it showed only with REP results. The results presented in this chapter are discussed in the following chapter.

CHAPTER 6: DISCUSSION AND CONCLUSION

6.1 Introduction

This study aimed to determine if multi-temporal imagery can detect changes in ephemeral wetland ecosystems with different management levels and also given the fact that they have relatively small scale. This was done to compare and assess their temporal and spatial vegetation changes. Accuracy assessment for validating the reliability of the image classification results is covered. Trends in land cover classes between conserved and under-managed area are discussed in this chapter. This study further investigated whether the spectral information of dominant vegetation at species level within wetland ecosystems of different management regimes can be discriminated. This was done by using NDVI and REP variables. Recommendations for future research are suggested and overall summary and conclusion is drawn.

6.2 Accuracy assessment

Accuracy assessment is the integral part of the classification and mapping process. Classified maps were compared against referenced maps to provide an indication of the consistency of the classification. Classification was subject to an error as indicated by the error matrix in APPENDIX A, however, accuracy assessment results showed "substantial to almost perfect results". Since this study was done on small, ephemeral wetland ecosystems, difficulties were encountered in some land cover types. It was recognized that some of them would not be separable based on spectral reflectance values. Some were too small and showed inconsistent spectral value to produce adequate training data for example floating vegetation. According to Jiao *et al*., (2011), generally there is a unique challenge for remote sensing classification in wetland systems due to the complexity and heterogeneity of wetland vegetation causing difficulties to attain a good classification.

6.3 Land cover changes between the conservancy and NMB MOSS area wetland sites

In the present study, post-classification change detection analyses indicated that there was a high percentage of bare surface in the NMB MOSS area. When comparing bare surface area between two areas, NMB MOSS showed significant difference as opposed to conservancy area. This can be related to conservation status since public open areas are exposed to many anthropogenic activities. Conservancy sites showed a decrease in percentage of bare surface which might be attributed to the fact that the area, which is conserved now, was initially a series of farms fenced in 2009 that made a bare surface area percentage drop from 17% in 2006 to 7% in 2012. A reduction in dense vegetation between the years 2006, 2008 and 2010 with a slight increase in 2012 was noticeable in both two areas. The sudden reduction of dense vegetation might be triggered by fact that the wetland area was unprotected between the years 2006 and 2008 and the low average monthly rainfall could be a factor. However, after being protected in 2009, the dense vegetation started being restored in the conservancy sites, hence the slight increase. Rainfall status for year 2012 could also be a factor in the slight increase of dense vegetation in both areas. There was a large proportion of bare surface in the NMB MOSS sites across all the years as opposed to the substantial coverage of dense vegetation shown in the conservancy sites (Figures 5.7 and 5.8). Along with the management type and rainfall, these proportions may also be attributed to other factors such as topography and wetland morphology. Wetland sites in the conservancy area were bowl shaped depressions which slows the evaporate rate of surface water, whereas the NMB MOSS sites were more pan-like, depressions with a large area of flat bottom, .where evaporation rates of surface water would be higher

Statistically, there was no significant difference in bare surface area between sites in the conservancy area (p-value, 0.897); however there was a significant difference between two sites in the NMB MOSS (p-value, 0.003). The Hopewell Conservancy sites were more less the same in size (1.88 and 1.58 hectares), both under the same management regime and have the same topography and morphological features; hence there was no significant difference between them. These site to site differences between NMB MOSS wetlands could be attributed to their size, and location (Figure 4.2). The 947 site was considerably smaller (0.37 hectares than in site 945 (1.63 hectares). These dimensions determine the volume of water stored in wetlands. Proximity to disturbance could also have been a factor; site 947 was located closer to the road, therefore easily accessible by grazers compared to site 945.

Similar change detection studies (Feleke 2003; Shalaby and Tateishi 2003; Smith 2012) using post-classification have been conducted and pointed out that threats including agriculture and invasion of alien species can cause degradation and land cover changes. Comparing the pre-conservation and post-conservation of sites 910 and 944, it shows that there was a reduction of bare surface land cover especially in site 944 (Figure 5.6). The percentage proportion of bare surface land cover decreased more in year 2012 because of the rainfall that was received.

6.4 Vegetation surveys

Wetland vegetation types in South Africa are poorly known (Sieben, 2011). Sieben (2011) further state that the recent vegetation map of South Africa by Mucina and Rutherford, (2006) included wetland vegetation, but the authors indicated that these vegetation types still require more attention. There is still a lot of gaps in the vegetation, more sampling is necessary particularly in the Eastern Cape (Sieben, 2011). Vegetation survey defines vegetation types and helps understand differences among them, which is important for biodiversity and environmental monitoring (Egbert *et al*., 2002; He *et al*., 2005; van Deventer and Cho, 2014). It is also important to conduct vegetation surveys since vegetation can be used as one of the indicators for early signs of degradation in wetland systems and also an indicator of water quality and integrity (Cronk and Fennessy, 2001). In the current study, quarterly surveys were done between sites of different management regimes. Vegetation data collected on the present study will add on the wetland vegetation of the Eastern Cape in closing the gap in vegetation data highlighted by Sieben (2011). However, the main aim of conducting field surveys was to integrate remote sensing information to validate image classification results in order to get better classification accuracy and performing field spectroscopy.

Shifts in species composition and dominants were noted. Facultative and obligate wetland species for example *S. africanus, P. distichum and L. hexandra* remained dominant in almost all seasons because they have 99% occurrence in wetlands. Terrestrial wetland species such as *S. lindenbergiana* was not dominant in all seasons; however it was dominant in November 2012 which was related to the high average monthly rainfall of 214.8 mm that was received in October of 2012. According to Kotze and Marneweck (1999) wetland plant species like *P.distichum* are found on seasonal to permanent wetness zones, which keep them growing and robust in almost all seasons, unlike terrestrial ones, which grow further away from water.

In terms of the spectroscopy results, *S.africana* which was common between sites 944 and 947 showed a difference in NDVI, whereby site 944 had a value of 0.45 and 0.26 for site 947 and mean REP values of 720.7 and 720 respectively. This means *S. africana* for site 944 was healthier than site 947. This could be attributed due to the fact that site 944 was protected unlike site 947 which was publicly opened for anthropogenic activities. Similar study to this by van Deventer and Cho (2014) based on the *Phragmites australis* impacted by acid mine drainage between non-polluted and polluted sites found that the mean REP for the affected site was lower than the non-polluted one.

6.5 Discrimination of wetland vegetation species at species level

Respective spectra for dominant vegetation species were taken in four study wetland sites. These were *Cynodon dactylon*, *Cyperus* sp., *Eleocharis limosa*, *Isolepis sepulcralis*, *Merxmuellera disticha*, Schoenoplectus *decipiens*, *Sporobolus africana, Stenotaphrum secundatum*, *Thamnochortus lucens* and *Typha capensis.* The spectral curves showed similar reflectance responses; therefore, it was challenging to separate spectra of vegetation species. Spectra of the underlying soil, hydrologic regime and atmosphere are combined with the spectra of wetland vegetation canopies; hence they have similar reflection responses (Lin and Liquan, 2006). Vegetation species comprise the same basic components that contribute to spectral reflection which include chlorophyll a and b, carotene, xanthophyll, and other light absorbing pigments such as water, proteins, starches, and waxes (Price, 1992; Kumar *et al*., 2001; Kokaly *et al*., 2003). Spectral reflectances might look the same, but they can be discriminated using vegetation indices (Schmidt and Skidmore, 2003). As a result, species type, plant stress and canopy can all affect near infrared reflectance and making it difficult to distinguish between vegetation types (Smith, 2001a). One of the objectives of this study was to determine if spectral information of wetland vegetation at species level could be used to discriminate plant species. Becker *et al* (2005) performed a similar study to this current one; however, it was based on the discrimination of coastal wetland plant communities. Becker's *et al* (2005) study also emphasised the importance of hyperspectral remote sensing for identifying and differentiating vegetation spectral properties from narrow bands focusing on the visible and near-infrared regions.

In order to support results obtained from one-way ANOVA and Student's T-tests, Tukey HSD tests proved that there was a significant difference among plant species and between the sites by showing, which ones were statistically different and ones that were not. The difference between plant species can be attributed to the distinct structure, conservation status and due to the fact that they were from different family groups. The study by Dutcher (2013) also confirmed that the difference in plant species could be caused by the distinct structure of plants including thinner stalks and leaves, smaller and waxier leaves. The common plant species like *S. africana* showed significant differences with NDVI between two areas and between two sites in the NMB MOSS. Differences on NDVI for the *S.decipiens* between site 945 and 947 was due to the fact that site 947 quickly gets drier because of its size and easy accessibility than site 945. Sites in the conservancy area had the NDVI value of 0.44 while the ones in the NM MOSS had 0.32. This means *S. africanus* of the Conservancy area was healthier than the NM MOSS which might be attributed to the conservation status of the two areas. REP and NDVI values of *Cyperus* sp. of site 910 (0.44; 737) were higher than of site 947 (0.27; 722). This also means that the health status of *Cyperus* sp. species was better in the conservancy area than NM MOSS. More data is required since *Cyperus* sp. was only dominant in sites 910 and 947 for comparison.

Others plant species like *S. decipiens* did not show any significant differences between the two areas. Hopewell Conservancy area is a newly managed area, therefore it might happen that *S. decipiens* has not been restored as yet, hence no significant differences between the 2 areas, however more research is required. From the pair's means, it can be noted that different vegetation species have different spectral responses, which helps in their discrimination. After Tukey's HSD was applied, it was observed that some of the vegetation species were not significantly different. This means some of the plant species cannot be used for discrimination purposes. Plant species in a conserved area, 910 and 944 showed significant differences when using REP and NDVI variables after Tukey HSD. The similar study by Mafuratidze (2010) also performed statistical tests to compare four individual wetland vegetation using REP's and vegetation indices. The results confirmed statistical analyses together with REP's and vegetation indices can discriminate hydrophytic vegetation.

Conservation status can be influential in spectral discrimination. The results confirmed that using REP and NDVI could be a dependable method as shown by one-way ANOVA and Tukey HSD tests. Previous studies by Mafuratidze (2011) and Mutanga (2004) have shown that red edge position is insensitive to atmospheric interference and to the reflectance of the soil background (Guyot *et al*., 1992; Mutanga, 2004). Therefore, it is considered suitable in discriminating wetland plant species. Mafuratidze (2011) aimed to discriminate plant species using their spectral reflectance by evaluating the potential of the red edge position and hyperspectral vegetation indices to distinguish *Cyperus papyrus*, *Phragmites australis*, *Echinocloa pyramidalis* and *Thelypteris interrupta*. The study confirmed that different vegetation can be differentiated at the species level with the addition of water content and biomass variables. Dutcher (2013) also confirmed the capability of hyperspectral remote sensing in discriminating four wetland plants, *Phragmites australis*, *Typha latifolia*, *Typha angustifolia* and *Phalaris arundinacea*. *P. arundinacea* had a higher reflectance value in the near-infrared and red edge regions than other three plant species. The difference was attributed to a distinct structure, including thinner stalks and leaves, smaller stature and waxier leaves that may reflect more light. In the visible spectrum *T.arunndinacea* and *T.latifolia* were distinct. In the present study, plant species like *T. capensis* and *Cyperus* sp. had the higher reflectance in the near-infrared and red edge region than other dominant plant species identified. The difference was also due to their thinner stalks and leaves. It can be concluded that *T.capense* can be useful in discriminating it from other wetland plant species

Other studies, like Cho and Skidmore (2006) and Mafuratidze (2011) used linear extrapolation developed by Cho and Skidmore (2006) to extract red edge position. Linear extrapolation was designed to mitigate the problem of the double peak feature between chlorophyll and REP and also to track changes in slope near 700 and 725 where derivative peaks occur. In the present study, Lin inter technique referred to section 4.3.2 was used because vegetation species spectral curves didn't have multiple curves in the red edge position region. This technique was able to extract the red edge position for plant species found in the Conservancy and NMB MOSS areas. According to Mutanga (2004) and Cho and

Skidmore (2006) red edge parameters extracted from hyperspectral data are vital since they encompass many narrow bands that are linked to basic biochemical and biophysical properties of plant species.

NDVI which is used to determine the level of greenness of plant species which in turn reflects health or photosynthetic activity (Kovacs *et al*., 2005) was calculated for the respective dominant wetland plant species. According to Bartholy and Progracz (2005), a level close to zero represents no vegetation/ unhealthy vegetation, whereas values close to 1 indicate higher density of green leaves/ healthy vegetation. Comparing the two areas, one-way ANOVA test results confirmed that NDVI for the compared sets of sites was statistically different. Average value of 0.43 for two sites 945 and 947, was less than of the sites 910 and 944, with a value of 0.54. This demonstrates that the overall vegetation health was better on the conservancy side of the study. Globally, the amount of anthropogenic activities has grown along with the increase of human population and living standards which put pressure on open, publicly wetland areas (Bradley and Mustard, 2008).

6.6 Evaluation of remote sensing techniques

Remote sensing demonstrated to be useful in monitoring wetland vegetation changes over time. Post- classification change (PCC) detection and supervised classification techniques were applied to analyse the change in small wetlands in areas with different management levels between 2006, 2008, 2010 and 2012. According to Singh (1989), the PCC detection technique is regarded as the common and most reliable technique when detecting changes in landscapes. The PCC detection technique has a capability of providing a matrix of change information and reducing the external impact of atmospheric and environmental differences between multispectral images (Lu *et al*., 2004). The PCC detection technique also has an advantage of providing “from to” information between each class showing which land cover class changed into another (Ernani & Gabriels, 2006). A PCC detection technique successfully differentiated results obtained from the supervised classification (Maximum likelihood). However, most of the studies used object-based classification rather than supervised classification (pixel based). Results acquired from the PCC detection technique showed the change in land cover classes between 2006, 2008, 2010 and 2012. These results clearly revealed that wetland sites of the under-managed area were more degraded than managed ones. Temporal remotely sensed data enabled the assessment of wetland vegetation condition as far back as 2006; therefore remote sensing provided an effective tool in analysing changes of vegetation in small, ephemeral wetlands of different management regimes.

Field spectroscopy also showed its capability in differentiating wetland plant spectral responses between areas with different protection levels. From this study, it is clear that field hyperspectral remote sensing was a useful method in determining wetland plant species composition and health. However, more research needs to go into the development of this as a tool requiring more baseline data collected on a broader range of plant species.

6.7 Limitations of the study

Landsat TM has a long history of dataset dating back from 1982; however, because of its low resolution it was considered inappropriate since it was difficult to derive land cover information. These findings confirm the observations made by Ozesmi and Bauer (2002) that the spatial resolution of most satellite imagery (20-30 m) makes it difficult to identify small wetlands. This also corresponds to the studies done by Mwita *et al* (2010) and Sparks (2012) where Landsat TM made it difficult to identify wetlands because of poor spatial resolution where aerial photographs were then used. In the present study, short-term change detection was then done using SPOT 5. SPOT 5 was only available post 2005, which limited long-term change detection. Long-term detection would have improved post-classification change detection results. It was possible to identify different land cover classes using SPOT 5; since it has a spatial resolution of 10m, which is better than Landsat TM, however still with SPOT 5 some other land cover classes were not recorded because of insufficient pixels to represent all land cover classes. Therefore, imagery with higher spatial resolution can be utilized for a future study that will not only improve the classification accuracy, but also help in a classification of higher details. These results would have improved as well, if SPOT 5 scenes covered both wet and dry seasons in helping discriminating healthy and degraded vegetation, unfortunately scenes were available in a dry period. The use of object-based classification would have improved the results than pixel-based classification. Pixel based classification only uses the spectral information in the image while object based classification uses spectral, spatial, contextual, and textual information (Flanders *et al*., 2004, Leukert 2004). In object-based classification, the image is segmented into objects that form the classification units, which improves classification accuracy (Manakos *et al*., 2000; Niemeyer and Canty, 2003). Obtaining software such as ERDAS and eCognition for object-orientated analyses was difficult; hence, only pixel-based classification was used.

Assessing the impacts of grazing activity on wetland areas as one of the anthropogenic activities evidenced in the present study could have given a clear picture in land cover changes since both areas experienced grazing, wild game and cattle in a conservancy area and unmanaged grazing of cattle, goats and other animals in the NMB MOSS. This could be useful in determining how the grazing pressure has impacted on the change of percentages of land cover classes over different years; however, it was difficult to ascertain how the number of grazers has been increased over the years. Cattle herders and land owners of the Hopewell Nature Reserve were not willing to disclose if the number of grazers has increased over the years.

The use of hyperspectral data for all seasons could have improved the results of dominant wetland vegetation species in terms of their differences in spectral responses in the conservancy and NMB MOSS area. Vegetation behaves differently in different seasons. However, due to costs and unavailability of resources, field spectroscopy was done once off, in one season (early spring). A study by Best *et al*., (1981) showed that spectral measurements were taken in different seasons during the periods of early emergent, flowering, early seed and senescent phenological stages. Their findings showed that the best period to discriminate among plant species was the flowering and early seed stages. Comparing the present study, spectral measurements with previous spectral libraries would have served an advantage; unfortunately, there is a lack of information on previous studies for wetland vegetation spectral libraries in the entire South Africa. Mapping of wetland vegetation with reasonable results has been done internationally (Ndzeidze, 2008).

6.8 Recommendations

The following recommendations were made based on the results found:

- Protection of open publicly wetlands should be considered to avoid further degradation by well-known threats including agriculture, and invasion of alien species.
- Studies like this are needed in other parts of the Eastern Cape which will help inform the public to make informed decisions for wise use of wetland resources.
- Remote sensing which provides a continuous source of temporal data should be used as a key tool for better monitoring of wetlands.

6.9 Summary and overall conclusion

The present study has provided an insight into the condition, spatial and temporal changes in vegetation in small scale wetlands between 2006, 2008, 2010 and 2012. This was achieved by analyzing land cover between wetland sites within different management levels. According to Franke *et al* (2009) and Sakane *et al* (2011) small wetlands can have ephemeral qualities, therefore not included when inventories are being compiled; whistle large systems receive a bigger proportion of scientific interests. This causes small wetlands to be susceptible to degradation and vulnerability given the fact that their services are not often evaluated. This study further investigated the capability of field spectroscopy at the species level in discriminating dominant plant species in all sites. This was done in order to determine the health status of vegetation condition of wetlands within different management regimes. Wetland vegetation can be used as one of the indicators when there is any form of degradation in wetland systems.

Wetland systems are being destroyed because of the influence of natural disturbance and anthropogenic activities (Barbier, 1993; Kotze and Breen, 1994; Kotze *et al*., 1995; OECD, 1996 and Lindley, 2003). It is therefore imperative to have updated spatial information on the current status of wetlands for the sustainable use management. Remote sensing is regarded as one of the best methods for monitoring, mapping and discriminating wetland vegetation (Lee and Lunetta, 1996, Schmidt and Skidmore, 2003), however a lot still needs to be done since there is still a lack of information for wetland vegetation spectral libraries in South Africa (Ndzeidze, 2008; Mafuratidze, 2010).

The present study achieved all three objectives presented in Chapter 1, such that:

1. The comparison of wetland condition within conserved and non-conserved was achieved by using multi-temporary imagery and field hyperspectral remotely sensed data.
2. The assessment of temporal and spatial changes in wetland vegetation was achieved by analysing a series of multi-temporary images using post-classification and cross-tabulation.
3. In order to determine the spectral characteristics of the dominant wetland vegetation, statistical analyses were performed for NDVI and REP results using field spectroscopy data.

From this study, it can be concluded that SPOT imagery can be used to assess and compare small, ephemeral wetland condition and land cover changes between the areas of different management regimes. It can also be concluded that REP and NDVI can discriminate spectral reflectance of wetland vegetation at canopy level; therefore, it is possible to discriminate wetland vegetation at species level using field spectroscopy.

The present study has demonstrated the vegetation changes in small, ephemeral wetlands between conservancy area and under-managed area through multispectral and hyperspectral remote sensing techniques. These techniques were useful and suitable in studying small wetlands. Depending on the spatial resolution of a satellite sensor and availability of image data, multispectral remote sensing is fast and can be used to study small wetlands. Field spectroscopy on the other hand can also be useful in discriminating wetland vegetation at the species level; however it is expensive and time consuming. Therefore, new approaches and innovative methods such as airborne and satellite hyperspectral remote sensing need to be considered for better, quick identification and evaluation of wetland vegetation species. Based on the results it can be concluded that NMB MOSS was more degraded than conservancy area whereby the area of bare surface was larger. This is also qualified by the plant species from the conserved area which were healthier compared to NMB MOSS. NDVI analyses showed that plant species found at wetland site 947; non-conserved site showed to be low with an average of 0.26. This site was observed to be more overgrazed. NDVI values for plant species in the conservancy area were noted to be higher which were between 0.53 and 0.55 respectively. NDVI and REP results of plant species for both sites in a conservancy area showed significant differences, as opposed to the non-conserved ones. By implication, wetland vegetation in its less degraded condition can be spectrally discriminated, unlike the most degraded plant species in under-managed wetlands.

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APPENDICES

Appendix A

Accuracy Assessment Error Matrix for site 910-2006

User/Reference class	W	DV	SV	BS	U	Total
Water	333	28	21	0	0	**382**
Dense Vegetation	10	815	366	0	0	**1191**
Sparse Vegetation	4	23	683	139	0	**849**
Bare Surface	0	0	2	477	0	**479**
Unknown	0	0	0	0	934	**934**
Total	**347**	**866**	**1072**	**934**	**934**	**3835**
Producer	0.96	0.94	0.64	0.51	1	
User	0.87	0.68	0.80	1	1	
Overall Accuracy	0.85					
KIA	0.80					

Accuracy Assessment Error Matrix for site 910-2008

User/Reference class	W	DV	SV	BS	U	Total
Water	335	22	0	0	0	**357**
Dense Vegetation	170	721	0	0	0	**891**
Sparse Vegetation	264	42	319	40	0	**665**
Bare Surface	108	1	205	674	0	**988**
Unknown	0	0	0	934	934	**934**
Total	**877**	**786**	**524**	**714**	**934**	**3835**
Producer	0.38	0.92	0.61	0.94	1	
User	0.94	0.81	0.48	0.68	1	
Overall Accuracy	0.78					
KIA	0.72					

Accuracy Assessment Error Matrix for site 910-2010

User/Reference class	W	DV	SV	BS	U	Total
Water	565	746	191	18	0	1520
Dense Vegetation	68	661	0	0	0	**729**
Sparse Vegetation	31	0	303	1	0	**335**
Bare Surface	0	0	20	297	0	**317**
Unknown	0	0	0	0	934	**934**
Total	**664**	**1407**	**514**	**316**	**934**	**3835**
Producer	0.85	0.47	0.59	0.94	1	
User	0.37	0.91	0.90	0.94	1	
Overall Accuracy	0.72					
KIA	0.64					

Accuracy Assessment Error Matrix for site 910-2012

User/Reference class	W	DV	SV	BS	U	Total
W	322	0	641	0	0	**973**
DV	0	436	0	0	0	**436**
SV	0	0	212	2	0	**214**
BS	0	0	109	1169	0	**1278**
U	0	0	0	0	934	**934**
Total	**322**	**436**	**962**	**1171**	**934**	**3835**
Producer	1	1	0.22	1	1	
User	0.33	1	0.99	0.92	1	
Overall Accuracy	0.80					
KIA	0.75					

Accuracy Assessment Error Matrix for site 944-2006

User/Reference class	W	DV	SV	BS	U	Total
Water	1291	521	398	96	0	**2306**
Dense Vegetation	80	297	0	0	0	**377**
Sparse Vegetation	28	0	262	2	0	**292**
Bare Surface	28	0	33	403	0	**464**
Unknown	0	0	0	0	1421	**1421**
Total	**1427**	**818**	**693**	**501**	**1421**	**4860**
Producer	0.91	0.36	0.38	0.80	1	
User	0.56	0.79	0.90	0.87	1	
Overall Accuracy	0.76					
KIA	0.67					

Accuracy Assessment Error Matrix for site 944-2008

User/Reference class	W	DV	SV	BS	U	Total
Water	267	110	557	176	0	**1110**
Dense Vegetation	64	990	384	1	0	**1439**
Sparse Vegetation	0	0	368	52	0	**420**
Bare Surface	0	0	9	461	0	**470**
Unknown	0	0	0	0	1421	**1421**
Total	**331**	**1100**	**1318**	**690**	**421**	**4860**
Producer	0.87	0.90	0.28	0.67	1	
User	0.24	0.69	0.88	0.98	1	
Overall Accuracy	0.72					
KIA	0.65					

Accur acy Assessment Error Matrix for site 944-2010

User/Reference class	W	DV	SV	BS	U	Total
Water	1163	140	134	48	0	**1485**
Dense Vegetation	142	1046	52	0	0	**1240**
Sparse Vegetation	64	0	406	0	0	**470**
Bare Surface	71	0	0	173	0	**244**
Unknown	0	0	0	0	1421	**1421**
Total	**1440**	**1186**	**592**	**221**	**1421**	**4680**
Producer	0.81	0.88	0.69	0.78	1	
User	0.78	0.84	0.86	0.71	1	
Overall Accuracy	0.90					
KIA	0.82					

Accuracy Assessment Error for site 944-2012

User/Reference class	W	DV	SV	BS	U	Total
Water	607	183	9	10	0	**809**
Dense Vegetation	22	38	786	0	0	**846**
Sparse Vegetation	72	0	408	11	0	**491**
Bare Surface	314	0	0	979	0	**1293**
Unknown	0	0	0	0	1421	**1421**
Total	**1015**	**221**	**1203**	**1000**	**1421**	**4860**
Producer	0.60	0.17	0.34	0.98	1	
User	0.75	0.45	0.83	0.76	1	
Overall Accuracy	0.71					
KIA	0.63					

Accuracy Assessment Error for site 945-2006

User/Reference class	W	DV	SV	BS	U	Total
Water	121	1	0	0	0	**122**
Dense Vegetation	50	783	63	2	0	**898**
Sparse Vegetation	0	30	608	74	0	**712**
Bare Surface	0	3	42	1214	0	**1259**
Unknown	0	0	0	0	1021	**1021**
Total	**171**	**817**	**713**	**1290**	**1021**	**4021**
Producer	0.71	0.96	0.85	0.94	1	
User	0.99	0.87	0.85	0.96	1	
Overall Accuracy	0.93					
KIA	0.91					

Accuracy Assessment Error Matrix for wetland site 945-2008

User/Reference class	W	DV	SV	BS	U	Total
Water	801	182	1	26	0	**1010**
Dense Vegetation	69	573	99	2	0	**743**
Sparse Vegetation	15	0	424	0	0	**439**
Bare Surface	149	0	18	632	0	**799**
Unknown	0	0	0	0	1021	**1021**
Total	**1034**	**755**	**542**	**660**	**1021**	**4012**
Producer	0.78	0.76	0.78	0.96	1	
User	0.79	0.77	0.97	0.79	1	
Overall Accuracy	0.86					
KIA	0.82					

Accuracy Assessment Error Matrix for wetland site 945-2010

User/Reference class	W	DV	SV	BS	U	Total
Water	425	90	0	0	0	**515**
Dense Vegetation	99	183	42	0	0	**324**
Sparse Vegetation	64	150	51	16	0	**281**
Bare Surface	26	264	371	1210	0	**1871**
Unknown	0	0	0	0	1021	**1021**
Total	**614**	**687**	**464**	**1226**	**1021**	**4012**
Producer	0.69	0.26	0.11	0.99	1	
User	0.83	0.57	0.18	0.65	1	
Overall Accuracy	0.72					
KIA	0.63					

Accuracy Assessment Error Matrix for wetland site 945-2012

User/Reference class	W	DV	SV	BS	U	Total
Water	95	150	0	0	0	**245**
Dense Vegetation	465	0	0	168	0	**633**
Sparse Vegetation	0	0	409	0	0	**409**
Bare Surface	3	0	19	1682	0	**1704**
Unknown	0	0	0	0	1021	**1021**
Total	**563**	**150**	**428**	**1850**	**1021**	**4012**
Producer	0.17	0	0.96	0.91	1	
User	0.39	0	1	0.99	1	
Overall Accuracy	0.80					
KIA	0.72					

Accuracy Assessment Error Matrix for wetland site 947-2006

User/Reference class	W	DV	SV	BS	U	Total
Water	95	18	1	5	0	**119**
Dense Vegetation	29	115	17	0	0	**161**
Sparse Vegetation	26	3	193	0	0	**222**
Bare Surface	12	0	20	148	0	**180**
Unknown	0	0	0	0	298	**290**
Total	**162**	**136**	**231**	**153**	**298**	**980**
Producer	0.59	0.85	0.84	0.97	1	
User	0.80	0.71	0.87	0.82	1	
Overall Accuracy	0.88					
KIA	0.83					

Accuracy Assessment Error Matrix for wetland site 947-2008

User/Reference class	W	DV	SV	BS	U	Total
Water	65	26	0	0	0	**91**
Dense Vegetation	3	249	45	0	0	**297**
Sparse Vegetation	0	6	106	0	0	**112**
Bare Surface	0	0	46	136	0	**182**
Unknown	0	0	0	0	298	**298**
Total	**68**	**281**	**197**	**136**	**298**	**980**
Producer	0.96	0.89	0.54	1	1	
User	0.71	0.84	0.95	0.75	1	
Overall Accuracy	0.87					
KIA	0.83					

Accuracy Assessment Error Matrix wetland site 947-2010

User/Reference class	W	DV	SV	BS	U	Total
Water	93	14	37	5	0	**149**
Dense Vegetation	11	100	16	17	0	**144**
Sparse Vegetation	11	0	128	0	0	**139**
Bare Surface	17	0	9	224	0	**250**
Unknown	0	0	0	0	298	**298**
Total	**132**	**114**	**190**	**246**	**298**	**980**
Producer	0.70	0.88	0.63	0.91	1	
User	0.62	0.69	0.92	0.87	1	
Overall Accuracy	0.86					
KIA	0.82					

Accuracy Assessment Error Matrix for wetland site 947-2012

User/Reference class	**W**	**DV**	**SV**	**BS**	**U**	**Total**
Water	65	3	0	0	0	**68**
Dense Vegetation	0	246	0	0	0	**246**
Sparse Vegetation	0	2	98	35	0	**135**
Bare Surface	0	0	0	233	0	**233**
Unknown	0	0	0	0	298	**298**
Total	**65**	**251**	**98**	**268**	**298**	**980**
Producer	1	0.98	1	0.87	1	
User	0.96	1	0.73	1	1	
Overall Accuracy	0.96					
KIA	0.95					