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Vegetation dynamics in a semi-arid freshwater wetland: a measure for restoration success

By

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DECLARATION

I, **Florence Mazwi Murungweni,** declare that this research titled - "**Vegetation dynamics in a restored semi-arid freshwater wetland: a measure for restoration success"** is my original work and has not been submitted for any degree at this or any other university or institution. The research does not contain other people's writing, unless specifically acknowledged and referenced accordingly.

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Florence Mazwi Murungweni

ABSTRACT

The functioning of wetland ecosystems is impacted by human anthropogenic activities, which affect wetlands' vegetation development and their ability to offer ecosystem services. The need to understand vegetations' natural regeneration, in previously degraded wetlands of semi-arid regions is essential to measure restoration success. Nylsvley freshwater wetland is the largest inland flood plain found in the semi-arid region of South Africa and a Ramsar site of worldwide conservation importance. It provides a habitat to some endangered species; however, it is facing degradation problems leading to a declining of its biodiversity. The importance of Nylsvley wetland prompted an initiation into its ecological restoration, to try and reverse the ecosystem degradation and monitor vegetation development of this Ramsar site.

This study aimed to evaluate restoration efforts, through an analysis of vegetation dynamics, in a restored semi-arid freshwater wetland, so as to understand the success story of restoration efforts. The first objective of the study examined historical rainfall trends in the Nyl River system as rainfall affects vegetation productivity. Daily rainfall data was measured from eight rainfall stations for the period, 1950 to 2016, to generate seasonal and annual rainfall data. The Mann-Kendall and quantile regression were applied to assess trends in this rainfall data. Normalized Difference Vegetation Index derived from satellite images from between 1984 and 2003, utilising zonal statistics was correlated with rainfall of the same period to assess vegetation dynamics. The Mann-Kendall and Sen's slope estimator showed that only one station had significant increased rainfall trend, annually and seasonally, at $p < 0.05$, whereas all the other stations showed insignificant trends during these rainfall seasons. Quantile regression showed that 50% and 62.5% of the stations had increasing annual and seasonal rainfall, respectively. Three of the eight stations had data which were statistically significant at $p < 0.05$, indicating increasing and decreasing rainfall trends. These rainfall trends show that the rainfall at Nylsvley decreased

between 1995 and 2003. The R^2 between rainfall and Normalized Difference Vegetation Index of Nylsvley is 55% indicating the influence of rainfall variability on vegetation productivity.

The second objective assessed spatio-temporal changes of natural vegetation development within Vogelfontein, part of Nylsvley, utilising 1984, 2005 and 2016 satellite imagery which provided at least 10 years' evaluation of conditions, before and after restoration. Land cover maps were generated from classified Landsat images using maximum likelihood classification algorithm with five land uses - old fields, water, bare ground, sparse and dense vegetation. The results showed a worsening of natural vegetation regeneration from 1984 until 2005, as bare ground and old field increased by over 19%. This decline was attributed to cultivation, which ended in 1996 in Vogelfontein. The period 2005 to 2016 saw the classes gaining in natural recovery of vegetation (7%). This indicates the necessity for wetland restoration, as there was evidence of vegetation recovery in a landscape facing a degradation trajectory. Overall, the area covered by vegetation from the 1984 to 2016 period remained in the negative, despite the increase of vegetation cover between the 2005 to 2016 period.

The third objective assessed vegetation development in three project sites, namely, A61C-01, A61C-02 and A61C-03, to evaluate restoration interventions made and how they are linked to vegetation development in Nylsvley. Initial monitoring results showed restored sites with monitoring data at implementation stage with identified impacts of hydrology, geomorphology and vegetation and their change score, based on the WET-health assessment recorded. The photographs from previous documents played a key role in providing wetland status before and during implementation in addition to WET-Health data. The records indicated that to improve flood attenuation, road strip with reno gabion structure was constructed across the wetland; to curb soil loss, berms and road strips have been constructed on most roads and some degraded roads were closed to allow vegetation regeneration. The natural hydrological function of the wetland was improved by destroying berms previously constructed to divert water from the floodplain.

Local plant biodiversity was improved by fencing off previously-degraded areas from grazers, whilst old trees along the berms were kept, as they are potential seed banks.

Finally, the fourth objective aimed to quantify composition and diversity of species in Nylsvley wetland to comprehensively outline the vegetation restoration success. Ten circular quadrants of 10-meter radius were utilised using Adapted Point Centre Quarter method to collect woody vegetation structural measurements. The Simpson's Diversity Index was used to determine diversity and composition of species in the measured sites. The Analysis of Variance results shows that reference plots have significantly more trees, higher species richness, as well as taller and more woody species density per hectare than the treatment plots.

This study provides beneficial information for management to understand the influence of historical rainfall patterns on climate variability in the Nyl River system and how they impact on vegetation growth and recovery of the reserve as there is a strong relationship between rainfall and Normalized Difference Vegetation Index of Nylsvley. The study will also help researchers to understand the annual and seasonal variability of rainfall over the study region and should serve as a foundation for further studies. The study will further shape the wetland restoration discourse through evaluation of ecosystems restoration efforts that have not been widely adopted. The study utilizes Geographic Information Systems and Remote Sensing tools as management strategies to monitor vegetation-cover change, before and after restoration in Nylsvley. This extends the frontiers of knowledge through providing an understanding of natural changes in vegetation, in space and time; this is a critical indicator of vegetation development and restoration success of Nylsvley. Finally, an evaluation of the restoration activities done in Nylsvley and the quantification of vegetation species in the restored sites will form the basis for additional monitoring of vegetation regeneration in Nylsvley and with a potential for upscaling to other similar semi-arid freshwater wetlands.

Keywords: Composition; Normalized Difference Vegetation Index; Nylsvley; rainfall; restoration; vegetation; wetland.

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DEDICATION

This research is dedicated to my living God, the Almighty, the creator of heaven and earth and to my family - husband Thomas, children Tariro Petty, Kundai Thelma and Kudakwashe Tanya for their prayers and constant support throughout the study period; thanks so much. To God be the Glory.

PREFACE

Each chapter in this thesis is stand–alone and one of the chapters have been published in *Sustainability*, an international peer-reviewed journal. A second article is submitted to *South African Journal of Geomatics*, hence, there may be some repetitions in the abstract, introduction and methods sections of each of the chapters.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA:	Analysis of Variance
APCQ:	Adapted Point Centre Quarter
ARC:	Agriculture Research Council
DAFF:	Department of Agriculture Forestry and Fisheries
DCA:	Detrended Correspondence Analysis
DEA:	Department of Environmental Affairs
DEAT:	Department of Environmental Affairs and Tourism
DPSIR:	Driver Pressure State Impact Response
DWAF:	Department of Water Affairs and Forestry
DWS:	Department of Water Affairs
ENSO:	El Nino Southern Oscillation Cycle
EPWP:	Expanded Public Works program
GIS:	Geographic Information Systems
GLCF:	Global land Cover Facility
IPCC:	Intergovernmental Panel on Climate Change
LRC:	Levuvhu River Catchment
MK:	Mann Kendell
MWP:	Mondi Wetland Project
NDVI:	Normalized Vegetation Index
NEMA:	National Environmental Management Act
NIR:	Near Infra-Red
NNR:	Nylsvley Nature Reserve
NRS:	Nyl River System
QR:	Quantile regression
RS:	Remote Sensing

SA:	South Africa
SAS:	Statistical Analysis Software
SAWS:	South Africa Weather Services
SER:	Society for Ecological Restoration
SMME:	Small, Medium and Micro Enterprises
SST:	Sea Surface Temperature
UN:	United Nations
USA:	United States of America
US EPA:	United States Environmental Protection Agency
USFWS:	United States
USGS:	United States
UTM:	Universal Transverse Mercator
WET Health:	Wetland Health
WfW:	Working for Wetlands
WIAMS:	Wetland Inventory, Assessment and Monitoring
WRC:	Water Research Council

LIST OF CONFERENCES AND PUBLICATIONS

Presentations at international conferences

1. Murungweni F.M. (2018). *Rainfall trends in the Nyl River System of South Africa from 1950 to 2016*, Conference on 1st Pan African International Research Congress on Knowledge Generation and Dissemination, 18th to the 21st of June 2018, Grand Royal Swiss Hotel, Kisumu, Kenya.
2. Murungweni F.M. & (2019). *Spatial-temporal patterns of land use/cover change in restored floodplain wetland ecosystem*, 8th World Conference on Ecological Restoration, Century City Conference Centre, Cape Town, South Africa, 24th to the 28th of September 2019.

Publications Title, Year and Journal

1. *Rainfall Trend and Its Relationship with Normalized Difference Vegetation Index in a Restored Semi-Arid Wetland of South Africa*, 2020. *Sustainability MDPI Journal*

Under review

2. *Spatial-temporal patterns of land use/cover change in a restored floodplain wetland ecosystem*, 2021, submitted to *South African Journal of Geomatics*.

1. INTRODUCTION

1.1 Background

A wetland ecosystem has a water table that is near or above the surface or is flooded for a long time enough to support aquatic processes and where various kinds of biological and physical activities have adapted to the wet conditions (Breen *et al.*, 1997). According to Ramsar Convention for wetland conservation, 'wetlands' are " areas of marsh, fen, peat land, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salty, including areas of marine water, the depth of which does not exceeds six meters" (Finlayson and Moser, 1991; Secretariat, 2016). Other various and detailed wetland definitions are also provided by the (Cowardin, 1979) and National Research Council (1995). Wetlands form part of river systems which also encompass strips of vegetation along rivers, referred to as "riparian zone"s. Wetlands were formally regarded as wastelands (Finlayson and Moser, 1991), however, they were transformed into vital lands used for traditional agricultural activities, forestry, construction, among others (Juliano and Simonovic, 1999; Junk *et al.*, 2013). This is despite the fact that wetlands are rich in flora and fauna, which make them biologically diverse ecosystems, globally.

Wetlands maintain communities of ecological and economic value, harboring aquatic and semi-aquatic biota (Keddy, 2010; Cherry, 2011) as they also provide habitat to many species, including migratory and waterfowl birds (Cherry, 2011). In addition, wetland areas perform essential hydrological and biogeochemical functions, such as carbon sink, flood mitigation, recharge of ground aquifers, among others (Mitsch and Gosselink, 2000; Tooth and Mccarthy, 2007; Whitcomb *et al.*, 2009; Cherry, 2011); this is despite the fact that wetlands only constitute 6% of the earth's surface (Cherry, 2011; Junk *et al.*, 2013). Freshwater wetlands are very rich in biodiversity supporting approximately 100 000 species of the 1.8 billion of the world's species

(Dudgeon *et al.*, 2006). The economic value provided by wetlands, as highlighted by Costanza *et al.,* (1997), exceeds that provided by either lakes, forests, or grasslands, estimating wetlands' value close to that of coastal estuaries.

Research shows that the world lost more than half of its wetlands from 1900 onwards with the loss and severity of destruction varying with geographic regions (Finlayson and Spiers, 1999; Owino and Ryan, 2007; Davidson, 2014). In southern Africa, wetlands are increasingly being lost due to anthropogenic activities and climate variability (Matiza and Chabwela, 1992; Breen *et al.*, 1997; Owino and Ryan, 2007; Stocker, 2014). Kotze *et al.* (1995) indicated that South Africa has lost more than 50% of its wetland areas, for instance, the Tugela Basin in Natal, has lost over 90% of its wetland area (Taylor *et al.*, 1995) and the Mfolozi catchment has lost 58% of its wetland areas to agricultural activities (Jogo and Hassan, 2010; Sieben *et al.*, 2014; Turner *et al.*, 2014). Wetland loss creates environmental problems that include vegetation loss, leading to their degradation (Netando *et al.*, 2010; Mesta *et al.*, 2014). Wetlands, since time immemorial, have played an integral role in the development of humans and their survival in addition to providing unique habitats for breeding, feeding and hiding of fauna species (Cherry, 2011; Mitsch *et al.*, 2015). Vegetation in and around wetlands are threatened by anthropogenic activities, such as agriculture which leads to declining biodiversity of its ecosystems.

Jogo and Hassan (2010) revealed constraints to sustainable wetlands' management in the southern Africa region. They indicated that decision-makers and wetland users have little understanding of the environmental consequences of alternative management on functions of these ecosystems. Wetland management requires paying attention to ecological integrity, social well-being as well as economic efficiency of wetland areas (Setlhogile *et al.*, 2011). Modifying wetland environment, through various means, has a potential to degrade them and undermine their ability to provide future valuable services. The ability of wetlands to continue providing services and benefits entirely depend on humanity's ability to conserve them by reducing negative

factors affecting their proper functioning conditions (Millennium Ecosystem Assessment, 2005; Ramsar, 2010). Lack of adequate information on issues of sustainable environmental management and restoration success stories of vegetation monitoring in wetland areas, often influence management to make wrong decisions (Kotze *et al.*, 2019). Ecosystem restoration has shifted its focus from pure rehabilitation to include delivery of ecosystem services (Friberg *et al.*, 2016). In this study, the term, 'rehabilitation' will be used interchangeably with 'restoration' as they both aim to bring the rivers or wetlands to their natural condition after human disturbances.

Countries, noticing the critical roles of wetlands' ecosystems, have put into place laws, regulations and plans for the conservation and restoration of these systems. To scale up these restoration activities, recently, the United Nations (UN) General Assembly in March 2019, declared the period 2021 to 2030 as UN decade of ecosystem restoration (Young and Schwartz, 2019; United Nations, 2019). The period was intended to extensively scale up the restoration of destroyed and degraded ecosystems as a measure to fight the climate change crisis and improve food security, biodiversity conservation and water supply. Rivers and wetlands are amongst the ecosystems that need to be continuously restored. Restoration in semi-arid wetland regions is not an exception as it is now a global cry, as is proved by the United Nations granting a further decade of ecosystem restoration.

Studies globally indicate that about 20% of vascular flora species will become extinct in the next 30 years (Wilson, 1998; Sax and Gaines, 2003; Helm *et al.*, 2006; Van Vuuren *et al.*, 2006; Smith *et al.*, 2007; Shin *et al.*, 2012). This study, hence, was motivated by the need to evaluate the success of natural vegetation regeneration in restored wetland ecosystems of semi-arid regions using Nylsvley floodplain, a Ramsar site, as a case study. To this end, it was, necessary to understand the historical rainfall pattern within the Nyl River System (NRS) and to further assess rainfall-NDVI relationship within the floodplain to understand the implications of rainfall on vegetation development. Climate change is real (Intergovernmental Panel on Climate Change,

2007; 2014), hence, the need to investigate if rainfall patterns are playing significant role on vegetation dynamics, over time, within the wetland ecosystems, as water is key for development of these systems. Rainfall variations have impact on plant species' development (Barbosa *et al.*, 2015). The study also linked restoration efforts made in Nylsvley wetland ecosystems to vegetation development and evaluated the success of these restoration projects. The research further quantified vegetation species in previously disturbed Nylsvley areas to determine woody species composition of these sites and this data will be utilised for continuous assessment of natural vegetation regeneration in the reserve; the data is also ideal for future validation of remote sensing imagery (Davis-Reddy, 2018). The historical rainfall trend and its relationship to vegetation development, spatial changes and quantification of vegetation changes in the restored sites, thus, are vital to inform decision-makers on how best to manage these zones (Grundling *et al.*, 2013).

1.2 Conceptual Framework

The Drivers Pressures State Impact Response (DPSIR) model states that anthropogenic activities, such as poor agricultural practices or over-harvesting of natural resources can be a source of environmental pressure affecting the state of natural resources and human response to the state (Maxim *et al.*, 2009; Tscherning *et al.*, 2012; Rouillard *et al.*, 2018; Lu *et al.*, 2019). The response is through restoration, monitoring and assessments to understand the relationship between pressure, state and management response, which is guided through monitoring (Kristensen, 2004). Figure 1.1 shows the DPSIR structure.

The drivers can be economic or social, such as land use, tourism or agriculture. These give rise to pressures which result in, either clearance of vegetation, water flow regulation, abstraction or channeling of water or changes in land use to meet driving forces' needs. The state of a site refers to the general quality of the environment, such as wetland loss, siltation, or habitat loss.

The impact can be the changes in the biological state of the environment and the response refers to the environmental impacts, such as human wellbeing, production of ecosystem services and regulating services, such as Normalized Difference Vegetation Index (NDVI) (Kristensen, 2004; Tscherning *et al.*, 2012). The responses also lead to feedback to society in the form of policy development and restoration projects; for these governments mainly provide funds.

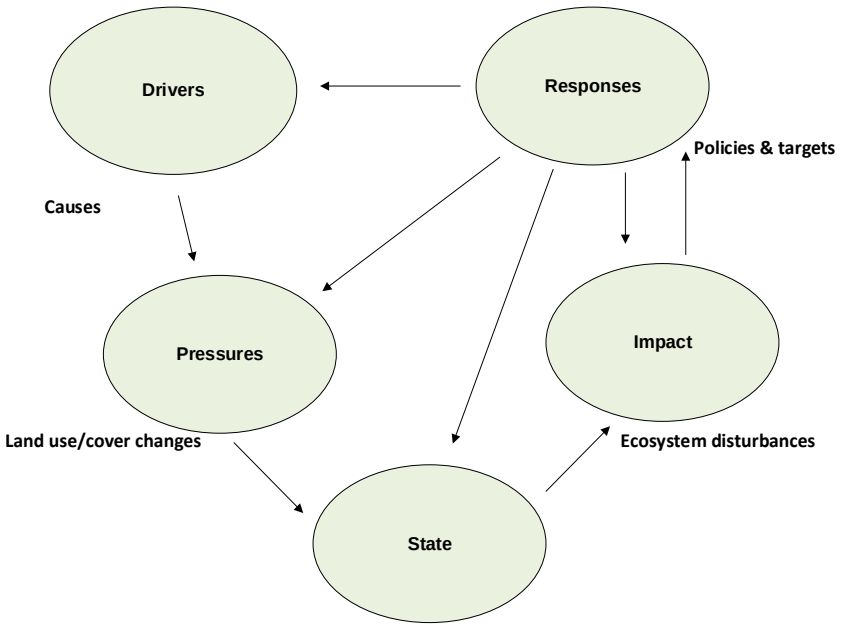

Figure 1.1: The Drivers Pressures State Impact Response Framework
Source: Adapted from Kristensen (2004)

Globally, rivers and wetland zones are negatively impacted by agricultural intensification (channeling water), invasive species, variations in climate and urbanization (Dudgeon *et al.*, 2006; Murungweni, 2013; Gallant *et al.*, 2014; Dalu *et al.*, 2020a). Agricultural and urban activities result in clearance and removal of vegetation, leaving most surfaces bare.

The conceptual framework (Figure 1.2) shows the spatial hierarchy of factors that control rivers and wetland areas; these are ultimately controlled by climate, land use and geology of the area. Geology factors are only partially dealt with in this study, hence, are placed outside of the box. The study focuses on impacts of climate and land use on vegetation development done at the

expense of some geological factors. Geology is an important factor, however, the current study did not focus much on soil characteristics, as they will be incorporated in detail in future restoration studies in Nylsvley. Land use factors, which include agriculture, (because of previous crop production), water channeling or over-grazing by animals will play an essential role in determining land cover changes within the Nylsvley nature reserve. The study interrogated further the responses provided by governments, through restoration activities and assessed their success through analysing vegetation development within the Nylsvley.

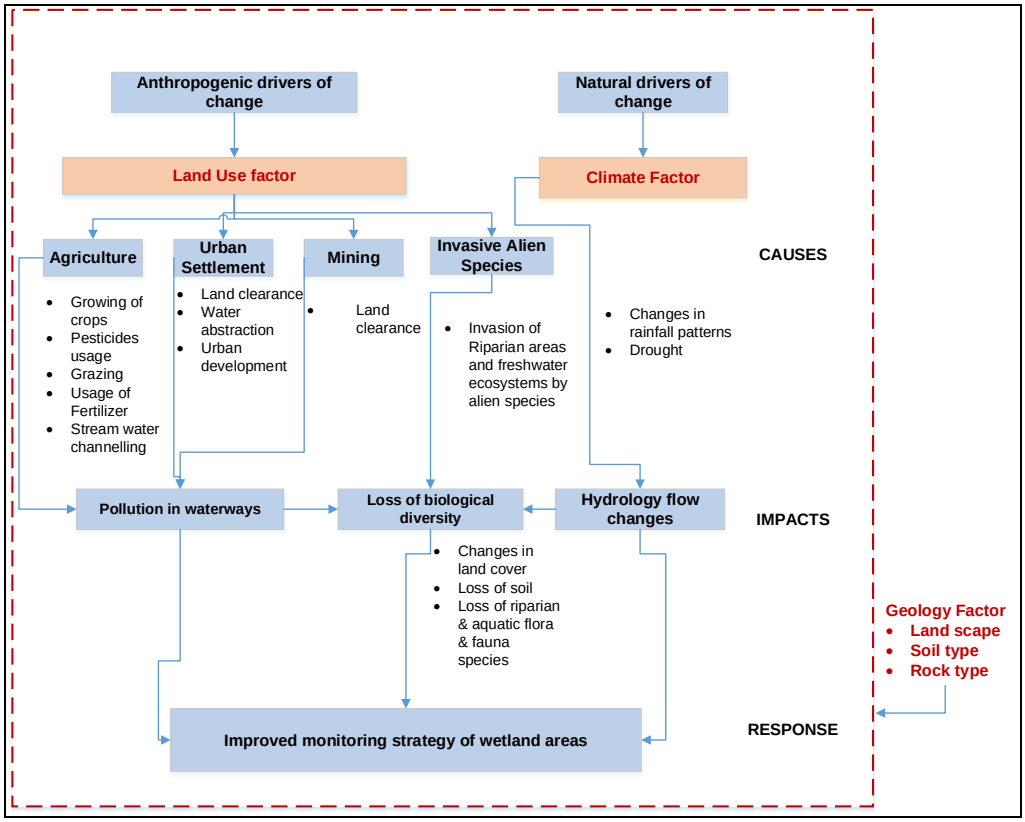

Figure 1.2: Conceptual framework showing factors controlling wetland areas

The changes in land use/cover will assist in evaluating the success of natural restoration through natural vegetation regeneration in the reserve. Sources of disturbance occur mostly outside the wetland area, but they are assessed at the wetland level; for instance, clearance of vegetation in a wetland's vicinity leads to siltation of the river, affecting the wetland's ecological functions.

1.3 The Problem Statement

Lack of vegetation development monitoring data to assess success of restoration projects is a challenge when evaluating these projects. This lack of information limits our understanding of the state of vegetation development and condition of the restored wetland ecosystems. This leads to misinformed policy decisions, especially, on the state and condition of vegetation recovery of restored ecosystems. Studies done in Nylsvley for the past decade have dwelt, mainly, on water and sediment quality, quantifying aquatic bird species, biomonitoring and development of wetland vegetation database for monitoring South African wetlands (Greenfield *et al.*, 2007; Greenfield *et al.*, 2012; Sieben *et al.*, 2014). Some of the studies are on hydrologic modelling of the floodplain, the geomorphological characteristics of the Nyl system, origin of the flood plain wetland and on savanna tree phenology (Kleynhans *et al.*, 2006; Mccarthy *et al.*, 2011; Tooth and Mccarthy, 2007; Whitecross *et al.*, 2016). There are also recent studies, on invasive species colonization, metal distribution and sediment quality of the wetland (Dalu *et al.*, 2020a; Dalu *et al.*, 2020b). All these studies have been conducted in the Nylsvley wetland owing to the site's importance as a Ramsar site, however, there is still a dearth of literature focusing on assessing the dynamics of vegetation development in the reserve.

1.4 Justification

Nylsvley, a Ramsar site of international importance is managed as a nature reserve, following the Ramsar wetlands prescribed management criteria (Ramsar, 2013). The management plan utilises the following principles as stipulated by Haskins and Kruger (1997):

i. Controlled sustainable use
ii. Rehabilitation/ restoration
iii. Environmental education
iv. Promotion of ecotourism

v. Maintenance of integrity of the system, focusing mainly on species diversity
vi. Linking development to the resource potential, and
vii. Maintaining aesthetic quality as well as subscription to agreements (treaties) to which South Africa (SA) is party.

The reserve has set goals and objectives for restoration which initially excluded monitoring (Greenfield, 2008). The author saw this as a need and developed an assessment protocol for water quality monitoring within Nylsvley and the Nyl River System (NRS). This and many other studies conducted in Nylsvley have not focused on assessing and quantifying natural vegetation development since the restoration of the reserve. The studies also fell short in identifying tools to assist management in monitoring vegetation development in the reserve, before and after restoration. Such an important component has not been included as a management strategy, yet monitoring forms the basis for successful evaluation of restoration projects. Semi-arid regions, which include South Africa, have had minimum such evaluations done, due to, among others, limited research and resources to undertake such endeavours (Kotze *et al.*, 2019).

With this background, this study utilised Geographic Information System (GIS) and remote sensing (RS) tools to monitor spatial vegetation development, before and after restoration of the reserve. To provide at least 10 years' evaluation of before and after-restoration periods, satellite imagery of 1984, 2005 and 2016 were utilised for vegetation spatial changes. This study is motivated by the need to provide management with comprehensive information necessary for sustainable management of Nlysvley flood plain and similar wetlands.

1.5 Aim and Objectives of the Study

The study aimed to evaluate restoration efforts, through analysis of vegetation dynamics, in a restored semi-arid freshwater wetland of the Nylsvley reserve, to understand the success story of restoration efforts. The specific objectives of the study were to:

1. determine rainfall trends and their relationship to Normalized Difference Vegetation Index (NDVI) development in Nylsvley;
2. assess natural vegetation development in Nylsvley for the years 1984, 2005 and 2016 using Landsat 5 and 8 imageries;
3. evaluate restoration activities and their relationship to vegetation development in Nylsvley, and,
4. quantify woody species composition and diversity in restored sites in Nylsvley.

To address all the above research objectives, several data-collection methods, statistical techniques and satellite remote sensing data were employed.

1.5.1 Hypotheses

- There is a trend in rainfall and vegetation in Nylsvley wetland.
- Natural vegetation regeneration has successfully increased since the restoration of the Nylsvley floodplain.
- Evaluation of restoration efforts improves with monitoring and management of vegetation in Nylsvley and ensures its conservation of biodiversity.
- There are less woody-species' diversity in restored/ treatment sites as compared to reference sites in Nylsvley.

1.6 Outline of the Thesis

The first chapter has provided the background of the study, motivation, problem statement, aim, objectives, hypotheses and conceptual framework. Chapter 2 will focus on literature that is relevant to this study. Relevant literature on research on local, national and global wetland restoration activities done, including legislations related to wetland conservation and restoration theories were reviewed in Chapter 2. The literature review builds up to the next research

component on the relationship of rainfall and NDVI through trend analysis. The succeeding chapters are research-objective-specific and each chapter consists of its detailed method. Chapter 3 provides the characteristics of the study area. The research, firstly, analysed the historical rainfall patterns and looked at the relationship between rainfall and NDVI in Nylsvley, as rainfall is key in vegetation development (Chapter 4). The methods applied attempted to successfully show the implications of low mean monthly-seasonal rainfall on NDVI (vegetation greenness) development; longtime rainfall and NDVI series data were utilized to achieve this objective.

Next, the research focused on natural restoration of vegetation development in the wetland by critically assessing different land use/ land cover classes in the floodplain (Chapter 5). The main intention was to establish if vegetation has naturally recovered since the incorporation of Vogelfontein, part of Nylsvley wetland, as a nature reserve in 1997. Restoration (rehabilitation) projects have been implemented in the reserve, hence, it was also necessary in this study to evaluate restoration efforts done in the wetland and link them to its vegetation development in an attempt to conserve Nylsvley and its biodiversity (Chapter 6). Details about the success or failure of restoration efforts are critical in understanding how vegetation has recovered in previously-disturbed areas of the reserve. Chapter 7 quantifies vegetation species composition and diversity in restored sites, for continuous monitoring of vegetation growth in the reserve.

To understand vegetation dynamics in the wetland, historical rainfall trends for NRS were initially assessed to understand whether climate variability affects water availability in the system; this was followed by assessing rainfall-NDVI relationship in the wetland. Anthropogenic effects, such as agriculture, which influence land cover changes were examined to establish and to fully understand the spatial vegetation changes in the reserve. This was followed by the establishment of vegetation monitoring sites in the restored areas of the reserve and a quantification of woody species in established restored sites. Finally, the study's contributions to the general subject of

wetlands restoration were provided in chapter 8, together with conclusions, limitations encountered and proposals for future research.

2. LITERATURE REVIEW

2.1 Introduction

To place the study in context of scientific research, this chapter reviews existing relevant literature. The key role played by the literature review was to critically summarise current knowledge about vegetation restoration in wetland areas, which in turn would help to identify the knowledge gap. The objectives of the study were guided by the initial literature review. The first part of the literature gives an overview of wetland definitions and their ecological significance. This is followed by international and national approaches to wetland restoration, ecological theories and woody species composition and diversity. The next section will dwell on wetlands management policies and their conservation strategies, while the last section, briefly, introduces the data-collecting methods used in the study.

2.2 Wetland Areas

A wetland ecosystem has a water table that is above or near the ground surface or is flooded for a long period of time to support aquatic processes and where various kinds of physical and biological activities have adapted to the wet conditions. (Breen *et al.*, 1997; Ramsar, 2010). The riparian zones, which are strips of vegetation along river banks (Naiman and Decamps, 1997) constitute part of the wetland zones. Wetlands are classified into five classes - Marine, Lacustrine, Palustrine, Riverine and Estuarine. Of these five, Palustrine and Estuarine are found all over the world and constitute marshes and swamps (Williams, 1993). South Africa as a country adopted the classification from Cowardian wetland classification system in the year 1997, for its comprehensiveness and appropriateness to the South African wetland state (Dini *et al.*, 1998; Matavire, 2015). Wetlands are dynamic and complex habitats; they are not always assigned to one exclusive system (Kim and Park, 2020), however, this research looked at the riverine system and/ or vleie that are found in the Nyl River of South Africa.

2.2.1 Ecological and socio-economic importance of wetlands

Ecology, according to Campbell (1993), is the scientific study of the interactions between organisms and their environment. This scientific study incorporates several aspects of the environment that include all biotic (living organisms) and abiotic factors, such as light, temperature, nutrients and water. Wetland ecology, thus, is the study of the interrelatedness of the components of a wetland ecosystem (Campbell, 1993). When one of the factors is disturbed within the ecosystem, it affects the other components of the ecosystem. The research is confined to assessing vegetation dynamics in the Nysvley through assessing vegetation growth in relation to rainfall trends, land use/cover change analysis and an evaluation of restored sites; the process was then related to vegetation development in Nysvley and finally the establishment of vegetation monitoring sites in the restored areas in the reserve.

Wetland areas are integral components of the environment as they provide diverse habitat corridors for birds, plants and provide a life support systems for humanity (Dodman and Rose, 1997; Frenken and Mharapara, 2002; Cherry, 2011). They provide important nursery and breeding areas for birds and fish (Donnelly *et al.*, 2019). Darwall *et al.* (2009) identified 117 aquatic vascular plant species, 38 of which are found in both landscape and wetland habitats of the southern African region; a clear indication that wetlands are of biological importance in this region. Chenje (2000) saw wetlands as water and life, hence, it is necessary to maintain the water quality as sediments can settle when water passes through them. Wetlands play an integral role in the purification of water, because of their ability to hold water for a long period (Kotze *et al.*, 2009; Nel *et al.*, 2009). Wetlands assist in water quality improvement in rivers, estuaries and streams by intercepting pollutants from the uplands before they enter the rivers (Cunningham *et al.*, 2001; Reddy and Delaune, 2008; Kebede *et al.*, 2014). For instance, plants in wetlands can absorb some pollutants like Phosphorus, Nitrogen and Sulphur (Cunningham and Saigo, 1995; Omwoma *et al.*, 2012). They act as water storage or reservoirs in areas prone to water shortage and release

it in periods of drought (Keddy, 2010; Sheng *et al.*, 2012), therefore, during dry periods, animals resort to grazing in these areas. The Table 2.1, show some of the wetlands functions.

In Kampala, Uganda, a research on the Nakivubo wetland showed its significance in sinking much of Kampala's industrial and domestic effluents (Emerton *et al.*, 1999; Kansiime *et al.*, 2005). As nutrients are removed, wetlands decrease the chances of algal blooms forming downstream; this helps in improving the quality of both ground and surface water. Research done in South Africa indicates that using wetlands for water treatment is possible and may be cheaper than the current methods being employed (Omwoma *et al.*, 2012).

Wetlands play a hydrological function of flood mitigation, ground water discharge and recharge as well as regulating river flows and recycling nutrients (Hirji *et al.*, 1994). As velocity of water is low in wetlands, it results in the decomposition of eroded materials during the stay of the water, thus, reduces siltation of reservoirs downstream. They absorb large quantities of water temporarily and release it slowly (Abraham, 2015); this results in the recharge of ground water tables around the wetland, giving natural springs a continued flow of water for long periods (Martínez-Santos *et al.*, 2018). Rivers are, thus, protected from peak flows and are less subjected to erosion, hence, protecting them from degradation.

Table 2.1: Functions of wetland and conservation concerns

Wetland Function	Wetlands Performance / Function	Conservation Concern
Flood storage	Some wetlands store and slowly release flood waters	Fills or dredging of wetlands reduces their flood-storage capacity
Flood conveyance	Some wetlands serve as flood-way areas by conveying flood flows from upstream to downstream points	If flood flows are blocked by dikes, fills or other structures, increased flood heights and velocities result, causing damage to adjacent upstream and downstream areas.
Erosion control/wave barriers	Wetland vegetation, with rhizome systems and massive roots, binds and protects soils. Vegetation also acts as wave barriers.	Vegetation removal increases erosion and reduced capacity to moderate wave intensity.
Sediment control	Wetland vegetation binds soil particles and retards the movement of sediment in slowly-flowing waters	Destruction of wetland vegetation or topographic contours decreases the wetland capacity to filter surface runoff and act as sediment traps
Pollution control	Wetlands act as settling ponds by removing nutrients and other pollutants through filtering and causing chemical breakdown of pollutants	Natural pollution-control capacity is decreased by destruction of wetland vegetation and contours
Fish and wildlife habitat	Wetlands provide water, food supply and nesting and resting areas.	Damming, fills, dredging and other alterations destroy and damage fauna and flora and decrease productivity
Recreation	Wetlands provide wild areas, scenery, habitat, wildlife and water for recreational purposes	Dredging, fills, or other interference with wetlands cause loss of area for swimming, boating, bird watching, fishing and hunting.
Surface water supply	Some wetlands store floodwater and reduce the timing and amount of surface runoff.	Dredging or fills accelerate runoff and increased pollution.
Aquifer recharge	Some wetlands store water and slowly releases it to groundwater deposits.	Drainage or fills may destroy aquifer recharge capability, thereby reducing base flow to streams.

Source: *Kupchella and Hyland (1993)*

Wetlands can recycle nutrients, which makes them highly productive ecosystems (Hammer and Bastian, 2020). Fungi and bacteria breakdown dead animals and plants for other animals and plants to use (Cunningham and Saigo, 1995; Houlahan and Findlay, 2003; Millennium Ecosystem Assessment, 2005; Cherry, 2011). Peat wetlands hold approximately 1.5% of the estimated total global carbon storage (Millennium Ecosystem Assessment, 2005). In South Africa, of the 11 peat-identified eco-regions, 25% of these have been destroyed causing about 300 000 tons of carbon to be released in 2008 alone (Millennium Ecosystem Assessment, 2005). Wetlands are used as storehouses for knowledge about ecological communities and scientific research. To date a lot of scientific effort is looking at current peat wetlands conditions to gain understanding of how they function in relation to the changing climate.

Wetlands provide a facility for crop cultivation, brick making, papyrus harvesting, and fish farming, mainly, for the surrounding communities (Emerton *et al.*, 1999). Due to their richness in soil fertility, wetlands are utilized for both commercial and subsistence farming in South Africa, Brazil, China, Zimbabwe and other countries (Emerton *et al.*, 1999; Musasa and Marambanyika, 2020). Working for Wetlands (2006) reported that some wetland plant species, such as River Pumpkin (*Gunnera perpensa* L.) are used for medicinal purposes. The economic value of Nylsvley as an international Ramsar site is mainly from attracting tourists for bird watching. The Ramsar Convention on wetlands, signed in 1971, agreed on international conservation and the promoting of wise use of global wetlands (Kingsford *et al.*, 2021). The surrounding community benefits as animals can graze in the wetlands, hence, have continual availability of pasture. Harvesting of wetland goods, such as reeds as well as cultivation of wetlands result in a deterioration in their quality, thereby, contributing to the loss of wetlands.

2.2.2 Threats and disruption of habitats in freshwater wetlands

Most inland wetland areas are subject to many pressures resulting in their degradation or loss (Reis *et al.*, 2017). With their location at the margins between water and land, wetlands are sensitive to both water and land management changes. The number of Ramsar supporting parties stand at 171 by 2021 and the number of listed sites are 2 210 (Ramsar, 2010), despite this, the wetlands continue to be destroyed and lost. Non-sustainable agricultural activities and escalating human population pose threats to wetlands (Xu *et al.*, 2019). African wetlands suffer from desertification, poor financial resources and insufficient technical capacity to work in wetlands (Dodman and Rose, 1997). The Continent has, however, formulated strategies that prioritize wetland programs. Educational campaigns are done through the media and Non-Governmental Organizations (NGOs) to give people information on the value of wetlands.

South African wetlands, like in other regions, are threatened by human activities such as agriculture, invasive alien species, mining and urban settlement as they alter the hydrology of the catchments or river system. In South Africa, wetland zones are cleared for agricultural purposes exposing them to pollution from herbicides, pesticides and cattle dung (South Africa Department of Environmental Affairs and Tourism, 2006). Continued anthropogenic activities in the wetland may close the drains that feed the wetland, thus, the natural flooding that is vital for the functioning of the wetland, is prevented. In South Africa, legislation prohibit any cultivation within 30 to 40 m from stream banks and wetlands (Department of Agriculture. Forestry & Fisheries, 1983; Republic of South Africa, 1998). This regulation is implemented to protect water sources from becoming silted by eroded sediment as well as nutrient enrichment in water courses.

Begon *et al.* (1996) note that human influence on wetlands may adversely affect habitats in three different ways. Firstly, habitat of specific species may be destroyed during land preparation either for wood or food production. Secondly, pollution may also affect the habitats, such that conditions

may become unbearable for certain species. Finally, any chemical application may also affect non-target organisms resulting in bio-accumulations and consequently affecting organisms, mostly those at the topmost of the food chain (South Africa Department of Environmental Affairs and Tourism, 2006). Begon *et al.* (1996) add that habitat fragmentation has been responsible for local extinctions of species. It is crucial, thus, to thoroughly check on aspects, such as the need to maintain natural and socio-economic functions of the wetland in a sustainable manner. This can give the wetland users ideas and ways that can be employed to mitigate future disturbances of the wetlands.

2.3 Ecological Restoration in Wetland Areas

Choi (2004), Clewell *et al.* (2004) and the Society for Ecological Restoration (SER), Society for Ecological Restoration (2004) describe ecological restoration as a process to assist an ecosystem to recover after it has been degraded, destroyed or damaged. It involves activities such as habitat protection, enhancing species composition and provision for natural regeneration of vegetation (Wortley *et al.*, 2013; Berrahmouni *et al.*, 2015). Ecological restoration attempts to recover the natural range of the ecosystem structure, composition and dynamics (Falk, 1990; Allen *et al.*, 2002; Palmer *et al.*, 2005; Karami, 2017). Its focus is on returning an ecosystem to some historical but sustainable state, in as much as the impossibility of achieving such is well recognized (Hobbs, 2013). This practice has received immense attention as it offers hope of recovery from environmental damage caused by human misuse or improper management of natural resources (Perrow and Davy, 2002). Restoration also allows the ecosystem to recover through natural ecological processes after being degraded. The level of ecosystem damages vary as some ecosystems are pushed beyond their ability to spontaneously recover (Hobbs, 2013). Restoration success story is determined by the goals of the restoration, which should, however, be practical.

Globally, wetland restoration projects have exponentially increased since the year 2000 (Nakamura *et al.*, 2006; An and Verhoeven, 2019; Nasab and Rahnama, 2020). Restoration projects' main purpose is to link the sustainable or wise use of wetlands with human well-being. It is critical to note that restoration plays a vital role in management of the environmental and policy development for purposes of monitoring (Bernhardt *et al.*, 2005). Projects for the restoration of wetlands have been carried out for various reasons which include bringing these places closer to their original or to better functional state (Washitani, 2007). Simenstad *et al.* (2006) view the 21st century as a period to fix some global environmental challenges that were due to ignorance of human beings. The desire of the 21st generation is to restore or rehabilitate disturbed areas and evaluate the progress of these activities. Such initiatives could be in the form of global restoration of rivers and wetlands. The functioning of the ecosystem is impacted by changes that occur in the landscapes, although, most areas have been restored through converting cultivated areas to nature conservation areas and rehabilitation efforts. Vegetation-cover change helps in understanding benefits of natural restoration, especially in semi-arid regions of protected nature reserves, such as NNR, for habitat conservation. In addition, vegetation composition and abundance usually reflect the sediment and hydrology characteristics of wetlands making them a significant diagnostic attribute (Aronson and Galatowitsch, 2008). Wetland ecosystems take long time to recover after disturbances; ecological studies are critical in the advancement of a scientific basis for wetland restoration and decision-making (Aronson and Galatowitsch, 2008). Most wetland restoration initiatives were motivated by issues over water quality and soil loss and this gave an opportunity for landscape-scale habitat restoration (Aronson and Galatowitsch, 2008). This situation also enables researchers to study diversity of plants in restored wetlands and to evaluate how successful restored wetlands are, for both natural and assisted restored wetlands. The restoration process of degraded or damaged natural ecosystems promotes sustainability and health of ecosystems (Gann *et al.*, 2019), however, the process requires evaluation to check on the adaptive management approaches that were implemented. To avoid implementation

challenges of flawed restoration projects, monitoring and evaluation need to be given priority (Nilsson *et al.*, 2016).

Wortley *et al.* (2013) in their evaluating stories on ecological restorations, showed that studies have been fair in ensuring species diversity, abundance and vegetation structure in their investigations but these studies were biased toward United States and Australia and of late, towards Europe (Lu *et al.*, 2019). These studies revealed the need for research to focus more on measures of socio-economic outcomes and their benefits in ecological restoration and the need for its use and support in management of natural-resource. Wortley *et al.* (2013) highlight that restoration is not a straight-forward nor an easy concept as there are many debates on what characterizes successful restoration, as well as how it can be measured, evaluated or monitored. The evaluation aspect is lacking making it necessary to conduct this study. The appraisal of success is determined by the objectives of the restoration activity (Kentula, 2000). Success in this study is understood as establishing a sustainable or viable wetland ecosystem with the goal of a self-supporting system that is resilient and able to function naturally, without assistance (Ruiz-Jaen and Aide, 2005).

Some of the ecosystem attributes to be used as guide for measuring restoration success were prepared by the Society for Ecological Restoration (2004) and these are:

- similarity of diversity and community structure as compared to the reference sites,
- the availability of native species,
- the physical environment must have capacity to sustain reproducing populations,
- normal functioning of the ecosystem,
- possibility of threats to be eliminated,
- the system should be resilient to natural disturbances and
- the system to be self-sustainable.

2.4 Ecological Theories

Ecological restoration provides facility for testing and refining theory (Palmer *et al.*, 2016). Restoration ecology can be considered as a special field of ecological research, that is necessitated by a natural ecosystem that has been altered or disturbed. The world currently faces global challenges which include, biodiversity loss, pollution, climate change, increased human population, among others (Vitousek *et al.*, 1997; Dash *et al.*, 2020). Restoration ecology is aimed at understanding how a system can be returned to a less disturbed state in a process to fix global environmental challenges (Defries *et al.*, 2012). In this process, restoration theories confirm the design, the implementation and the assessment of restoration projects situated at places ranging from small sites to catchments. These theories include those on biodiversity, biogeochemical, community assembly or disturbance ecology (Young, 2001). Theories provide logic paths and templates for predictions; they are used to explore the implications of our assumptions about ecosystem development and deviation from these theories can assist inform future research (Palmer *et al.*, 2016). Theory is fundamental to practice and advancement in the field of ecological restoration (Palmer *et al.*, 2016). This study will look deeper at the biodiversity theory with special focus on ecological succession theory, which is more relevant to the development of vegetation species. The succession theory has provided relevant interventions in plant development through the use of satellite imagery and NDVI (Perring *et al.*, 2015), which measure vegetation greenness.

2.4.1 Ecological succession theory

The study will utilize the ecological succession theory to understand better, aspects of species' ecosystem development. Ecological succession theory or ecosystem development is the change

of biological communities over time, until a stable or climax community is reached (Tivy and O'hare, 1981; Glenn-Lewin *et al.*, 1992; Pickett *et al.*, 2011). Ecological succession can either be caused by autogenic factors linked to biological communities, or allogenic succession, which is

triggered by changes in climatic conditions, such as drainage and human interference (Gall and Saxe, 1977; Botkin and Keller, 1995; Van Der Valk, 1998). Ecological succession occurs as either primary succession or secondary succession (Prach and Walker, 2019).

Primary succession is when a community develops on land that has not been occupied before by other plant communities, due to factors such as volcanic surfaces or mining spoils. Pioneer species or early successional species, such as lichens often colonize bare rock surfaces. Primary succession takes a variety of forms which include - dry habitats succession (xeroseres), bare rock succession (lithoseres) or succession that takes place in freshwater (hydroseres) (Botkin and Keller, 1995; Miller *et al.*, 2006; Prach and Walker, 2019).

Secondary succession occurs where a community was previously occupied and follows a disturbance either by humans, (including agriculture, mining or urban development) fire or flooding (Botkin and Keller, 1995; Miller *et al.*, 2006; Prach and Walker, 2019). In this study, secondary succession, especially, hydroseres, will be used in determining disturbances in Nylsvley nature reserve as this follows clearance of land for agriculture and grazing purposes. The theory will be complemented by use of Driving-Pressure-State-Impact-Response (DPSIR) Model (Kristensen, 2004), (Figure 1.1) which states that anthropogenic activities are sources of environmental pressure (Wantzen *et al.*, 2019) affecting the state of global natural resources.

2.5 The Decade of Ecosystem Restoration

On 1 March 2019, the United Nations (UN) General Assembly declared the period 2021 to 2030 as UN decade of ecosystem restoration. During this period, it is aimed to promote scaling up of restoration of destroyed and degraded ecosystems as a measure to enhance water supply, food security, biological diversity and fight the climate crisis. Monitoring will be done to measure the restoration achievements (Cooke *et al.*, 2019) and other aspects of the restoration practices. The

same authors argue that having a decade focusing on restoration may lead to a waste of resources, continued environmental destruction as well as perceptions of failure of conservation.

Young and Schwartz (2019) disagrees with Cooke *et al.* (2019) as they feel that the world is not yet ready or prepared for this proposed decade of restoration, although, they agree that protection and restoration efforts play a critical role in nature conservation. Conservation seeks to protect issues of habitat loss and degradation, while restoration focuses on advancing conservation through rebuilding nature. Currently, the world has moved passed the stage where protecting natural-intact ecosystem is perceived as the primary mode of conservation, into restoring ecological composition, function and structure, as they provide the greatest hope for nature. In fact, restoration ecology should be part of a restoration culture (Cross *et al.*, 2019).

Young and Schwartz (2019) acknowledge, for instance, that ecological restoration has progressed as a science without proper measures of evidence-based success. There are issues of common partial restoration success, which are not necessarily failures but there is a necessity to preclude what the planet needs, especially, dedicated to restoring degraded systems. In as much as the authors agree that improved monitoring for effective restoration (cost-effective) is an uppermost priority, it must not justify putting a break on large-scale commitment to current restoration initiatives.

For effective restoration monitoring, guidelines have been developed (Mcdonald *et al.*, 2016; Food and Agriculture Organization *et al.*, 2021); these incorporate the social context and the seeming benefits of monitoring (Sanchirico *et al.*, 2014). In this study, the natural regeneration approach was used, where plant populations are allowed to recolonize and recover on their own, in degraded areas over time (Mcdonald *et al.*, 2016). Vegetation cover was removed mostly through agriculture (growing of crops or grazing) or road construction for tourism, however, brush packing can be considered as assisted regeneration approach, indicating the usage of a combination of

approaches. The cause of degradation was removed to allow for regrowth of vegetation, in this case, animals were fenced off (through brush packing) to reduce overgrazing in some areas. Cross *et al.* (2019) stipulate that the UN declaration envisioned that people will engage in monitoring and restoring of their own habitats. Restoration success story of increases and effectiveness of grassland restoration has been told in California and Missouri (Young and Schwartz, 2019). The authors concluded that there may always be limits to what humans can fully restore in their ecosystems, as defined objectives and the accountability processes might always be faced with insufficient resources to fully evaluate them.

2.6 Factors Influencing the Success of Wetland Restoration Programs

It is critical to evaluate the success of ecological restoration projects in a way to justify its use in natural resources management and to improve on its implementation in restoration programs (Wortley *et al.*, 2013). Restoration of a habitat can include removing a negative effect by repairing or restoring the impacted environment (Grayson *et al.*, 1999). Wetland restoration experiences differ according to the area in which the wetland is found as well as its type. Restoring productive land is an essential aspect of restoration practice (Wortley *et al.*, 2013). Common problems in restoration projects include - lack of scientific knowledge, poor planning, inadequate management and monitoring of restoration projects, inability to maintain water level, failure to execute the project as per plan, improper site conditions, combination of heritage and archaeological functions among social and ecologic systems (Wetzel *et al.*, 2017). In this study, affected environments were restored or rehabilitated but monitoring of the projects and their evaluation are still lacking.

Evaluation of project objectives to assess restoration status is critical in detecting flaws in the project design, planning or implementation and to allow for extra restoration measures if objectives have not been met (Woolsey *et al.*, 2007; Food and Agriculture Organization *et al.*, 2021). Whatever is learned through restoration process, be it on the success or failure of the

project is still valuable as it will improve future restoration projects (Palmer *et al.*, 2005). Evaluation of restoration projects, hence, is vital as it can provide information on what action to be taken to keep wetlands in a sustainable way. Nilsson *et al.* (2016) developed a conceptual diagram, which shows the three major restoration phases (planning, implementation and monitoring) and the six evaluation steps (1, 3, 5, and 2, 4, 6) that assist in data collection for evaluation purposes. These steps are shown in Figure 2.1.

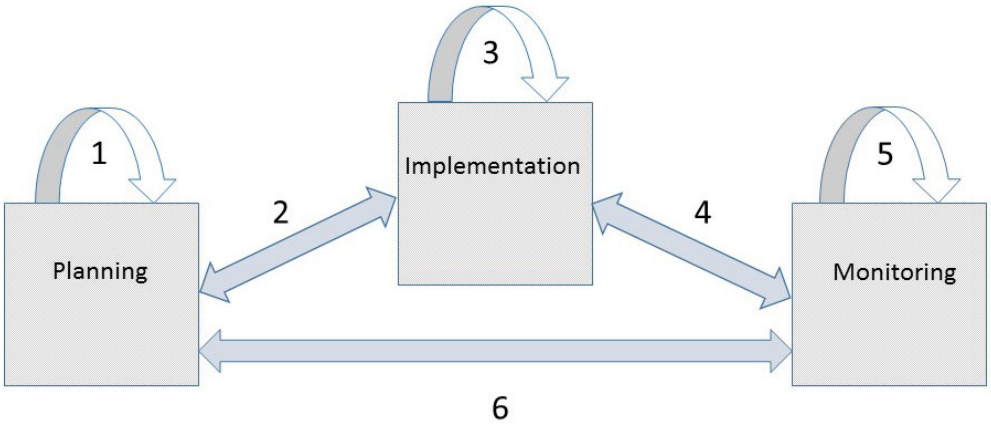

Figure 2.1: Conceptual diagram for the planning, implementation and monitoring phases (**Source:** Nilsson *et al.* (2016)**.**

It should be noted that the evaluation process goes back and forth as it is not a single-loop or a once-off practice. This process is essential in evaluating a Ramsar site of international importance; monitoring helps in reducing project mistakes.

2.7 Land Use/Cover Change and its Impact on the Wetland Environment

Land cover can be clearly observed, both in the field and from images, as it comprises the physical cover of the landscape with materials, such as vegetation, crops and soils (Verburg *et al.*, 2009). Land use is more difficult to distinguish, therefore, in many cases, it is inferred from an observable activity (for example, cultivation) (Verburg *et al.*, 2009). The level of disturbance in landscapes influences the occurrence and abundance of plant species including those found in wetlands

areas (Xie *et al.*, 2012). The changes in land use or land cover do not necessarily suggest the degradation of the land's surface, but the removal of vegetation cover implies shifting of land use patterns which impacts on biodiversity, water availability and other processes (Riebsame *et al.*, 1994). In Nylsvley, the land had been cleared for either agriculture, construction of roads or tourism purposes. These activities had influenced the land cover change and consequently, the plant biodiversity of this reserve.

The vegetation in wetlands plays an integral role in balancing temperature in aquatic systems (Trimmel *et al.*, 2018). Clearance of vegetation in these areas allows more light to penetrate resulting in increased turbidity from the exposed soil (Kent and Coker, 1992; Trimmel *et al.*, 2018). Land-use change through cultivation, settlement or irrigation results in diversion of the usual streams' or rivers' temporal flows, causing wetlands to receive less water for their aquatic life. Understanding the consequences of land use change on vegetation, particularly, of wetland zones is necessary to allow for planning and evaluation of restoration activities for conservation of wetland areas and their biodiversity (Gang *et al.*, 2015). The analysis of land use change in wetland zones is performed using change-detection techniques of vegetation, through satellite imagery.

Monitoring vegetation in wetlands provides information needed to guide management with planning and maintaining them in their proper functioning condition, where vegetation and debris are present (Finlayson and Spiers, 1999; Rebelo *et al.*, 2007). Wetlands are characterized by high density in both flora and fauna species, however, they are regarded as not properly functional when available vegetation, soil or water are at risk of loss (Aguiar *et al.*, 2011). Monitoring of vegetation in wetlands and rivers, thus, indicates whether there is a need for restoration strategy to address the causes of vegetation loss (Brooks *et al.*, 1998). Nakamura *et al.* (2006), highlight in their study that wetlands are among the most threatened ecosystems globally. Indicators of environmental change, such as changes in rainfall or vegetation patterns, are used in monitoring

wetland areas as they provide early-warning signs of ecological problems (Niemi and Mcdonald, 2004; Siddig *et al.*, 2016). Human activities, such as livestock grazing, cultivation, irrigation, dam construction, settlement and others in combination with climate variability prevent wetlands from achieving their maximum functional capability (Karr and Chu, 1997). Having noticed human impact on the environment, restoration efforts to correct such have been introduced worldwide to curb further environmental damages.

2.8 Climate Variations and Availability of Water in Wetlands

The climate of the world has fluctuated ever since humans inhabited the earth, resulting in concerns like, water insecurity (Change, 2014a; b). There is a significant relationship between climate variations and available water in rivers and wetlands. Climate change warms the atmosphere, changes precipitation patterns, as well as their timing; these leave some parts of the globe dryer and others wetter than before (Lavergne *et al.*, 2010; Change, 2014a). These conditions then affect the flow of water in rivers and wetlands, as well as the quality of aquatic environments and vegetation development. The effects - which include droughts, drying up of rivers, flooding, sea-level rise and poor surface water quality – have negative impact on biodiversity (Heller and Zavaleta, 2009; Bellard *et al.*, 2012). When there is less water flowing in rivers and wetlands, habitat of animals living in these areas will also be affected. This could be worse in regions where some of the water is drained for agricultural or mining purposes; these impacts can either be immediate or long-term.

Climate change impacts need to be integrated in water resource planning as it is critical for vegetation development in ecosystems (Heller and Zavaleta, 2009). It is necessary, therefore, for nations to integrate climate change into water resource management schemes. Long-term rainfall data contribute to understanding implications of climate variations in semi-arid regions and the information is ideal, if it is correlated with vegetation (NDVI) to determine their relationship in the

climate change era (Faramarzi *et al.*, 2018). Studies in some semi-arid regions (Herrmann *et al.*, 2005; Martiny *et al.*, 2010; Barbosa *et al.*, 2015; Liu *et al.*, 2019), have proved that rainfall correlates well with vegetation greenness, hence, it is necessary to determine if climate change (rainfall) is playing a role in vegetation restoration efforts of Nylsvley, particularly, in conserving the floodplain.

2.9 Factors Driving Species' Diversity and Composition

Species diversity and composition are mainly associated with local climatic and geographic factors (Emerson and Kolm, 2005). As stipulated by Holmes *et al.* (2005), species distribution is related to environmental gradients together with their complex interactions in landscape, such that flooding remains the crucial driver. In other studies, species distribution and abundance are related to natural and human impacts (Gregory *et al.*, 1991; Malanson, 1993). Land use and landscape structure, river management and variations in climate are drivers of species' diversity and composition (Catford *et al.*, 2011; Méndez-Toribio *et al.*, 2014). Anthropogenic changes of flooding paths can, however, decrease species' diversity, whilst reduction in flooding tends to increase species' diversity (Malanson, 1993; Naiman and Decamps, 1997; Emerson and Kolm, 2005; Poff and Zimmerman, 2010).

Species diversity includes species evenness, which refers to the relative abundance of species. This also includes species which have the largest population (species dominance) (Gotelli and Chao, 2013). Species diversity also includes species' richness, which refer to the total number of species within a certain community; this is mostly affected by competition between species, predation, environmental stability, spatial heterogeneity and age of ecosystem or the ecosystem's level of productivity (Botkin and Keller, 1995; Miller *et al.*, 2006; Seaby and Henderson, 2006). To determine the number of species per hectare in any given ecosystem, density is used as a unit of measurement. In this study, the composition and density of plant species in restored or previously-

disturbed sites were determined to assess the influence of human activities and for future measurements of restoration success.

2.10 The Role of Conventions and Legislations in Wetland Conservation

Over the past decades, wetlands were considered as high agricultural productive area for which governments would give incentives to communities to work with, to promote more agricultural production (Strydom *et al.*, 2009), therefore, most of the wetlands, globally, were cleared and drained for agricultural purposes (Glazewski, 2011). In South Africa, for instance, through the Department of Agriculture, Forest and Fisheries, either directly or indirectly, effective ways of utilizing wetlands for improved agriculture through use of new technology were modelled (Strydom *et al.*, 2009; Morardet *et al.*, 2010). At the realization of the importance of wetlands and the need for their protection from further human impacts, conventions and strategies have been put in place to protect the world's wetlands. Some of these relevant conventions are the Ramsar and Convention on Biological Diversity, which play a vital role in protecting South African's wetlands, thus, these are further discussed in this section.

The Ramsar Convention is an inter-governmental agreement that provides a framework for international cooperation for the wise use and conservation of wetlands (Dodman and Rose, 1997; Gardner and Finlayson, 2018). The meeting was held in 1971 in Ramsar, Iran, where conservation strategies of wetlands and their habitats were discussed. Wetlands are floral and faunal-rich, thus, the broad objectives of the Ramsar Convention were to ensure their wise use within nations' land-use planning (Gardner and Finlayson, 2018). The establishment of nature reserves was also one of the strategies that the convention came up with as a way of promoting wetland conservation (Dodman and Rose, 1997).

The convention drew up an inventory based on wetlands of worldwide significance in terms of zoology, ecology, hydrology and botany. Dodman and Rose (1997), note that parties to the

Convention agreed to maintain the ecological attractiveness of all listed sites and to show cooperation for the management of shared wetlands and their species. The Convention came into force in 1971, and since then, 169 nations in the globe, of which 31 out of 54 countries in Africa are Ramsar Convention members (Stevenson and Frazier, 1999; Peck, 2004). This has culminated in the protection of 81 million hectares of wetlands around the world. South Africa (SA) became a member in 1975 and has successfully designated about 22 sites as wetlands of global importance; this has helped in protecting the wetlands from further negative human effect (Unesco, 1996; Collins, 2005). The Convention deliberates on the sustainable utilization and wise use of wetlands for the benefit of mankind. Sustainable utilization refers to wetlands exploitation by humans to yield the utmost continuous benefits to the present generations while maintaining their potential to meet the future generation's needs (Frenken and Mharapara, 2002).

The Convention on Biological Diversity aims to promote a balanced share of various natural resources among different stakeholders while maximizing their utilization (Driver *et al.*, 2005). South Africa became party to this convention in 1995. The Convention gave rise to various legislations and policy frameworks in South Africa regarding biodiversity conservation and management of coastal resources, freshwater and forests (Driver *et al.*, 2005). It has led to the formulation of National Environmental Management Biodiversity Act of 2004 that brought together various legislative pieces that protect biodiversity, such as the National Environmental Management Act 107 of 1998 (Collins, 2005).

Various pieces of legislation protect wetlands in South Africa, however, they do not have a legislation that fully protects them, such as the National Water Act of 1998 (Coetzee, 1995). In South Africa, most wetlands fall in privately-owned properties, hence, leading to complications in formulation of policies that protect them (Coetzee, 1995). The following sections, look at the Water Act 36 of 1998, National Environmental Management (NEMA) Act 107 of 1998 and the Conservation of Agricultural Resource Act 43 of 1983, in trying to conserve South Africa wetlands.

They guide and provide direction on sustainable and wise use of water resources, such as the Nly River and the floodplain.

2.10.1 The Water Act 36 of 1998

The Department of Water and Sanitation (DWS), formally Department of Water Affairs and Forestry (DWAF), functions under the National Water Act and has the mandate for the assessment, management and monitoring of all South Africa water resources (Dwaf, 2005). The Act provides an outline for sustainable use of South Africa's natural resources; in the Act all water users are advised to cooperate and effectively monitor all water resources in the country (Kuntonen-Van't Riet, 2007).

2.10.2 The National Environmental Management (NEMA) Act 107 of 1998

The NEMA Act 107 of 1998 is housed under the Department of Environmental Affairs and Tourism (DEAT) (Van Der Linde, 2009); it came as a replacement to the Environmental Conservation Act 73 of 1989 (Van Der Linde, 2009). The NEMA policy serves as a significant framework for decisions on sustainability management of natural resources (Kuntonen-Van't Riet, 2007). This is important as the policy provides guidelines in maintenance of South Africa's natural systems, which include species diversity and ecological processes, among others. The NEMA Act 107 of 1998 prohibits construction of buildings, roads and other non-conforming activities in and within 32 meters from wetlands without an Environmental Impact Assessment (EIA) approved report (Van Der Linde, 2009).

2.10.3 The Conservation of Agricultural Resource Act (CARA) 43 of 1983

The CARA Act 43 of 1983 was established to protect, among others, water sources such as marshes, vleie, rivers, streams and any water course, from poor farming practices (Strydom *et al.*, 2009). This Act prohibits the channeling of water through draining of wetlands for crop

production or irrigation without prior permission from the Department of Agriculture (Collins, 2005). There are no agricultural activities permitted within 20 meters of any water body as decreed by the National Water Act 36 of 1998. Draining of water for agricultural purposes was one of the problems in the study area.

2.11 Global Approaches to Monitoring Freshwater Wetlands

The three-main international wetland-monitoring approaches are those suggested by the Ramsar Convention, Australia and the United States of America (USA). The monitoring approaches require identification of the problem and its adverse effects, the degree of the problem and the risks associated with it. The identified concerns are attended to through risk management and the outcomes are then monitored (California Wetlands Monitoring Working Group, 2012; Brooks *et al.*, 2006).

In the USA, key agencies involved in wetland assessment are the United States Environmental Protection Agency (US EPA), the US Army Corps, the US Geological Survey (USGS) and the US Fish and Wildlife Service (USFWS) (Yaffee, 1996). Monitoring methods are developed to assess length of intensive developments and their effects on wetland functions as well as to accomplish the US section 404's requirements of the Clean Water Act. By the year 2012, over 40 methods for wetland function assessment had been developed. The US was eager to develop multi-metric approaches modelled on the Index of Biological Integrity (IBI) and this has made the field of bio-assessment new in the US (Karr, 1981; Moya *et al.*, 2007; California Wetlands Monitoring Working Group, 2012). The biota used in US wetland assessment include – the vascular plants, amphibians, algae birds, macro-invertebrates and fish, to a lesser extent.

Australia's focus is on policy objectives of National Wetlands, which include monitoring condition of wetlands and providing state of environment with details on the condition and extent of riparian and wetland resources. None of the Australian states had monitoring programmes in place for

wetlands, by 2003. A new programme was developed in New South Wales for monitoring outcomes of environmental flow allocations to wetlands (Haase and Nolte, 2008), whilst in Western Australia, a rapid assessment method based on invertebrate sensitivities has been tested on coastal wetlands (Oliver and Beattie, 1996; California Wetlands Monitoring Working Group, 2012). In Asia, they have developed a framework for a Wetland Inventory, Assessment and Monitoring System (WIAMS); this approach warrants some examination for consideration by South Africa. In the Mediterranean, the initiative named, MedWet, aims at making an inventory of wetlands, as well as the development of wetland monitoring methods to improve on management of wetlands and help reduce wetland degradation.

In South Africa, government departments and agencies have responsibilities regarding management, conservation and wise use of wetlands. The national programme by Working for Wetlands, focuses on the rehabilitation of degraded wetlands in SA and is the only major initiative that is currently active in the country (Department of Water Affairs & Forestry Resource Quality Services, 2004). It is a collaborative initiative of the Departments of Environmental Affairs (DEA), Water and Sanitation (DWS) and Department of Agriculture Forestry and Fisheries (DAFF). The programme's mandate is to rehabilitate degraded or damaged wetlands and the protection of pristine wetlands, throughout SA. It complies with the Expanded Public Works Programme (EPWP) principles of skills development, transfer, job creation; it also increases communities' capacity to earn an income by utilizing only the local Small, Medium and Micro Enterprises (SMMEs) within the project areas (South African National Biodiversity Institute, 2014b).

The Working for Wetlands Programme is currently managing 37 projects in SA, including Nylsvley wetland, which is one of its restoration project's site. The vision of the Working for Wetlands Programme is to facilitate the rehabilitation, conservation, protection and the wise use of wetlands in SA, following national policies and as an indication of commitment to regional relationships and international conventions (Department of Environment Forestry & Fisheries, 2020). The main goal

of the Programme is wetland conservation in South Africa, and this is conducted in a way that ensures reduction in poverty through employment and skills development amongst marginalised and vulnerable groups.

Another programme is the Mondi Wetland Project (MWP), which acts as a catalyst in sustainable use and rehabilitation of wetlands that are outside protected areas in SA. The WRC has several wetland research projects and works in partnership with other projects, programmes or agencies. One of their projects is integration of wetlands into catchment management and wetland water quality and river health component (Department of Water Affairs & Forestry Resource Quality Services, 2004). This allows for site-specific restoration and mitigation measures to be developed; these will fundamentally assist in the sustainable management of any proposed development, which is acceptable to the surrounding environment, hence, will not cause further destruction of aquatic and terrestrial habitats.

2.12 Remote Sensing and Geographic Information Systems Tools

Remote Sensing (RS) and Geographic Information Systems (GIS) tools are used in monitoring, assessment and environmental management (De Sherbinin *et al.*, 2014). Geographic Information System analyses and displays geographic data (Lillesand *et al.*, 2004; Heywood *et al.*, 2006). In wetland conservation, management and restoration ecology, a knowledge of functional relationships between wetlands and their components (elevation, hydrophytes, soils, hydrology combined with other influencing factors like climate and human interferences) is essential (Georgiadou *et al.*, 2004; Lowry, 2006). All these components can be spatially represented and built in GIS because of its capability to store, analyse, retrieve information and to query data to determine relationships and patterns (Lillesand *et al.*, 2004; Heywood *et al.*, 2006; Lowry, 2006).

Remote Sensing (RS) and GIS in combination with historical and field survey data or information have contributed meaningfully to identifying the extent and spatio-temporal degree of the effects

of cultivation on wetlands (Berka *et al.*, 2001; Dahl, 2004; Murungweni, 2013; Xu, 2015). An analysis of the high resolution imagery gives the historical data on changes in the vegetation, overtime (Kollar *et al.*, 2013; Mutanga *et al.*, 2016). Aerial photography has been used for over 40 years in monitoring wetland areas to detect changes in agricultural land use and wetland mapping (Kollar *et al.*, 2013; Murungweni, 2013; Klemas, 2014). Remote Sensing and GIS have proved essential in monitoring and detecting vegetation changes in landscapes over time and facilitates development of better monitoring strategies, through mapping (Landres *et al.*, 1999; Johansen *et al.*, 2007; Davranche *et al.*, 2010; Duro *et al.*, 2012; Kollar *et al.*, 2013; Russell and Ward, 2014). The enhanced understanding of previous vegetation composition and its spatial extent gives a history of the land uses and management strategies. Remote Sensing assists us in understanding the system under study better, as it notices hidden problems that help to interpret results more efficiently (Lillesand *et al.*, 2004; Silva *et al.*, 2007; Jensen, 2009; Dube and Mutanga, 2016).

In this study, to assess vegetation dynamics, rainfall will be correlated with vegetation (Normalized Difference Vegetation Index) and land use/cover spatial analysis, using Landsat TM5 and 8 sensors. Aerial photographs of 2005 will assist with image classification, hence, Remote Sensing data will play a key role in this study.

2.12.1 Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) has become a popular vegetation health index since 1979 and was the first vegetation index used for vegetation health and density assessment (Tucker, 1979). It measures the photosynthetic activity with ranges of between negative one (-1) and positive one (+1) for low and high photosynthetic activity, respectively (Onema and Taigbenu, 2009). Values close to +1 (0.8 - 0.9) in NDVI indicate the highest probable density of green leaves whereas zero means no vegetation (Kogan, 1995).

During the process of photosynthesis, solar radiation is absorbed by green and healthy vegetation to use as source of energy. Vegetation pigment absorption causes the reflected red energy to decrease, whilst the reflected Near Infra-red (NIR) energy increase because of strong scattering of green (Brown *et al.*, 2006). Expressing the values of the Red and NIR bands as a ratio enhances the detecting of the health of vegetation, of any area. Kogan (1995) highlights that detecting vegetation health status of a given area could be enhanced if the values of two bands, that is, NIR and Red are expressed as a ratio. The NDVI is, thus, a simple ratio between the near infra-red and the red bands calculated using the following formula:

$$NDVI = (NIR - RED)/ (NIR + RED)$$

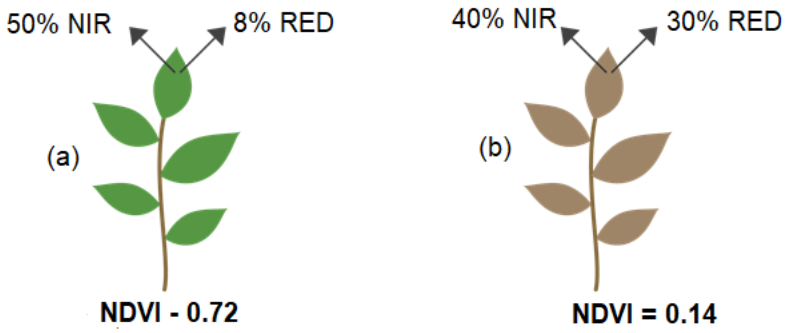

Figure 2.2: Reflectance of healthy and stressed vegetation

Key: (a) Healthy (b) Stressed

As indicated in Figure 2.2, healthy vegetation (a) absorbs more of the red light whilst reflecting a large portion of near-infrared light, while the less healthy vegetation (b) reflects more red light with less near-infra-red light. The numbers shown on Figure 2.2 represent real values, but actual vegetation is much more diverse. Normalized Difference Vegetation Index values are influenced by environmental factors like soil, vegetation type and topography (Wang *et al.*, 2003; Onema and Taigbenu, 2009). Several studies have explored the relationship between rainfall and

vegetation; among these are, those utilising NDVI, which is a good proxy for vegetation productivity and greenness (Onema and Taigbenu, 2009; Pan *et al.*, 2018).

NDVI is derived from satellite images and has been used in examining vegetation spatio-temporal trends and can be correlated with rainfall to determine long-term climatic effects (Anyamba and Tucker, 2005; Pan *et al.*, 2018). Correlating rainfall and NDVI was done in the Northern coastal regions and recently in the semi-arid regions of China (Zhong *et al.*, 2019). Foody (2002) reported that the Ordinary Least Squares (OLS) regression analysis has shown a strong and significant relationship of 99% confidence level between NDVI and rainfall. In areas receiving mean annual rainfall of between 200 mm to 1200 mm, there is a good relationship between rainfall and NDVI variation (Nicholson and Entekhabi, 1987). Rainfall plays an important role in flooding of wetlands and agricultural practices in the semi–arid regions of Africa. Martiny *et al.* (2010) highlight that the relationship between rainfall and NDVI differs in terms of linearity as well as efficiency in rain.

2.13 Conclusion

The chapter reviewed literature that assisted to address the objectives of the research. It was critical for the study to understand why restoration has come into play in environmental management. Various legislations that protect wetlands in South Africa and at international level, were also discussed. Highlights of the methods used were given, such as RS, but a detailed description of all methods used is also provided under each chapter. The following chapter, is on the description of the study area.

3. DESCRIPTION OF THE STUDY AREA

3.1 Introduction

This chapter describes the characteristics of the study area which include its location, climate, soil, elevation and land use/cover. It also presents a summary of the research approach utilized to address the study objectives whilst detailed research methods are presented in each chapter, (4 - 7).

3.2 Characteristics of the Study Area

3.2.1 Location and Description of the Study Area

Nylsvley floodplain is located to the East of Waterberg District between Mookgophong and Modimolle towns in Limpopo Province of South Africa; it is 3 975 hectares in size. The flood plain is located at 28^{o} 42.00' East and 24^{o} 39.00' South, within the Nyl River system which is managed by the Limpopo Conservation Authority. It was declared a Ramsar site of worldwide conservation importance in 1998, and the wetland is largely recognised as one of the most significant avian conservation region in South Africa wetlands (Greenfield, 2004; Scholes and Walker, 1993; Mccarthy *et al.*, 2011).

The nature reserve is within the national freshwater ecosystem priority area and is critical for harboring South Africa's largest freshwater wetland and a variety of bird and other faunal species (Scholes and Walker, 1993) The floodplain is a habitat for over 100 aquatic bird species, 57 of which breed in this wetland. This makes it a crucial feeding and nesting site for migratory birds and several endangered species. There are 23 waterfowl bird species found in this wetland and these are listed in the International Union for Conservation of Nature Red data of threatened species (Tarboton, 1987; Reserve Management Documents, 2013). The wetland, apart from its conservation value, is also agriculturally important as it provides animals with extensive

grasslands for grazing, all year-round. Figure 3.1 shows the location of Nylsvley Nature Reserve within the Nyl River system.

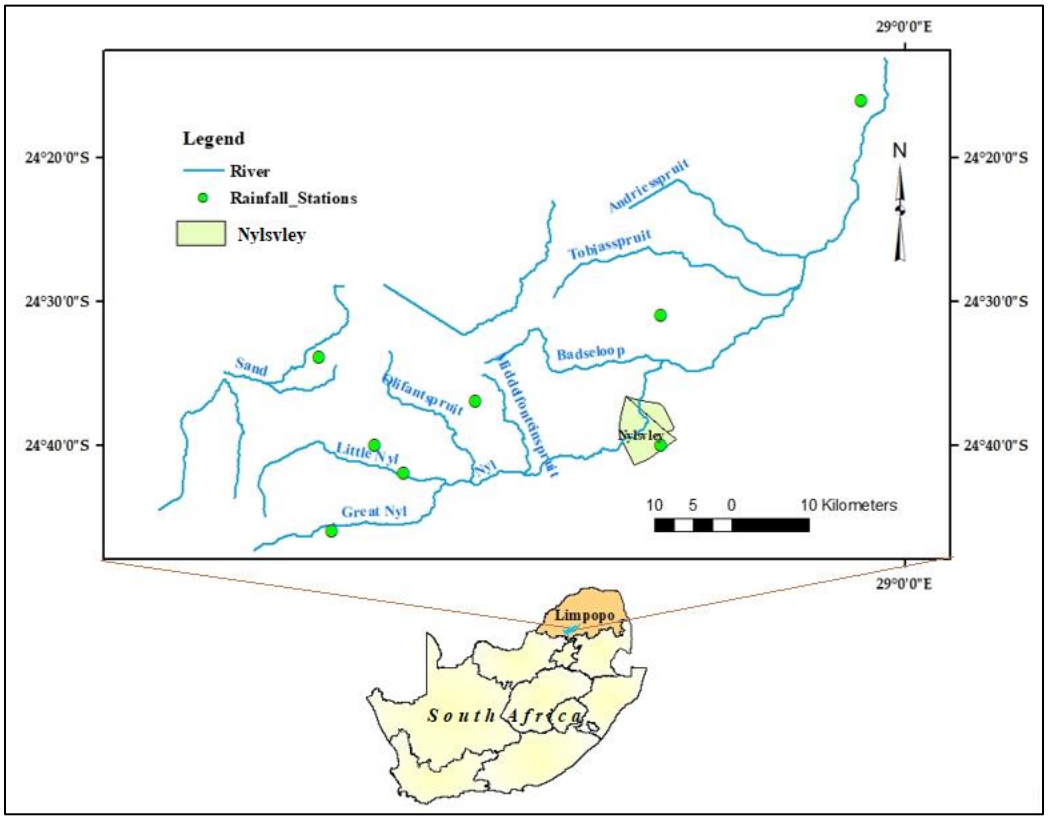

Figure.3.1: Location of Nylsvley and distribution of rainfall stations in Nyl River system
Source: GIS data sets, University of Venda

Nylsvley Nature Reserve (NNR), which is a Ramsar site of worldwide importance, has been under threat for the past two decades. Studies show that the water quality of the reserve is poor and the population of aquatic-bird species visiting the NNR wetland has reduced drastically by 80-90% (Greenfield, 2004; Greenfield *et al.*, 2007; Greenfield *et al.*, 2012). In addition, the frog population (originally, there were nineteen frog species) has declined, although it has not yet been determined by how much. Only a few can be heard calling after the rains, indicating their reduced numbers in the wetland (Greenfield, 2004; Khoza *et al.*, 2012).

This freshwater ecosystem is the largest inland floodplain that covers an area of about 16 000 ha when fully inundated. The wetland's ability to provide ground water recharge throughout the year makes it valuable and prompts the need for its conservation (Scholes and Walker, 1993). Rowberry *et al.* (2011) note that the ecological status of the freshwater wetland has been threatened by the increasing developments within and from upstream catchments; this is affecting the availability of water and vegetation in the floodplain.

Sustainable conservation and management of wetlands require regular monitoring and assessments to check on status and changes in vegetation in the wetland zones (Scott and Jones, 1995). Wetland assessment involves inventory and mapping of vegetation species within the wetlands (Scott and Jones, 1995; The United States Department of Agriculture Forest Service National Riparian Technical Team, 2014). Identification, mapping and assessing conditions of freshwater wetlands are of paramount importance for various management and planning activities at global, regional and local levels (Brooks *et al.*, 1998; Skidmore *et al.*, 1998; Gallant *et al.*, 2014). These activities offer information on wetland vegetation types, their distribution and phenology and act as a good indicator for assessing wetland deterioration (Skidmore *et al.*, 1998; Netando *et al.*, 2010; Mesta *et al.*, 2014).

Nylsvley Nature Reserve was part of a privately-owned property that was active in agriculture. Due to the reserve's, unique landscape and biodiversity, it was commissioned to government in 1974 (Nylsvley reserve size 3120 ha) and the other portion, Vogelfontein (850 ha) was added in 1997. This brought the total area of the floodplain to about 3970 hectares. From the year 2000, the improvement of ecological integrity has become a key objective with a clear shift from projects at habitat scale to integrated projects of entire ecosystem (Nakamura *et al.*, 2006). Simenstad *et al.* (2006), view the 21st century as a period to fix some global environmental problems that occurred due to human ignorance. The desire of the 21st generation is to restore disturbed areas and assess the progress of such restoration activities as ecosystem functioning is impacted by

alterations or changes in the landscapes (Simenstad *et al.*, 2006). It is vital to note that restoration plays a critical role in environmental management and policy development for monitoring purposes (Bernhardt *et al.*, 2005). This helps in understanding the benefits of most restoration efforts today, especially, the development of vegetation in semi-arid regions during the climate-change projected period.

3.2.2 Climate

Nylsvley is in a semi-arid region characterized by hot to wet and warm to dry seasons with average annual rainfall of 630 mm (Tarboton, 1987; Scholes and Walker, 1993; Higgins *et al.,* 1996). There is highly seasonal rainfall and 95% of it occur between November and March (Higgins *et al.,* 1996) with a mid-season dry spell, during significant periods of growth. Winters (May to July) are dry and springs (September) have little to no rainfall (10 mm on average). The average annual temperature is 18°C with temperature ranging from –6 °C in winter to 39 °C in summer (Low and Rebelo, 1998).

3.2.3 Soil

The NRS catchment is underlay by sedimentary rocks of the Waterberg, mainly composed of sandstone, grit, mudstone, siltstone, shale and conglomerate (Dye and Croke, 2003). The soils are predominantly acidic sands (which are highly variable), gravels, and loams occurring at ~1200 mm depth with altitude ranging from 1180m to 1508 m (Dye and Croke, 2003). The Nylsvley flood plain, located in the middle of NRS is characterized by both well and poorly-drained soils, black clay and alluvial soils (Tarboton, 1987; Scholes and Walker, 1993; Higgins *et al.,* 1996).

3.2.4 Elevation

The reserve has a landscape of low relief with undulating terrain of about 1 100m in altitude (Lubke *et al.,* 1983).

3.2.5 Land use/cover

The catchment area lies in ~90% natural savanna bushveld and 10% croplands (Low and Rebelo, 1998). Nylsvley has a history of being a grazing site for domestic and non-domesticated animals. Land use activities include agriculture (growing of crops and rearing of animals), game farming and settlements. The Nyl River system consists of small tributaries which lie in the Waterberg plateau (Higgins *et al.,* 1997).

Different wetland vegetation species cover the park, including those in the salt marshes floodplain, grasslands; these are mostly *Leersia hexandra, Eleocharis dregeana* and the rice grass *Oryza longistaminata*, which is restricted to Nylsvley (Mucina and Rutherford, 2006b). The most dominant species found in Nylsvley freshwater swamps are reeds (*Phragmites australis*). The unique biodiversity of plant and animal life is supported by the rich underlying geological formations (Mucina and Rutherford, 2006a).

3.3 Research Approach

The research approach for the study comprises the steps as shown in the flow diagram, Figure 3.2.

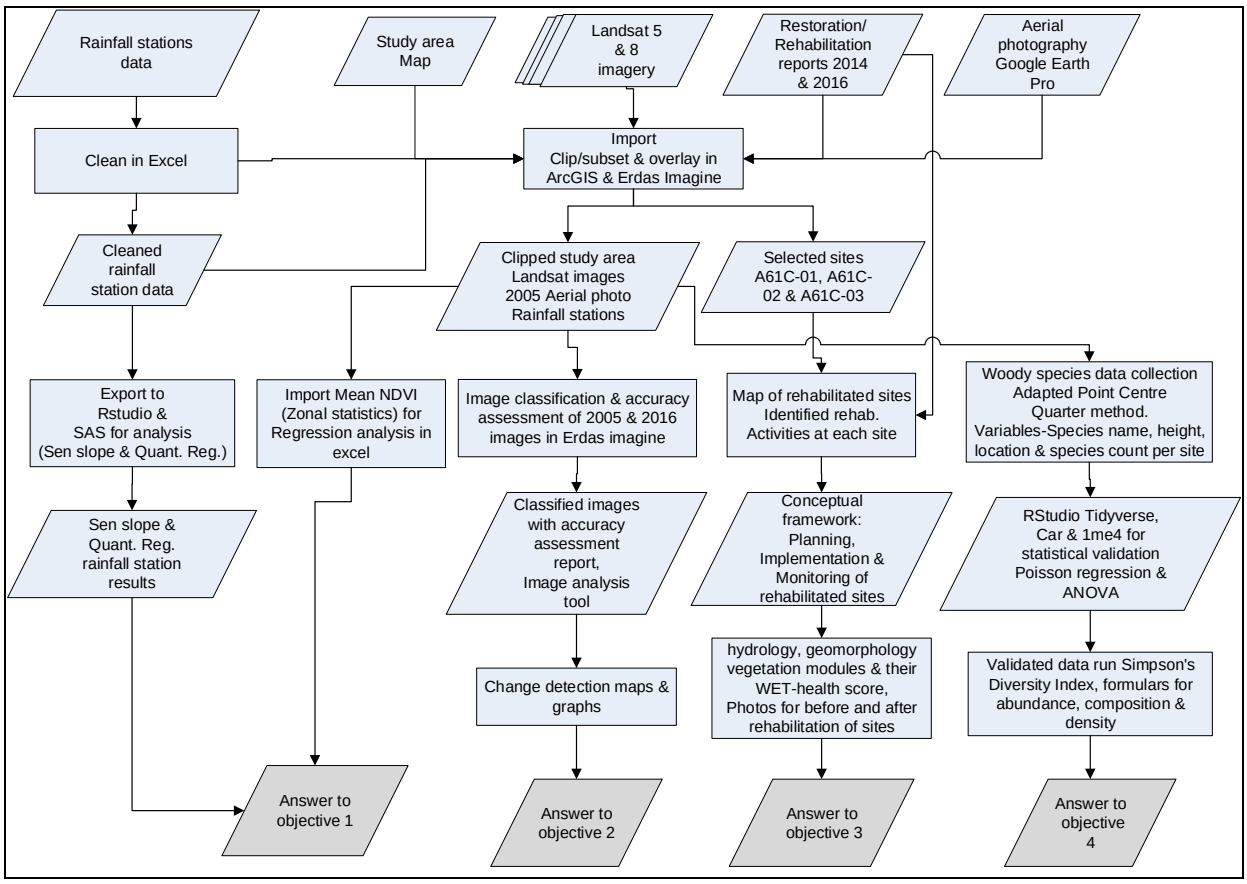

Figure 3.2: Flow diagram of the research methodology

4. RAINFALL TREND AND ITS RELATIONSHIP WITH NORMALIZED DIFFERENCE VEGETATION INDEX IN A RESTORED SEMI-ARID WETLAND OF SOUTH AFRICA

This Chapter has been published in Sustainability, MDPI journal.

Abstract

Clearance of terrestrial wetland vegetation and rainfall variations affect biodiversity. The rainfall trend–NDVI (Normalized Difference Vegetation Index) relationship was examined to assess the extent to which rainfall affects vegetation productivity within Nylsvley, Ramsar site in Limpopo Province, South Africa. Daily rainfall data measured from eight rainfall stations between 1950 and 2016 were used to generate seasonal and annual rainfall data. The Mann-Kendall and quantile regression were applied to assess trends in rainfall data. NDVI was derived from satellite images from between 1984 and 2003 using Zonal statistics and correlated with rainfall of the same period to assess vegetation dynamics. The Mann-Kendall and Sen's slope estimator showed only one station had a significant increasing rainfall trend annually and seasonally at $p < 0.05$, whereas all the other stations showed insignificant trends in both rainfall seasons. Quantile regression showed 50% and 62.5% of the stations had increasing annual and seasonal rainfall, respectively. Of the stations, 37.5% were statistically significant at $p < 0.05$, indicating increasing and decreasing rainfall trends. These rainfall trends show that the rainfall of Nylsvley decreased between 1995 and 2003. The R^2 between rainfall and NDVI of Nylsvley is 55% indicating the influence of rainfall variability on vegetation productivity. The results underscore the impact of decadal rainfall patterns on wetland ecosystem change.

Keywords: Mann-Kendall; NDVI; quantile regression; rainfall; vegetation; wetland

4.1 Introduction

Vegetation is critical for assessing conditions of terrestrial wetland ecosystems impacted by global

climate changes (Huang *et al.*, 2020). A wetland's vegetation plays crucial roles in the provision of habitat for wildlife, preventing soil loss, slowing water movement and in the process removing of pollutants and purifying water (Sun *et al.*, 2015; Han *et al.*, 2019; Huang *et al.*, 2020). Climate change warms the atmosphere, changes rainfall patterns and timing, leaving some parts of the world drier and others wetter than before (Lavergne *et al.*, 2010; Some'e *et al.*, 2012; Change, 2014b; Zhao *et al.*, 2019); this impacts on wetland ecological processes (Sun *et al.*, 2020) The potential of climate change together with its effects on rainfall distribution are a threat to vegetation development. In the continent of Africa, rainfall amounts are predicted to decrease, especially in Sub-Saharan Africa forcing already high temperatures to further increase (Martiny *et al.*, 2010; Intergovernmental Panel on Climate Change, 2014; Asfaw *et al.*, 2017). The more rainfall received at a time implies more vegetation cover (Yang *et al.*, 2015), especially, in semi-arid regions where rainfall is erratic which is exacerbated by global climate change. Rainfall affects both the spatial and temporal patterns of water availability on the earth's surface and is used in climate science to trace the magnitude and extent of variability of climate change (Intergovernmental Panel on Climate Change, 2007; Taxak *et al.*, 2014; Adarsh and Janga Reddy, 2015). The emphasis here is on investigating the dynamics of rainfall and vegetation through constant monitoring as the results provide policy-makers with information for making informed decisions and can predict future patterns (Kent and Coker, 1992; Yang, 2007; Sieben *et al.*, 2014).

Several studies have investigated the relationship between vegetation and rainfall (Onema and Taigbenu, 2009; Vrieling *et al.*, 2013; Zhao *et al.*, 2015; Pan *et al.*, 2018; Wilson and Norman, 2018) utilising Normalized Difference Vegetation Index (NDVI), which is a good proxy for vegetation greenness and productivity. NDVI is derived from satellite images and has been used to examine vegetation trends and analysis over time and can be correlated with rainfall to determine long-term climate change effects (Anyamba and Tucker, 2005; Huber *et al.*, 2011;

Shisanya *et al.*, 2011). Rainfall on the other hand is discrete in nature and difficult to measure in space but correlates well with NDVI (Martiny *et al.*, 2010). Detecting changes using annual and seasonal rainfall overtime may depict some trends in rainfall over time (New *et al.*, 2006; Aguilar *et al.*, 2009) which can assist to explain vegetation growth and climate-change effects. This data is obtained mainly through networks of rainfall stations in any given area. Yang *et al.* (2015) noted that rainfall records are prone to incomplete measured rainfall data or shortage of rainfall stations, particularly, in sub-Saharan region, except for South Africa.

Within Nylsvley, a Ramsar site of international recognition, restoration activities have been implemented since 2014, to promote natural vegetation regrowth from previous anthropogenic activities that impacted on the wetland's vegetation. A study by Huang *et al.* (2020) stipulates that vegetation clearance lead to excessive soil, water and biodiversity loss (Greenfield, 2004; Hefting *et al.*, 2005; Khoza *et al.*, 2012) making it a serious issue which prompted the Government of South Africa to implement restoration activities to save Nylsvley and its unique biodiversity. About 80 million South African Rands is spent annually on wetland-restoration projects with Nylsvley having a budget of over 7 million South African Rands, in 2016 alone (Cowden *et al.*, 2014), hence, the need to fully understand climate variations to make informed restoration decisions. Pan *et al.* (2018) stipulated that removal of vegetation in wetland ecosystems is reflected in poor vegetation productivity in these ecosystems. Nylsvley has been linked to previous anthropogenic activities such as agriculture and grazing which has impacted on vegetation recovery since the formation of the reserve in 1974 (Higgins and Rogers, 1993; Higgins *et al.*, 1996).

Nylsvley, despite its importance, is at risk of further deterioration, hence the need to analyse if rainfall received in this region has been constant over time and relate Nylsvley station rainfall to NDVI of the reserve. This will provide critical information for understanding climate change impacts on natural vegetation development in this restored wetland ecosystems (Jensen, 2002). Several studies in Nylsvley by (Greenfield *et al.*, 2007; Greenfield *et al.*, 2012; Sieben *et al.*, 2014)

including those by (Kleynhans *et al.*, 2006; Mccarthy *et al.*, 2011; Tooth and Mccarthy, 2007; Whitecross *et al.*, 2016), however, did not attempt to assess climate change impacts in this wetland. Elsewhere in Limpopo Province of South Africa, a study by (Odiyo *et al.*, 2015) focused only on rainfall trends in Levubu catchment without relating it to environmental attributes, particularly, vegetation. Both process, however, are crucial as availability of water in wetland systems is critical for flora and fauna which in-turn attracts tourists and boosts the regional economy; despite all these studies conducted in the Province and in Nylsvley wetland owing to its importance, there is a dearth of literature that focuses, specifically, on the impacts of climate change on this semi-arid restored wetland. Limited information on these impacts results in a limited understanding of how climate change impacts on this wetland.

An attempt is made here to study long term rainfall trends and their relationship to vegetation, in reaction to climate change. Correlating rainfall and NDVI has been done in some Northern coastal regions and most recently in semi-arid regions of China (Zhong *et al.*, 2019) and to the best of our knowledge, assessing the relationship of NDVI and rainfall remains unresolved, especially, in restored wetlands of semi-arid regions of South Africa. Asfaw *et al.* (2017) states that micro-scale studies of rainfall trends are critical in understanding local scale manifestation of the effects of climate change since they lead to the development of specific interventions or monitoring tools. For development of better management options, local level rainfall-trend-analysis data are used as compared to country or regional data sets. To bridge this gap, a co-correlation model, will be utilized for NDVI-rainfall relationship to understand the impact of climate on regeneration of vegetation of this area. Moreover this Ramsar site has unique biota, such as the grass, *Oryza longistaminata*, which is available only in the Nylsvley, in South Africa (Mucina and Rutherford, 2006b).

The findings provide additional insights for understanding climate variability within Nyl River system including the restored Nylsvley wetland. More light will also be shed on our understanding

of climate change impacts on vegetation growth in wetlands of semi-arid regions to assist with the proper management and monitoring of this and similar wetlands for early warning of negative effects. An attempt, thus, was made to investigate the diurnal seasonal and annual rainfall in the NRS to determine the significant trends in rainfall from the year 1950 to 2016. The study also explored the seasonal rainfall-NDVI relationship in Nylsvley between 1983 and 2003 as a contribution towards understanding local level impacts of climate variations in the restored wetland vegetation ecosystem. In addition, there is little evidence of studies that show long-term trend changes in rainfall and their ecological impacts on vegetation growth within the Nylsvley wetland. Restoration activities are costly, hence, the need to conduct such a study to fully understand climate change impacts within this wetland.

4.2 Objective

To determine rainfall trends and their relationship to Normalized Difference Vegetation Index (NDVI) development in Nylsvley.

4.2.1 Hypothesis

There is a trend in rainfall and vegetation in Nylsvley wetland.

4.3 Materials and Methods

4.3.1 Study area

The detailed description of Nylsvley floodplain and Nyl River system is as provided in Chapter 3, section 3.2.1. Figure 3.1 also show the distribution of the rainfall stations studied. The stations are spread along the Nyl River system (Figure.3.1) including the Nylsvley wetland.

4.3.2 Availability of data

4.3.2.1 Rainfall data source and quality

The spatial locations of the stations studied and the source of data for each station are as shown in Table 4.1.

Table 4.1: Location of rainfall stations and source of data

Station Name	Latitude	Longitude	Data source
Buffelspoort	-24.76666641	28.33333397	Agriculture Research Council
Elandspoort	-24.66666603	28.38333321	Agriculture Research Council
Modimolle	-24.70000076	28.41666603	South Africa weather services
Groenfontein	-24.61666679	28.5	Agriculture Research Council
Mookgophong	-24.51666641	28.71666718	Agriculture Research Council
Nylsvley	-24.66666603	28.71666718	South Africa weather services
Moorddrift	-24.26666641	28.95000076	Agriculture Research Council
Polokwane	-24.56453	28.31893	Agriculture Research Council

To assess and understand the trends in rainfall within the NRS, daily rainfall data was measured from eight rainfall stations ranging from 27 to 66 years, between the years 1950 and 2016. One station with 27 years of data recorded was considered since it is closer to 30 years. The selected long-term period provided a common data set for rainfall and allowed for reliable climatic variations in this study. The rainfall data set was obtained from the South African Weather Service (SAWS) and Agriculture Research Council (ARC), two and six stations, respectively. This data has the advantage of quality control with information on missing or unaudited data explained. The first treatment applied to the rainfall data was the quality assurance and control as a precondition for the statistical analysis (Duhan and Pandey, 2013). The data was checked for any irregularities like missing data and outliers. It should be noted however, that climate time series data are affected by a number of non-climatic factors which include changes in instruments, human errors or different observation practices (Fan and Chen, 2016). The quality analysis of the rainfall data revealed that data was statistically clean except for a few days of missing data. Where rainfall

stations had gaps due to missed records for some days, the gaps were filled through interpolation from data of the nearest and high correlating neighboring stations. This can help to reduce unwanted spatial inhomogeneity (Msovu *et al.*, 2020), hence, more rainfall stations were studied before relating the vegetation of the wetland to Nylsvley wetland rainfall station, to check on the reliability of this station's data. Total daily rainfall values were used to come up with a monthly mean as well as a seasonal and annual rainfall. The mean monthly rainfall was correlated with mean NDVI in Nylsvley from 1984 to 2003. Nylsvley rainfall station data was limited up to the 2003 period, forcing the analysis to also end in the same period. Seasonal rainfall time series were selected to show changes that may not be depicted by total annual rainfall. Mazvimavi (2010) highlighted that overtime changes in rainfall at smaller spatial scales have the potential to show interesting trends and climate change impacts at localized scale.

4.3.2.2 Acquisition of Landsat 5 imagery

NDVI data was derived from Landsat 5 images downloaded from USGS through earth explorer website, (https://earthexplorer.usgs.gov/) and have been geometrically and radiometrically corrected. The imagery at 30 m resolution with, temporal resolution of 16-days, row 170/077, UTM projection acquired in the summer season for some years between 1984 to 2003, were considered in this study; (See Table 4.2, for selected images). The selected sensor was the best available cloud-free image in the study area for the period. The beginning of seasons' images was selected as most were free from cloud cover (October month). The winter vegetation coverage of semi-arid regions is mostly poor, hence, we focused on the summer season (October to March) utilising cloud-free images. NDVI values were, thus, averaged and utilized for analysis in this study.

Table 4.2: Landsat 5 imagery used to derive the NDVI data

Satellite sensor	Path/ row	Spatial Resolution	Acquisition Date	Season	Projection
Landsat 5	170/077	30m	281084	Summer	UTM
Landsat 5	170/077	30m	021086	Summer	UTM
Landsat 5	170/077	30m	010191	Summer	UTM
Landsat 5	170/077	30m	031193	Summer	UTM
Landsat 5	170/077	30m	281195	Summer	UTM
Landsat 5	170/077	30m	021297	Summer	UTM
Landsat 5	170/077	30m	221298	Summer	UTM
Landsat 5	170/077	30m	120399	Summer	UTM
Landsat 5	170/077	30m	181103	Summer	UTM

Research done in semi-arid regions in the 1980s and 90s periods demonstrated the seasonal relationship between NDVI and rainfall variations (Tucker and Nicholson, 1999). NDVI enables us to examine ecosystem dynamics and long-term trends in vegetation (Eklundh and Olsson, 2003). Vegetation indices estimate vegetation cover from RS imagery. The indices are generated as a combination of RS bands. NDVI (vegetation greenness) is most common and widely used spectral index in vegetation analysis. The detailed properties of NDVI are provided in many other studies including, (Ichii *et al.*, 2002; Martiny *et al.*, 2010; Shisanya *et al.*, 2011; Barbosa *et al.*, 2015) and in the following section on data analysis.

4.4 Data Analysis

To analyse trends in rainfall data, statistical methods have been developed and applied in studies over many years, (Sayemuzzaman and Jha, 2014; Odiyo *et al.*, 2015; Singh and Kumar, 2016; Fan and Chen, 2016). Most of the above studies have used linear regression models based on ordinary least squares regression which are used mostly in linear trends studies. These have limitations in providing information on mean condition of indices, but ignoring other aspects of the lower or upper tails of index distributions that are more important than the mean trends in climate trend studies (Tareghian and Rasmussen, 2013). Odiyo *et al.* (2015) highlight that using more than one method in trend analysis has the advantage of improving the results. To boost accuracy of and confidence on the study results, thus, the Mann-Kendall trend test (MK), Sen's slope

estimator and quantile regression (QR) were used to analyse annual and seasonal rainfall data of NRS and the final trend station results were compared. Tareghian and Rasmussen (2013) and Lee *et al.* (2013) note that the QR method has recently been introduced in climate - related studies, hence, it is fairly new in rainfall-application studies in Southern Africa (Chamaillé-Jammes *et al.*, 2007; Mazvimavi, 2010).

The non-parametric MK method has been preferred over parametric test method in analysing data trends as it also estimates trend direction (Sayemuzzaman and Jha, 2014). Sen's slope method is used for estimating the slope of a linear trend. It has been widely used for determining the trend magnitude in hydrological and meteorological time series data (Partal and Kahya, 2006; Jain *et al.*, 2013; Adarsh and Janga Reddy, 2015). Asfaw *et al.* (2017) note that non-parametric statistical tests are suitable for data that is not normally distributed and with missing data - a common phenomenon in hydrological time series data. Shapiro-Wilk Test of Normality (R-Studio software) was used for testing normality distribution of the data of all the rainfall stations. MK was used in detecting the significance of the trend in rainfall time series and it works well with data that has outliers (Asfaw *et al.*, 2017). The MK test is based on the statistic *S* defined in the following formula:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn\left(x_j - x_i\right) \quad (1)$$

where N stands for number of data points, x_j and x_i represent the values at time *j* and *i* (*j*>*i*), respectively; *sgn* stands for *sign* (Adarsh and Janga Reddy, 2015). Sen's slope estimator determined the magnitude of the trend in rainfall data. Pohlert (2016) states that Sen's slope test computes the linear rate of change and intercept as follows:

$$d_k = \frac{X_j - X_i}{j - i} \quad (2)$$

$$for\ (1 < i < j < n)$$

where d = slope, $_k$ = median, X denotes the variable, n = number of data and i, j = indices. Sen's slope is therefore calculated as the median from all slopes: b = Median d_k. These intercepts are computed for each time step t, and a is intercept as shown in the formula below:

$$a_t = X_t - b * t \quad (3)$$

This function computes the upper and lower confidence limits for Sen's slope.

The results of Sen's Slope have the negative sign representing the decreasing trend and positive sign shows the increasing trend (Motulsky, 2007). Long-term trend analysis has the advantage that it can reveal starting point of trend year, changes occurring over time as well as detections of abrupt changes in time series. The Sen's slope estimator imbedded within MK was used to determine the magnitude of trends in time series. MK, a non-parametric test is ideal for analysing hydrological and climatological data which are characterised by missing data or non-normally distributed data as this is a common feature (Yue and Pilon, 2004).

The QR is an extension of least squares regression method (Fan and Chen, 2016) and examines functional relations between variables for all portions of a probability distribution as well as estimates multiple rates of change (slopes) from the minimum to maximum responses (Koenker and Bassett Jr, 1978; Cade and Noon, 2003). It provides a complete picture of the relationships among variables when both the lower and upper quantiles are of interest in a study (Chen, 2005). Changes in rainfall regime may not equally affect all rainfall percentile values (Shiau and Huang, 2015), hence, the need to examine changes in several quantiles in detecting trends among different rainfall distributions. In this study, QR was used in an estimation of slopes of trends in quantiles 0.1, 0.2, 0.5, 0.7 and 0.9 of total recorded daily rainfall values which were used to compute seasonal and annual rainfall for NRS. Quantiles 0.1 and 0.2 represent low rainfall, 0.5 and 0.7 median and 0.9 indicates high rainfall events (Koenker and Bassett Jr, 1978; Koenker

and Hallock, 2001; Cade and Noon, 2003). The first order QR model has X which is defined as covariant of Y and τ and X = x, as follows:

$$Y(\theta)\backslash x = \beta(\theta)_0+\beta(\theta)_1 X+\xi \quad (4)$$

where, *Y* is a random variable of the total rainfall time series and θ has values ranging from $0 \leq \theta \leq 1$ with *Y* probability being equal or less than τ which signifies the θ^{th} quantile. The $\beta(\theta)_1$ is the coefficient, the $\beta(\theta)_0$ is the intercept depending on the θ^{th} quantile value and ξ signifies an error with the exception of zero (Mazvimavi, 2010; Fan and Chen, 2016). The QR estimates also the *p*-values, *t*-statistics, standard errors and confidence intervals. A negative or positive trend detection that is different from zero indicates that the θ^{th} quantile of rainfall is either decreasing or increasing, signifying low or high rainfall, respectively. Each rainfall station is considered independently in this study.

The QR estimates and MK results were compared through values of slope coefficients, and *p-values* across quantiles (Mcmillen, 2012). The Statistical Analysis System (SAS) '*quantreg*' package software (SAS v94), was run for the QR analysis and the MK for trend analysis. The SAS v94 software version can show upper and lower tails' distributions that provide additional crucial information on changes in all parts of the distribution of a series (Fan and Chen, 2016). A regression model with heterogenous variance implies that there is not a single rate of change that characterises the variation in probability distributions. To focus only on analysing changes on means may under or overestimate or even fail to distinguish real non-zero changes in heterogenous distributions (Cade *et al.*, 1999). Trends in all quantiles were compared using *p*-values and slope coefficients to investigate their similarities and differences in explaining different quantile regression slopes.

The acquired Landsat 5 images were imported in ArcGIS 10.7 environment, for analysis. The study area was extracted through clipping the image with Nylsvley boundary in ArcGIS 10.7. All

downloaded images were refined using Erdas 2018 and ArcGIS 10.7 tools and the images were clipped to the study area shapefile boundary, before extracting the mean NDVI values. The study area being a nature reserve with limited air pollution, being inland and no specific intra-class vegetation, analysis needed to be done, atmospheric corrections for haze was not done as cloud-free day images were used. The Landsat scene is larger than the study area, hence, it was clipped to the size of Nylsvley using the shapefile boundary of the study area. Unnecessary imagery data were, thus, removed as this helps with speedy imagery processing (Fernández-Manso, 2015). The study area's shapefile has the same projection system as the images (UTM zone 35S, Datum WGS84). The clipped images were enhanced to improve their interpretability using image enhancement process (Aggrawal and Maini, 2009).

The NDVI, as described in (Shisanya *et al.*, 2011; Ayele *et al.*, 2018) was used for developing NDVI maps using spatial analysis tool within the ArcGIS 10.7 software. NDVI is based on the notion that chlorophyll that accumulate within leaves of healthy green vegetation absorbs red wavelengths, with the mesophyll leaf structure and water within the leaf scatter near infrared light. The NDVI calculation uses the Near InfraRed (NIR) and the RED bands, as vegetation strongly reflects in NIR. In this study Band 4 and band 3 of Landsat 5 are used to generate NDVI maps. The NDVI formula is as follows:

$$NDVI = NIR – RED/NIR + RED \quad (5)$$

The NDVI values range between -1 to 1, with positive values indicating high amounts of vegetation with negative values responding to poorly, sparsely or non-vegetated areas. Using the image analysis toolbar in ArcGIS 10.7, NDVI maps showing areas of healthy and non-healthy vegetation were produced. Mean NDVI values were created using Zonal statistics as table tool in ArcGIS 10.7. Correlation coefficient which measures the strength of linear relationship of two variables was computed as postulated in (Onema and Taigbenu, 2009). Research done in semi-arid

regions in the 1980s and 90s period demonstrated the seasonal relationship between NDVI and rainfall variations (Tucker and Nicholson 1999). NDVI enables us to examine ecosystems' dynamics and long-term trends in vegetation (Eklundh and Olsson 2003).

The magnitude of correlation between NDVI and rainfall in Nylsvley was measured in the period 1984 and 2003, with statistical significance at a confidence level of 95% (p = 0.05) The R-squared (R^2) which reveals a goodness of fit in a linear regression model was used in an analysis of rainfall and NDVI data. The R^2 formula used is as follows:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 - (y_i - \bar{y})^2}} \quad \text{..... (6)}$$

where r = correlation coefficient of variables rainfall and NDVI, x_i i^{th} of the first variable (rainfall), y_i = i^{th} of the second variable (NDVI), $\bar{x}$ = mean for rainfall, $\bar{y}$ = mean for NDVI. The extracted NDVI values were exported to Excel for creation of graphs with NDVI and rainfall trend patterns. The study hypothesised that there is trend in both NDVI and rainfall time series.

4.5 Results

4.5.1 Rainfall variability across stations

The eight stations had rainfall data observations ranging between 27 to 66 years with Groenfontein and Modimolle stations having the least and most observations, respectively (Table 4.2). Positive and negative Sen's slopes indicated increase and decrease in annual rainfall, respectively. This study used the MK and Sen's slope, non-parametric trend statistic methods to determine the trend significance and magnitude, that is ideal for comparison of total annual and seasonal rainfall variations within the Limpopo Province (Kruger, 2006). The analysis of the annual rainfall showed four (50%) of the eight stations (Mookgophong, Modimolle, Baffelspoort and Elandspoort) with increasing rainfall trends and the other four (50%) of the eight stations

(Groenfontein, Moorddrift, Nylsvley and Polokwane) gave decreasing rainfall trends over the years under study. Seasonally, an additional station, Groenfontein, showed an increasing rainfall trend over the years, making 62.5% of the stations to be with increasing rainfall and 3 stations (37.5%) with decreasing rainfall (Table 4.3).

Table 4.3: Results of the Mann-Kendall trend test for total annual and seasonal rainfall for the eight rainfall stations.

Station Name	Years of observations	No of observations in Years	p-value	MK Statistic (S)	Sen's Slope (mm)	Trend direction
Annual Rainfall						
Baffelspoort	1951-1979	29	0.56	3.20	3.02	Increasing
Elandspoort	1951-1993	43	**0.03**	203.00	5.33	Increasing
Groenfontein	1951-1977	27	0.12	-75.00	-7.75	Decreasing
Modimolle	1951-2016	65	0.50	1.13	0.68	Increasing
Mookgophong	1951-2012	61	0.88	2.80	0.19	Increasing
Moorddrift	1951-1991	41	0.10	-146.00	-2.72	Decreasing
Nylsvley	1951-2003	53	0.06	-250.00	-2.29	Decreasing
Polokwane	1951-2003	53	0.19	-172.00	-1.87	Decreasing
Seasonal Rainfall						
Baffelspoort	1951-1979	29	0.33	52.00	4.08	Increasing
Elandspoort	1951-1993	43	**0.03**	211.00	5.52	Increasing
Groenfontein	1951-1977	27	1	1.0	0.06	Increasing
Modimolle	1951-2016	65	0.34	1.59	1.03	Increasing
Mookgophong	1951-2012	61	0.72	6.50	0.43	Increasing
Moorddrift	1951-1991	41	0.15	-130.00	-2.66	Decreasing
Nylsvley	1951-2003	53	0.52	-8.40	-0.86	Decreasing
Polokwane	1951-2003	53	0.70	-5.00	-0.58	Decreasing

Key: *Values in bold: - Statistically significant stations*

The QR model trend analysis highlighted annual and seasonal rainfall results (Table 4.4).

Table 4.4: Annual and seasonal rainfall for the eight rainfall stations in Nyl River system

	0.1			0.2			0.5			0.7			0.9		
Station	*P*-Value	Slope coefficient	Significance	*P*-Value	Slope coefficient	Significance	*P*-Value	Slope coefficient	Significance	*P*-Value	Slope coefficient	Significance	*P*-Value	Slope coefficient	Significance
Annual Rainfall															
Baffelspoort	0.94	1.57	NS	0.96	-0.43	NS	0.52	3.53	NS	0.15	8.40	NS	0.70	8.75	NS
Elandspoort	0.60	5.63	NS	0.23	4.33	NS	**0.01**	6.96	S	**0.05**	5.01	S	0.90	-1.27	NS
Groenfontein	0.69	-19.4	NS	**0.01**	-14.5	S	0.28	-6.97	NS	0.89	0.96	NS	0.43	-12.0	NS
Modimolle	0.46	1,62	NS	0,43	0.83	NS	0.77	0,39	NS	0,64	-0.99	NS	0.40	2.47	NS
Mookgophong	0.85	-0.60	NS	0.81	0.48	NS	0.51	0.83	NS	0.72	0.58	NS	0.99	-0.02	NS
Moorddrift	0.45	-4.42	NS	0.44	-2.15	NS	0.28	-2.61	NS	0.37	-2.82	NS	0.23	-4.31	NS
Nylsvley	**0.01**	-3.56	S	**0.00**	-3.24	S	0.28	-2.18	NS	0.46	-1.79	NS	0.92	-0.61	NS
Polokwane	0.38	-2.91	NS	0.09	-2.05	NS	0.38	-1.95	NS	0.44	-1.98	NS	0.52	3.53	NS
Seasonal Rainfall															
Baffelspoort	0.84	3.30	NS	0.91	0.62	NS	0.23	6.88	NS	0.18	8.52	NS	0.70	3.87	NS
Elandspoort	0.54	7.79	NS	0.22	5.56	NS	**0.01**	7.73	S	**0.03**	6.64	S	0.98	0.12	NS
Groenfontein	0.99	0.17	NS	1.00	**0.00**	NS	0.86	-0.97	NS	0.54	4.30	NS	0.77	-3.62	NS
Modimolle	0.66	1.01	NS	0.18	1.93	NS	0.10	2.05	NS	0.80	0.39	NS	0.87	-0.47	NS
Mookgophong	0.48	1.64	NS	0.59	0.79	NS	0.76	0.48	NS	0.74	0.50	NS	0.79	-0.60	NS
Moorddrift	0.80	-1.29	NS	0.81	-0.55	NS	0.26	2.71	NS	0.30	-2.21	NS	0.30	-4.16	NS
Nylsvley	0.30	-1.53	NS	0.53	-0.77	NS	0.42	-1.44	NS	0.64	-0.86	NS	0.6	2.69	NS
Polokwane	0.77	-0.78	NS	0.57	-0.82	NS	0.92	-0.19	NS	0.78	-0.56	NS	0.95	-0.29	NS

Key: *Values in bold: - Statistically significant stations*

The negative slope coefficients show decreasing trends in all quantiles of either annual or seasonal rainfall, while positive slope coefficients show increasing rainfall trends in both seasons that were studied. Polokwane was the only rainfall station showing decreasing seasonal rainfall trends in all quantiles. Table 4.3 clearly shows the stations with increasing or decreasing annual and seasonal rainfall trends in respective quantiles in NRS.

The results, thus, show that 37.5% of the rainfall stations were statistically significant in specific quantiles with either increase or decrease in annual or seasonal rainfall. Nylsvley station showed decrease in all and most quantiles for annual and seasonal rainfall, respectively, whilst Elandspoort showed increase in most and all quantiles for annual and seasonal rainfall,

respectively. Groenfontein showed decrease in most quantiles of annual rainfall and middle and upper quantiles of seasonal rainfall whilst lower quantiles (0.1, 0.2) showed increasing seasonal rainfall. The mean and median trends as described by Fan and Chen (2016), reflect long-term trends in either lower or upper tails of the conditional distributions of the annual and seasonal rainfall. The trends in the median are like those in mean, unlike the lower and upper tails that show different trends from the mean slopes (see Table 4.4 for slope distribution of the plotted stations).

The annual and seasonal rainfall of the eight rainfall stations analysed for the period between 1950 and 2016 are as presented in Figures 4.1 and 4.2. Some of the data used to plot the seasonal and annual rainfall of the stations in R-studio using trend and tidyverse libraries are shown in appendices 9.1, 9.2 and 9.3.

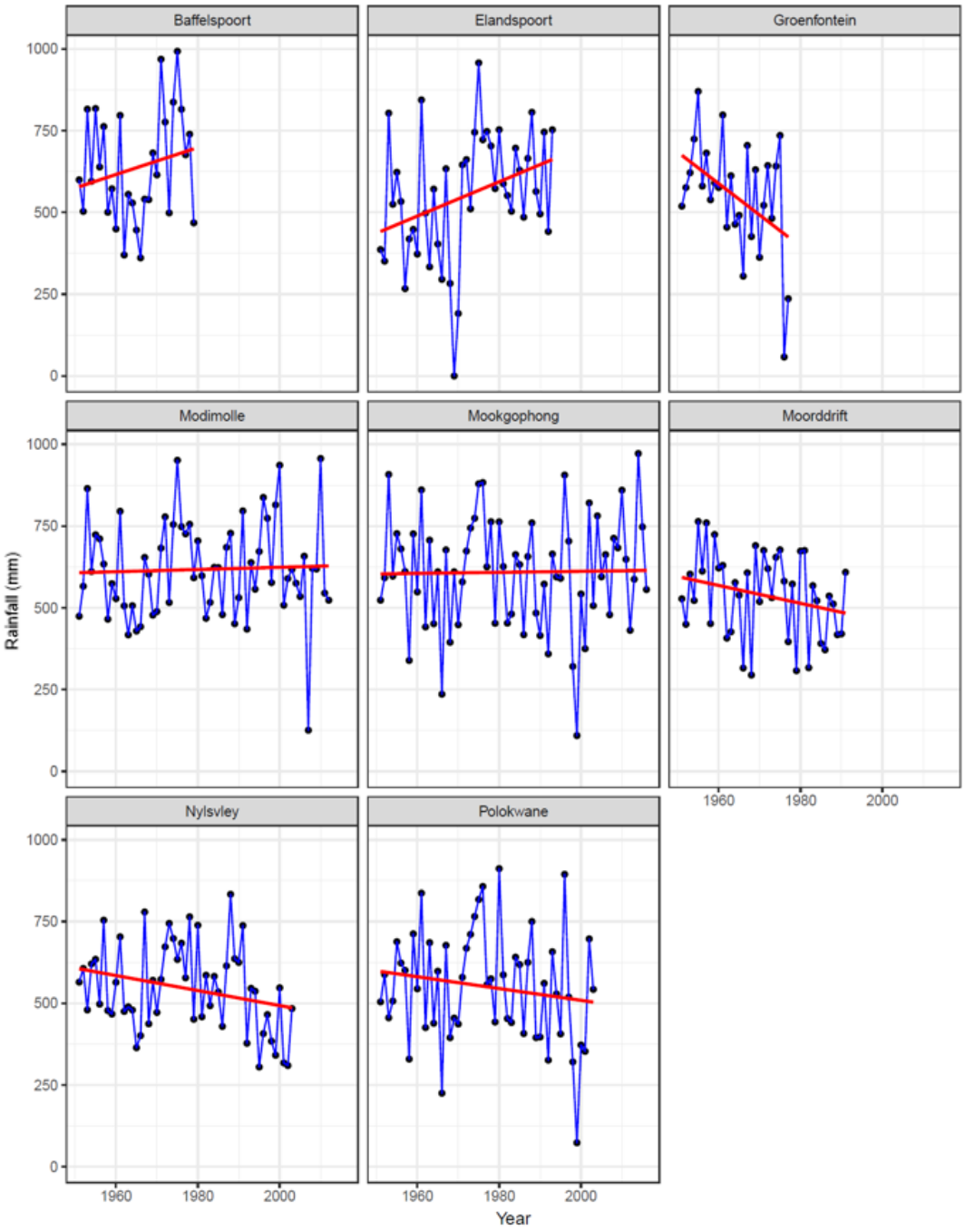

Figure 4.1: Annual rainfall for the eight stations between 1950 and 2016 in Nyl River system

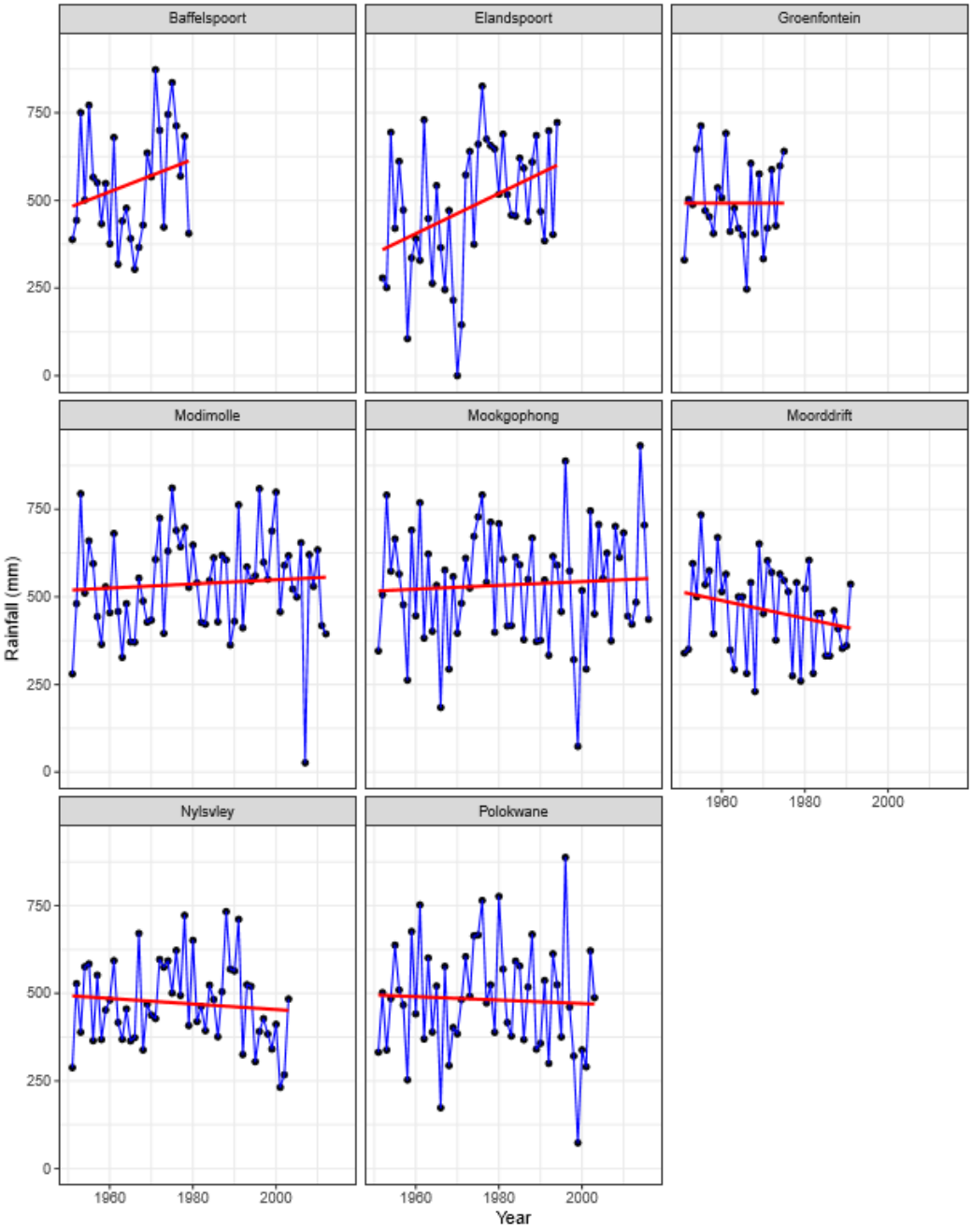

Figure 4.2: The Mann-Kendall trend test for the eight seasonal rainfall stations between 1950 and 2016 in Nyl River system

The spatial distribution of stations with statistically significant change in rainfall are shown in Figure 4.3. Elandspoort rainfall station that has statistically significant increase in rainfall is in the upstream of Nylsvley Nature Reserve (Figure 4.3). Nylsvley station which is located inside the Nature Reserve has reported a decrease in rainfall as revealed by rainfall data recorded for 53

years as indicated in this study, whilst Groenfontein station, which had statistically significant decreasing annual rainfall is located upstream of Nylsvley Nature Reserve.

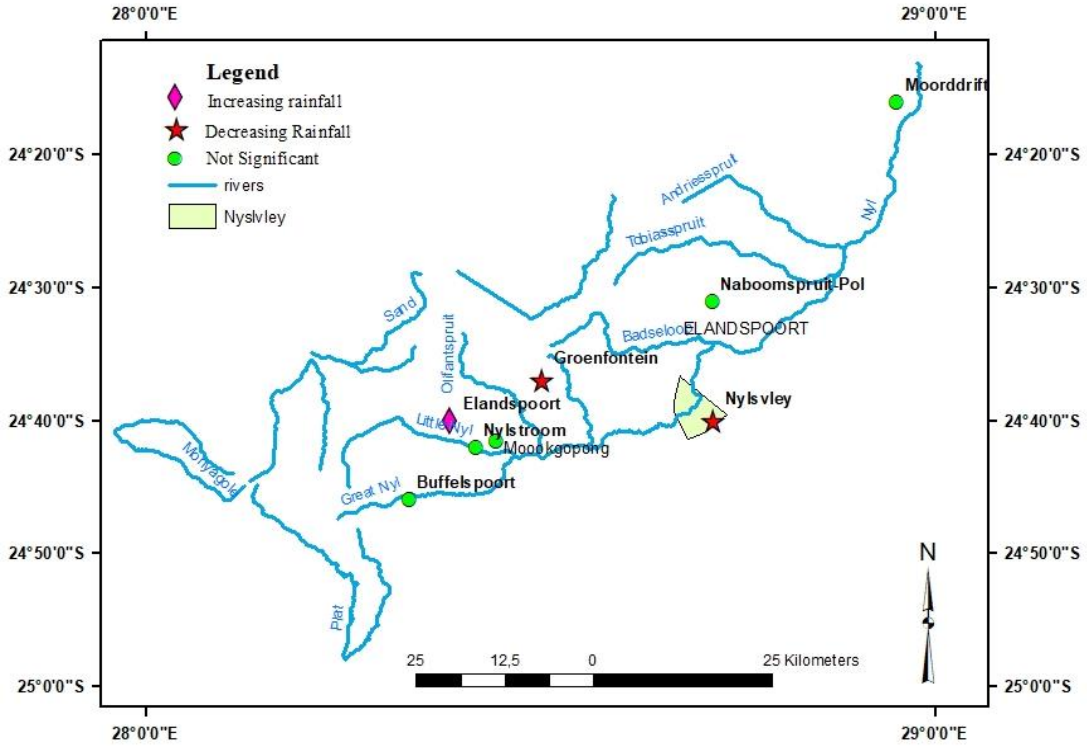

Figure 4.3: Location of rainfall stations with statistically significant increasing (Elandspoort) and decreasing (Groenfontein, Nylsvley) rainfall along the Nyl River system

4.5.2 Validation of rainfall results

The Mann-Kendall trend test showed only one station (Elandspoort), had both annual and seasonal rainfall with significant increase at $p < 0.05$, (Table 4.4). The QR results, with *p*-values that are greater than α (0.05) show non-statistically significant increasing or decreasing rainfall trends in the stations studied. Elandspoort station is statistically significant with increasing annual and seasonal rainfall at median quantiles, 0.5 and 0.7. The statistically significant stations at the 5% significance level vary per quantile. For instance, Groenfontein station was statistically significant in lower quantile (0.2), while Nylsvley station was also statistically significant in lower quantiles (0.1 and 0.2) and Elandspoort was statistically significant in median quantiles (0.5 and

0.7) for annual rainfall trends. Statistically significant stations are shown in Table 4.3 in bold and Figure 4.4 shows QR slopes of these statistically significant stations.

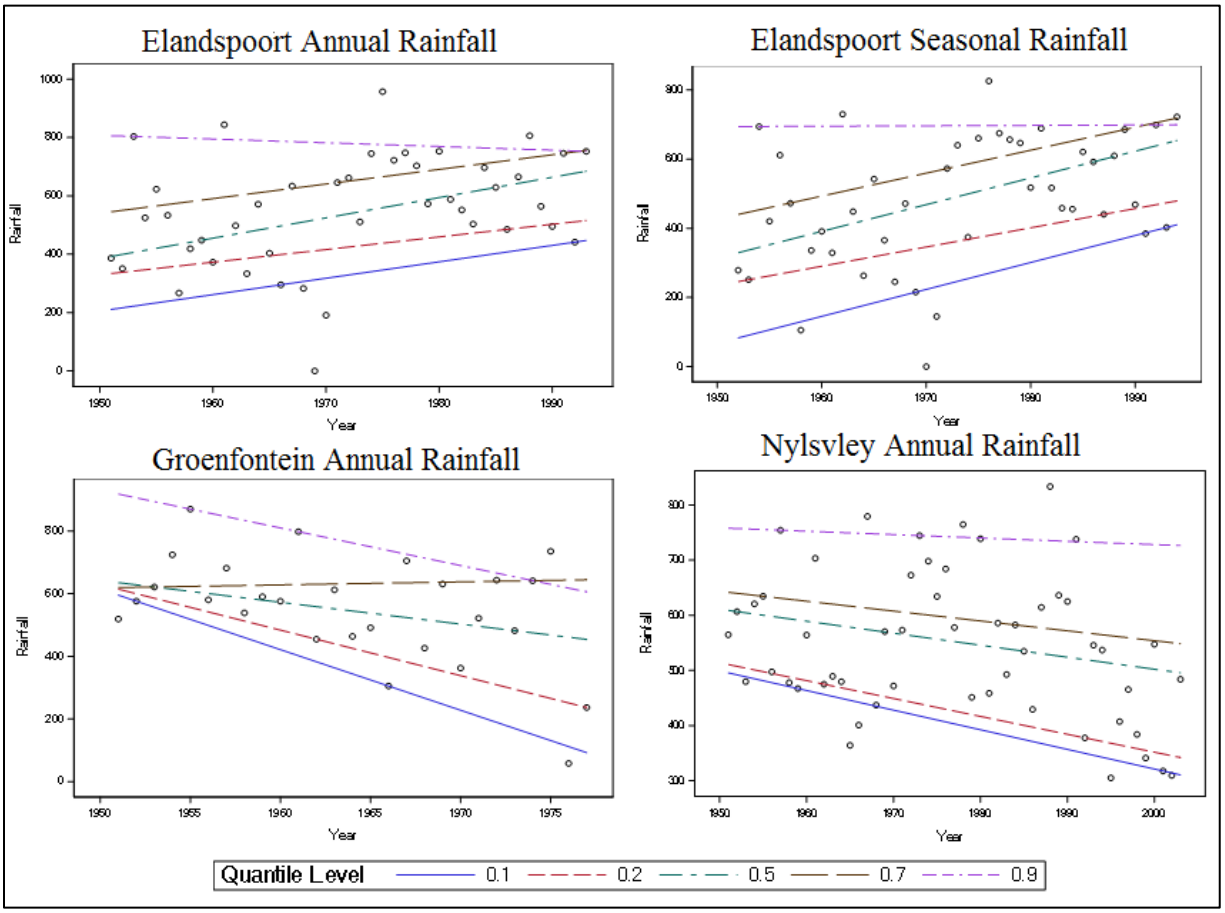

Figure 4.4: Statistically significant stations in both annual and seasonal rainfall using Quantile Regression

The five dotted lines in the figure represents different quantiles, ranging from the lower to higher quantile (0.1, 0.2, 0.5, 0.7 and 0.9). Appendix 9.4 shows part of quantile regression analysis data of one station produced, using SAS v94.

4.5.3 Mean monthly rainfall and NDVI results

The results of the average monthly summer rainfall and mean NDVI are as shown in Figures 4.5. and 4.7 and Appendices 9-5 and 9-6. The average summer season rainfall from 9 different months of separate years between 1984 and 2003, explains that there is positive significant relationship

between rainfall and NDVI in Nylsvley shown by the correlation of 0.74 at $p < 0.02$ which is less than alpha 0.05. The regression, R^2 explains that 55% of the data fits well on the model, Figure 4.6. Onema and Taigbenu (2009) highlight that correlation measures the strength of two variables in a linear relationship and in this study, the strength of NDVI and the rainfall was measured using rainfall and NDVI data for 9 years.

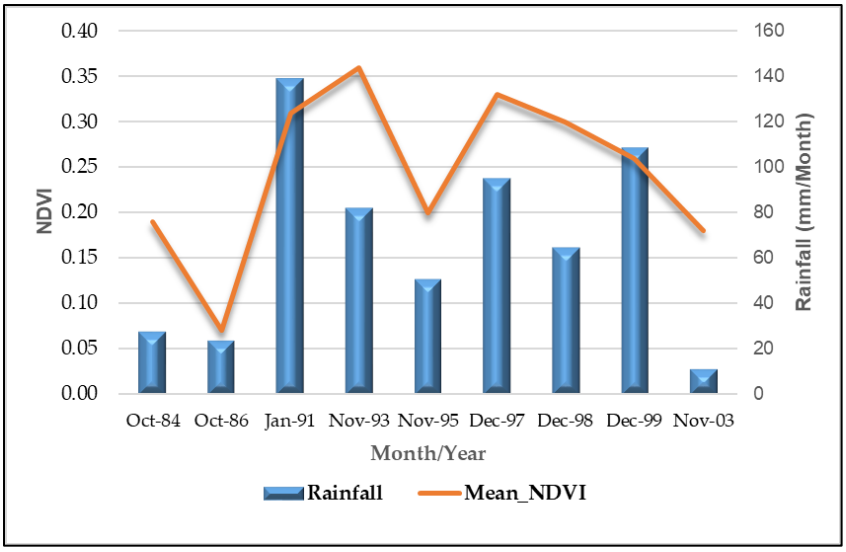

Figure 4.5: The Mean NDVI and rainfall effects in Nylsvley wetland for the years studied

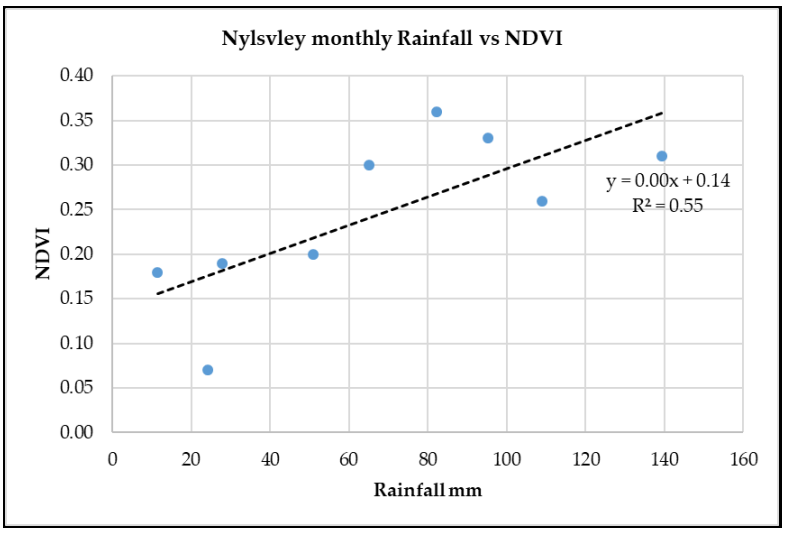

Figure 4.6: Correlation of rainfall and NDVI in Nylsvley wetland

Figure 4.7 shows the trend of mean NDVI and average monthly rainfall in summer season in Nylsvley wetland. Examining the relationship between NDVI and summer rainfall, as shown in Figure 4.7, indicates that there is a general agreement between rainfall amount and availability of vegetation. Where rainfall increases, NDVI tends to increase too, between the 1986 and 1991 period (See Figure 4.7). The years ,1993 and 1995 saw a decrease in both rainfall and NDVI. From the period 1997, as rainfall decreased, NDVI continued to drop, despite rainfall increases as from 1998. This shows that vegetation takes time to recover and regrow. By 2003, both rainfall and NDVI showed a downward trend, Figure 4.7. The mean monthly rainfall and mean NDVI values are high, mainly in the months of November – January, indicating the strong relationship between the two. The beginning of season months, such as October, receive lower rainfall and have low vegetation as indicated by the low NDVI.

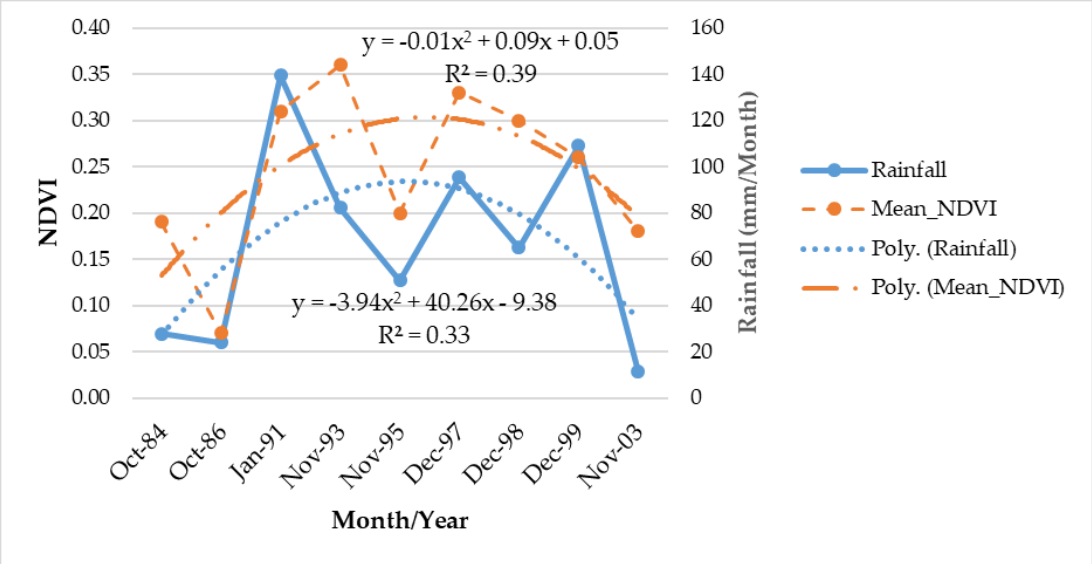

Figure 4.7: Trend of mean NDVI and average monthly rainfall in Nylsvley wetland

The Figures. 4.5 and 4.7 show a detailed visualization of the relationship between NDVI and Rainfall of Nylsvley wetland during the summer rains' season months.

4.6 Discussion

This study used the MK and Sen's slope, non-parametric trend statistic methods to determine the trend significance and magnitude, that is ideal for comparison of total annual and seasonal rainfall variations within Nylsvley in the Limpopo Province (Kruger, 2006). The study observed that both MK and Sen's slope methods gave similar trends for rainfall series of all the eight stations studied (Table 4.3). From annual and seasonal analyses, four and five of the eight stations showed increases in annual and seasonal rainfall, respectively, in the NRS. Using QR, the results showed that about half of rainfall stations reported decreasing annual rainfall trends in most quantiles while 37.5% of rainfall stations showed decreasing seasonal rainfall trends, thus, most of the rainfall stations (62.5%) showed increasing seasonal rainfall trends in most of the quantiles. There are two rainfall stations, Moorddrift and Nylsvley, with constantly decreasing annual and seasonal rainfall trends on all and most of the quantiles, respectively (Table 4. 3).

New *et al.* (2006) in their study on precipitation from 1961-2000, highlighted that few stations in 14 African nations studied showed decreases in rainfall, although the depicted trends by these authors were also not statistically significant. This agrees with the studies by Hulme *et al.* (2001) and Kruger (2006) who reported that most stations studied in South Africa, between 1901 and 1995 showed no significance in trends. This study even though done on a localised scale and with data length varying (27-66 years) it agrees with previous studies that equal number of stations at annual or fewer stations at seasonal in the region showed non-statistically significant decreases in annual or seasonal rainfall, respectively, (Kruger, 2006). The results also show the significant increasing trend in both annual and seasonal rainfall at the Elandspoort station, whilst the rest of the stations with increasing trends have statistically non-significant increasing trends.

The decreases and increases in trends shown in the data could be as a result of increases and decreases in extreme and inter-annual inconsistency of rainfall, within some years, in some provinces of South Africa (Kruger, 2006). This can explain why Elandsport and Groenfontein stations, both in the upstream of Nylsvley (Figure 4.3) have increasing or decreasing rainfall

respectively. Odiyo *et al.* (2015) investigated variability in rainfall using long-term data (1931/1932 – 2005/2006) of Luvuvhu River Catchment (LRC) of South Africa. Two of the six studied rainfall stations showed decreasing trends in 5 and 10-years mean rainfall, with decadal fluctuation in 10-year mean of daily rainfall. Their study concluded that the variability of rainfall has increased in LRC over 86 years. Various other studies on long-term rainfall changes in South Africa include studies on analyses of rainfall data from 157 stations between 1880 and 1972 (Tyson *et al.*, 1975). A study by Nicholson (1986) reveals no trends in mean annual rainfall over Southern Africa between 1900-1970 and 1961-1990 periods. Kruger (2006) reports significant decreases in annual precipitation in some parts of South Africa that include Northern Limpopo, Western KwaZulu Natal, North Eastern Free State and the South-Eastern regions of Eastern Cape and increases in rainfall were projected in Northern, Western and Eastern Cape Provinces. Lynch (2004) notes gradual rainfall increases in the Potchefstroom area from 1925 to 1998, whilst Warburton and Schulze (2005) report a decrease in median annual rainfall in the Limpopo Province over the latter half of the 20th century.

All rainfall stations located in the upper section of the NRS, namely, Mookgophong, Modimolle, Elandspoort, and Buffelspoort have generally received increased rainfall in both seasons that were studied. In the middle section of NRS two stations, Nylsvley and Polokwane, received decreased rainfall, both annually and seasonally. The decrease in rainfall in Nylsvley over the years contributes to less water being available in the Nylsvley floodplain. Moorddrift station situated in the lower section of the NRS has also faced decreased rainfall, both annually and seasonally in this study (Figures 4.1 and 4.2). These differences can be explained by either natural climatic factors or differences in microclimates (Türkeş and Sümer, 2004; Tabari and Talaee, 2011). The main causes of long-term rainfall variability across the southern Africa region and the continent at large, are complex as they are influenced by the changes taking place on the oceans together with atmospheric circulation. These include the ENSO (El Nino southern

oscillation cycle (Anyamba and Tucker, 2005) and the fluctuations in sea surface temperature (SST) which has no relationship with the ENSO (Nicholson and Entekhabi, 1987) and human anthropogenic activities on the environment leading to land cover changes (Hulme *et al.*, 2001). The results of this study and previous studies on rainfall trends show a clear indication of how variable rainfall has been, over the centuries.

This study showed no widespread evidence that rainfall in NRS had decreased or increased due to climate variations. This is based on the results from the eight stations studied on annual and seasonal rainfall and showed no strong evidence that seasonal or annual rainfall has declined or increased since only three stations of the eight stations had statistically significant results. This study, therefore, rejects the null hypothesis as most of the stations (62.5%) showed a statistically insignificant change over time. Using two methods revealed that rainfall trends from three stations are statistically significant. Mk had depicted Elandspoort station as having statistically significant increasing rainfall trend. Additional stations, Nylsvley and Groenfontein were depicted by QR method as having statistically significant decreasing trends in annual rainfall.

Nylsvley rainfall station located within the flood plain with over 53 years of recorded annual rainfall data has received maximum and minimum annual rainfall of 733 mm in 1988 and 231 mm in 2001, respectively (Figure 4.1). Nylsvley rainfall station is crucial as it provides rainfall statistics of the flood plain and the Nature reserve. The trend of low annual rainfall in Nylsvley has been recorded from the years 1995 to 2003, which received between 231 mm and 483 mm. This decrease could impact on vegetation growth and the availability of flooding water within the flood plain and its biological diversity. This decrease agrees with the results of the current study, that the flood plain has consistently received low rainfall as shown by the decreasing trends in both rainfall and NDVI (Figure 4.4). The decrease in rainfall in the Nylsvley agrees with the ideology that the flood plain is experiencing dry years which has been exacerbated by low rainfall being received in some years.

Many stations showed decreasing rainfall trends, although, they were mostly not statistically significant or proven; this could imply that there are inter-annual and seasonal variations of rainfall in NRS. The insignificant trends can also be linked to a relatively high year-to-year variability of rainfall in South Africa (including Limpopo Province) which is associated with some cloud band and ENSO (Chikoore, 2016). Mazvimavi (2010) highlighted no changes, over-time, for rainfall in Zimbabwe and stated that global warming may cause changes in rainfall patterns, but these effects were not statistically significant. The latter author stipulated that the southern Africa region is semi-arid to arid with inter-annual rainfall variability. In the region, include Limpopo Province of South Africa, there is a need to be vigilant to such decadal or inter-annual changes so as to be ready to respond to uncertainty raised by climate change and/or anthropogenic factors. New *et al.* (2006) in their study highlighted the decrease in precipitation in southern Africa, even though not statistically significant too. Onema and Taigbenu (2009) also emphasised in their study that NDVI-rainfall relationship is linked, hence, they expected to see a trend in most of their data. This trend has also been shown in Nylsvley wetland indicating that, when restoration activities are taking place in the wetland, management should be informed of the water challenges, that is needed for vegetation growth and other life forms, including flooding in the wetland.

The major decrease in rainfall in the years between 1991 and 1993 agrees with studies by (Richard *et al.*, 2001; Usman and Reason, 2004), as there was a serious drought in the southern Africa region that caused significant summer rainfall variations. This could have led to decrease in NDVI in the Nylsvley as the area could have received less rainfall to promote plant vigour. The annual and seasonal rainfall trends for Nylsvley station since 1953 to 2003 have shown a decreasing trend, Table 4.2. A study on vegetation greenness (NDVI) and rainfall variability conducted in the Sahel region in the period 1982-2003 concluded that rainfall remains the main causative factor for vegetation greenness increase (Herrmann *et al.*, 2005). Other studies by (Martiny *et al.*, 2010; Barbosa *et al.*, 2015), also support NDVI-rainfall relationship, although

anthropogenic factors impact negatively too (Shisanya *et al.*, 2011). The decrease in NDVI within the study area could also be attributed to other factors such as anthropogenic activities, for example, agriculture in the area (Scholes and Walker, 1993). Agriculture leaves most surfaces as bare ground with infertile soils and vegetation in these old fields take a long time to naturally recover (Ruwanza and Mulaudzi, 2018); this could be the case in some parts of Nylsvley.

Nylsvley is known for its history of being a site for grazing, by both domesticated and wild animals (Scholes and Walker, 1993). Growing of crops ceased in parts of the wetland in 1974 and the remaining parts in 1997 as it became a protected area. The degradation of the wetland through removal of vegetation, has made the government, through its project implementer (Working for Wetlands) to embark on restoring the wetland so that it can return to its natural state. Removal of vegetation cover in semi-arid regions is linked to alteration in the microclimate and shrub development as bare-soil areas increase; this allows for more thermal energy to be stored in the soil causing increases in night land surface temperatures that favor shrub growth over grasses (Ravi *et al.*, 2010; Liu *et al.*, 2015; Marquart *et al.*, 2019).The decrease in NDVI, due to less rainfall received, has implications in ecosystem development and services. In Nylsvley wetland, for instance, game animals obtain their food through grazing in this wetland and less vegetation has implications for planning for these grazers. Vegetation also provides with habitat for migratory birds that visit Nylsvley, and this attracts tourist to visit for bird watching; these activities bring income to this region and employment creation in the tourism sector. The rainfall-NDVI relationship, thus, is critical as it helps managers to prepare for early negative climatic effects.

4.7 Conclusions and Recommendations

This study addressed the historical rainfall trends in NRS and rainfall-vegetation relationship to assess climate effects on wetland vegetation growth. NDVI was, thus, used as proxy of vegetation and showed that as rainfall decreased or increased over the years under study, NDVI seemingly

followed suit as seen in Figures 4.5 and 4.7. The study utilised two methods in assessing historical rainfall trends; the results revealed that 3 stations (Groenfontein, Elandspoort and Nylsvley) and not only one station have fluctuating rainfall patterns with Nylsvley consistently reporting decreasing rainfall trends. Three out of the eight rainfall stations studied demonstrated changes in annual and seasonal rainfall patterns. The decrease in rainfall in Nylsvley has negatively impacted the floodplain wetland with implications, for example, for tourists intending to visit it for bird watching and other activities.

The trend of mean NDVI and monthly rainfall shows positive relationship in some years under study with some years showing negative NDVI increase; this may suggest a combination of years of drought and effects of negative human activities, such as grazing, which is still active in Nylsvley. The changes seen in this study area require proper management and monitoring for sustainable protection of this Ramsar site. This study also suggests that the knowledge of changes in rainfall and NDVI patterns could be used in planning for effective utilisation of water resources throughout the Nyl River system. In the study, some stations indicated decrease and others increase in rainfall trends, therefore, there is need to investigate the effects of anthropogenic changes, such as land cover/use changes which affect the availability of water resources and the success of natural vegetation restoration within Nylsvley.

5. SPATIAL-TEMPORAL PATTERNS OF LAND USE/COVER CHANGE IN RESTORED FLOODPLAIN WETLAND ECOSYSTEMS

Submitted to South African Journal of Geomatics

Abstract

Ecological restoration provides new insights for conservation of biodiversity and management of wetland ecosystems. Evaluating restoration efforts is critical for policy development and monitoring procedures for vegetation management strategy of rivers and wetlands. Restoration of Vogelfontein in the Nylsvley wetland started in 1997 to provide additional protection to Ramsar wetland's unique vegetation. This study evaluated ecological restoration efforts through assessing natural vegetation development and patterns of change within Vogelfontein, using 1984, 2005 and 2016, imagery which provided at least 10 years' evaluation of before and after restoration. Land-cover maps were generated from classified Landsat images using maximum likelihood classification algorithm with five land uses - old fields, water, bare ground, sparse and dense vegetation. The results show a worsening of natural vegetation regeneration from 1984 until 2005, as bare ground and old field increased by over 19%. The period 2005 to 2016 saw the classes gaining in natural recovery of vegetation (7%). This indicates the necessity of wetland restoration, due to the evidence of vegetation recovery in a landscape facing degradation trajectory. Overall, the area covered by vegetation from 1984 to 2016 period decreased despite the increase of vegetation cover between the 2005 to 2016 period. The continued decline in vegetation is attributed to the effects of cultivation, rainfall unavailability and tourism factors. The findings can help decision-makers to improve vegetation management plans of the Ramsar site and protect its rich biodiversity. The study recommends further steps in protecting this Ramsar wetland through quantifying vegetation species composition and diversity in Vogelfontein, since restoration.

Keywords: Ecological; land; restoration; vegetation; wetland

5.1. Introduction

The anthropogenic activities on wetlands have impacted on the functioning of wetland ecosystems and their ability to offer ecosystem services (Kotze *et al.*, 2012). These activities include intensive grazing, irrigation, construction and cultivation; they contribute to wetland degradation and deterioration through vegetation loss. Anthropogenic actions prevent wetlands from achieving their maximum functional capability. Wetlands are characterized by high density of both flora and fauna species and are regarded as not properly functional when available vegetation, soil or water are at risk of loss (Aguiar *et al.*, 2011; Kindu *et al.*, 2015). The transformation of wetland ecosystems through cultivation or grazing leads to habitat destruction and consequently loss of habitats for species existence in these areas. Having noticed human negative impacts on wetland ecosystems, restoration efforts to correct such have been introduced worldwide to curb further environmental damages to the wetlands (Choi, 2004; Palmer *et al.*, 2016).

Ecological restoration attempts to recover a natural range of the ecosystem structure, composition and dynamics (Palmer *et al.*, 2005; Karami, 2017); they assist wetlands to return to their natural ecological status, although, the impossibility of fully achieving such is widely recognised (Washitani, 2007; Hobbs, 2013). Some restoration efforts allow the ecosystem to recover via natural ecological processes, as vegetation naturally grow when undisturbed. The level of wetland ecosystem damages vary; some are pushed beyond their ability to spontaneously recover (Hobbs, 2013). The global increase in rivers and wetland restoration projects since the year 2000 (Nakamura *et al.*, 2006) has led to restoration of most wetland areas through their conversion from cultivated areas to protected areas. Despite these progressive efforts, the still-standing

question is - *How much vegetation cover has been restored in these areas and which tools quantify vegetation recovery?*

In South Africa for instance, Nylsvley a Ramsar site of international recognition is managed as nature reserve and follows the Ramsar wetlands management criteria (Haskins and Kruger, 1997). Monitoring tools have been developed to assess the health of Nylsvley's aquatic systems (Greenfield, 2008), however, the process has disregarded the quantification and identification of appropriate tools for monitoring vegetation over time, which this study intends to address. Identifying tools to monitor vegetation development in the reserve before and after restoration of Nylsvley has not been part of the management strategy, hence, this study utilised Geographic Information system and remote sensing tools in monitoring spatial vegetation development before and after restoration of Vogelfontein, part of the Nylsvley.

Wetland vegetation contributes to unique ecosystems that perform a variety of ecological functions like provision of food and organic material for macro-invertebrates and other wetland organisms (Smith *et al.*, 2007). Vegetation in wetland ecosystems takes long to recover after disturbances, hence, ecological studies are critical in advancement of scientific basis for wetland restoration (Aronson and Galatowitsch, 2008; Zhang *et al.*, 2017). Assessing the success of natural vegetation restoration is also critical in justifying the use of the process in wetland resource management. This then provides information needed to guide and plan the maintaining of wetlands in their proper functioning condition where vegetation and debris are present.

Land use/cover change is utilized in monitoring spatial changes in natural wetland vegetation growth. It provides early-warning signs of ecological problems and provides understanding on the impact of both climate and human activities on the environment (Niemi and Mcdonald, 2004; Siddig *et al.*, 2016). This indicates the need for a mitigation strategy to address the causes of vegetation loss in wetland systems; in this case, natural vegetation restoration has been attempted but with unknown results. Mapping and assessing the condition of wetland vegetation

through land use/cover change is critical for monitoring global wetlands as it offers information on wetland vegetation types, their distribution and phenology; this also acts as a good indicator in cases of assessing wetland deterioration efforts (Skidmore *et al.*, 1998; Netando *et al.*, 2010; Mesta *et al.*, 2014).

Changes in wetland vegetation generally occur slowly, but they are linked to decline in vegetation species composition which is detrimental to the functioning of the ecosystem (Jenberu and Admasu, 2019). From the year 2000, the global key objective has been the improvement of ecological integrity with a distinct shift from projects at habitat scale to integrated projects of whole ecosystem (Nakamura *et al.*, 2006). Land cover are the natural physical features, such as soil, vegetation or water, while land use refers to human activities, like agriculture, on the landscape (Rawat and Kumar, 2015). Land use or cover change pattern of an area is a result of natural or socio-economic factors and their effects in space and over time (Murungweni, 2013; Rawat and Kumar, 2015; Arowolo and Deng, 2018).

Availability of Landsat images has made it possible to map land use/cover changes at different time scales and carry out analysis of the changes over specified period and in areas that are inaccessible (Mutanga *et al.*, 2016). There are, however, few studies that have assessed natural vegetation changes in semi-arid restored flood plain wetlands, despite the widespread utilisation of remotely-sensed data utilising change detection techniques (Singh, 1989; Pullanikkatil *et al.*, 2016; Aliero *et al.*, 2017; Ayele *et al.*, 2018; Abdi, 2020). With so much change-detection research having been done on wetlands of semi-arid regions, none to our knowledge has quantified recovered vegetation overtime for effective and better ecological management of freshwater wetland ecosystems. The ideal scenario would be to make use of high-spatial resolution images as emphasised by Akasheh *et al.* (2008), Kollar *et al.* (2013) and Mutanga *et al.* (2016), since these images account for the spatial natural heterogeneity, although, they are costly. Griscom *et al.* (2010) also stipulate that moderate-scales images enable researchers to depict spatial

distribution patterns of land use/cover and quantify the extent and the pattern of changes that have occurred over time. Li *et al.* (2014) state that RS is the most reliable tool for monitoring varied spectrally-sensitive changes of the earth as it identifies areas of rapid change, to target management monitoring efforts. Making detailed analysis of vegetation changes before and after the establishment of Vogelfontein in 1997, means that part of Nylsvley Nature Reserve (NNR) can provide necessary information that would assist proper management and monitoring of the Nylsvley vegetation, for early warning.

The study hypothesised that natural vegetation regeneration has successfully increased since the restoration of Vogelfontein in 1997. It was, thus, crucial to understand Vogelfontein vegetation cover before the restoration, utilizing 1984 imagery, together with two other dates after restoration. We focused our study on the success of natural vegetation regeneration in Vogelfontein utilizing Landsat 5 and 8 imagery of 1984, 2005 and 2016 in quantification of land use/cover. These were used as indicators of change over time for the benefit of ecological species existing in NNR and similar environments to ascertain whether restoration has enhanced natural vegetation development in Nylsvley.

5.2. Objective

To assess natural vegetation development in Nylsvley for the years 1984, 2005 and 2016 using Landsat 5 and 8 imageries.

5.2.1. Hypothesis

Natural vegetation regeneration has successfully increased since the restoration of Vogelfontein in Nylsvley floodplain and since its proclamation as a nature reserve in 1997.

5.3. Materials and Methods

5.3.1. Study area

The location of Nylslvley floodplain is as described in section 3.2.1., in Chapter 3 of this study.

Cultivation has ceased in Vogelfontein since its proclamation as a nature reserve in 1997 but some grazing and browsing practices are still in place due to rearing of wild animals in the nature reserve (Scholes and Walker, 1993). Figure 5.1 shows the location of Vogelfontein within NNR and the floodplain (Scholes and Walker, 1993; Mccarthy *et al.*, 2011).

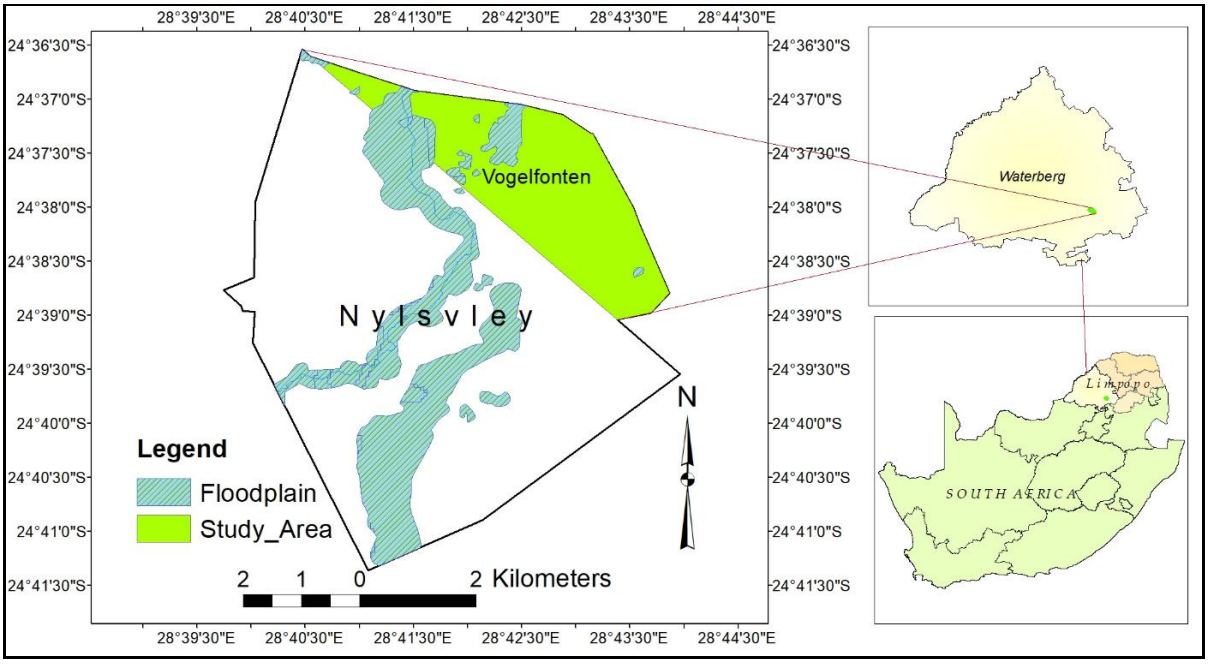

Figure 5.1: Location of study area in Waterberg District
(The data sets for map production were obtained from University of Venda, GIS laboratory, Projection: WGS 84).

The reserve hosts a portion of the threatened and endangered Springbokvlakte thornveld vegetation and vulnerable central sandy Bushveld vegetation units which are poorly protected in South Africa (Mucina and Rutherford, 2006a). Land use in the floodplain through cultivation and grazing or browsing, threatens the natural vegetation growth; unfortunately, still, not much of vegetation cover changes is known since the commissioning of Vogelfontein as part of the nature

reserve. Vegetation changes on such ascale affect the ground water table, flow of water and landscape level biodiversity, among others (Palamuleni and Turyahikayo, 2015). Vogelfontein, like the rest of the reserve was previously actively utilized for farming activities, mostly intensive grazing and growing of crops (Scholes and Walker, 1993). This contributed to the degradation and deterioration of the flood plain through loss of vegetation. The ecological status of this freshwater wetland has also been threatened by increased development within and along the upstream catchments; these are affecting the availability of water needed for vegetation growth in the floodplain (Rowberry *et al.*, 2011).

The reserve has very high species and habitat diversity and is threatened by both natural and human-induced activities, such as dry seasons, fire, over-grazing and cultivation. The disturbances in this freshwater ecosystem affect the habitat, which is the determinant of species diversity. Land use/cover in the catchment is predominantly farming, orchards, crop production, grazing pastures with areas of nature reserves in the upper-catchment of the floodplain. Like many crucial rivers in South Africa, the Nyl River and the Nyl floodplain have been deteriorating with little water passing through the floodplain, forcing the number of birds and frog species to decline. The deterioration of the Nyl floodplain's biodiversity poses an increased threat to the water security of the district.

This study focused on land use/cover changes in Vogelfontein portion; this was recently turned into a nature reserved (1997). Google maps played a critical role as it provided aerial photography of before and after rehabilitation of the wetland.

5.3.2. Data preparation

Landsat 5 (Enhanced Thematic Mapper) and 8 (Operational Land Imager)) imagery at 30m

resolution of 1984, 2005 and 2016 were selected for land use/cover classification and vegetation change analysis. The satellite imagery covering the study area were obtained from the global land cover facility (GLCF) and earth explorer website, https://earthexplorer.usgs.gov/. The selected sensor is the best available cloud-free image of the study area for the period and provides an ideal spectral resolution to conduct vegetation analysis utilising the visible and Near infrared bands that are good for monitoring vegetation cover changes; these images were taken during cloudless days. These are 21 May, 18 and 16 July for the years 1984, 2005 and 2016, respectively, as shown in Table 5.1.

Table 5.1: Acquired Landsat 5 imagery

Satellite sensor	Path/ row	Spatial Resolution	Acquisition Date	Season	Projection
Landsat 5	170/077	30m	1984/05/21	Winter	UTM
Landsat 5	170/077	30m	2005/07/18	Winter	UTM
Landsat 8	170/077	30m	2016/07/16	Winter	UTM

The extracted Landsat 5 imagery of 1984, 2005 and 2016 shows the study area with band combinations of false colour, Red, Green and Blue, (RGB, 4 3 2 (1984 and 2005) and 5 4 3 for 2016 imagery), Figure 5.2. These images were used to derive NDVI maps that assisted with image classification.

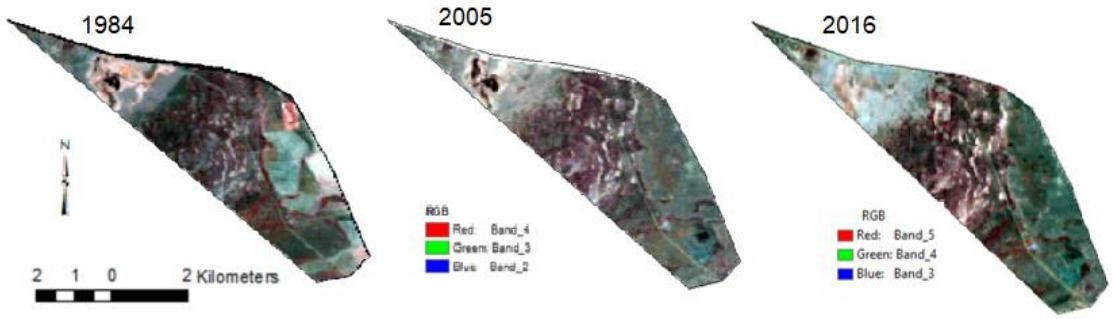

Figure 5.2: Landsat image for 1984 and 2005 showing Red, Green and Blue band combination

The acquisition dates were maintained to reduce the effects of seasonality. To determine human influences on land use/cover in the Vogelfontein, secondary data were collected. Secondary data

included digital aerial photographs from the Department of Rural Development (2005) and from Google Earth Pro (2016). The acquired Landsat 5 and 8 images were imported in ArcGIS 10.7 environment and ERDAS imagine 2018 software for pre-processing (See Chapter 3 for detailed image pre-processing) and analysis.

5.3.3. Land use/cover classification data

A land use/cover classification system was designed consisting of five classes. These classes are - (i) old field (cultivation has ceased since 1997, Old field name is used), (ii) bare ground, (iii) sparse, (iv) dense vegetation and (v) water. Full description of the delineated classes is provided in Table 5.2.

Table 5.2: Description of delineated classes

Class Name	Description
Water	River, ponds, open water and reservoirs
Old field	Previously cultivated areas
Bare ground	Areas of the land's surface with exposed soil and barren area due to nature or human influence
Sparse vegetation	Mostly grassland areas with fewer and spaced woody trees.
Dense vegetation	Mixed vegetated land dominated by woody tree species that are in proximity with each other.

The supervised maximum likelihood classifier method was adopted in this study. Lu and Weng (2007) summarized various classification methods, which require many several training samples for implementation of image classification. Reference data for Vogelfontein, since it is a nature reserve, are not easily accessible for most areas, therefore, data was obtained through visual interpretation of 2005 and 2016 aerial photography with very high-spatial resolution. Where there are constraints to accessing sites for field verification and to obtain ground data, high spatial resolution imagery was utilized as surrogate for ground observation (Estes *et al.*, 1999). The 2005 aerial photography was obtained from National Geo-Spatial Information of South Africa in digital format, whilst the 2016 aerial photography was accessed through Google Earth Pro. The reference data of 115 points were randomly generated and split into validation and training data

sets of 30% and 70%,. The set of training data was utilized in training the classification data and these trained values were considered as reference values (Islam *et al.*, 2018). The validation data set was utilized in performing accuracy assessment. We identified all the randomly-generated points and they were assigned various classes. Visual image analysis techniques also helped in identifying ground features.

5.3.4. Spatial land use/cover changes

Changes in land use/cover of Vogelfontein classes were determined by the comparison of image of earlier date against the later date to establish the percentage change. As postulated by Lu *et al.* (2004), good change detection must provide, among other data, the rate and spatial distribution of changes. The three date-classified raster images of 1984, 2005 and 2016 were first converted to shapefiles and intersected (Geoprocessing tool in ArcGIS environment) to generate area change and spatial maps. A pairwise comparison of two date images was used in determining the changes by intersecting 1984 to 2005 and 2005 to 2016 images. To assess increase or decrease of vegetation in the reserve, all classes with vegetation were merged to calculate the percentage increase or decrease of area covered by vegetation between 1984 and 2016. Area of change for each classified image was extracted from the attribute information provided from the shapefiles and exported to excel for further processing. Appendices 8-7 and 8-8 show spatial analysis and area calculation in ArcGIS 10.7.

5.3.5. Accuracy assessment

Accuracy assessment for recent dates of the classified images was conducted using the 2 × 2 error-matrix method (Griscom *et al.*, 2010) and the 30% validation data from the field. Expert knowledge and familiarity of the study area was utilized in classifying the image of 1984 as valuable land cover maps were missing (Wayman, 2000; Sivanpillai and Latchininsky, 2007). Accuracy assessment parameters, such as Kappa Coefficient (Adam *et al.*, 2014) and overall

accuracy for 2005 and 2016 imagery were generated from the reference and classified data in ERDAS 2018 software, under the report section and expressed as a percentage. The overall percentage indicates accuracy of the classification, as related to the reference data.

5.4. Results

5.4.1. Classified images

To protect the wetland from further degradation, the Vogelfontein, wetland area was converted to

a nature reserve in 1997 and became part of the Nylsvley nature reserve. This was ideal for the conservation of the floodplain as it was intended to reduce further vegetation loss through agricultural practices which would lead to habitat loss of species in this reserve. A total of five land use/cover classes were identified to assist in assessing vegetation recovery of the wetland through natural restoration over the years under study (1984, 2005 and 2016). The land use/cover map was prepared using supervised and knowledge of expert-based classification of the study area. The classified map for Vogelfontein for 1984, 2005 and 2016 is shown in Figure 5.3 and Table 5.3.

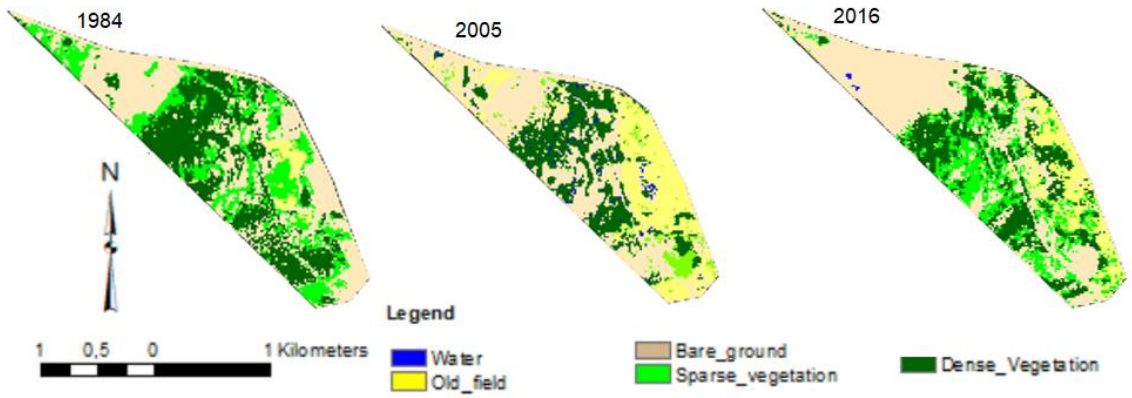

Figure 5.3: Supervised classification maps of 1984, 2005 and 2016

Table 5.3: Land use/cover classes and area in hectares

Cover type	1984 area in ha	%	2005 area in ha	%	2016 area in ha	%
Old Fields	27.45	3,16	214.02	24,61	107.46	12,36
Sparse Vegetation	199.62	22,95	41.13	4,73	162.18	18,65
Dense Vegetation	267.93	30,81	220.05	25,3	191.61	22,03
Bare Ground	372.51	42,83	383.22	44,06	407.07	46,8
Water	2.25	0.26	1.134	1,3	1.44	0,17

The Figure 5.3 and Table 5.3 summarizes the classification results which are also shown in percentages.

5.4.2. Change detection

The spatial change map of the period between 1984 to 2005 and 2005 to 2016 are shown in Figures 5.4 and 5.5. The major land use changes are also shown, graphically, in Figures 5.6 and 5.7. Appendices 9-9 and 9-10 show the area changes in hectares and in percentages. The extent of the area used for land use/cover classes is provided in Table 5.3; this reveals the area covered by each class as obtained from the classified images of Vogelfontein. The classified results reveal that dense vegetation covering an area of about 30.80% of the total area in 1984 decreased to 25.32% and 22,03%, by 2005 and 2016, respectively, indicating a change of -5,48% and -3.29 (Table 5.3). The major decline in respect to vegetation cover is revealed by the increase in bare-ground class over the years under study. Bare ground covered about 42.82% of the study area in 1984 and increased to 44.05% by 2005 and again increased to 46.79% by 2016 making overall increases of 1.23% and 2.74, respectively. Sparse vegetation decreased from 22.95% to as low as 4.73% vegetation cover and increased to 18.64% from 1984, 2005 and 2016, respectively, making overall increases of -18,22% and 13,91% of the class cover in the years under study. Vegetation in old fields occupied initially 3.16% of the total area in 1984 and increased to 24,60% by 2005 and decreased again by 2016 to cover about 12,35% of the study area. Water was initially

0.28% in 1984, increased to 1.3% and went down to 0.19% in 2005 and 2016 respectively. The water pixels were poorly classified, hence, were not easy to interpret.

Figures 5.4 and 5.6 show the spatial changes, declines or gains of each class. In the period 1984 to 2005, dense vegetation was lost to old fields, sparse vegetation and bare ground by 1.8, 1.7 and 8.5% (15.4, 14.1 and 72.7 hectares), respectively. This indicated that bare ground gained from the densely-vegetated areas by 8.8%. The period between 1984 until 1996 saw agriculture dominant through the growing of crops and grazing of domesticated animals. This could have led to the loss of densely-vegetated areas through removal of trees for cultivation leading to the formation of more bare surfaces. The results also reveal that sparse vegetation lost to dense vegetation (2.7%) and to bare ground (10.7%), while bare ground gained due to the same reasons elaborated above. The bare-ground class also lost to old field (12.6), to sparse vegetation (1.4 and to dense vegetation (4.4%). The decline of bare-ground class indicates that the area was used for growing of crops, hence, it was a gain to the old fields class. This comparison of each class between the years 1984 to 2005 showed a marked land use/cover change during the period under study of about 21 years, with old fields gaining about 22.3% of the area followed by bare ground that gained 19.1% in the period under study. The rest of the other classes were below 10% in changes as can be seen in Figure 5.4. Bare ground and old field classes both show negative growth in vegetation of the wetland as they both indicate the clearance of vegetation.

Figure 5.6 indicates changes of land-use cover classes in the period 2005 to 2016. In this period, Vogelfontein was a fully restored nature reserve, where growing of crops had ceased in 1997 but grazing continued, and this time by game animals and not domesticated animals. The results show declines in old field to sparse vegetation (3.4%), dense vegetation (3.6%) and to bare ground (7.7%). Sparse vegetation lost to old field (0.7%), dense (0.6%) and bare ground (3.0%). The gain by the bare ground class is a threat as it is an indication of loss of vegetation. This could be due to overgrazing by animals in the reserve. Densely-vegetated areas were also lost to

sparsely-vegetated areas by 5.7%, to old field by 0.5% and to bare ground by 5.4%. Bare ground area was also lost to sparse vegetation (8.8%), to old field (1.3) and to dense vegetation (3.5%).

The bare ground, during the 11 years covered by the study gained by 10.2% as compared to 19.1% gain in 1984 to 2005 period, which indicates that vegetation in the reserve is recovering. A loss in bare ground class of about 8.9% indicates that vegetation is recovering in this reserve even under negative human activities caused by overgrazing and construction of roads for game drives in the reserve. Graphs presented in this study clearly show these changes as either loss or gain of each class (Figures 5.6 and 5.7). Old field class gained by 2.5% compared to 22.3% by 2005. In addition, this shows that the decline of cultivation in Vogelfontein has promoted growing of vegetation, be it sparse or dense vegetation. The sparsely-vegetated areas gained by 9.8% compared to 3.1% in the period 1984 to 2005.

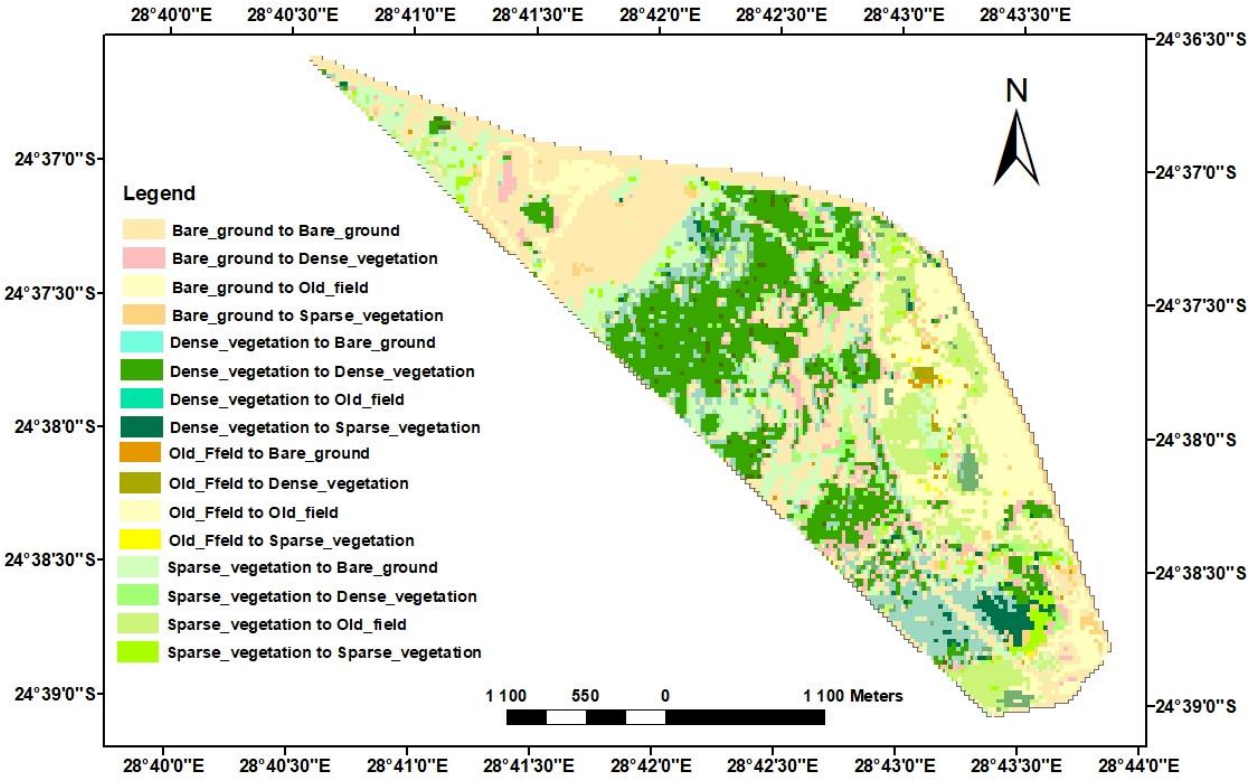

Figure 5.4: Change detection map of 1984 to 2005

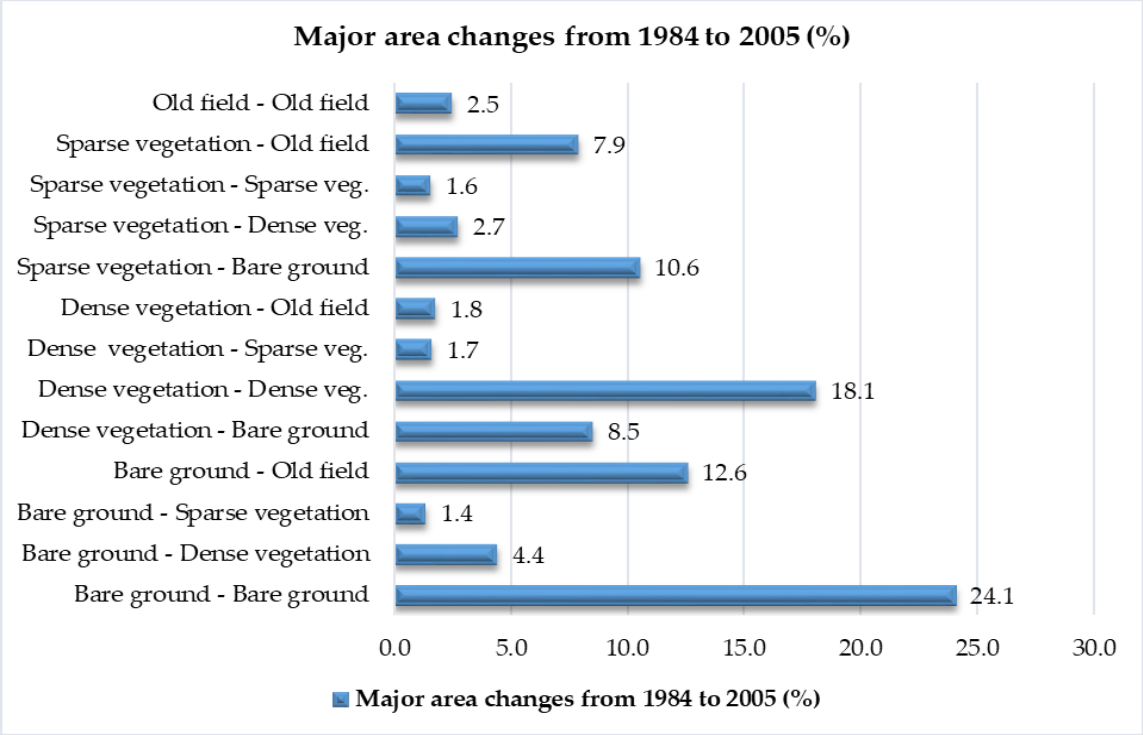

Figure 5.5: Major land use changes in Vogelfontein from 1984 to 2005

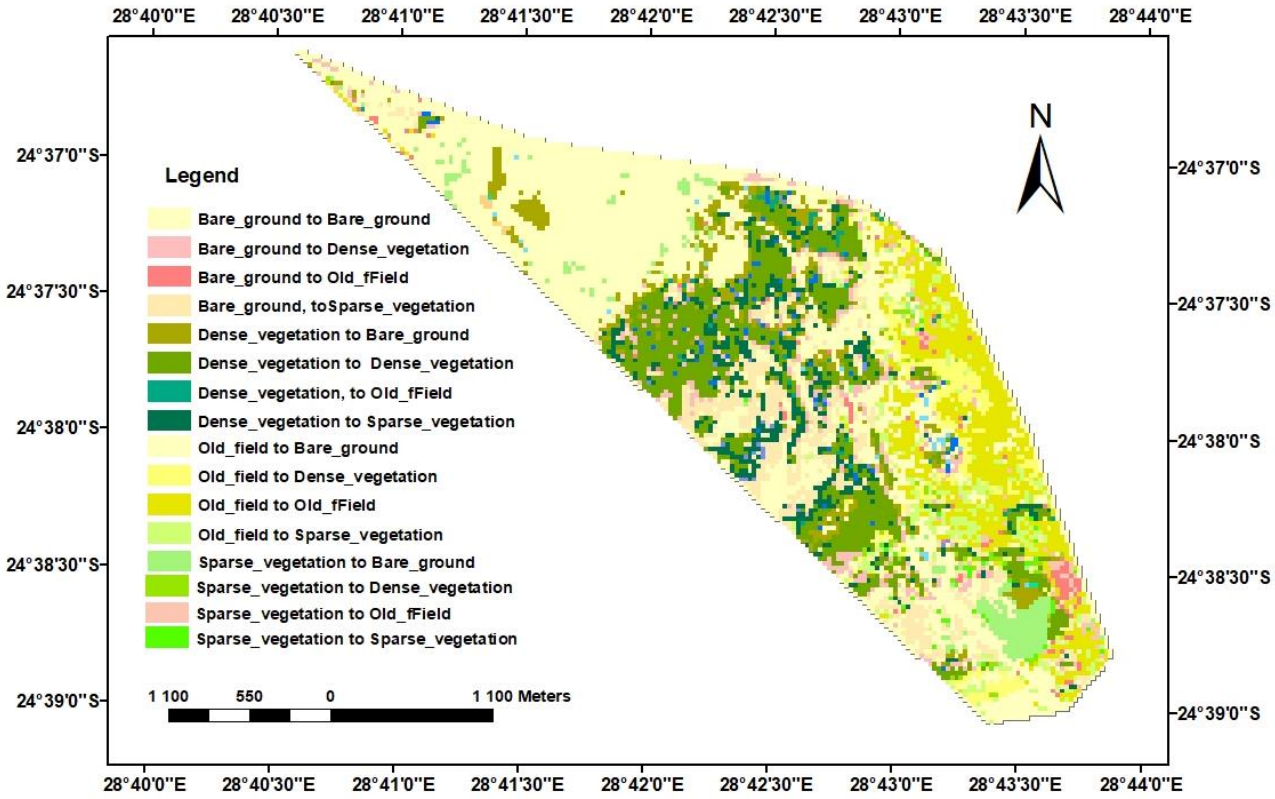

Figure 5.6: Major land use changes in Vogelfontein from 2005 to 2016

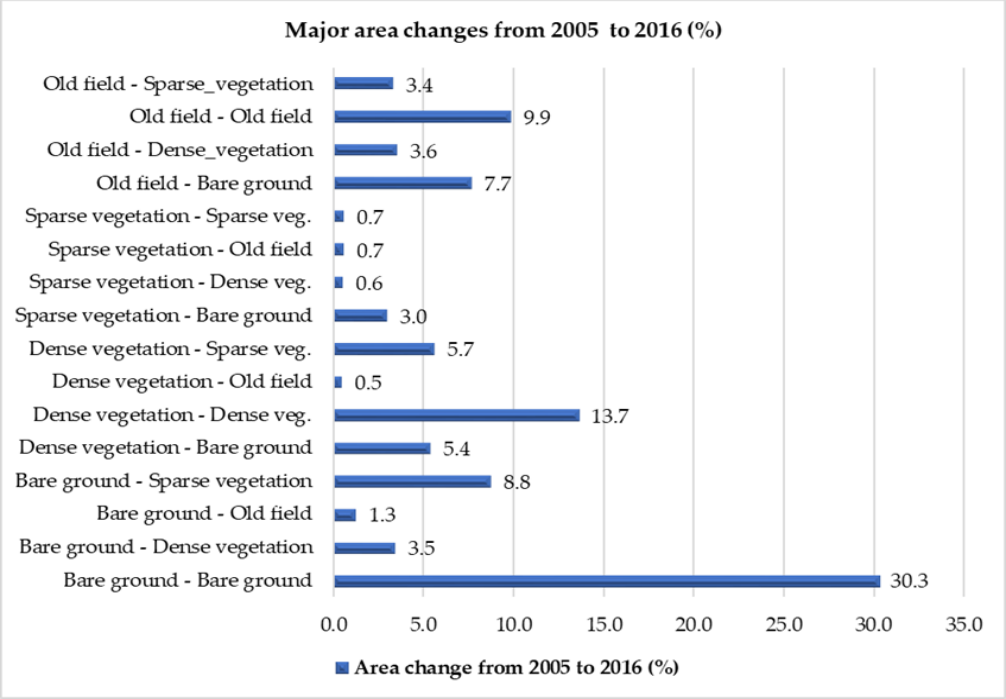

Figure 5.7: Major land use changes in Vogelfontein from 2005 to 2016 period

Vegetation decreased between the years, 1984 and 2016 by -3.88% (See Table 5.4). This generally indicates negative growth of vegetation in the study area, by 2016.

Table 5.4 Change in area covered by vegetation in 1984 and 2016

Cover type	1984 area in ha	%	2016 area in ha	% change	Change in 2016 & 1984 in %
Vegetation cover	495	56.91	461.25	53.03	-3.88
Bare Ground	372.51	42.83	407.07	46.80	3.97
Water	2.25	0.26	1.44	0.17	-0.09

5.4.3. Accuracy assessment

'Accuracy assessment' is the term used in thematic mapping to express the level of correctness of a classified map or image (Foody, 2002; Butt *et al.*, 2015). Campbell and Wynne (2011) stipulated that accuracy refers to the level to which the classified image agrees with the reality. The accuracy assessment, as elaborated in Section 5.2.5 above, used 35 points (30%) of the

randomly-generated points from 2005 and 2016 images, yielding an overall accuracy of 88.57% and 68.57% with Kappa coefficients of 0.8228 and 0.5145, respectively. As stipulated in Islam *et al.* (2018), Kappa statistics measures referenced and user-classified data. The Kappa values check accuracy of classified image as it considers all elements of the confusion matrix, while accuracy assessment considers the correctly classified pixels (Yang and Lo, 2002; Van Vliet *et al.*, 2011).

These findings are similar to those found by Hudson *et al.* (2006) and Koranteng *et al.* (2016) who concluded that the range allows performance of further analysis and formulation of valid conclusions. The study reveals that the use of supervised classification for land use/cover classification in restored areas yields positive results as it assists in revealing land use/cover changes in the restored wetland. The overall image classification accuracy of 2005 and 2016, together with Kappa values were ideal to detect if there were changes in vegetation cover in the restored wetland (Zhao *et al.*, 2017). Lack of historic maps or aerial photographs to validate satellite imagery has been found to be a major challenge in most developing nations (Griscom *et al.*, 2010). This lack of validation data for 1984 image, meant that accuracy assessment was not performed on this image; the accuracy assessment, Kappa statistics and other values are as shown in Tables 5.4 and 5.5. (See also Appendices 9.11 and 9-12).

Table 5.5: Accuracy and Kappa statistics report of 2005 supervised land use/cover classification of Vogelfontein

	Fields (1)	Sparse Vegetation (2)	Dense Vegetation (3)	Bare Ground (4)	Water (5)	Row Totals	Producer Accuracy %	User Accuracy %
Old Fields (1)	**6**	0	0	2	0	8	85.71%	75.00%
Sparse Vegetation (2)	0	2	0	0	**0**	2	66.67%	100.00%
Dense Vegetation (3)	0	0	7	0	0	7	100.00%	100.00%
Bare Ground (4)	1	1	0	16	**0**	18	88.89%	88.89%
Water (5)	-	-	-	-	**0**	0	-	-
Column Totals	**7**	**3**	**7**	**18**	**0**	**35**		
Overall classification accuracy = 88.57%, **Overall Kappa statistics** = 0.8228								

Table 5.6: Accuracy and Kappa statistics report of 2016 supervised land use/cover classification of Vogelfontein

	Fields (1)	Sparse Vegetation (2)	Dense Vegetation (3)	Bare Ground (4)	Water (5)	Totals	Producer Accuracy %	User Accuracy %
Old Fields (1)	**4**	0	1	0	0	5	66.67%	80.80%
Sparse Vegetation (2)	1	**2**	1	0	0	4	40.00%	50.00%
Dense Vegetation (3)	0	1	**3**	2	0	6	42.86%	50.00%
Bare Ground (4)	1	2	2	**15**	0	20	88.24%	75.00%
Water (5)	-	-	-	-	**0**	0	-	-
Totals	6	5	7	17	0	**35**		
Overall classification accuracy = 68.57%, **Overall Kappa statistics** = 0.5145								

5.5. Discussion

The chapter aimed to assess success efforts for vegetation restoration through land use/cover analysis in the floodplain, to save the Nylsvley wetland, a Ramsar site. The study expected the results to provide information on spatio-temporal changes in vegetation of Vogelfontein overtime utilising RS tools. The results have revealed crucial information about vegetation cover changes in the study area through a classified and combined changes in the “to and from” classes. The period 2005 to 2016 showed an increase of 7% in vegetation cover of Vogelfontein. Vegetation of the reserve showed an overall decrease by -3.88% in the 22 years under study, considering the analysis from the two dates (1984 to 2016), (Table 5.4). Many factors could have attributed to this decrease, which include grazing by game and road construction for ecotourism. The decreasing or increasing tendency of land use/cover change in the floodplain strengthens the fact that economic forces are a major stimulus to anthropogenic change of land (Wang *et al.*, 2008). Even though the study area had shifted from involvement in agricultural activities, (cultivation and grazing by domestic animals), since 1997, it still suffers from economic activities, such as game farming for eco-tourism purposes; this has resulted in continued overgrazing and browsing of the

reserve. A study by Butt *et al.* (2015), on land-use map-change analysis of Simly watershed in Pakistan revealed that bare soil increased due to deforestation which exposed the land surface; continued demand for agricultural land also led to more area left bare and barren, as the soil became infertile. This study's results agree with these authors' points as bare ground surface increased in the study area and only reduced when restoration activities came into place in the floodplain.

The results in this study reveal this decline in bare ground areas from 2005, from the loss to other classes as 19.1% to 10.2% by 2016. The fact that old field space declined too, from 22.3% loss to other classes by 2005 to 2.4% by 2016 indicates that vegetation in the reserve is gaining through natural restoration process as anthropogenic activities have been minimized in this floodplain. Similarly, studies by (Shafiq *et al.*, 1997; Arfan, 2008) elsewhere, highlights that grazing by animals have deformed the floodplains, leaving land surface barren. Animals also loosen soil, especially, in the floodplain and on water hole points within the reserve, contributing to vegetation loss.

The classification results in this study support the above facts that area covered by vegetation, be it sparse or dense, decreased at the expense of agriculture, which resulted in creation of more bare ground surfaces. The decrease of sparse vegetation from 22.9% in 1984 to as low as 4.3% by 2005 and up again to 18.65% by 2016 clearly shows that land use activities impact on the availability of vegetation in the reserve. Studies by Brink and Eva (2009) and (Gibbs *et al.*, 2010) note that agricultural activities degrade natural vegetation, hence, it has also been established as impacting negatively on land use/cover changes in Africa. In sub-Saharan Africa, most natural land including wetlands were lost annually to agriculture between 1975 and the year 2000 (Brink and Eva, 2009). The study area has also been impacted by economic activities, such as tourism. The construction of roads in the reserve to allow for tourism, game and sight-seeing has also

negatively impacted on the availability of vegetation in the reserve, as it is cleared to pave a way for roads.

This study reveals information that bare surfaces increased at the expense of other classes, which promoted vegetation growth during the period under study. The increase in bare soil area was due to continued overgrazing by animals, especially, in the floodplain areas, which would remove the vegetation cover from the land leaving it bare. In most cases, agricultural practices lead to soil loss and left the land less productive (Butt *et al.*, 2015). Similarly, a study by Ruwanza and Mulaudzi (2018) in the old agricultural fields of Lapalala also showed that it takes many years for fields to have natural vegetation recovery. The classification results show that natural regeneration of vegetation in the Vogelfontein did not get better from 1984 to 2005, as bare ground and old field class increased, but reduced from 2005 to 2016, indicating natural recovery of vegetation in the wetland. The study hypothesised that natural vegetation regeneration has successfully increased since the restoration of Vogelfontein floodplain after the site's proclamation as a nature reserve. This is accurate, to a certain extent, as the vegetation in the reserve has improved with decreases in bare ground and old field classes. Generally, the classified images of 1984 and 2016 show a negative increase in vegetation while the analysis of the period 2005 and 2016 indicated increase of vegetation, even though the figures are in the negative.

With previous agricultural activities represented by old fields in the classification, the study showed that, 22 years after the actual growing of crops, the surface is still struggling to have permanent vegetation cover. Growing of crops and other agricultural practices impact negatively on natural vegetation growth which leads to loss and less nutritious soil (Ruwanza and Mulaudzi, 2018), leading to siltation of water ways and wetlands. Studies have revealed that SA lost over 50% of wetlands through agriculture (Kotze *et al.*, 1995) and Nylsvley contributed to this loss, as this study reveals that wetland agricultural practices in Nylsvley over the years have negatively impacted on vegetation recovery. Previous agricultural practices together with variability in climate

contribute to reduced rainfall necessary for vegetation growth in wetland ecosystems; this has been elaborated in Chapter 4 of this study. Information on the alarming rate of land use/cover changes in restored wetland ecosystems is necessary to understand the success of vegetation recovery efforts, in restored wetland areas, for their proper management and monitoring.

The water class area was poorly represented over all the years under study with less than 1% cover in 1984 and 2016. In 2005, the water area represented 1.3% of the total area. The changes in all the other land uses affect this water class. As animal accessed the drinking water, they leave their dung; this enriches the water bodies resulting in polluted water. Upstream of the Nyl River is Modimolle town that releases its sewerage into the river (Greenfield, 2004) and also rearing of poultry and other agricultural practices (use of herbicides and pesticides) lead to river and floodplain water pollution (Butt *et al.*, 2015). The satellite imageries were taken in May and July when there was less water flowing in the river and blue-green algae dominated; this is classified as vegetation as there is water underneath. A study by Greenfield (2004) on the wetland showed sewerage disposal into the Nyl River from the upstream Modimolle town. The unavailability of vegetation in old fields and flood plain, contributes to increased surface runoff (Mendoza *et al.*, 2011).

5.6. Conclusion

Mapping land use/cover change is essential in protected areas to determine vegetation restoration benefits. In this study, the trend and rate of land use/cover over the past two decades, 1984 till 2016, were quantified in Vogelfontein. The study area previously experienced considerable amount of environmental change through overgrazing and cultivation before it was classified as a nature reserve. To determine the spatio-temporal changes in land use/cover in the reserve, in 1984, 2005 and 2016, supervised classification techniques were utilized. Five major

land use/cover units were determined - water, bare ground, old fields, sparse and dense vegetation. Densely-vegetated areas have been decreasing over the years.

The findings of this study provide a crucial monitoring basis for investigations of changes in the natural vegetation over time; this would help decision-makers to improve on management plans of the reserve, in terms of vegetation recovery, for the protection of the rich biodiversity of Nylsvley floodplain wetland. The use of RS imagery in this study aided with wetland restoration monitoring has an advantage of providing previous data for comparison purposes; in nature reserves that may not be easy to access. RS data may also be utilized in assessing vegetation changes. A combination of previous land use practices together with eco-tourism in this area have implications for land-use changes. Studies on wetland restoration had not capitalised on ecological insights obtained through land use/cover change analysis on restored wetlands over time; this study addressed the issue.

The study found it necessary to evaluate restoration activities taking place in Nylsvley wetland to see if restoration has improved vegetation regeneration of the wetland, hence, the following chapter focuses on linking restoration activities in the reserve to vegetation development of the wetland.

6. LINKING ECOLOGICAL RESTORATION ACTIVITIES TO VEGETATION DEVELOPMENT IN NYLSVLEY

Abstract

The functioning of wetland ecosystems is negatively impacted by human anthropogenic activities, which affect wetland vegetation development and its ability to offer ecosystem services. The study examined wetland restoration efforts to establish whether they reflect the intended restoration outcomes in Nylsvley. Three project sites, with various interventions - A61C-01, A61C-02 and A61C-03 - were investigated. All restoration objectives were analysed and evaluated for their success against project site-document review; the processes were linked to restoration phases (planning, implementation and monitoring) and data was obtained through field photographs. Initial results from the monitoring showed restored sites with clear impacts on hydrology, geomorphology and vegetation and their change score was based on the WET-health assessment recorded. Photographs of the wetland status before restoration were obtained through document review. Aerial photographs and previous documents played key roles in providing wetland status before and during evaluation, in addition to WET-Health data. The restoration process, including the monitoring strategies were critically reviewed on the project reports. To improve flood attenuation, road strip with reno gabion structure was constructed across the wetland. To curb soil loss, berms and road strips were constructed on most roads and some degraded roads were closed for alternative access. The natural hydrological function of the wetland was improved by destroying berms previously constructed to divert water from the floodplain. Local plant bio-diversity was improved by fencing off previously degraded areas from grazers and old trees along berms were kept. The study proposes the establishment of long-term vegetation monitoring sites within the reserve to monitor vegetation development.

Keywords: Ecosystems; monitoring; Nylsvley; restoration; vegetation; wetland,

6.1 Introduction

Human activities negatively impact on functioning of river and wetland ecosystems affecting their ability to offer ecosystem services (Kotze *et al.*, 2012). These ecosystems have been widely recognized as needing restoration in an attempt to reverse the human impacts (Palmer *et al.*, 2004). Restoration is when interventions are made within rivers and wetlands to return their natural ecological driving forces in degraded vegetated areas; this in an effort to assist them recover their ecosystem services including structure, function or biotic composition (Grenfell *et al.*, 2007). Vegetation loss in these systems results in major environmental global problems that lead to biodiversity loss (Jansen and Di Gregorio, 2002; Rawat and Kumar, 2015; Kindu *et al.*, 2015). These changes generally occur slowly, but they are linked to decline in vegetation species composition, which in turn is detrimental to the functioning of the ecosystem (Jenberu and Admasu, 2019) as vegetation provides habitat, food and other ecological services.

There have been increases in wetland restoration projects globally (Gore, 1985; Gregory, 2006; Angelopoulos *et al.*, 2017; Lu *et al.*, 2019) and the commitment of resources by governments including South Africa (Ntshotsho *et al.*, 2011), despite this, post-project evaluation is lagging behind (Kondolf and Micheli, 1995; Rubin *et al.*, 2017). The failure to link restoration activities to development of natural vegetation in river and wetland zones limits our understanding of restoration benefits, despite the huge costs involved in these projects together with the essential role played by vegetation in these ecosystems. In South Africa, Nylsvley wetland alone in 2016 had a restoration budget of over R7 million out of R80 million that is spent annually on river and wetland restoration projects (Cowden *et al.*, 2014). Linkage of river and wetland restoration project planning objectives and how they monitor vegetation development in degraded areas in the reserve, however, is not clear.

One of the management plans for Nylsvley uses the rehabilitation (restoration) principle (Haskins and Kruger, 1997) with no clear vegetation-development monitoring options. Globally, most restorations fall short in meeting their intended objectives (Bernhardt and Palmer, 2007) for despite governments having planning guidelines in place, river and wetland practitioners are not keen to follow them, leading to limitations in project evaluation (Roni and Beechie, 2013). For communities to benefit and improve guidelines of future restoration efforts, these current challenges ought to be understood and resolved.

Evaluating restoration projects is a daunting and not a straight forward task as various reasons are advanced supporting failure to evaluate restoration projects (Palmer *et al.*, 2007; Wortley *et al.*, 2013). The challenges include, in general, inadequate funding (Bernhardt *et al.,* 2007 and Mcconnachie *et al.,* 2013) or minimum funding availability (Kotze *et al.,* 2019) or lack of advanced project planning, which is critical in a project (Kondolf and Micheli 1995, Angelopoulos *et al.,* 2017). Guidelines to evaluate projects have since been developed (Woolsey *et al.,* 2007), using for instance, WET-Health monitoring tool (Macfarlane *et al.,* 2007) as is the case in South Africa. Restorers must do the evaluation, as it is necessary for them to measure the successes of their restoration projects. Without conducting evaluation and disseminating the outcomes, lessons will not be learnt from successes and failures, and the field of wetland restoration will fail to advance (Kondolf and Micheli 1995, Woolsey *et al.*, 2007). The authors suggest that post-project evaluation must be fused into the initial project design, thus, making it part of the planning. The evaluation feedback will provide good insights for future restoration projects, broaden research-based scientific knowledge, and provide informative project outcomes that are needed when reviewing projects and ways to improve restoration techniques (Downs and Kondolf 2002, Morandi *et al.,* 2014). The evaluation technique to be used should be dependent upon the project goals and specific objectives.

As explained above, it is difficult to evaluate whether a project is successful or not and even to identify what a successful ecological project is, however, the best way to measure success in wetland restoration projects is through evaluation of project compliance and its functional success (Kentula, 2000). Evaluation is meant to check if a project achieved its intended goal, whilst at the same time checking whether the restored area has achieved its ecological intentions (Palmer *et al.*, 2005; Giller, 2005; Nakamura *et al.*, 2006). The success is, thus, evaluated by a comparison of indicator values before and after the restoration measures have been undertaken (Woolsey *et al.*, 2007). Giller (2005) emphasises that, restoration success is measured by self-sustainability and resilience of the restored system. What it implies is that, for successful evaluation, natural reference data should be available. Even good ecological potential is considered a successful measure of restoration (Morandi *et al.*, 2014). Palmer *et al.* (2005) highlight that evaluation success of a restored site must include five set aspects, which include:

- A healthy system as a replacement of a degraded system,
- Signs of ecological sustainability to show in the restored site,
- An improved measurable ecological condition,
- No further environmental harm to occur during restoration and
- The project must be evaluated before and after implementation.

River and wetland restoration projects have been implemented in South Africa (SA) like in some other regions on the globe - USA, Europe, Japan and Asia - among others (Morandi *et al.*, 2014; Lu *et al.*, 2019). Most of these projects have failed to critique their sustainability, as well as the success or otherwise, of their restoration efforts, hence, the urgent need to professionally evaluate the Working for Wetlands restoration project in Nylsvley wetland. As asserted by Palmer *et al.* (2007) ecological restoration practices can be improved through monitoring and evaluation of existing site projects. Lack of adequate information on issues of sustainable environmental management and restoration success stories on the monitoring of wetland areas, often influence

management to make wrong decisions (Kotze *et al.*, 2019). In addition, lessons learnt during restoration projects need to be scientifically communicated to benefit similar future projects.

There has been implementation of very crucial projects in the Waterberg District, particularly, in Nylsvley, however, there has been limited evaluation of such projects to check on their success, even though this is critical for decision makers. Assessment of the site's ecological response was conducted in Nylsvley wetland in 2016, prior to restoration in the same year. In this study, the project objectives were examined against monitoring data collected and evaluation tools applied. The questions answered in this study are - (1) *What is the project goal for restoring Nylsvley? (2) Was there baseline data collected prior to restoration efforts in the study area? (3) Was the project monitored, which indicators were used and has the project been evaluated before? (4) What did the researcher find as evidence of restoration on the ground?* Answering these questions made it possible to achieve the study aim, which was to evaluate achievements of Working for Wetlands restoration projects in the Nylsvley.

The key research objective for this chapter was to determine if the projects implemented in the Nylsvley reflect the intended outcomes of the restoration activity - evaluating river and wetland restoration efforts. About R80 million per year is spent on wetland-restoration projects in South Africa (Cowden *et al.*, 2014), hence, it is absolutely necessary to measure their success. For instance, between 2016 and 2017, the estimated cost of new interventions in Nylsvley wetland was about R 7 445 539.00. The Nylsvley Wetland is of international biodiversity and eco-tourism value and is declared a Ramsar site. The wetland is significant for flood attenuation, streamflow regulation, water quality and biodiversity maintenance. Limited formal evaluation of ecological restoration outcomes, especially, on vegetation development of Working for Wetlands restoration projects in Nylsvley wetland need to be addressed.

6.2 Objective

To evaluate restoration activities and their relationship to vegetation development in Nylsvley.

6.2.1 Hypothesis

The study hypothesised that construction of road strips, gabions and destruction of berms in the reserve strongly contribute to availability of more water and vegetation in the floodplain and the river.

6.3 Materials and Methods

6.3.1 Study area and project summary

The Nylsvley study site was selected due to its importance as a Ramsar site of worldwide importance and because restoration activities were already in place. The wetland is significant for the services it provides to flood attenuation, stream flow regulation, water quality and biodiversity maintenance. As indicated in section 3.2.5, the land use types of Nylsvley are mainly grazing and browsing by game and tourism; the latter includes bird watching and game drive. Game drive promotes construction of roads through the reserve, to make it possible for tourists to access bird hideouts and view game.

The Nylsvley project area was previously impacted by the cultivation of crops, water abstraction through channels for agricultural purposes as well as grazing by both domestic and wild animals. These developments impacted negatively on the floodplain ecosystem. In the period between 2014 and 2016, restoration measures which include the destruction or where necessary, the construction of berms to allow free water movement and to trap soil loss was implemented. Gabions were also constructed across the river and the wetland to trap sediments and soil, thus, reduce river siltation, however, the results of restoration with respect to vegetation recovery of the wetland are still not clear; this was the focus of this study. Tools to assess the aquatic health of

floodplains, like Nylsvley have been developed (Greenfield, 2008). The selected wetland sites have had restoration interventions in place since 2014 and there are clear set objectives for conducting restoration in Nylsvley, which is still ongoing.

A document review of the reports on the projects provided an understanding the roles of the different project actors involved in the project, as their roles were clearly explained and how they implemented the objectives of the projects; the reports also provided outcomes of restoration. The project actors include, the Department of Environmental Affairs (DEA), Public Works Programme, Working for Wetlands, Environmental Control Officer, Environmental Practitioner and the communities employed by Public Works (Working for Wetland Programme, 2016).

There are three main project sites within the Nylsvley, labelled A61C-01, A61C-02 and A61C-03 in Figure 6.1. In the background of Figure 6.1 are the vegetation categories of Nylsvley. The site spatial locations are provided in Table 6.1.

Table 6.1: Identified wetlands within the Nylsvley floodplain

Wetland Number	Wetland Name	Latitude	Longitude
A61C-01	Nysvley wetland	$24^0$37’17.59” S	$28^0$42’17.93” E
A61C-02	Nysvley wetland: Tributary 1	$24^0$36’44.69” S	$28^0$40’35.92” E
A61C-03	Nysvley wetland: Tributary 2	$24^0$38’04.52” S	$28^0$40’15.54” E

Source: *Working for Wetland Programme (2016)*

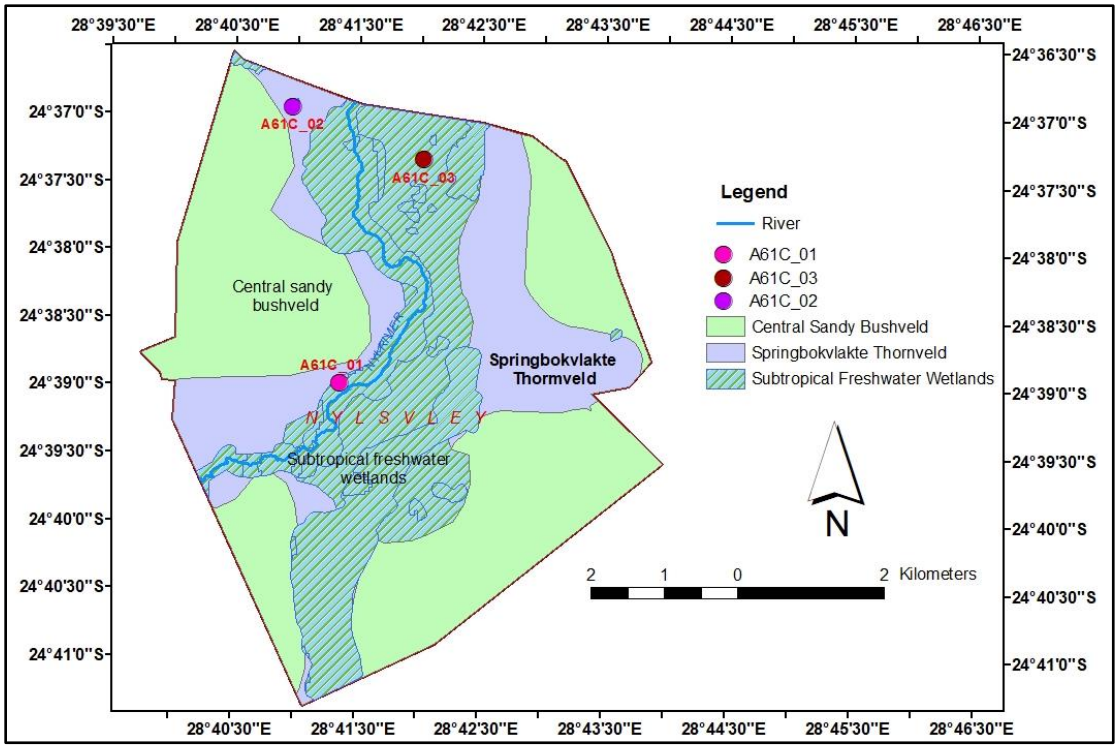

Figure 6.1: Location of the three restored sites, A61C-01, A61C-02 and A61C-03 in Nylsvley

The treatments in each site vary due to the different ecological challenges and expectations from the restoration. The interventions made at various sites include, construction of road strips and gabions along the roads or across the river or floodplain, closure of some roads, and berm destructions or construction where necessary. These selected sites in NNR were evaluated for their restoration success, in this study. The advantage of external evaluation of such projects is to reduce self-evaluation bias (Zedler, 2007).

6.3.2 Data availability

Field data collection was carried out in July and in December of 2019 (See field preparatory letter for July 2019, Appendix 9-14). It involved collecting relevant information such as site locations, photographs of the restoration structures, the type of structures erected, year erected and the responsible authority. The restoration project reports were searched online from South African National Biodiversity Institute (2014a). The 2014 and 2016 restoration projects' reports from

Waterberg District were reviewed to critically understand the project objectives. This Chapter combines a desktop review of restoration literature and field verification. Field verification of restored sites was done to affirm what is reported in the literature. Pictures or photographs of developments were taken using a camera. Google maps were valuable as they provided a qualitative descriptive data of before and after-restoration interventions. Appendices 9-15 show the google area view photographs of some restored structures' positions in Nylsvley which included the aerial photography of restored sites. The research looked for post-restoration activities in the floodplain, which included components of hydrology, geomorphology and vegetation activities; these were used to enable a comparison of pre-and post-restoration.

The evaluation relied only on grey literature, that is reports of 2014 and 2016, which did not clearly distinguish the three project phases - planning, implementation or monitoring. The first pages of reports where data was extracted are shown in Appendices 9-13. They include checks on the presence of vegetation in restored sites, road interventions to conserve soil and gabion interventions across the wetland that would allow water to pass, as currently, sediments are trapped.

6.3.3 Project document review

Available documents on Nylsvley restoration project were reviewed. The project was initiated in 2014 in the reserve, beginning with restoration structures at site A61C (South African National Biodiversity Institute, 2014b) and by 2016 there were three sites identified for restoration activities in Nylsvley (Working for Wetland Programme, 2016). The restoration documentation was reviewed to assess project activities at each of the three project stages - planning, implementation and monitoring. These were done utilising the restoration framework of Nilsson *et al.* (2016) which assisted with project evaluation at each stage. The framework evaluates ecological restoration process, which makes it useful for this study as it seeks to evaluate ecological restoration activities

in Nylsvley and identify what transpired at each stage as the restoration was in progress. The details of this framework are also provided in Section 2.6 of Chapter 2.

Field site visits of the project took place to check on project objectives and what had been achieved on the ground, regarding restoration activities. This was done to supplement the project documentation review. Field data assisted with verifying project goals, and to ascertain if baseline data was collected and whether monitoring of the project was going on. Information on the improvements on hydrology and geomorphic integrity were recorded in all treatments during the field visits, by means of pictures. Woodhill (1998) and (Nilsson *et al.*, 2016) state that an appropriate level of evaluation can be selected, as different stages (planning, implementation or monitoring) are considered, despite this, initial evaluation data is necessary to successfully evaluate each stage of a project, hence, the need to review the documents to obtain such data.

6.4 Data Analysis

To anaylse the collected data, all project objectives were listed in Table 6.2. Project objectives were then assessed before and after acquiring field photos, using Google image maps and the 2016 monitored data of the three modules of WET-Health tool - hydrology, geomorphology and vegetation (Beuel *et al.*, 2016) of the restored areas in Nylsvley. Hydrology focuses on the movement and distribution of water passing through the wetland together with the soil effects. The main characteristics that affect water distribution, patterns and supply in the wetland are factors, such as head cut or erosion. With geomorphology, the focus is on sediment distribution and retention. This is done through evaluating indicators of excessive sediment loses or input into the system through assessing for presence of metals or organic material (peat). For vegetation, evaluation is done on its structure and composition. The idea is to evaluate the state of vegetation using the current state and the historic onsite transformation or disturbance.

The framework in Figure 6.2 assisted in understanding what happened at each stage of restoration in the reserve utilising the framework, the objectives and field photos collected for evaluation. Evaluation is a two-way process and can be done at any stage as indicated in Figure 6.2 (2, 4, 6) and (1, 2, 5).

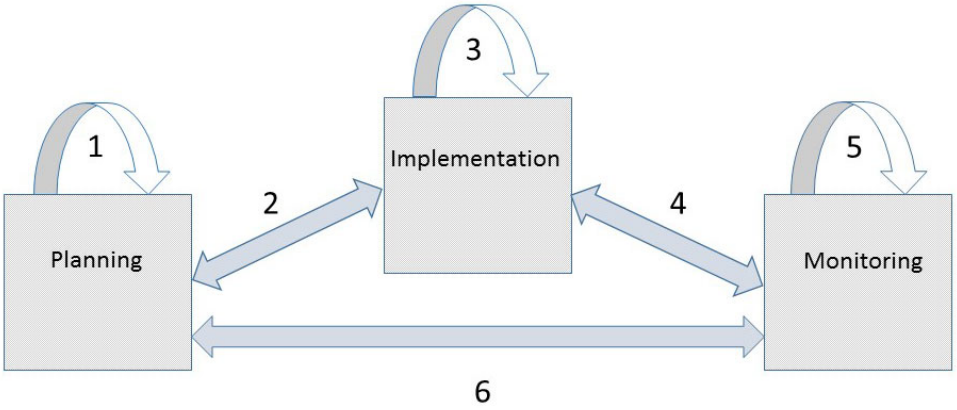

Figure 6.2: Conceptual diagram showing the planning, implementation and monitoring phases and the six evaluation steps.
Source: Nilsson *et al.* (2016)

Google Earth Pro provided some of the before and after photography for the study sites. In other words, the study focused more on evaluating what was done structurally, rather than, whether interventions introduced in the wetland necessarily measured the ecological impact. The study by Morsing *et al.* (2013) analysed 13 completed Danish restoration projects by focusing their evaluation on ecosystem structures. In as much as it is not sufficient to assess the recovery of ecosystem processes, measuring structure is sometimes the key to evaluating the processes as direct quantification of the processes is financially expensive and requires detailed long-term research studies, even though this process is not impossible (Ruiz-Jaen and Aide, 2005; Beuel *et al.*, 2016). The structures are put in place to promote ecosystem restoration; hence, their evaluation is equally necessary to indicate the state of an ecosystem restoration.

This long-term field measurement data, such as species composition, woody species densities, and structure can be equated with satellite time series data which can assist in interpreting vegetation change processes in landscapes or at plot level. The detailed changes in vegetation on the ground will, thus, be known at tree, shrub or grass level (Tian *et al.*, 2016).

6.5 Results

6.5.1 Project sites and document review

Table 6.2 shows evidence of initial monitored data recorded from the three wetland treatment sites (A61C-01, A61C-02 and A61C-03), in 2014; assessing the Hydro-geomorphic (HGM) conditions of these wetland sites was done using WET-Health tool by Macfarlane *et al.* (2007). The initial monitored results for the three wetland sites for 2014 showed identified impacts of hydrology, geomorphology and vegetation and their change score based on WET-health assessment (Macfarlane *et al.*, 2009; Kotze *et al.*, 2018). These initial monitored results and their interpretation are: *2 - meaning wetland state would likely improve significantly over the next 5 years; 1- meaning the wetland will likely improve; 0 - remain stable; -1- slowly deteriorate and -2 - rapidly deteriorate over a 5-year period with no intervention in place.*

Photographs of the status of the wetland before restoration structures were also obtained through the document review. This study referred to these photographs as - initial or original restoration photographs. Some of these initial photographs are shown in Figure 6.2 in column two, titled “original status”. The overall impact score of the three sites, as obtained from the monitoring report of 2014 were 2.00, 4.24 and 2.29, for A61C-01, A61C-02 and A61C-03, respectively (Working for Wetland Programme, 2016).

Table 6.2: Initial monitored results for three sites within Nylsvley (A61C-01, A61C-02 and A61C-03) in 2014

	Hydrology		**Geomorphology**		**Vegetation**			
Site Number	Impact score	Change score	Impact Score	Change score	Impact score	Change score	Size in Hactare	Overall Impact score
A61C-01	2.0	1	3.2	-1	0.8	1	1905	2.00
A61C-02	7.5	2	2.2	-1	1.4	1	44	4.24
A61C-03	3.9	2	0.8	-1	1.4	1	259	2.29

Source: *Working for Wetland Programme (2016)*

6.5.2 Effectiveness of restoration efforts

To evaluate the effectiveness of the restoration or rehabilitation activities in Nylsvley wetland, each restoration objective was measured against each treatment site-activities implemented on the ground. These were also linked to any one of the planning, implementation or monitoring processes in the restoration phases. The initial wetland status photographs as at restoration time were placed together with the current photographs, taken after restoration structures, showing the new status of the same area. The initial photographs (planning phase) showed a degraded landscape of the wetland ecosystem as shown in Figure 6.3, under ‘original status’ column. The column ‘current status’, in the same figure show implementation or monitoring stage. The comment section in Figure 6.3 briefly explains these photographs and the interventions made.

This chapter’s main objective was to evaluate restoration activities and their relationship to vegetation development in Nylsvley. To achieve this, the study evaluated all restoration objectives in Nylsvley and assessed their roles in assistance with vegetation development, within the degraded areas in the wetland. Human activities, such as cultivation and overgrazing in the wetland has resulted in the removal of vegetation, which traps soil, preventing it from being eroded. Erosion of soil negatively impact on the floodplain as it leads to siltation of the river, ponds and waterways, which leads to less water for water-fowls and other animals in the wetland. Figure

6.3, thus, listed the restoration objectives and their roles in conservation of the wetland and these are further discussed in this section.

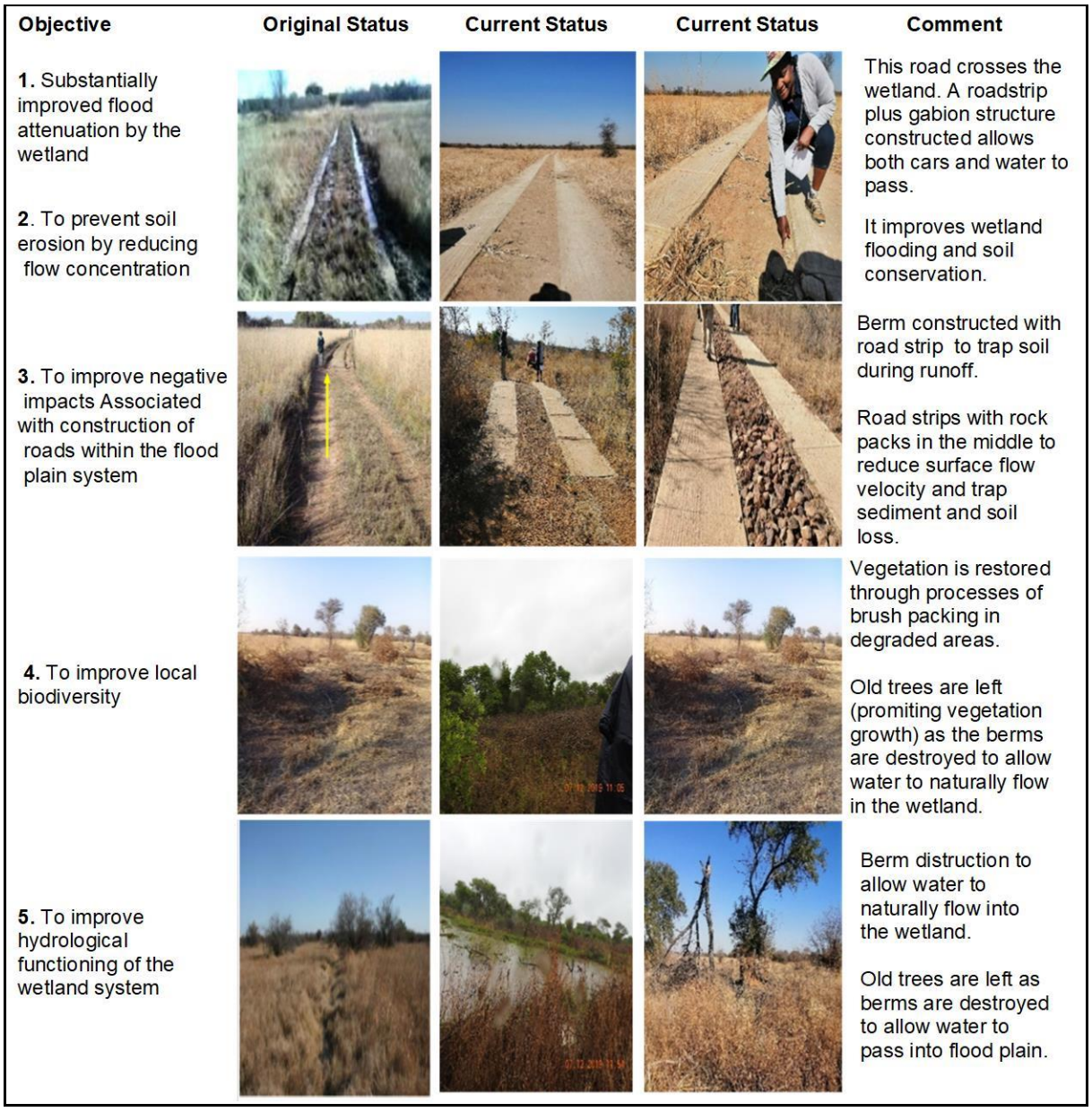

Figure 6.3: Restoration objectives, initial wetland status in 2014 and status after restoration interventions implemented, in Nylsvley wetland, in 2019

The pictures under 'original status' in Figure 6.3 show degraded roads and foot paths and loss of soil from the floodplain due to vegetation removal. The role played by each of the restoration

objective in conservation of the wetland are discussed further in this section. It should, however, be noted that for evaluation of this project, literature or document review played a key role in addressing the objectives and evaluation data.

The first and second restoration objectives in Figure 6.3, aimed to substantially improve flood attenuation and prevent soil erosion by reducing water flow in the wetland (A61C-01 site). A road strip with gabion structure was constructed across the wetland. The pictures show the initial status of wetland, then, after the road strip construction. The third picture shows the gabion structure placed between the road strip. Water is filtered through, hence, sediments are trapped and vehicles pass with no soil erosion or soil loss anymore.

Objective three aimed to improve the negative impacts associated with roads constructed within Nylsvley for ecotourism purposes, (A61C-02 site). Many roads have been constructed to allow tourists' game drives and viewing. To curb soil loss and further degradation of the area, berms together with road strips have been constructed on most of the roads. Some roads have been closed to avoid further erosion and loss of soil into the floodplain. In some areas, road strips were constructed together with rock packs, (See Objective three pictures in Figure 6.3).

For Objective four, which aimed to improve local plant bio-diversity, previously degraded areas were mostly fenced off from grazers through brush packing (A61C-01 and A61C-03 sites). Where berms were destroyed, or constructed, brush packing was also done. The purpose of brush packing is to promote vegetation growth in disturbed sites of the reserve. Old trees along berms were not removed as they are necessary to maintain biodiversity of the area and to provide seed banks, (See photographs in Figure 6.3, under Objective four).

Water has been trapped by creating ponds along streams that feed the wetland. To improve on

the natural hydrological function of the wetland, berms that were constructed to block free movement of water into the floodplain by draining it for agricultural purposes, were destroyed and

are continuing to be destroyed; these berms are found on two sites, A61C-01 and A61C-03. Under Objective five in Figure 6.3, pictures show where the berms have been destroyed and how the site looked like before restoration started. This also helps to improve the flood attenuation of the wetland.

6.6 Discussion

6.6.1 Project sites and document review

Document review was very critical as it provided the base information of how the restoration project in Nylsvley was done. The documents showed the treatment sites and the initial or level of disturbance in the wetland as measured using the WET-health tool. WET-health, an assessment method records the amount of deviation from the natural reference condition using three components which are: geomorphology, hydrology and vegetation. Photographs of the area before restoration were required as these were used in viewing the sites before and after the restoration. Cowden *et al.* (2014) in their study of restoration response to two wetlands in KwaZulu Natal, indicated that photographs portray different disturbance types within wetlands and can map the disturbance units which can be used in wetland evaluation at a later stage. The photographs made it possible for this study to evaluate the situation in the flood plain as the before-restoration photographs are available. This demonstrates that qualitative data such as pictures can be utilised to evaluate a project.

A study by Nilsson *et al.* (2016) as they developed a conceptual framework to evaluate ecological projects recommend that such projects can either be evaluated formally or informally. Considering the project actors involved in Nylsvley restoration project, chances are that any evaluation done is a mandatory process, although limited, due to expenses incurred in the process. This is the reason there is limited evaluation data for Nylsvley; as reported by Kotze *et al.* (2019), ecological outcomes are not easily assessed due to cost implications and limited resources in South Africa,

making Nylsvley not an exceptional. To successfully evaluate a project, monitoring data must be available; without this data, evaluation will not be possible. What is essential is that evaluation must be done at any level during the restoration process and it must be ongoing (Kondolf and Micheli, 1995; Nilsson *et al.*, 2016).

This study was intended to evaluate the restoration projects in Nylsvley, through a review of project planning documents and field assessments. If monitoring data is available, evaluation of restoration project can take place; in Nylsvley, for instance, the initial project planning had initial data captured which was used to evaluate the project. Restoration process comes in three phases - planning, implementation and monitoring (Tischew *et al.*, 2010). This means that evaluation can be done at each of these phases rather than to wait for post-project evaluation. Aradottir and Hagen (2013) maintain that in most cases, evaluation results, if published, are mostly grey literature such as reports and are inaccessible by scientists. This led to the suggestion by Nilsson *et al.* (2016) that all restoration documentation be archived in open searchable databases for easy access. With Nylsvley, restoration planning data, however, is available online or through request from WFW, even though it is grey literature found online. Taking into consideration the different stakeholders involved in the wetland restoration projects in South Africa, it is ideal to create a common database of all restoration projects done currently, not only for Nylsvley and Waterberg District but also for the whole country.

The study established that the project has several stakeholders involved, thus, there is need for clear communication lines to improve the projects' management and evaluation processes. The project reports revealed various stakeholders involved in the restoration projects in Nylsvley; these include, the project implementer (WfWetlands), the planners, Expanded Public Works Program (EPWP), the monitoring team (WfWetlands and DEA staff), Working for Water, Friends for Nylsvley, Limpopo Department of Tourism and university researchers, among others.

The field visits to verify the structures put in place in the restored sites in Nylsvley provided additional insights to information obtained from the reports; these structures were erected during implementation stage of the restoration projects. The structures put in place, such as gabions, reduced water flow velocity and in some cases, allowed vegetation to regrow. These field visits made it very clear how the restoration is being done in the wetland and this approach is supported by Nilsson *et al.* (2016), who state that some evaluation results should be obtainable through field visits or via internet. Field visits complemented literature, thus, providing a wealth of information for this study. The interactions with Friends of Nylsvley indicated their interest in trying to understand if vegetation in the reserve will be developing over time as it provides habitat for some bird species found in Nylsvley (Murungweni Personal Communication).

A long-time project monitoring and evaluation has the danger of missing some crucial events that may occur during or after the implementation phase. For instance, during the site visits to Nylsvley, site A61C-01 had been colonized by milkweed (*Gomphocarpus physocarpus) (*Fig. 6.4).

Figure 6.4: Photographs showing July and December visits to site A61C-01 where a berm was destroyed.

This happened barely five months after the demolition of one of the berms, (See Figure 6.4, showing the stretch where the berm was destroyed) and this resulted in the suppressing of the wetland grass.

Nilsson *et al.* (2016), report on the failure of a long-term monitoring project in Canada where native species were replaced by exotic species. This means that after demolition, monitoring should be done within a short space of time to check on colonizers, if need be, control measures may be implemented. The best way is to manage the weeds rather than to completely eradicate them from the wetland as they have already spread to most parts of the wetland (Dalu *et al.*, 2020a); in fact they had completely colonized this site more than anywhere else in the floodplain. The study by Dalu *et al.* (2020a) detailing the distribution and abundance of the milkweed in Nylsvley revealed that the weed has colonized most parts of the wetland but differs in abundance due to differences linked to soil properties of the surveyed sites. It is critical, therefore, for management to know that sites respond to restoration actions differently, hence, should be monitored to note down their different responses.

6.6.2 Effectiveness of restoration efforts

The main objective of establishing restoration activities in the floodplain was to improve the hydrological functioning of the wetland and associated condition of wetland vegetation through reinstating more natural water distribution and retention patterns. The study evaluated if the general restoration objective was addressed by activities done throughout the Nylsvley wetland. The wetland ecological status was impacted considering the initial monitoring data obtained from the wetland using the WET-Health tool, which focused mainly on the wetland hydrology, geomorphology and vegetation. In terms of hydrology, the wetland was previously impacted by grazing and cultivation within the valley bottom, as evidenced by studies by Scholes and Walker (1993) and the topographical maps of 1965 and 1967 in Figure 6.4.

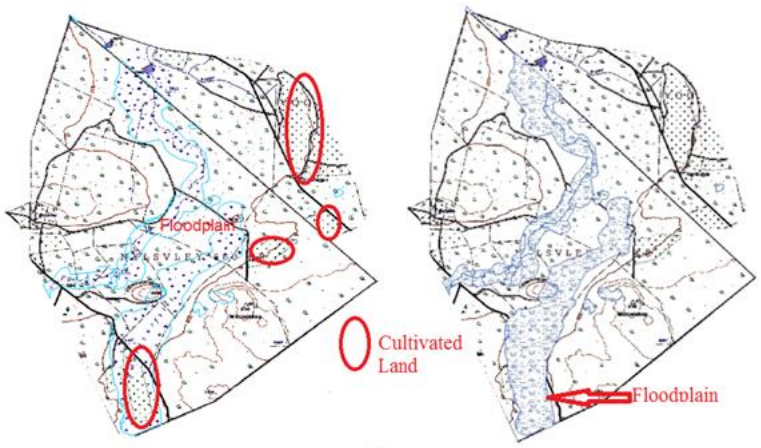

Figure 6.5: Topographical map of Nylsvley showing cultivation in the floodplain in 1965
Source**:** Adapted from Chief Directorate National Geo-Spatial Information, Rural Development, 2009

This supports the need to improve the site's hydrology through various interventions elaborated in the results section. Hydrology of the wetland has further been affected by roads constructed, with some across the floodplain; this has contributed to the removal of vegetation leading to loss of soil which may, ultimately, lead to siltation of the river. Siltation results in loss of wetland biodiversity as most water-loving flora and fauna species are lost as less water is kept in the river and floodplain.

The geomorphological impacts that were looked at in the study focused on berms, either their construction or destruction where necessary; where they impeded water flow, they were destroyed. The general modification of the wetland by previous berm construction or roads modified the vegetation of the wetland. To address the problem, however, in site A61C-01 and 03, old trees along berm sites were not destroyed and these species indicate the secondary species that had colonised the area before the human impacts; these should be kept as they may provide seed banks for future species. Where a berm was destroyed (site A61C-01), the area has been colonised by invasive species, such as the balloon milkweed (*Gomphocarpus physocarpus*), (See Figure 6.4). This plant species usually grow in wetlands, along road sides, agricultural fields

or disturbed areas (Woodson, 1954). The name is evident of the type of species as it releases milky toxic latex sap, which it uses as mechanism for defense to protect itself from herbivores (Wilbur (1976). It shows that the weed has dominated the seed bank.

The milkweed species is invasive to South Africa and many other African countries (Ward *et al.*, 2012)**.** In this part of the floodplain, grass species are needed, usually, to slow down water movement and trap sediments in the floodplain. This brings in a new management challenge of dealing with the weed in this part of the floodplain without further negatively impacting on the wetland. Monitoring and evaluation projects play key roles in such instances and intervention can be anytime in the project cycle, as postulated by Woodhill (1998) in their land-care project in Australia. The Society for Ecological Restoration has set restoration-monitoring site parameters that are useful as they focused on the intended original restoration goals and objectives, which may include suppression of invasive species and promoting ecological function of the ecosystem (Society for Ecological Restoration International, 2020).

Soft engineering interventions, such as brush packing has been a common and ideal method used in the wetland in trying to restore vegetation where it has been lost either during construction of road strips or due to previous agricultural activities. The wetland is ecologically sensitive and only soft interventions are suitable, rather than hard interventions.

Evaluation may not necessarily give satisfactory answers as projects tend to focus on evaluating structures rather than processes. Morsing *et al.* (2013) report that with 13 completed restoration projects in Denmark, and because their evaluation focused more on structures, the activity did not necessarily show changes in the ecosystem processes. Measuring the structures is mostly a common way to evaluate success of restoration activities, for direct quantification process is rather difficult to measure, in as much as it is possible (Ruiz-Jaén and Aide, 2005). This clearly indicates that evaluation of projects despite being complicated must be done to try and measure

restoration success. The ideas gathered from different evaluated projects can be combined and used to come up with better evaluation methods. As observed by Woolsey *et al.* (2007), failure to prove restoration success risks projects losing public support for funding, as the processes are generally expensive. Monitoring data was available for this study; however, the formal evaluation process was not properly documented nor did the results appear as pictures or some written documentation; these do not demonstrate the success or measure the direct project changes from the restoration activities. Evidence in photographs showing deep erosion tracks in some roads in the wetland were addressed by constructing road strips to reduce the impacts of road construction in Nylsvley.

6.7 Conclusion

The Chapter evaluated the success of restoration efforts in Nyl River floodplain against the Working for Wetlands set objectives. Aerial photographs played a key role in providing wetland status before and during evaluation; there are several stakeholders involved in this wetland restoration project, therefore, communication becomes key to improving the evaluation process. The three modules of WET-Health - hydrology, geomorphology and vegetation - provided the initial monitoring scores; these are useful for successful evaluation of Nylsvley restoration efforts over time, even though the project did not show the current impacts. As has been established in this study, successful restoration is not a straight-forward and easy concept to measure, as there are many debates going on as to what characterises a successful restoration.

The following chapter focuses on composition and the diversity of vegetation species available in the previously degraded areas in the wetland. It is relevant to know which vegetation species are present and how they continue to increase and recover with time. The chapter will also give more room for the understanding of the current and future dynamics of vegetation changes in the

wetland. The study recommends further steps in protecting and restoring vegetation of this floodplain through quantification of vegetation in the reserve.

7. WOODY SPECIES COMPOSITION, DIVERSITY AND DENSITY IN RESTORED SITES OF NYLSVLEY

Abstract

The need to understand the possibility of vegetations' natural regeneration in previously degraded wetlands of semi-arid regions is necessary to measure restoration success. The study established vegetation monitoring sites and quantified woody species diversity, composition and density in established restored sites in Nylsvley. Ten circular quadrants of 10 m radius were established in the restored sites and their spatial locations recorded using a Garmin Etrex 10, Global positioning system. An adapted Point Centre Quarter method was used for vegetation structural measurements. Woody species diversity was quantified using Simpson's diversity index. The *Combretum apiculatum, Terminalia sericea and Vachellia tortillis* are the most prolific woody species in the study sites, represented by above 11% of the total species. Simpson's diversity index in treatment sites was 0.88, signifying lower species diversity compared to 0.95 when reference sites are included. The species richness in treatment sites is 16 with species composition of 45. The Analysis of Variance showed that there is significant difference between treatment and reference sites at $p < 0.001$ for woody species distribution and height differences whilst species richness is significant at $p < 0.05$. These results show that reference plots have significantly more trees, higher species richness, taller woody species and more woody species density per hectare than the treatment plots. The Detrended Correspondence Analysis revealed that sites with similar species composition are located close to each other. Biodiversity is threatened by vegetation removal, hence, the need to monitor woody-species regeneration overtime for conservation purposes.

Keywords: Composition; diversity; richness; species; vegetation; woody

7.1 Introduction

Ecological restoration attempts to recover a natural range of the ecosystem structure, composition and dynamics (Falk, 1990, Allen *et al.,* 2002, Palmer *et al.,* 2005, Karami, 2017). It, thus, endeavours to provide opportunities to test succession theories in previously-degraded ecosystems (Walker and Del Moral, 2009). An important question to be asked is, whether it is possible to naturally restore woody vegetation species in previously-degraded wetlands of semi-arid regions and be able to determine such species. The above question can possibly be answered with availability of initial monitoring data from established sites. The monitoring data can have, among others, parameters such as vegetation density, structure or composition which, thus, can then be used as indicators of degradation of the ecosystem (Palamuleni and Turyahikayo, 2015). Vegetation density, being the number of individual woody plant species per unit area (Johnson *et al.*, 2019) is ideal when monitoring vegetation regeneration changes over long time, in restored areas. Ecological restoration protects habitats, thereby, enhancing flora and fauna species' composition and diversity (Wortley *et al.,* 2013, Berrahmouni *et al.,* 2015). Wetland ecosystems take long time to recover after disturbances, hence, ecological studies are critical in an advancement of the scientific basis for wetland restoration and decision-making (Aronson and Galatowitsch, 2008). Most wetland restoration initiatives are motivated by concerns over water quality and soil loss; this gives an opportunity for landscape-scale habitat restoration (Aronson and Galatowitsch, 2008).

This chapter is motivated by the need to establish long-term vegetation monitoring sites in restored areas of the Nylsvley Nature Reserve. In Chapter 5 of this study, Section 5.2 on change detection, it shows that vegetation has improved since the restoration of Vogelfontein, part of the reserve. To have detailed developmental pattern between vegetation and restoration period and to measure their success, there is need, for a long term vegetation-regeneration monitoring data. The establishment of long term monitoring sites within the restored sites in the reserve will help

to improve our understating of natural vegetation development in the reserve and provide future validation data on Nylsvley's wetland vegetation development. Long term monitoring sites, thus, have been proposed and the initial stage is to examine the sites of the available woody species, their composition, diversity and richness and be able to evaluate the success of regrowth of natural vegetation in restored sites. Wortley *et al.* (2013) maintain that assessing the success of ecological restoration projects is crucial in justifying the use of restoration in wetland resource management and to improve on best practices. The global wetland restoration projects have increased exponentially since 2000 (Nakamura *et al.,* 2006). These projects need to be monitored due to the challenges they face along the way, hence, the establishment of monitoring sites within restored areas gives better foresight on how these restoration problems can be solved with minimum resource wastages and also combate issues of project failures (Garcia *et al.*, 2016). Initiating restoration study sites can be a good idea in trying to address the restoration questions raised above.

Matthews *et al.* (2009) report in their study, the uncertainty regarding the best way to monitor restoration progress. Measurable indicators on restoration progress, especially, on vegetation communities include, the percentage cover of native species or plant species richness that vary along different gradients of disturbed vegetation communities. Assessing the diversity, density and composition of plant species in previously-degraded areas can be the best answer. Areas that have been allowed to regenerate for decades need to be examined on their progress and success on vegetation growth (Garcia *et al.*, 2016). Establishing restoration monitoring sites in previously-degraded, areas, therefore, is necessary for vegetation monitoring and identifying species available for current and future monitoring. Where sites have already been established, quantifying vegetation species in these sites gives excellent opportunity to check on restoration success over time. Wortley *et al.,* (2013) in their study in assessing success stories of ecological restorations, conclude that studies have been fair on species diversity and abundance, and

vegetation structure, although the studies were biased towards United States and Australia. There is, hence, a need to establish long term vegetation monitoring sites for better understanding of outcomes and benefits of natural vegetation restoration, of semi-arid wetlands of southern Africa.

Globally, loss of plant biodiversity in terms of species and communities has become a serious issue (Solomon *et al.*, 2016). Species distribution and abundance are related to natural and anthropogenic factors (Poff and Zimmerman, 2010; Martins *et al.*, 2013). Zou *et al.* (2018) reveal that wetlands in most parts of the world have declined due to land drainage, reclamation and intensification of agricultural activities. The Assessment Millennium Ecosystem (2005) reports that plant biodiversity is fast diminishing with about two-thirds of existing terrestrial species most likely to become extinct by the end of this century. Furthermore, quite a number of these vegetation species will be unknown to science by the time they become extinct (Assessment Millennium Ecosystem, 2005). Mligo (2017) highlights that the differences in species composition and richness differ among landscapes because of various factors, such as temperature, seasonality, precipitation, disturbance regimes and nature of geology. Related vegetation studies done in Nyl River among others, include those by Scholes and Walker (1993); phenology of savanna tree (Kleynhans *et al.*, 2006; Whitecross *et al.*, 2016; Dalu *et al.*, 2020a) with little understanding of species composition and diversity in naturally-restored vegetation sites. The future success of restoration will depend on a number of environmental factors which require enhanced monitoring of the landscape (Crouzeilles and Curran, 2016). Garcia *et al.* (2016) stipulate that plant species colonization is affected by factors which include seed sources, soil degradation, anthropogenic disturbances, such as vegetation clearance for agriculture, settlement, overgrazing, browsing or burning. In naturally-restored sites, vegetation grows naturally with the help of human activities such as soil conservation and fencing to protect overgrazing/ browsing by animals. This is the case in some degraded sites in Nylsvley, as seen in chapter 6, where brash packing has been utilised to allow regeneration of the natural vegetation.

Chapters 4, 5 and 6 of this study hinted at many different studies conducted in Nylsvley with none of them monitoring woody species vegetation development in previously-disturbed areas of the Reserve. This is important as a measure to assess success of restoration activities especially, on vegetation development. Studies of vegetation development in fields where agriculture was previously practiced, have been done elsewhere in the same district, Waterberg, by Ruwanza and Mulaudzi (2018), but no similar study in Nylsvley, which is a Ramsar site of international importance, has been done. This chapter, hence, focused on woody vegetation species in a restored site in Nylsvley wetland aimed at establishing future vegetation monitoring sites to assist management with issues of vegetation recovery, soil conservation and plant biodiversity maintenance. This information is, thus, crucial for future management and conservation of Nylsvley. The study focused on woody species diversity, composition, richness, and density of species in restored sites in Nylsvley. It also investigated conditions created for tree re-establishment and recovery of other vegetation forms, after construction of roads and berms. The aim is to understand if the woody vegetation species of the area are naturally recovering.

7.2 Objective

The objective of this chapter is to quantify woody species composition and diversity in restored sites in Nylsvley.

7.2.1 Hypothesis

There is less woody species diversity in restored/ treatment sites as compared to reference sites in the Nylsvley.

7.3 Materials and Methods

7.3.1 Study area

The study was conducted in Nylsvley wetland. Chapter 3 provides, detailed description of Nylsvley

and Figure 7.1 shows the study sites. To date, grazing and browsing by game is still taking place in the reserve. This is in addition to other anthropogenic activities, which include road construction and previous agricultural activities in and around the floodplain; this makes it an ideal area to conduct this study. The construction of roads used by tourists and visitors for game drives, camping and bird watching contribute to the deterioration of the Nylsvley landscape. This is because the area has evidence of anthropogenic activities that influence the density, composition, and richness of plant species in the reserve. This information is needed for monitoring, future evaluation and to determine the success of natural vegetation restoration in this reserve.

Previous vegetation studies in Nylsvley focused on density, structure and pattern of vegetation (Lubke *et al.*, 1983), phenology of savanna trees (Scholes and Walker, 1993) and Nylsvley floodplain biodiversity (Tarboton, 1987). These studies overlooked the issue of establishing monitoring sites for restoration success which focuses on woody plant species diversity, composition and density in the disturbed wetland sites. The restoration sites were established in 2016 through Working for Wetlands projects within the Nylsvley wetland, hence, this is the first study on restoration of the reserve. The distribution of the study sites is shown in Figure 7.1

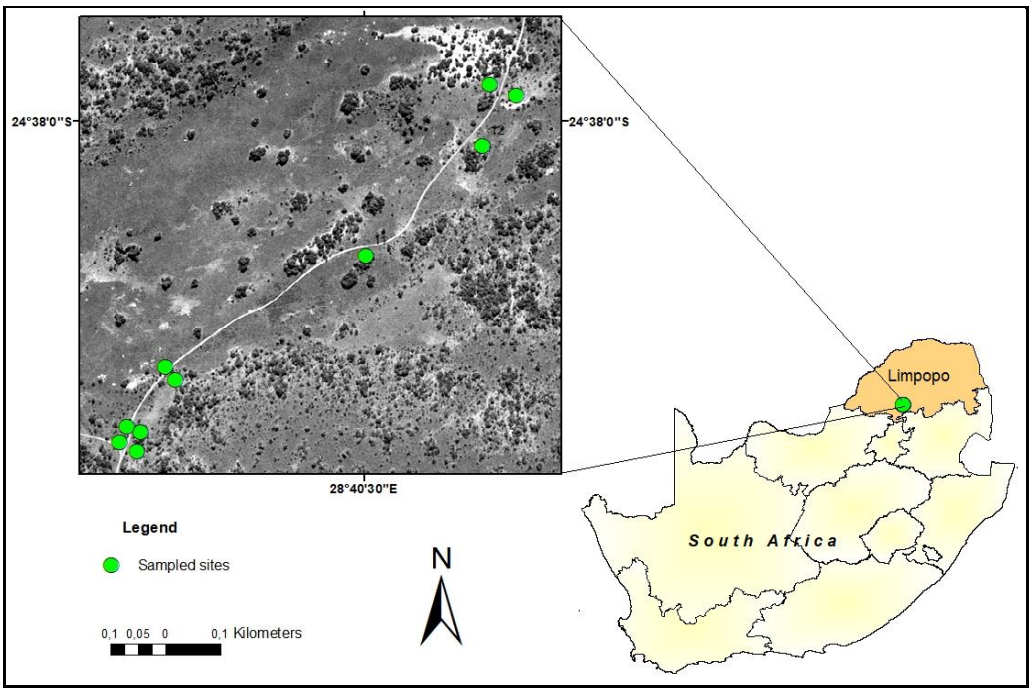

Figure 7.1: The location of study sites (1 to 10) in Nylsvley Nature Reserve

Nylsvley has a landscape of low relief with undulating terrain of about 1 100m in altitude (Lubke *et al.*, 1983).

7.3.2 Study plots

Vegetation structural measurements from the restored sites in Nylsvley took place in December 2019 in the summer season when species composition is best represented (Walker, 1976). This followed a field reconnaissance that took place in July 2019 by the researcher and Working for Wetlands representative's visit to different restoration interventions sites. The established restored sites were utilised for woody vegetation observations, measurements and recordings. Only woody species were used in this study for establishing the monitoring sites, as woody cover represented trees and shrubs. For identification and future vegetation monitoring, the researcher labelled the sites from 1 through to 10 as shown in Table 7.1 with the sites spatial locations recorded using a Garmin ETrex 10 Global Positioning System (GPS). A total of 10 circular

quadrants of 10m radius were established and inventoried. The reasons for the choice of the 10 circular quadrants of 10m radius are explained in paragraph 2 of Section 7.3.3. Sites, 9 and 10 were considered as reference sites representing less disturbed or close to natural vegetated areas in the reserve. Additional restoration activities in this part of Nylsvley took place in 2016 and these sites have been selected as initial vegetation monitoring sites to monitor the success of natural vegetation regeneration in Nylsvley.

Table 7.1: Spatial locations of circular quadrants where woody plant species data were collected

Quadrant Number	Latitude (y)	Longitude (x)	Description
1	-24,638651	28,6712	Treatment site
2	-24,638549	28,671007	Treatment site
3	-24,638398	28,671355	Treatment site
4	-24,638299	28,671129	Treatment site
5	-24,637405	28,672006	Treatment site
6	-24,637326	28,671761	Treatment site
7	-24,636309	28,673218	Treatment site
8	-24,636496	28,673302	Treatment site
9	-24,63552	28,67503	Reference site
10	-24,63373	28,67692	Reference site

Different conservation measures were practiced to restore the degraded sites. For instance, some sites have berms or road strips constructed along a gravel road to protect loss of topsoil and brush packing was done in most unvegetated areas to promote vegetation growth. The selected sites are parallel to the gravel road and are easily accessible. In all sites, natural tree regeneration is permitted, hence, there is no planting of trees. Brush packing is clear in Figures 7.2, 7.5 and 7,8. Figures 7.2 to 7.8 show restoration intervention in sites, either as constructed road strip or brush packing or a combination of both.

Figure 7.2: Pictures of established vegetation treatment monitoring site 1 with brush packing and berm construction.

Figure 7.3: Picture of established vegetation treatment monitoring site 2

Figure 7.4: Picture of established vegetation treatment monitoring site 3 with brush packing intervention

Figure 7.5: Picture of established vegetation treatment monitoring site 4 with brush packing and road / street intervention

Figure 7.6: Picture of established vegetation treatment monitoring site 5 with brush packing and road / street intervention

Figure 7.7: Picture of established vegetation treatment monitoring site 6 with brush packing and road / street intervention

Figure 7.8: Picture of established vegetation treatment monitoring site 7 with brush packing intervention

Figure 7.9: Picture of established vegetation treatment monitoring site **8**

7.3.3 Woody species data collection procedure and assessment

The restored sites' spatial locations were uploaded into a Garmin Etrex 10 GPS that was used to navigate the field sites for measuring vegetation composition and diversity. Downloaded google earth map was also used in locating restored sites in the field. Other field measurement tools such as tape measure, 2m calibrated rod, camera, pen, clip board and data collection sheets were also utilised in the field to collect and record data of woody species height, name and site location. The vegetation surveys fall within the A61C-02 restoration area, within Nylsvley (this area, A61C-02 is fully described in Chapter 6). This part of Nylsvley was also previously impacted by vegetation removal for cultivation, grazing and other human activities.

The choice of 10 circular quadrants of 10 m radius used for woody species sampling, which equated to 10 established sampling sites, follows Trollope *et al.* (2013) method of veld assessment, which is shown in Figure 7.10. Restored sites had a road strip (to trap soil loss) constructed in between sites, berms or road strip together with brush packing activities; all these were to allow regrowth of vegetation as animals are scared away by brush packing. A tape measure was laid on the ground to measure the quadrant radius. In each circular quadrant, all woody tree species including shrubs were recorded using 2 m calibrated rod or caliper depending on tree height, following Cottam and Curtis (1956) and Trollope *et al.* (2013) vegetation sampling method. The nearest tree/shrub, individually, was recorded from the center point in the four quadrants. The three different height classes, of <2 m, >2 m and the tallest of woody species were recorded in each quadrant. In this chapter, tree species recorded refer to rooted woody species that are self-supporting plants with a height of more than 3 m. The trunks of such species can be single or multiple. Shrubs, however, refer to tree species less than 0.3 m in height as described by Brown *et al.* (2005), however, when analysing the data, trees and shrub species were all treated as woody species. Woody plants that occur along the quadrant margins were included, so long as half of the rooted system is inside the quadrant (Walker, 1976).

The Adapted Point Centre Quarter (APCQ) method was employed in sampling woody plant species (Cottam and Curtis, 1956), as it reduces problems of over or under-sampling of both short and tall trees. Sampling sites were within the restored sites in the reserve. A random point is located, and the area around it is split into quadrants of 10m in radius as shown in Figure 7.10 and the woody tree species within were recorded.

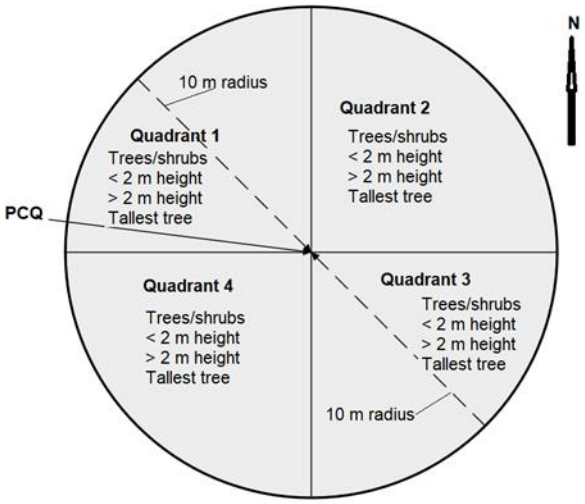

Figure 7.10: Procedure for using Adapted Point Centre Quarter method for collection of trees and shrubs data. The nearest tree/shrub individual is recorded from the center point in the four quadrants (quadrant 1 to 4). The three different height classes of tree/shrub were recorded (<2 m, >2 m and the tallest). Source**:** Adapted from Trollope *et al.* (2013)

Variables recorded included plant species' name, height and site. Tree species height, which is the vertical distance of a woody species from the ground to the tree top, was measured using a 2 m calibrated rod or caliper where necessary (Anderson and Ingram, 1993). In cases of multi-stem tree species, only one stem height was recorded. The density, which is the number of woody species per hectare, comprised of all the sampled woody species, from all the 10 circular quadrants (Næsset and Bjerknes, 2001).

An experienced field assistant helped with species identification in the field, although, unidentified species' specimens were collected for later identification using online resources, such as New Plants of Southern Africa (South African National Biodiversity Institute, 2019), the herbarium and text books (Van Wyk and Van Wyk, 2013). Plant picture species, leaves, flowers, and stem were taken for assistance with further identification. This method was selected because it is inexpensive, supplements results from textbooks and provides details of species that may not be in reference books.

7.4 Data analysis

7.4.1 Species diversity

Tables, figures and graphs were created to show the types and quantity of woody plant species found in the established restored sites. To determine diversity and composition of species, Simpson's Diversity Index was used to quantify diversity of woody species in sampled sites. Diversity is affected by total number of species, which is species richness and how species are distributed (evenness), hence, the two factors are considered when measuring diversity. Evenness refers to the relative abundance of measured different species that make up the richness of an area. The more the number of species in a sample, the richer the sample. If an ecosystem has abundance or is dominated by one species, which is not evenly distributed, the diversity of such an ecosystem is low. Simpson's Diversity Index formula for determining diversity and composition of species is shown below:

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)} \right)$$

Equation 1

Where,

n = the total number of organisms of a species

N = the total number of organisms of all species

***D Value* ranges between 0 and 1**

0 shows no or zero diversity while 1 indicates high diversity. It implies that the bigger the D value the higher the diversity. The value of D is subtracted from 1.

To determine the woody plant species abundance at each site, the following formula was used:

$$\%\ of\ abundance = \frac{Number\ of\ plants\ per\ species\ x\ 100}{Number\ of\ plants\ per\ site(s)} \qquad \textbf{Equation 2}$$

The variables included in the data analysis were species abundance, diversity, percentage of woody species richness, height and density. The results were presented in tables and graphs to depict comparison with established (experimental) sites visited.

To calculate woody species richness, the formula from Ayanaw Abunie and Dalle (2018) was used.

$$S = \frac{Number\ of\ species}{Plot} \qquad \textbf{Equation 3}$$

Collected woody species data were explored for statistical significance using RStudio version 3.6.2, Foundation for Statistical Computing Platform (Tidyverse, Car and 1me4 packages). The Poisson regression model analysis was used to check data distribution among reference and treatment sites. Poisson regression, therefore, was used in exploring species richness and distribution among treatment and reference sites, as the data is non-parametric and not normally distributed. Height of woody plant species is normally distributed hence, a mixed-effect model is used due to random effect variance introduced by each of the sampling sites. Finally, ANOVA was run to determine the significant differences among woody species in treatment sites, their species richness and differences in height.

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7.4.2 Woody species density

To determine species density and composition in sampled sites, the number of individual woody species in each sample was counted and recorded. Initial woody density per hectare was calculated using the area of sampled circular quadrants (r^2) to obtain total number of trees per hectare (density) as well as the total area sampled. In this study, Pie was considered as 3.14, hence, area covered by each quadrant equated to 314 m^2.

Density (plants per ha) for each plot was calculated using the formula:

$$Density\ (plants\ per\ Ha) = \frac{Number\ of\ woody\ plants\ x\ 10{,}000\ m2}{Quadrant\ area\ (m2)} \qquad \textbf{Equation 4}$$

7.4.3 Ordination (Multivariate) techniques and pattern of woody species

Ordination is the arrangement of plant species and/or samples along gradients. It contributes to pattern of analysis by showing directions of compositional change in small plant species' site data (Whittaker, 1982; Lubke *et al.*, 1983). Ordination has the advantage that it can reveal or give direction of compositional response that may not be easy to depict in the field. It also suggests comparative significance of these directions; this means that one can compare the woody species from different sites. In this study, to reveal the pattern in species distribution among sites, indirect ordination or Detrended Correspondence Analysis (DCA) was used (Ter Braak, 1995) on species abundance, in the different sites. Detrended Correspondence Analysis has the advantage that it can be used in the absence of environmental data where relationships are derived using species data only (Ter Braak and Smilauer, 1998). It is, however, limited to its sensitivity to outliers and the discontinuities in data. Sites which are close together or with similar woody species tend to be close to each other, unlike sites with dissimilar species composition that will be plotted further apart (Gauch and Gauch Jr, 1982; Ter Braak and Smilauer, 1998).

7.5 Results

7.5.1 Woody species identified in all sampled sites

In all the 10 sites sampled, 91 individual woody plants were identified, and these are shown in Figure 7.11 with species richness of 21 and the species diversity of 0.95 (Appendices 9-16). *Combretum apiculatum, Terminalia sericea and Vachellia tortillis* are the most identified woody species in the study sites, represented by 13.2%, 11% and 11% of the total species, respectively. The rest of the species were below 10% in abundance.

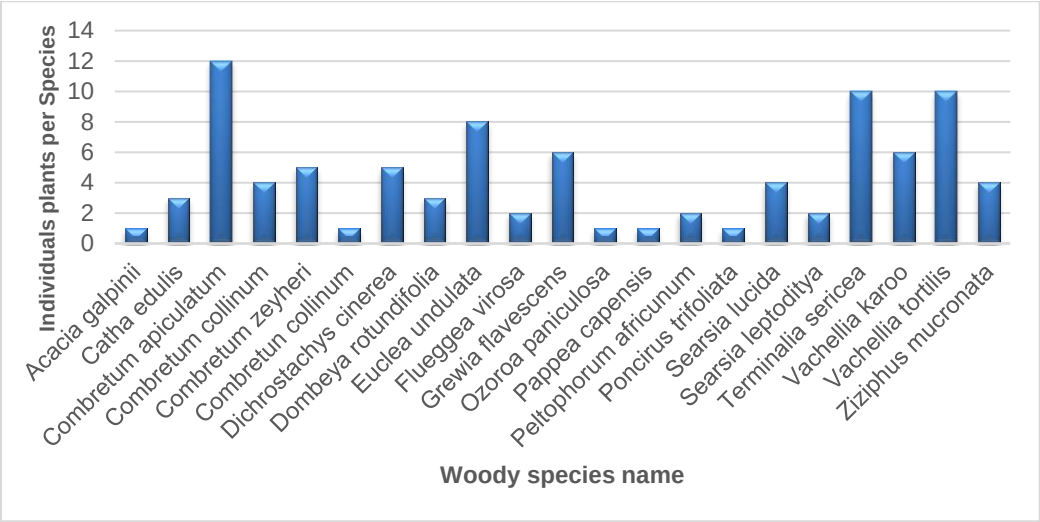

Figure 7.11: Woody plant species identified in the 10 experimental sites in Nylsvley

7.5.2 Composition of woody species in treatment sites

Sites 1 to 8 (treatment sites) were previously disturbed sites with woody vegetation cleared through previous anthropogenic activities, such as agriculture, whilst sites 9 and 10 had the least disturbances and were used as reference/undisturbed sites. The treatment sites had 49.5% of all the sampled species and the remainder of 50.5% were from the two reference sites. The Simpson's Diversity Index in treatment sites is 0.88, signifying low species diversity compared to when the reference sites are included, which gives a higher diversity index of 0.95. The species

richness in all the eight treatment sites was 16 with species composition of 45, (Figure 7.5 and Table 7.2)

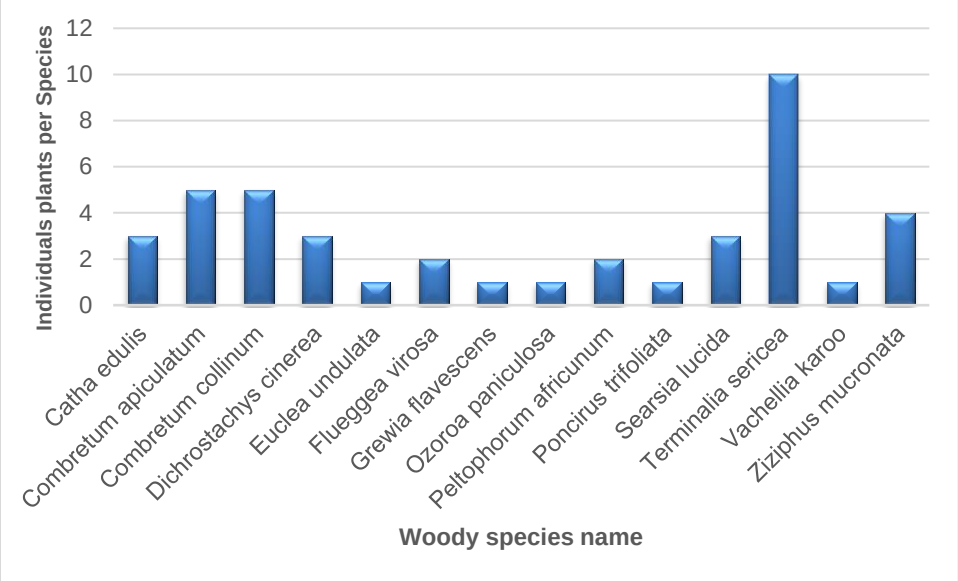

Figure 7.12: Woody Species composition and distribution in treatment sites in Nylsvley

Table 7.2: Woody plant species richness, abundance and diversity in treatment sites in Nylsvley

Species Name	No of Woody species/	Abundance %
Catha edulis	3	6,7
Combretum apiculatum	5	11,1
Combretun collinum	5	11,1
Dichrostachys cinerea	3	6,7
Diospyros dichrophylla	2	4,4
Dombeya rotundifolia	1	2,2
Euclea undulata	1	2,2
Flueggea virosa	2	4,4
Grewia flavescens	1	2,2
Ozoroa paniculosa	1	2,2
Peltophorum africunum	2	4,4
Poncirus trifoliata	1	2,2
Searsia lucida	3	6,7
Terminalia sericea	10	22,2
Vachellia karoo	1	2,2
Ziziphus mucronate	4	8,9
Composition	**45**	**100**
Species richness	**16**	
Diversity index	**0,88**	

Terminalia sericea species was the most abundant species in the sampled sites at 22.2%, followed by *Combretum apiculatum* and *Combretun collinum* species with 11.1% in woody species abundance. The rest of the species were below 10 to as low as below 5%. Appendices 9-17 show the identified species plotted in RStudio.

7.5.3 Statistical validation of woody species data

Identified woody species were grouped per site and explored to check how the sampled woody species data is distributed, statistically, among the different sites. Figure 7.6 shows the distribution of identified woody species per site. Site 8 had no woody species identified as it was bare ground. Reference sites, 9 and 10 have, 17 and 29 woody species, respectively, more than the other sites. Site 5 follows with 15 and site 7 with 12 woody plant species. The rest of the sites have 5 and below woody species with Site 2 having the least species of 2. Sites 1 to 7 in Figure 7.6 are treatment sites and 9 to 10 are reference/undisturbed sites. Site 8 has no woody species, hence, not recorded in the Figure.

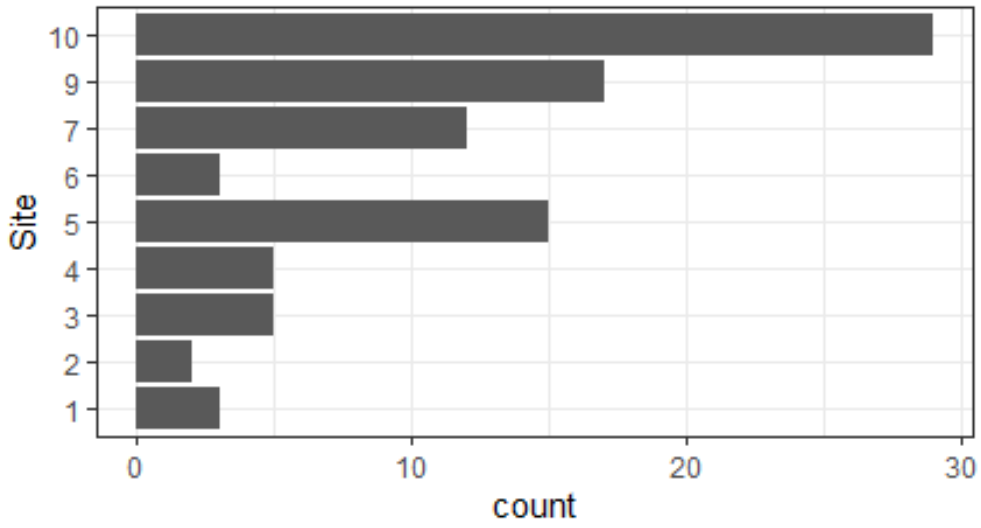

Figure 7.13: Woody species distribution grouped per site

The box plots in Figure 7.7 a, b and c show the woody species count data, richness and height differences in reference sites compared to treatment sites. In Figure 7.7, the box plots show that

reference sites have more woody species, which are higher in species richness and have taller trees. This has also been proved by the significance in ANOVA. Additional supplementary material, as shown in Appendices 9-18, indicates where box plots were plotted in RStudio.

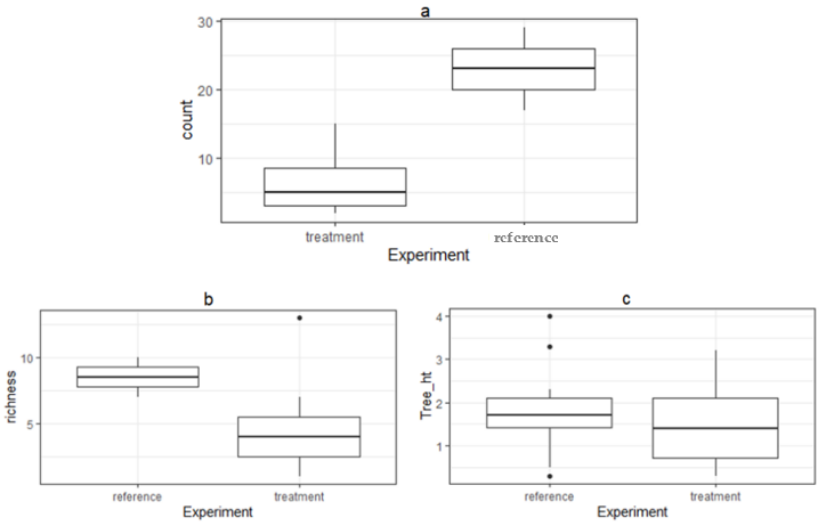

Figure 7.14: Box plots showing woody species data in treatment as compared to reference sites

Key: (a) species count (b) species richness (c) species height

Histograms were plotted to check woody species distribution, species richness and height differences in both treatment and reference sites as shown in Figure 7.8 and Appendices 9-19. The histograms for woody species count distribution and species richness were skewed to the left, not normally distributed and the data was non-parametrically distributed, hence, Poisson regression was used; the height data (c) was normally distributed. Mixed-effects model was used to account for the random effect, which is the variance introduced by each of the sampling sites as this is common in normally-distributed data.

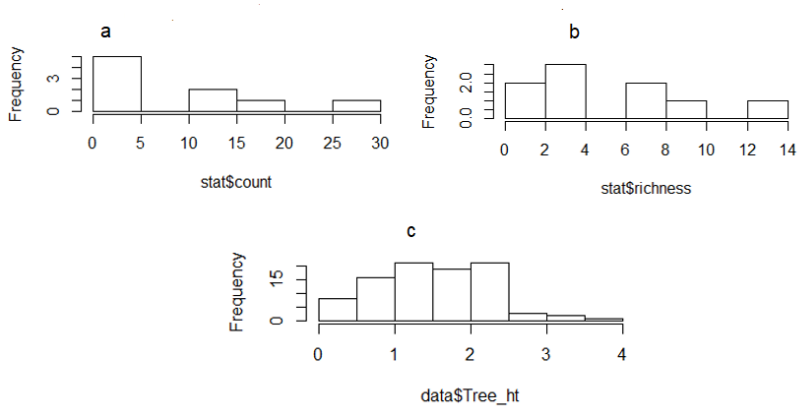

Figure 7.15: Species count data, richness and species height differences in reference versus treatment sites

An Analysis of Variance was run to determine the significance difference between woody species distribution, species richness and height differences in reference and treatment sites. The Analysis of Variance showed that there is a significant difference between treatment sites and disturbed/ reference sites at $p < 0.001$ for woody species distribution and height differences, whilst species richness is significant at $p < 0.05$, (See Appendices 9-20 for additional model results). The ANOVA results show that reference or disturbed plots have significantly more trees, higher species richness and taller woody species than the treatment plots.

7.5.4 Density of woody species in established treatment sites

The sampled area or each quadrant constituted 0.314 hectares, with 1 497 trees per hectare

identified. Table 7.3 shows woody species identified per site and the tree density per hectare. Reference sites had more woody species when converted to number of trees per hectare as they had 541 and 924 trees per hectare, for reference sites 9 and 10, respectively. These are then followed by treatment sites 5 and 7 with 478 and 382 trees per hectare, respectively. Site 2 has the least number of trees/hectare equivalent, with 64 species as shown in Table 7.3.

Table 7.3: Woody species identified per site and their density per hectare

Site	Woody species	Density of species/ha
1	3	96
2	2	64
3	5	159
4	5	159
5	15	478
6	3	96
7	12	382
8	0	0
9	17	541
10	29	924
Total Species	**91**	

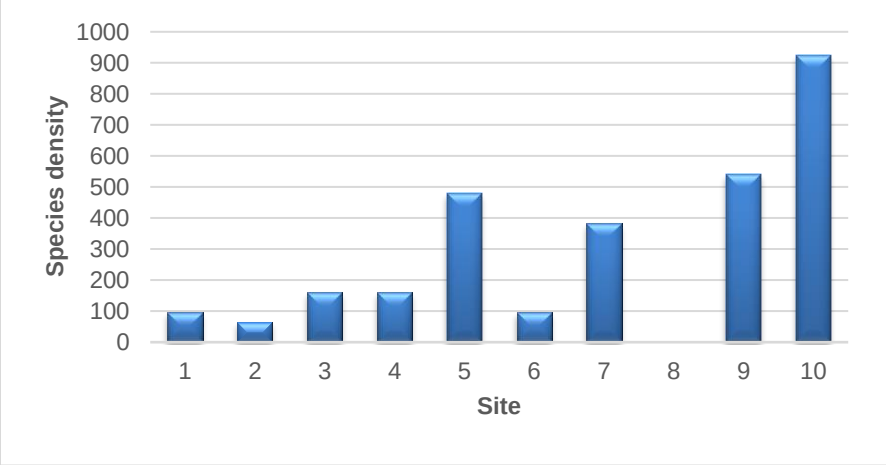

Figure 7.16: Density of trees identified per hectare at each site

7.5.5 Pattern of woody vegetation species distribution in experimental plots

Detrended Correspondence Analysis (DCA) based on experimental sites (1-10) distribution and available woody species was plotted and shown in Figure 7.10.

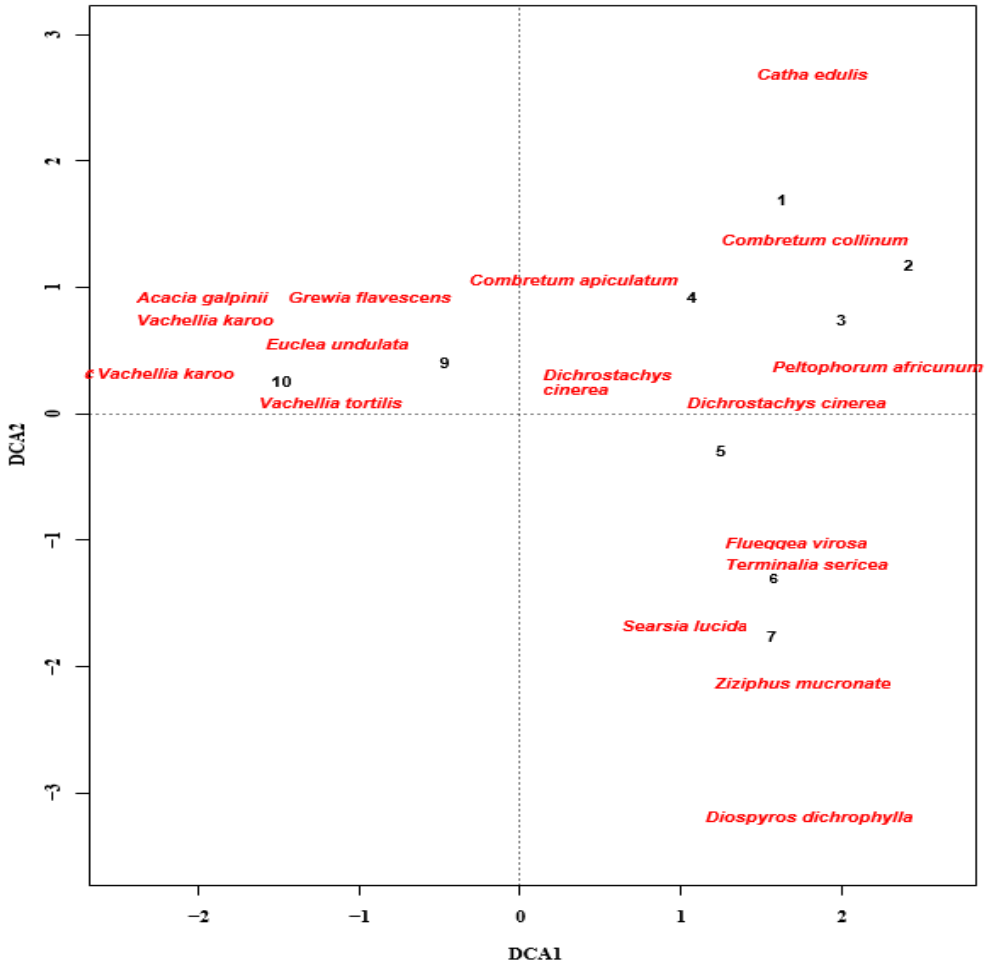

Figure 7.17: Detrended Correspondence Analysis ordination diagram based on species composition per each site and showing the separation of sites and species available.
Numbers 1-10 represent the established experimental sites in Nylsvley

Sites that are closer to each other were plotted closer together on the ordination diagram and these sites have similar woody plant species. Fig 7.10 shows sites grouped into 3 separate classes, sites 1, 2, 3 and 4, then sites 5, 6 and 7 and finally reference sites, 9 and 10. Sites with similar species composition were plotted closer together whilst those sites with dissimilar species composition were further apart from each other. Detrended Correspondence Analysis results support the site species composition locations. Sites 1-4 were close to each other with similar woody species or common woody species, which include *Catha edulis, Combretum apiculatum, Combretum collinu, Dichrostachys cinerea* and *Peltophorum africunum.* Sites 5-7 had *Flueggea virosa, Terminalia sericea, Searsia lucida, Diospyros dichrophylla, Ziziphus mucronate* as

common species and sites 9 and 10 had *Acacia galpinii, Vachellia karoo, Grewia flavescens, Euclea undulata* species among others, as shown in Figure 7.10.

7.6 Discussion

The chapter aimed at establishing permanent vegetation monitoring sites in Nylsvley. The sites are for long term vegetation management purposes to assist in monitoring regeneration of woody species within Nylsvley for better future veld management, as Nylsvley is used for eco-tourism, rearing and grazing by wildlife, among others. These activities continue to disturb natural vegetation recovery of the wetland from previous agriculture activities and continued browsing/ grazing by wildlife (Walker 1993). To initialize the monitoring process of natural vegetation regrowth in Nylsvley, a smaller pilot study site had to be surveyed first; this fell within the A61C-2 restoration site. Ten study sites, which included eight treatment and two undisturbed/ reference sites were identified and used for vegetation sample collection. A study by Trollope *et al.* (2013), used the Adapted Point Centred Quarter (APCQ) method in assessing veld condition of woody vegetation in thicket communities and African savanna. Their study revealed the use of a minimum of 10 quadrats as sufficient to reveal the amount of forage required for management and monitoring information on the amount of grass and woody species. Similarly, a study by Lawley *et al.* (2016) revealed that large numbers vegetation monitoring sites are compromised when data is being inventoried, due to costs associated with field data collection, hence, fewer study sites are ideal.

The monitoring sites form the basis for various other vegetation studies in restored sites in Nylsvley. Selecting and establishing monitoring sites is not a new idea in vegetation ecology as numerous studies have been conducted using long-term site monitoring data (Goldberg and Turner, 1986; Guo, 2004; Lawley *et al.*, 2013; Lawley *et al.*, 2016). The sites help with monitoring of regrowth of vegetation, especially, in semi-arid regions where vegetation takes long time to

recover after disturbances such as cultivation, as reported by Ruwanza and Mulaudzi (2018). The latter study focused on the recovery of vegetation in old fields in Lapalala wilderness in South Africa. Selected vegetation attributes are, thus, monitored in assessing vegetation regrowth (Lawley *et al.*, 2016), as is the case in this study, where attributes including species composition, richness, abundance and density were assessed and must be continuously assessed over time. Studies of vegetation dynamics in Kruger National Park along Limpopo and Levuvhu Rivers continue to exhibit new vegetation patterns due to rare events such as flooding (Pickett *et al.*, 2005). These authors also note that the vegetation patterns depend on when observations are initiated and for how long, making it necessary to continue vegetation monitoring of floodplains, such as Nylsvley.

The most identified woody species in the 10 study sites were *Combretum apiculatum, Terminalia sericea and Vachellia tortillis* represented by 13,2%, 11% and 11% of the total species, respectively. A study on tree layer composition encompassing 35 sampling plots in a different location within Nylsvley revealed that *Terminalia sericea* is among the dominant woody species in the area they studied (Mashile *et al.*, 2010). The same woody species is also dominating in this part of Nylsvley. Species richness of treatment sites is currently at 16 and this requires long periods of time; it takes about 30 years for sites under monitoring to have regrowth of woody species (Lu *et al.*, 2019).

Vegetation composition attributes which include species diversity or richness assisted in showing woody species differences in the established sites. For instance, sites with low identified woody species also have low density of woody species per hectare as shown in Table 7.3 and Figure 7.9. Areas surrounding the floodplain require vegetation monitoring as this would reduce long lasting impacts, such as sedimentation and habitat loss for species living within Nylsvley. If woody species are kept intact, biodiversity will also be maintained, however, the impacts felt on wetland

ecosystems come from far, as far as even the other catchment areas (Lake *et al.*, 2007; Kundu *et al.*, 2015).

Ecologists in environmental agencies are interested in understanding diversity of species, as it is an important factor for successful conservation of species. A stable ecosystem has diversity in its species (Goodman, 1975). The ecosystems with greater species diversity tend to be stable and healthy. The species should be fairly and evenly distributed in good-sized populations. To enhance management, protection or restoration of wetland areas, there must be a detailed comprehension of vegetation species including their composition, especially, if they border wetland ecosystems (Poff *et al.,* 1997). A study by Sundermann *et al.* (2011) concludes that when studying restoration success of wetland ecosystems, it is ideal to understand species pool of the immediate surroundings and their effect on the wetland ecosystem. As more woody species recover, it would mean less soil loss and more habitat for species living in the system. Natural regeneration of woody species must be monitored to assess success of vegetation growth in these restored semi-arid wetland areas, whose conditions have become worse during this period, as scientists have proved that the climate is changing and this affects global rainfall patterns; southern Africa is expected to receive less rainfall than before and consequently impacting negatively on woody species development (Intergovernmental Panel on Climate Change, 2007; Change, 2014b)

The study has also revealed in Table 7.3, that the more woody species per site, the more the species density per hectare. A study by Lawley *et al.* (2013), utilised 82 years of perenial recorded vegetation changes of four study quadrants within close proximity, to minimise differences from climatic impacts that affect species growth. Their study area was previously a grazing land which is similar to the current study area that has also been impacted by browsing/ overgrazing, construction of roads, in addition to cultivation.

The DCA revealed that sites with similar species composition are located closer to each other (Figure 7.10).

7.7 Conclusion

The chapter demonstrated the need to establish vegetation monitoring sites in a restored semi-arid wetland as key to monitor success of restoration efforts, through vegetation development for resource conservation. Biodiversity is threatened by vegetation removal, hence, the need to monitor woody species regeneration, overtime, for conservation purposes. The removal of vegetation has implications on habitat loss for species living in wetland areas; this leads to a general loss of biotic diversity.

In this study, only woody cover was used since the study aimed to establish initial vegetation monitoring sites and the woody cover is presumed to be representative of plant types, such as trees, shrubs or grasses. Woody vegetation, therefore, encompasses both short and tall vegetation, including trees and shrubs. The changes assessed through regeneration of vegetation overtime can also be useful when combined with satellite RS imagery to improve on accuracy of restoration assessments of natural vegetation development.

8. THESIS SUMMARY, RECOMMENDATIONS AND CONCLUSIONS

8.1 Introduction

The study was conducted in Nylsvley, Ramsar site of international importance and the Nyl River system, located in Waterberg District in Limpopo Province of South Africa. Nylsvley was selected because it is a Ramsar site with previous anthropogenic activities and restorations currently taking place in the wetland. This Chapter presents the main findings of the thesis developed from Chapters 4 to 7 in the context of climate change and rainfall vegetation relationship, spatio-temporal patterns in vegetation development as well as quantification of vegetation in restored sites. The chapter also provided an overview of the key study limitations, opportunities for future research avenues, together with the thesis' contribution to the body of knowledge. Finally, the general conclusion which summarized the study findings and recommendations to improve on the findings of the study are provided.

8.2 Main research findings

8.2.1 Rainfall variability across stations

The Mann-Kendall and Sen's slope estimator showed only one station had a significant increasing rainfall trend annually and seasonally at $p < 0.05$, whereas all the other stations showed insignificant trends in both rainfall seasons. Quantile regression showed that 50% and 62.5% of the stations had increasing annual and seasonal rainfall, respectively. Of the stations, 37.5% were statistically significant at $p < 0.05$, indicating increasing and decreasing rainfall trends. These rainfall trends show that rainfall at Nylsvley decreased between 1995 and 2003. The results underscore the impact of decadal rainfall patterns on wetland ecosystem change. The main causes of long-term rainfall variability across the southern Africa region and the continent at large are complex as they are influenced by ocean and atmospheric circulation. These include the El Nino southern oscillation (ENSO) cycle (Anyamba *et al.*, 2002) and the fluctuations in sea surface

temperature (SST) which has no relationship with the ENSO (Nicholson and Entekhabi, 1987). In addition, the human anthropogenic activities in the environment impact on land cover changes (Hulme *et al.*, 2001). Mazvimavi (2010) highlighted no changes over-time for rainfall in Zimbabwe, with semi-arid environment, and stated that global warming may cause changes in rainfall patterns, but the effects were not statistically significant. The latter author also stipulated that the southern Africa region is semi-arid to arid with inter-annual rainfall variability. The region, include Limpopo Province of South Africa, therefore, need to be vigilant to such decadal or inter-annual changes and be ready to respond to uncertainty raised by climate change and/or anthropogenic factors. The study showed no widespread evidence that rainfall in NRS had decreased or increased due to climate variations. The study based its evidence on results from the eight stations studied on annual and seasonal rainfall and showed no strong evidence that seasonal or annual rainfall has declined or increased since only three of the eight stations had statistically significant results. These results underscore the impact of decadal rainfall patterns on wetland ecosystem change (Hulme *et al.*, 2001).

8.2.2 Mean monthly rainfall and NDVI relationship results

The average summer season rainfall from nine different months of separate years, between 1984 and 2003, explains that there is a positive significant relationship between rainfall and NDVI in Nylsvley as evidenced by high correlation of 0.74 at $p < 0.02$ which is less than alpha 0.05. The regression, R^2 explains that 55% of the data fits well on the model as shown in Figure 4.6. Onema and Taigbenu (2009) highlight that correlation measures the strength of two variables in a linear relationship and in this study, the strength of NDVI and rainfall was measured by using rainfall and NDVI data for 9 years. Onema and Taigbenu (2009) also emphasized in their study that rainfall-NDVI relationship is linked, hence, they expected to see a trend in most of their data. This trend has also been shown in Nylsvley wetland indicating that, when restoration activities are

taking place in the wetland, management should be informed of the water challenges including flooding in the wetland, and the solutions needed for vegetation and other life forms' growth

8.2.3 Spatial land use/cover changes

The results show worsening of natural vegetation regeneration from 1984 to 2005 as bare ground and old field increased by over 19%. The period 2005 to 2016 saw the classes gaining about 7% in natural recovery of vegetation. This indicates the importance of wetland restoration, with evidence of vegetation recovery in a landscape facing a degradation trajectory. The decline of vegetation in 2005 was attributed to cultivation, which ended in 1996. Overall, the area covered by vegetation from the 1984 to 2016 period decreased, despite the increase of vegetation cover between the 2005 to 2016 period. The accuracy assessment for 2005 and 2016 images yielded an overall accuracy of 88.57% and 68.57% with Kappa coefficients of 0.8228 and 0.5145, respectively. As stipulated in Islam *et al.* (2018), Kappa statistics measure referenced and user-classified data. The Kappa values check accuracy of classified image as it considers all elements of the confusion matrix, yet accuracy assessment considers the correctly classified pixels (Yang and Lo, 2002; Van Vliet *et al.*, 2011). These results were similar to those obtained by Hudson *et al.* (2006), Koranteng *et al.* (2016), Zhao *et al.* (2017) who concluded that the range allows performance of further analysis and formulation of valid conclusions. The study reveals that the use of supervised classification for land use/cover classification in restored areas yielded positive results as it assisted in revealing land use/cover changes in the restored wetland. The accuracy assessment, Kappa statistics and other values are as shown in Tables 5.4 and 5.5. These findings would help decision-makers to improve management plans of the reserve and protect its rich biodiversity.

8.2.4 Evaluation of restoration activities in Nylsvley

To successfully evaluate a project, monitoring data must be available and without this data,

evaluation will not be possible. Evaluation is done at any level (planning, implementation or monitoring) during the restoration process (Tischew *et al.*, 2010) and it must be continuous (Kondolf and Micheli, 1995). This means that evaluation can be done at each of these phases rather than to wait for a post-project evaluation, hence it was necessary to evaluate the Nylsvley wetland project using the initial planning data from the projects' reports. These reports are mostly not made public for people to access the evaluation information, in some regions, but for South Africa, they are available online. Aradottir and Hagen (2013) stipulates that in most cases, evaluation results if published, are mostly grey literature, such as reports and not very accessible to the scientific field; Nylsvley is no exception as the reports are published as grey literature, however, the major findings are as follows:

- The study established that the project has several stakeholders involved in the restoration of Nylsvley and these actors work together for a successful restoration of the wetland. The field visits done by the researcher assisted in a better understanding of the restoration process in Nylsvley and this approach is supported by Nilsson *et al.* (2016), who note that some evaluation results can be obtained through field visits or via internet. A wealth of such information was indeed obtained through field visits to Nylsvley.
- Long-time project monitoring and evaluation has the danger of missing some important events that may occur during the implementation phase. For instance, during the site visits in Nylsvley, site A61C-01 was colonised by milkweed (*Gomphocarpus physocarpus)* barely five months after the demolition of one of the berms, as shown in Figure 6.4, where the wetland grass was suppressed. The milkweed plant species usually grows in wetlands, along roadsides, agricultural fields or disturbed areas (Woodson, 1954). Nilsson *et al.* (2016), also reveal the failure of long-term monitoring projects in Canada where native species were replaced by exotic species. Dalu *et al.* (2020a) indicated the distribution and abundance of the milkweed in Nylsvley; they also revealed that the weed has colonized

most parts of the wetland but they differ in abundance due to differences linked to soil properties of the surveyed sites. This is critical for management to know that sites respond to restoration actions differently, hence, sites should be monitored regularly to note down their responses.

- The initial monitored results of the three wetland sites for 2014 show identified impacts of hydrology, geomorphology and vegetation and their change score based on WET-health assessment (Kotze *et al.*, 2012).
- Photographs of the initial wetland status were also obtained through the document review.

8.2.5 Effectiveness of restoration efforts

In terms of hydrology, the wetland was previously impacted by grazing and cultivation within the valley bottom, as evidenced by the studies of Scholes and Walker (1993) and the topographical maps of 1965 and 1967 as shown in Figure. 6.5. The wetland ecological status was impacted in accordance with the initial monitoring data obtained on the wetland, using the WET-Health tool. Evaluation may not necessarily give satisfactory answers about the project as it tends to focus on evaluating structures rather than processes. Morsing *et al.* (2013) observed that in 13 completed restoration projects in Denmark those whose evaluation focused more on structures, did not show changes in the ecosystem processes. Measuring the structures is mostly a common way to evaluate success of restoration activities for direct quantification process, however, it is rather difficult to measure even if it is possible (Ruiz-Jaén and Aide, 2005). This clearly indicates that evaluation of projects, despite being complicated, must be done to try to measure restoration success. The ideas gathered from different evaluated projects can be combined and used to come up with better evaluation methods. As highlighted by Woolsey *et al.* (2007), failure to prove restoration success, risks projects losing public support resulting in low funding, as such projects are, generally, expensive. The following were however established:

- To improve flood attenuation, road strips with reno gabion structures were constructed across the wetland.
- To curb soil loss and degradation of the area, berms together with road strips have been constructed along most of the roads, thereby, closing some roads to reduce further soil loss into the floodplain.
- The natural hydrological functioning of the wetland was improved by destroying berms previously constructed to divert water from the stream and river.
- Local plant bio-diversity was improved by fencing off previously-degraded areas from grazers and old trees, although, berms were not removed (sites A61C-01 and A61C-03). These species indicate secondary species that have colonised the area before human impacts and should be kept as they may provide seed banks for future species.
- In as far as monitoring data is available for this study, formal evaluation process is not properly documented nor do results appear as pictures or some written documentation; these reports, therefore, do not demonstrate the success or measure the direct project changes due to restoration.

8.2.6 Composition of woody vegetation in established vegetation monitoring sites

The monitoring sites form the basis for various other vegetation studies in Nylsvley. Selection and establishing monitoring sites are not new ideas in vegetation ecology as numerous studies have been conducted using long-term site monitoring data, including studies by (Goldberg and Turner, 1986; Guo, 2004; Lawley *et al.*, 2013; Lawley *et al.*, 2016). The sites help with monitoring of regrowth of vegetation, especially, in semi-arid regions where vegetation takes a long time to recover after disturbances, such as cultivation as reported by Ruwanza and Mulaudzi (2018) in their study of vegetation recovery in old fields in Lapalala wilderness in South Africa. Furthermore, removal of vegetation cover in semi-arid regions is linked to alterations in the micro-climate which enhances shrub development over grasses as bare-soil areas increase; this allows for more

thermal energy to be stored in the soil causing increases in night land surface temperatures (Ravi *et al.*, 2010; Liu *et al.*, 2015; Marquart *et al.*, 2019). Selected vegetation attributes are thus monitored in assessing vegetation regrowth (Lawley *et al.*, 2016), as the case in this study where species composition, richness, abundance and density were assessed and will continuously be assessed. The following was established:

- The *Combretum apiculatum (22.2%), Terminalia sericea* (11.1%) *and Vachellia tortillis* (11.1%) are the most abundant woody species in the study sites, represented by above 11% of the total species.
- The Simpson's Diversity Index in the treatment sites is 0.88, signifying low species diversity compared to 0.95 when the reference sites are included.
- The species richness in treatment sites is 16 with species composition of 45.
- An Analysis of Variance showed that there is a significant difference between treatment and reference sites at $p < 0.001$ for woody species distribution and height differences, whilst species richness is significant at $p < 0.05$. The ANOVA results show that reference plots have significantly more trees, higher species richness and taller woody species than the treatment plots.
- Reference sites 9 and 10 have more woody species density per hectare of 541 and 924, respectively.
- The Detrended Correspondence Analysis revealed that sites with similar species composition are located closer to each other (Sites 1, 2, 3, 4 or 5, 6, 7, and 9, 10).

8.3 Limitations and recommendations for future research development

8.3.1 Limitations

- The most limiting factor in this research was lack of data
    - Lack of historic maps or aerial photographs that validate satellite imagery as noted by Griscom *et al.*, (2010) was found to be a major challenge in most developing

nations. As a result of lack of validation data for the 1984 Landsat image, accuracy assessment was not performed on this imagery.

- Unavailability of long-term rainfall data for Nylsvley station (records ended in 2003), meant that the NDVI-rainfall relationship could not be assessed beyond this period when utilising rainfall station data.

- There are various factors that contributed to and influenced the final land-cover change analysis (Chapters 4 and 5). These include, but however, are not limited to, environmental and climatic factors, such as climate and rainfall variability and various land uses, selected sensor/ imagery, availability of imagery, its quality (resolutions) and the structure or heterogeneous nature of the vegetation (Hill *et al.*, 2011; Whiteside *et al.*, 2011). To accurately assess land use/cover changes in heterogeneous environments of wetland ecosystems, needs a combination of satellite RS data and field measurements that are necessary to validate the model results (accuracy assessments) and assess distinct cover changes (vegetation clearance or development). The vegetation greenness (NDVI) derived from Landsat time series data analysis needs to be compared with long-term vegetation field measurements, such as tree density, structure and species composition. This will provide improved interpretation and quantification of vegetation change processes across the landscape using individual tree, shrub or herbaceous level scale. Such data are not available in many study areas and it is difficult to fully complement and utilise RS imagery, although, it is ideal in assessing land cover changes on the earth's surface. The field measurement results contribute to explaining the overall vegetation decrease in modelled landscapes as it would have been the case in Chapter 5 of this study. Long-term woody species monitoring data is an essential requirement for validating biophysical trend map.

8.3.2 Recommendations

The following recommendations can be considered for future research:

- The study recommends evaluation of the effects of anthropogenic activities on the availability of water and vegetation resources along the Nyl River system. This is because the ecological status of freshwater wetlands is also threatened by increased developments in upstream catchments further affecting the availability of water needed for vegetation growth in wetlands (Griscom *et al.*, 2010; Rowberry *et al.*, 2011; Kundu *et al.*, 2015)
- Assessing long-term trends such as shifts in vegetation phenology in response to climatic and environmental variables derived from satellite sensors, particularly land surface temperature and rainfall, rather than utilizing NDVI and rainfall only. A study by Chidumayo (2001) revealed that temporal dynamics of maximum and minimum temperature is also key in controlling woody vegetation phenology across southern Africa, thus, the fluctuating phenology of the different vegetation functional types, are the result of interacting environmental and climatic factors. This observation points to the requirement for utilizing both precipitation and temperature variables in assessing effects of vegetation development on Savannah ecosystems (Chidumayo, 2001).
- Vegetation-soil relationships in treatment and reference sites to be assessed for variation in vegetation composition in different sites and the effects of soil characteristics (soil depth, soil moisture, texture, and pH).
- To assess seed banks and soil physico-chemical properties in restored areas.
- Additional long-term vegetation monitoring sites to be established for continuous vegetation restoration assessments in all degraded areas of Nylsvley.
- Initial restoration monitoring data to be made available and made accessible to the public, including researchers (Database of all restoration findings).
- The rainfall variations and vegetation changes seen in this study require proper management and monitoring for sustainable wetland protection of this Ramsar site. This study also suggests that knowledge in changes of rainfall and NDVI patterns could be used in planning for effective utilisation of water resources throughout the Nyl River

system. The study showed some stations indicating decrease and others increase in rainfall trends, there is, therefore, a need to investigate the effects of anthropogenic changes, such as land use/cover changes, which affect the availability of water resources.

8.4 Main contributions to the field of research

The study anchors its foundation in ecological restoration framework with the main study contributions as stipulated below:

- The influence of historical rainfall on climate variabillty in the Nyl River system and the relationship between rainfall and NDVI of Nylsvley has been beneficial for management to understand rainfall variations of this area. The more the seasonal rainfall in Nylsvley, the more the vegetation grows.
- The findings of this study could help researchers to understand the seasonal and annual variability of rainfall over the study region and become a foundation for further studies.
- The thesis contributes to an understanding of the impacts of ecological restoration in a wetland ecosystem of international importance.
- Efforts to restore ecosystems have gained momentum over the past few years, but monitoring and evaluation of these restoration efforts have not been widely adopted (Food and Agriculture Organization *et al.*, 2021). The thesis will further shape the wetland restoration or rehabilitation discourse through evaluation, as the UN has declared 2021 - 2030, a decade of ecosystem restoration. To confirm the importance of restoration, the Food and Agriculture Oganization has recently introduced the new Framework for Ecosystem Restoration Monitoring (Food and Agriculture Organizatiom, 2020; Abhilash, 2021) that will help measure restoration efforts at various levels across key ecosystems and generate the data needed to drive private and public investments in restoration. This is in line with the UN Decade on Ecosystem Restoration, 2021-2030.

- The study thus provides methods such as GIS and RS which are ideal tools for monitoring vegetation cover change and the findings have informed on measures or strategies to understand the success of restoration efforts in wetlands. This extends the frontiers of knowledge through providing an understanding of natural changes of vegetation in space and time, a critical indicator of vegetation development and restoration success of Nylsvley.

Titles of publications in peer reviewed journals:

- *Rainfall Trend and Its Relationship with Normalized Difference Vegetation Index in a Restored Semi-Arid Wetland of South Africa*, (**Sustainability Journal).**
- *Spatial-temporal patterns of land use/cover change in a restored floodplain wetland ecosystem* (**Submitted to South African Journal of Geomatics).**

8.5 Overall conclusion

Vegetation cover plays a key role in keeping soil aggregate stability, as well as reducing and retaining surface water run-off. The reduction in vegetation cover exposes the land and increases risk to soil erosion, which leads to siltation of water ways, habitat loss and modification of ecological processes. The changes in land use and land cover do not necessarily imply degradation of the land's surface but the removal of vegetation cover implies shifting of land use patterns which impact on biodiversity, water availability and other processes (Riebsame *et al.*, 1994). The effects of animal grazing in freshwater wetlands in the Savannah wetland environments modify soil structure and chemistry as the animals practice selective grazing/ browsing of grasses and woody species. These factors impact the vegetation dynamics, especially, of woody species through the enhancement of seed dispersal and seedling establishment leading to woody species' development (Archer, 1994). Nylsvley comprises of the Savannah biome with heterogeneous vegetation species (grasses and woody species); the concern is understanding vegetation regeneration successes from previous human activities. The

study was guided by the DPSIR framework, where anthropogenic drivers (agriculture and tourism) and natural driver (rainfall variability) gave pressure and caused changes to the natural functioning of the wetland ecosystem. Vegetation loss leads to biodiversity loss of both plant and animals. This impacted on the biological state of the wetland environment leading to its deterioration. Ultimately the response to Nylsvley wetland challenges is seen through policy intervention that has allowed restoration and rehabilitation of this important Ramsar site.

This study initially addressed the historical rainfall trends in NRS and the rainfall-vegetation relationship to assess climate effects on Nylsvley vegetation growth. Nylsvley rainfall station consistently reported decreasing rainfall trends. This decrease in rainfall has negatively impacted on the floodplain wetland with implications for tourists intending to visit for bird viewing and other activities. Normalized Difference Vegetation Index as proxy for vegetation showed that as rainfall decreases or increases, NDVI followed suit which may suggest a combination of years of drought and effects of negative human activities, such as grazing, which is still active in Nylsvley.

Spatio-temporal changes of vegetation cover of the wetland were also assessed as they assisted in quantifying vegetation changes over time and to determine vegetation restoration benefits. The previous environmental changes due to overgrazing and cultivation in the study area before it was proclaimed a nature reserve, in conjunction with current eco-tourism activities aid, have further implications on land use changes. In nature reserves that are not easily accessible, RS data is ideal in assessing vegetation changes.

Aerial photographs and previous documents played a key role in providing wetland status before restoration, for evaluation purposes. Working for Wetlands' set objectives were evaluated against the restoration efforts to determine their effectiveness. The three modules of WET-Health, which are hydrology, geomorphology and vegetation provided the initial monitoring scores which were useful for successful evaluation of Nylsvley restoration efforts. Even though success is not a

straightforward and easy concept to measure, as there are many debates going on about what characterises a successful restoration.

The study established vegetation monitoring sites as key to monitor success of restoration efforts through vegetation development for resource conservation. Only woody cover was used in Chapter 7, since the study aimed to establish initial vegetation monitoring sites and the woody cover is assumed to be representative of plant types, such as trees, shrubs and grasses. The changes assessed through regeneration of vegetation overtime are presumed to be useful when combined with satellite RS imagery to improve on accuracy of restoration assessments. Biodiversity is threatened by vegetation removal, hence, the need to monitor woody species regeneration overtime for conservation purposes. The study concludes that change detection or regeneration of vegetation (vegetation greenness) in wetlands must be interpreted from both satellite imagery and long-term ecological field data to ensure accurate interpretation and promote effective monitoring of degraded areas. The long-term field data encompass the measurements of species composition, tree densities, and structure, to correctly interpret vegetation change processes across the landscape. Our research, thus, offers a starting point for addressing policy issues and mapping out future research efforts on landscape restoration.

There are multiple vegetation change processes that occur on the ground and demonstrate that the changes of vegetation measured using satellite RS imagery does not necessarily translate into woody species regeneration and reversal of degradation (Brandt *et al.*, 2016). The authors found that in real terms, this is accompanied by loss of diversity in species of both herbaceous cover and large tree species. Unpalatable grass and woody species tend to increase, thus vegetation changes identified using the Landsat imagery may suggest that non-original vegetation of the reserve was recovering and soil loss may still be occurring. Conservation through restoration programs is ideal, as measurable impact on vegetation cover changes in combination with RS imagery, although this needs to be strengthened. A study by De Cauwer *et al.* (2016) on

forest inventory revealed significant decreases in basal area together with mortality rates when utilising 40 years of recorded woody-species data. This long-term monitoring data has proved valuable in determining vegetation regeneration success in restored areas and in monitoring land-cover changes, but such data was not available for this research, making it necessary to have monitoring sites established in the reserve. The establishment of long-term monitoring sites in the reserve is a good starting point for future research and evaluation of vegetation development, as long-term monitoring data and RS change analysis may be interpreted together in future to provide improved analysis of land cover changes in the reserve.

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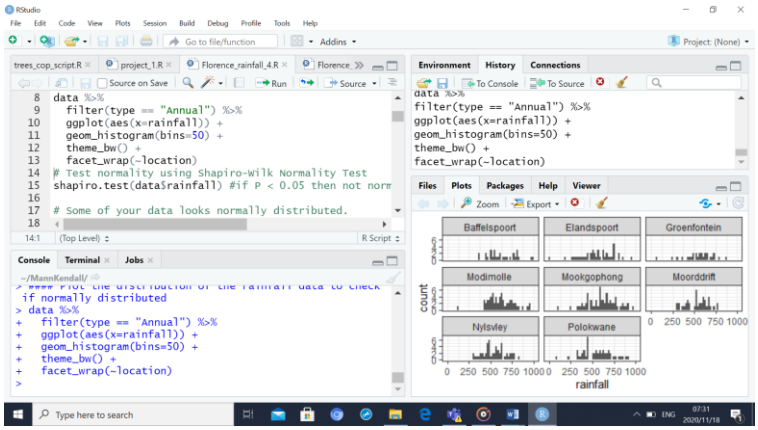
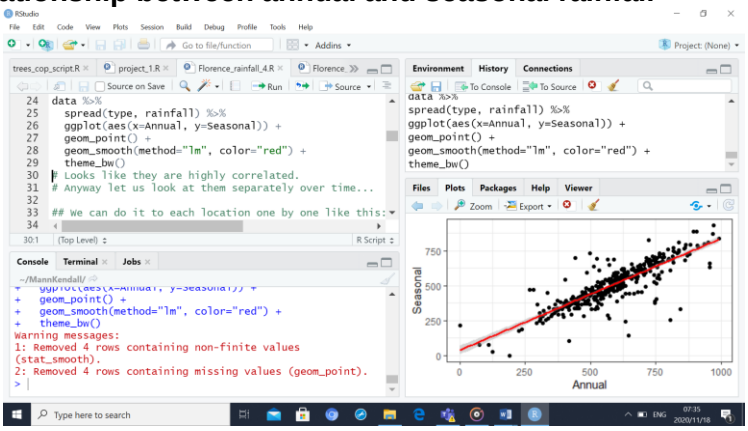
9. APPENDICES

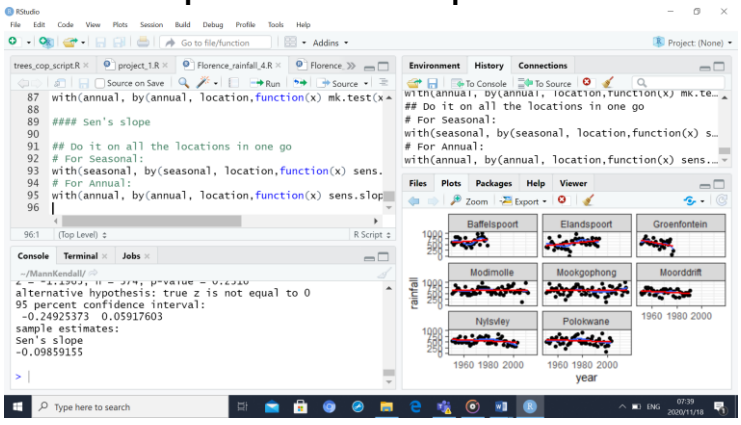
Appendix 9-1: Histogram for data distribution and Shapiro testing



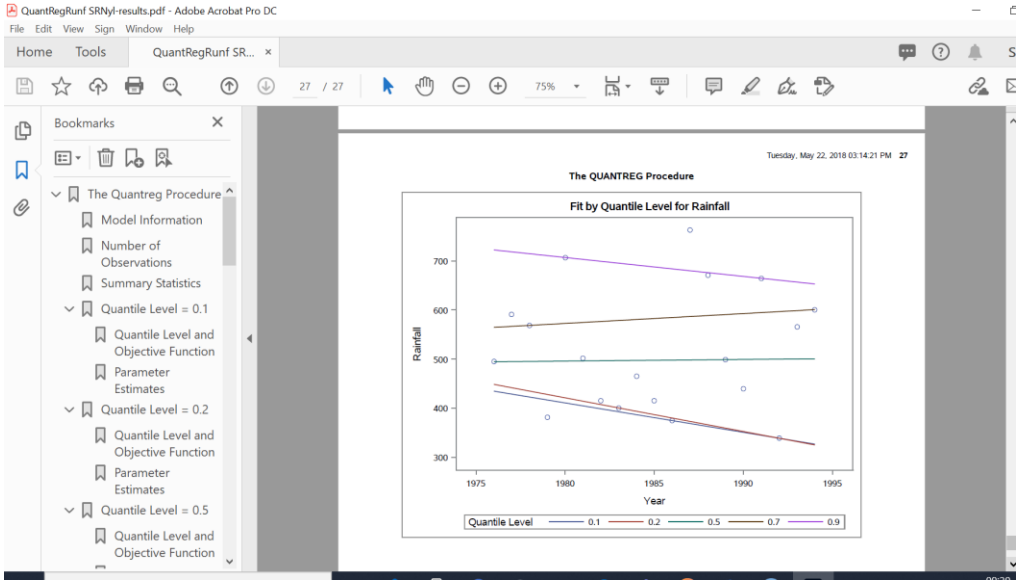
Appendix 9-2: Relationship between annual and seasonal rainfall



Appendix 9-3: Rainfall stations plots and Sen's slope results



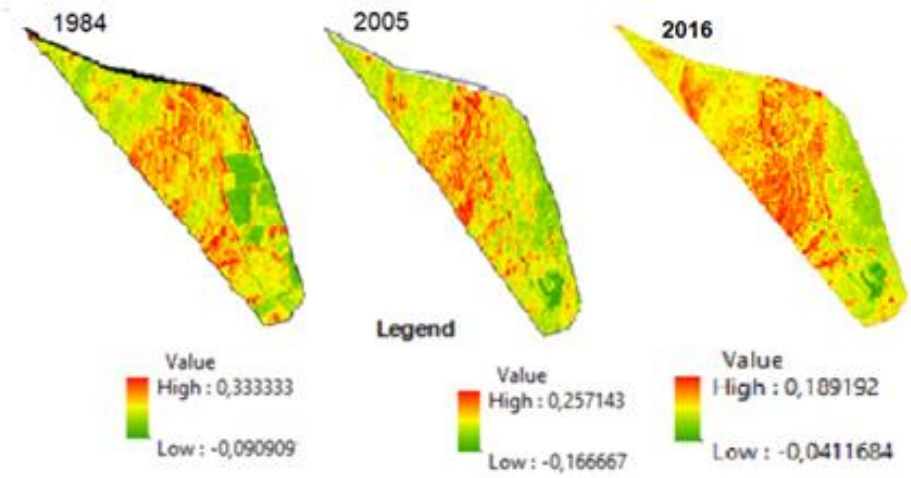
Appendix 9-4: Seasonal rainfall results of Nylsvley using quantile regression



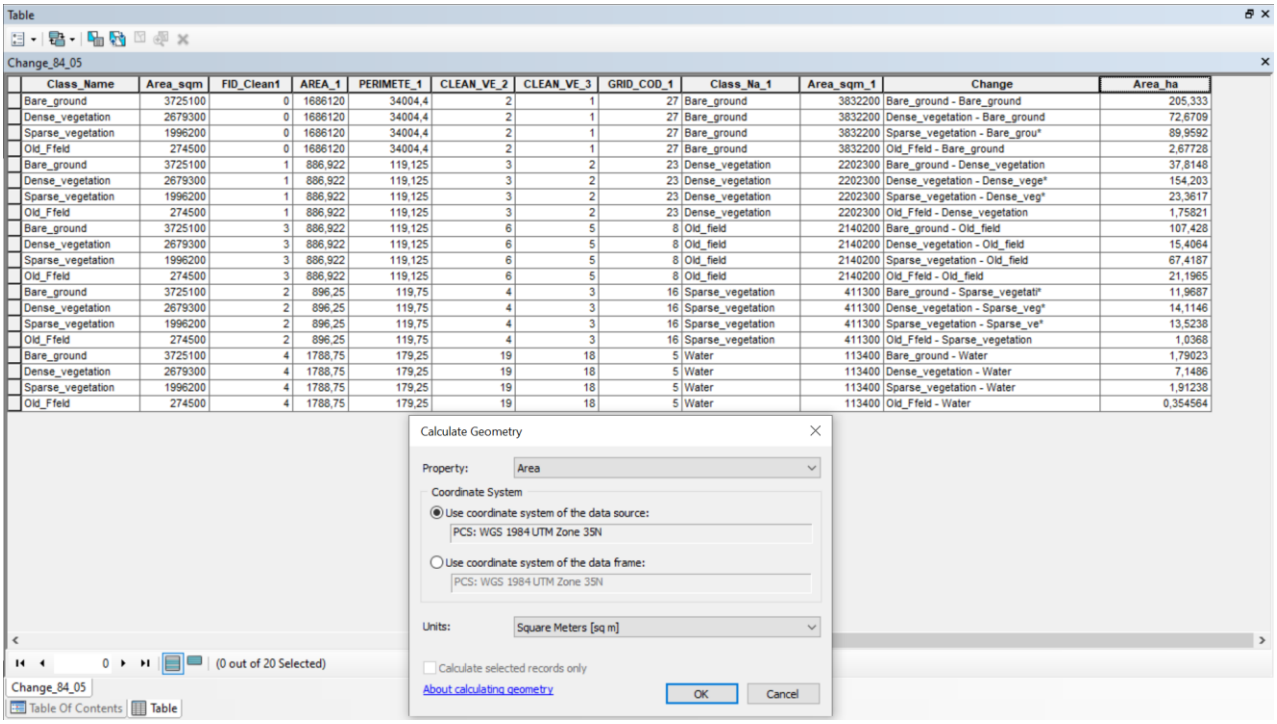
Appendix 9-5: Average Mean NDVI and Rainfall of Nylsvley

Month/Year	Mean NDVI	Mean Rainfall
Oct-84	0.19	27.9
Oct-86	0.07	24.1
Jan-91	0.31	139.3
Nov-93	0.36	82.2
Nov-95	0.20	50.9
Dec-97	0.33	95.3
Dec-98	0.30	65
Dec-99	0.26	109
Nov-03	0.18	11,4

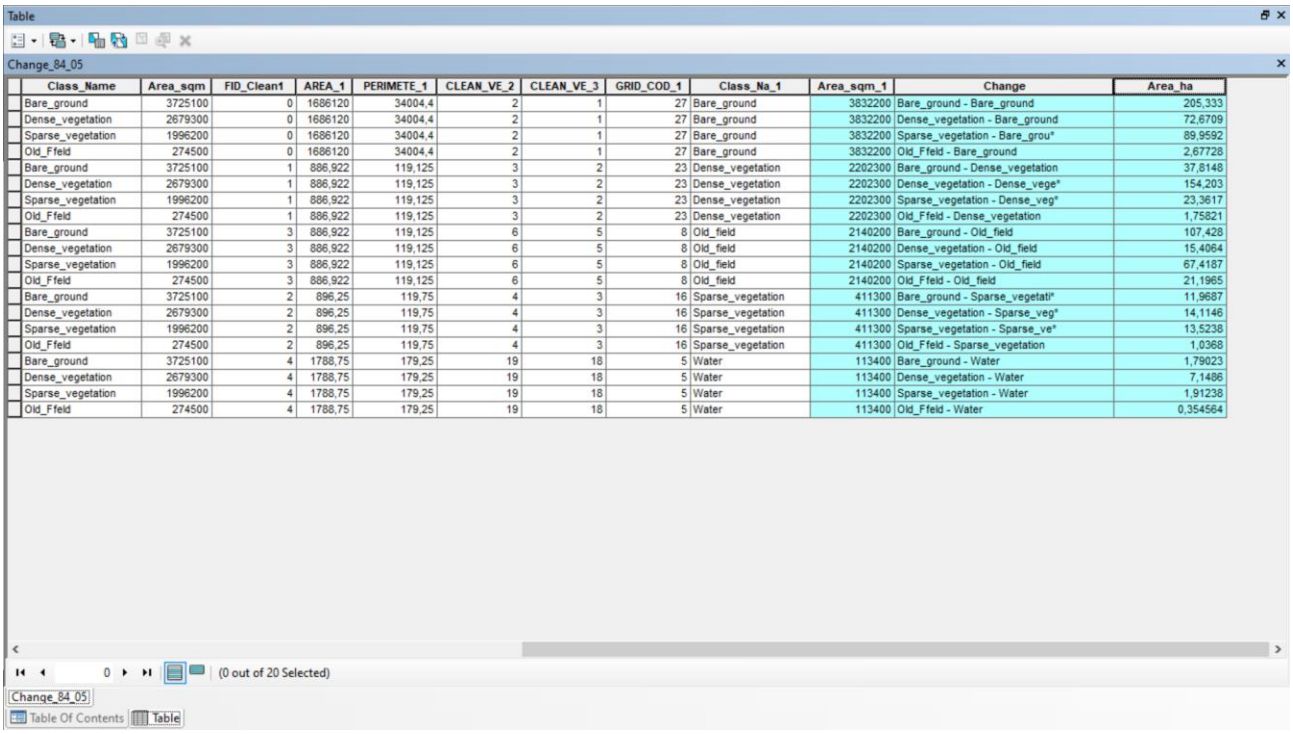
Appendix 9-6: NDVI Maps for 1984, 2005 and 2016



Appendix 9-7: A spatial analysis in ArcGIS



Appendix 9-8: Area calculation of land use/cover changes from ArcGIS calculations



Table

Change_84_05

Class_Name	Area_sqm	FID_Clean1	AREA_1	PERIMETE_1	CLEAN_VE_2	CLEAN_VE_3	GRID_COD_1	Class_Na_1	Area_sqm_1	Change	Area_ha
Bare_ground	3725100	0	1686120	34004,4	2	1	27	Bare_ground	3832200	Bare_ground - Bare_ground	205,333
Dense_vegetation	2679300	0	1686120	34004,4	2	1	27	Bare_ground	3832200	Dense_vegetation - Bare_ground	72,6709
Sparse_vegetation	1996200	0	1686120	34004,4	2	1	27	Bare_ground	3832200	Sparse_vegetation - Bare_grou*	89,9592
Old_Ffeld	274500	0	1686120	34004,4	2	1	27	Bare_ground	3832200	Old_Ffeld - Bare_ground	2,67728
Bare_ground	3725100	1	886,922	119,125	3	2	23	Dense_vegetation	2202300	Bare_ground - Dense_vegetation	37,8148
Dense_vegetation	2679300	1	886,922	119,125	3	2	23	Dense_vegetation	2202300	Dense_vegetation - Dense_vege*	154,203
Sparse_vegetation	1996200	1	886,922	119,125	3	2	23	Dense_vegetation	2202300	Sparse_vegetation - Dense_veg*	23,3617
Old_Ffeld	274500	1	886,922	119,125	3	2	23	Dense_vegetation	2202300	Old_Ffeld - Dense_vegetation	1,75821
Bare_ground	3725100	3	886,922	119,125	6	5	8	Old_field	2140200	Bare_ground - Old_field	107,428
Dense_vegetation	2679300	3	886,922	119,125	6	5	8	Old_field	2140200	Dense_vegetation - Old_field	15,4064
Sparse_vegetation	1996200	3	886,922	119,125	6	5	8	Old_field	2140200	Sparse_vegetation - Old_field	67,4187
Old_Ffeld	274500	3	886,922	119,125	6	5	8	Old_field	2140200	Old_Ffeld - Old_field	21,1965
Bare_ground	3725100	2	896,25	119,75	4	3	16	Sparse_vegetation	411300	Bare_ground - Sparse_vegetati*	11,9687
Dense_vegetation	2679300	2	896,25	119,75	4	3	16	Sparse_vegetation	411300	Dense_vegetation - Sparse_veg*	14,1146
Sparse_vegetation	1996200	2	896,25	119,75	4	3	16	Sparse_vegetation	411300	Sparse_vegetation - Sparse_ve*	13,5238
Old_Ffeld	274500	2	896,25	119,75	4	3	16	Sparse_vegetation	411300	Old_Ffeld - Sparse_vegetation	1,0368
Bare_ground	3725100	4	1788,75	179,25	19	18	5	Water	113400	Bare_ground - Water	1,79023
Dense_vegetation	2679300	4	1788,75	179,25	19	18	5	Water	113400	Dense_vegetation - Water	7,1486
Sparse_vegetation	1996200	4	1788,75	179,25	19	18	5	Water	113400	Sparse_vegetation - Water	1,91238
Old_Ffeld	274500	4	1788,75	179,25	19	18	5	Water	113400	Old_Ffeld - Water	0,354564

(0 out of 20 Selected)

Change_84_05

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Appendix 9-9: Land use/cover changes from 1984 to 2005

Changes in 1984 & 2005	Area in ha	Area changes %
Bare ground - Bare ground	205.3	24.1
Bare ground - Dense vegetation	37.8	4.4
Bare ground - Sparse vegetation	12.0	1.4
Bare ground - Old field	107.4	12.6
Dense vegetation - Bare ground	72.7	8.5
Dense vegetation - Dense veg.	154.2	18.1
Dense vegetation - Sparse veg.	14.1	1.7
Dense vegetation - Old field	15.4	1.8
Sparse vegetation - Bare ground	90.0	10.6
Sparse vegetation - Dense veg.	23.4	2.7
Sparse vegetation - Sparse veg.	13.5	1.6
Sparse vegetation - Old field	67.4	7.9
Old field - Old field	21.2	2.5

Appendix 9-10: Major land use/cover changes in 2005 and 2016 in hectares and percentages

Change in 2005 & 2016	Area change (ha)	Area change (%)
Bare ground - Bare ground	261.2	30.3
Bare ground - Dense vegetation	30.1	3.5
Bare ground - Old field	10.9	1.3
Bare ground - Sparse vegetation	75.6	8.8
Dense vegetation - Bare ground	46.6	5.4
Dense vegetation - Dense veg.	117.6	13.7
Dense vegetation - Old field	4.4	0.5
Dense vegetation - Sparse veg.	48.7	5.7
Sparse vegetation - Bare ground	25.9	3.0
Sparse vegetation - Dense veg.	5.1	0.6
Sparse vegetation - Old field	5.6	0.7
Sparse vegetation - Sparse veg.	5.6	0.7
Old field - Bare ground	66.3	7.7
Old field - Dense vegetation	31.0	3.6
Old field - Old field	85.3	9.9
Old field - Sparse vegetation	28.9	3.4

Appendix 9-11: Accuracy report for 2005 classified image

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : e:/restored_sites/subset_2005.img

User Name : flo
Date : Sat May 30 20:08:03 2020
ERROR MATRIX

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Water	0	0	0	---	---
Old_field	7	8	6	85.71%	75.00%
Sparse_Vegetati	3	2	2	66.67%	100.00%
Dense_Vegetatio	7	7	7	100.00%	100.00%
Bare_ground	18	18	16	88.89%	88.89%
Totals	35	35	31		

Overall Classification Accuracy = 88.57%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.8228

Appendix 9-12: Accuracy report for 2016 classified image

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : e:/restored_sites/subset_2016.img
User Name : flo
Date : Sat May 30 23:03:02 2020
ERROR MATRIX

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Water	0	0	0	---	---
Old_field	6	5	4	66.67%	80.00%
Bare_ground	17	20	15	88.24%	75.00%
Sparse_vegetati	5	4	2	40.00%	50.00%
Dense_Vegetatio	7	6	3	42.86%	50.00%
Totals	35	35	24		

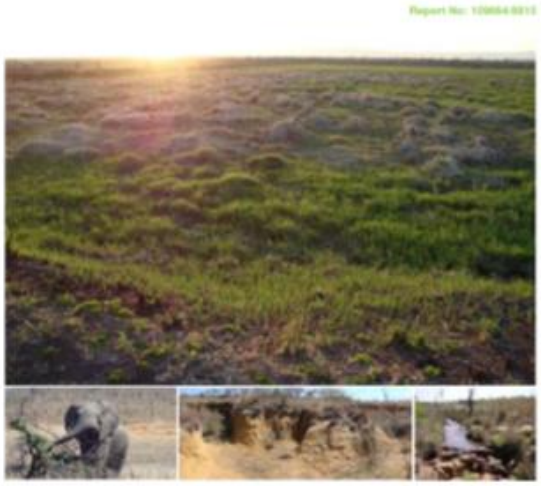
Overall Classification Accuracy = 68.57%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.5145

Appendix 9-13: Accessed reports for rehabilitation/restoration in Nylsvley and their references



REHABILITATION PLAN FOR THE WORKING FOR WETLANDS PROGRAMME, LIMPOPO

PROJECT: WATERBERG
A42D, A61B, A61C

APRIL 2014

REHABILITATION PLAN FOR THE WORKING FOR WETLANDS PROGRAMME, LIMPOPO PROVINCE

PROJECT: WATERBERG
A61C

MARCH 2016

This report is to be referred to in bibliographies as:

South African National Biodiversity Institute, South Africa. 2014. Rehabilitation Plan for the Waterberg Wetland Project, Limpopo: Planning Year 2014. Prepared by Franci Gresse and Bonnie Galloway, Aurecon South Africa (Pty) Ltd, as part of the planning phase for the Working for Wetlands Rehabilitation Programme. SANBI Report No.109664/8815.

This report is to be referred to in bibliographies as:

Working for Wetland Programme. 2016. Rehabilitation Plan for the Waterberg Wetland Project, Limpopo: Planning Year 2015/2016. Prepared by Franci Gresse, Aurecon South Africa (Pty) Ltd as part of the planning phase for the Working for Wetlands Rehabilitation Programme. Report No. 109664/10245.

Appendix 9-14: Plan of field activities from 10 to 12 July 2019 in Nylsvley

Prosed sites to be visited on the days. Since each site is unique and has its own challenges and characteristics, we can have a short briefing on each site. Things like aims, challenges if any etc.

Proposed field visit dates

Inbox

Florence Murungweni <fmmurungweni@gmail.com> Thu, May 30, 2019, 12:37 PM

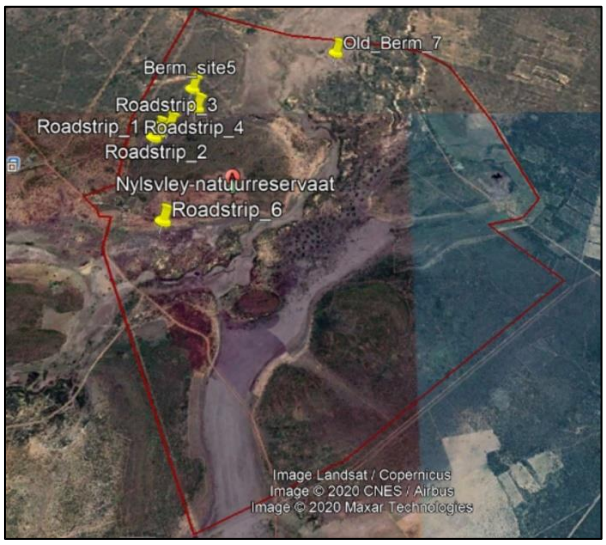
[redacted]

May I request for your permission to allow me visit rehabilitation sites in Waterberg District. I am available from 10-12 July 2019. Let me know your availability so that I start planning accordingly.

Kind Regards (Cand Sci. Nat)
Florence M Murungweni.

Date	Time	Activity
10 July 2019	14:00-17:00	Arrival and arrival
11 July 2019	08:00: to 1700	Site visit
12 July 2019	08:00	Departure

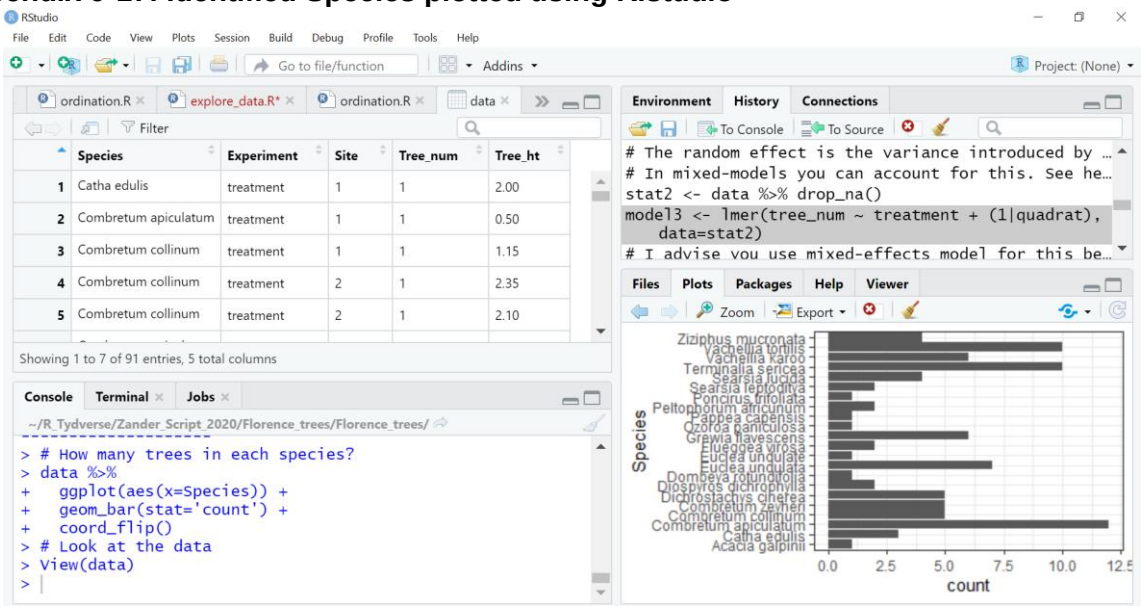
Appendix 9-15: Location of some restored sites in Nylsvley from google earth image



Appendix 9-16: Identified woody plants per species, their richness, abundance and diversity in the established restored 10 sites in Nylsvley including the reference sites

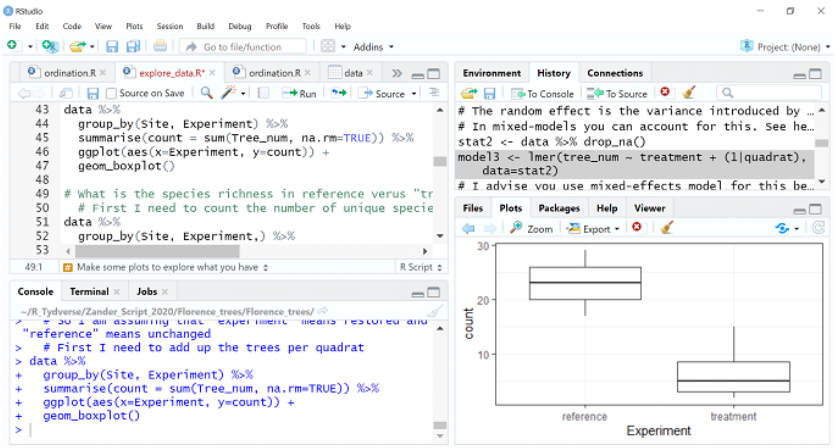
Species Name	No of woody species	Abundance %
Acacia galpinii	1	1,1
Catha edulis	3	3,3
Combretum apiculatum	12	13,2
Combretum collinum	4	4,4
Combretum zeyheri	5	5,5
Combretun collinum	1	1,1
Dichrostachys cinerea	5	5,5
Dombeya rotundifolia	3	3,3
Euclea undulata	8	8,8
Flueggea virosa	2	2,2
Grewia flavescens	6	6,6
Ozoroa paniculosa	1	1,1
Pappea capensis	1	1,1
Peltophorum africunum	2	2,2
Poncirus trifoliata	1	1,1
Rhus lucida	4	4,4
Searsia leptoditya	2	2,2
Terminalia sericea	10	11,0
Vachellia karoo	6	6,6
Vachellia tortilis	10	11,0
Ziziphus mucronate	4	4,4
Species Composition	**91**	**100**
Species richness	**21**	
Simpson's diversity index	**0,95**	

Appendix 9-17: Identified Species plotted using R.studio

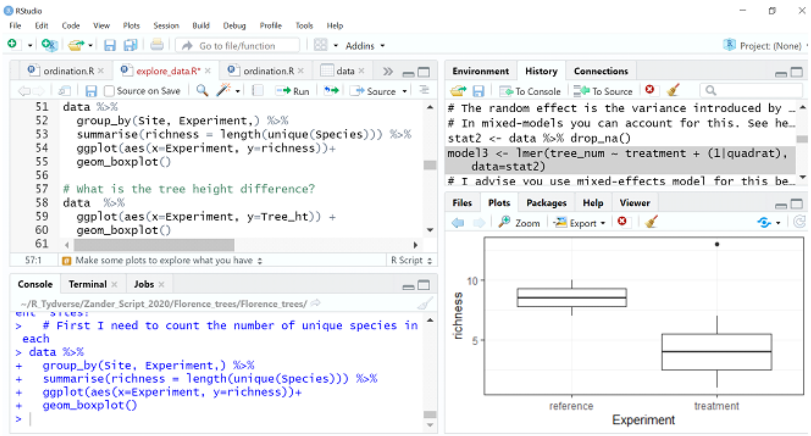


Appendix 9-18: Box plot of woody species count, richness, height differences in experimental sites using RStudio

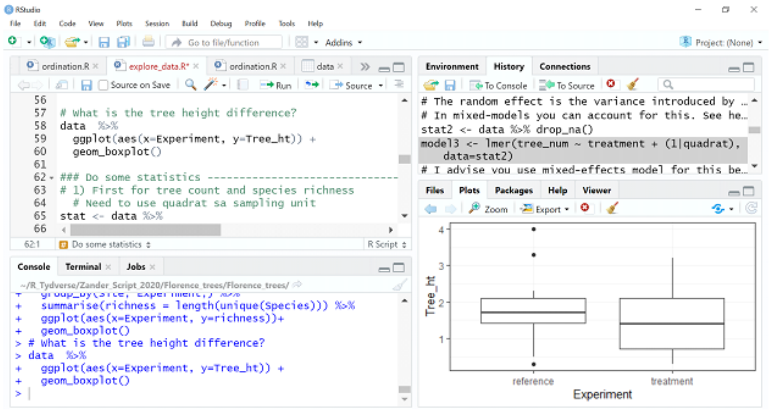
Box plot of woody species count of experimental sites using R.studio



Box plot of woody species richness in experimental sites using R.studio

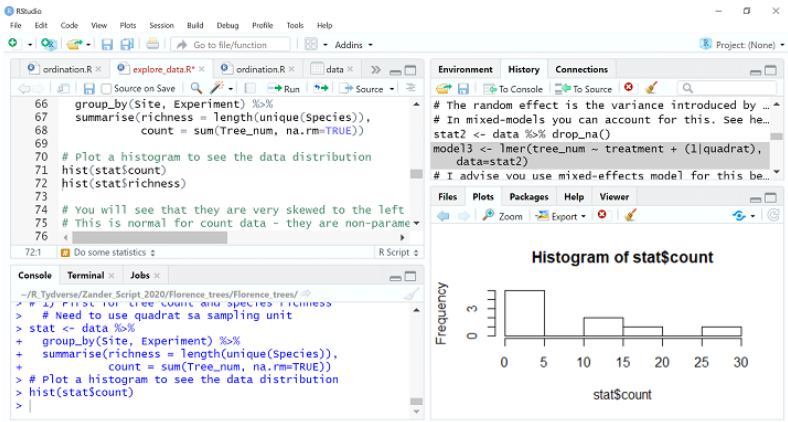


Box plot of species height differences in experimental sites using R.studio

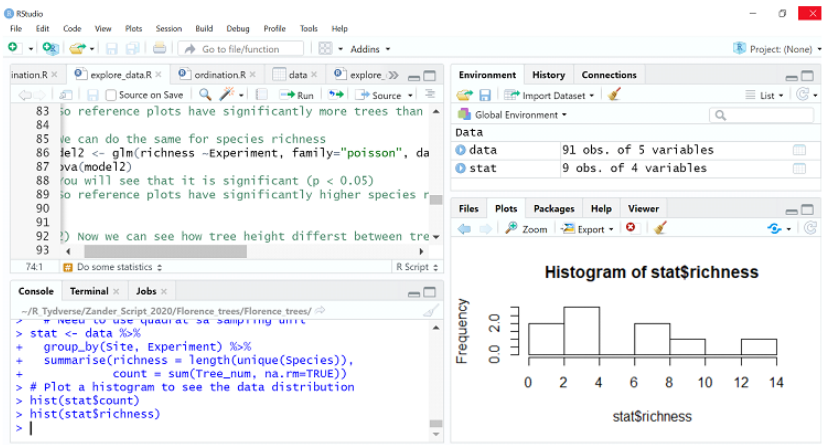


Appendix 9-19: Histogram of woody species count, richness and height in experimental sites using R. studio

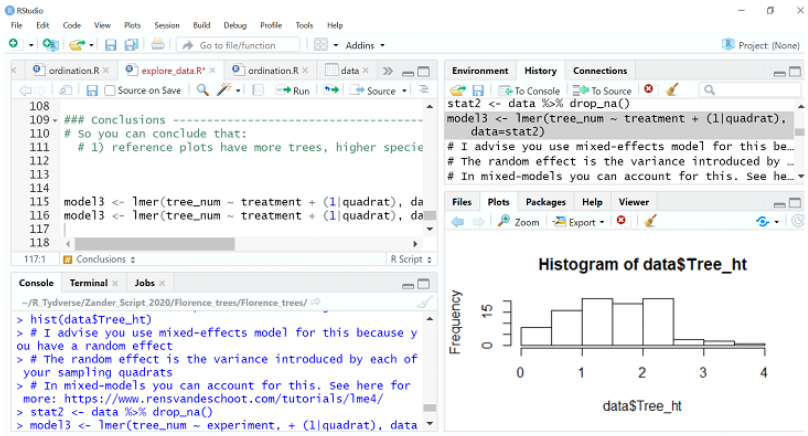
Historam of woody species count in experimental sites



Histogram of woody species richness in experimental sites.



Histogram of woody species height distribution in experimental sites



Appendix 9-20: Analysis of Variance results

```
# the data is skewed to the left
> # This is normal for count data - they are non-parametric
> # So there is need to use Poisson regression. Link for more: https://rcompanion.org/handboo
k/J_01.html
> # We use the glm() function which is for Generalized Linear Models
> model <- glm(count ~Experiment, family="poisson", data=stat)
```

It is significant at (p < 0.001)

```
# So reference sites have significantly more trees than the other sites
 # Now run an anova to see if there is a significant difference between Experiment
 s (reference vs treatment)
 > Anova(model)
 Analysis of Deviance Table (Type II tests)

 Response: count
           LR Chisq Df Pr(>Chisq)
 Experiment   34.852  1  3.558e-09 ***
 ---
 Signif. codes:
 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


 # I did the same for species richness
 model2 <- glm(richness ~Experiment, family="poisson", data=stat)
 Anova(model2)
 # You will see that it is significant (p < 0.05)
 # So reference plots have significantly higher species richness

 Anova(model2)
 Analysis of Deviance Table (Type II tests)

 Response: richness
           LR Chisq Df Pr(>Chisq)
 Experiment   3.3036  1    0.06913 .
 ---
 Signif. codes:
 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

 Tree_ht data


 # See if data meet assumptions of linear regression
 > hist(data$Tree_ht)
 # Data are normaly distributed (See histogram)

 Mixed-effects model is used for this because of a random effect
 > # The random effect is the variance introduced by each of the sampling quadrats
 /sites
 > # In mixed-models you can account for this. See here for more: https://www.rens
 vandeschoot.com/tutorials/lme4/

  summary(model)

  Call:
  glm(formula = count ~ Experiment, family = "poisson", data = stat)

  Deviance Residuals:
      Min       1Q   Median       3Q      Max
  -2.0461  -1.5114  -0.5865   1.2019   2.8768

  Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
  (Intercept)           3.1355     0.1474   21.27  < 2e-16
  Experimenttreatment  -1.2747     0.2097   -6.08  1.2e-09

  (Intercept)         ***
  Experimenttreatment ***
  ---
  Signif. codes:
  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

  (Dispersion parameter for poisson family taken to be 1)

      Null deviance: 59.575  on 8  degrees of freedom
  Residual deviance: 24.723  on 7  degrees of freedom
  AIC: 63.067

  Number of Fisher Scoring iterations: 5
```

Conclusions ----------
Therefore: reference plots have more trees, higher species richness, and taller trees relative to other plots