The use of remote sensing data for assessing water quality in wetlands within the Limpopo River Basin

UNIVERSITY of the WESTERN CAPE

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A thesis submitted in fulfilment of the requirements for the degree of Environmental and Water Science Magister Scientiae in the Department of Earth Sciences (Natural Sciences), University of the Western Cape.

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ABSTRACT

Wetlands are unique ecosystems that are acknowledged among the world's most productive and valuable ecosystems. They are recognized as being essential to sustainable development and human welfare due to their unique environmental and socio-economic value. These highly productive ecosystems provide functions such as recycling of nutrients, watershed protection and flood control as well as grazing resources. Wetlands provide the basis for human livelihoods in Africa through ecosystem services. However, these ecosystems are affected by internal and external factors within and outside their catchments, hence the importance of monitoring those changes around these wetlands. The aim of this study was to identify the major land use and land cover changes (LULC) from two selected wetlands (i.e. Makuleke and Nyslvei) and their impacts on water quality within the Limpopo Transboundary River Basin, South Africa. To achieve this aim, firstly the study assessed the impacts of LULC changes on these two wetlands between 2014 and 2018. Multi-date Landsat series data were used to map and estimate the rate of LULC changes in Makuleke and Nylsvlei wetland ecosystems during the study period. The results obtained showed that the spatial extent of Makuleke declined by 2% between 2014 and 2018, whereas the Nylsvlei wetland decreased by 3%. Some of the noticeable changes were that the coverage of natural vegetation tends to increase during the wet seasons. Secondly, Chlorophyll-*a* was predicted and mapped for Makuleke and Nysvlei between September 2018 and June 2019. Moderate resolution Landsat 8 images and in-situ field measurements were used to estimate and map chlorophyll-*a* concentrations from these two wetlands. Landsat-derived chlorophyll-*a* concentrations were validated using field-derived chlorophyll-*a* measurements. The results showed a variation of chl-*a* concentration in these two wetlands, with Makuleke wetlands concentrations ranging from 0 to 1.15 µg/L whereas for Nylsvlei wetland the ranges varied between 0 and 1.42µg/L. The finding of this study can be used in enforcing of wetland legislation and LULC management practices and highlights the relevance of remotely sensed data in assessing and routine monitoring wetland water quality.

Keywords: Chlorophyll-*a*; Land cover dynamics; Protected wetlands; Remote Sensing; Spatial characterization; Southern African Transfrontier River Basin; Water quality status

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PREFACE

This research study was conducted in the Department of Earth Sciences, Faculty of Natural Sciences, University of the Western Cape in South Africa from February 2019 to November 2020 under the supervision of Professor Timothy Dube and Professor Dominic Mazvimavi.

Full name: Tatenda Dzurume Signature: Dzurume Date: March 2021

As the candidate's supervisor, I certify the above-mentioned statement and have approved this thesis for submission.

Full name: Prof. Timothy Dube Signature: Date: March 2021

Full name: Prof. Dominic Mazvimavi Signature: Date: March 2021

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DECLARATION

I declare that the thesis entitled "**The use of remote sensing data for assessing water quality in wetlands within the Limpopo River Basin"** is my own work that it has not been submitted before for any degree or examination in any other university. All the sources I have used or quoted have been indicated and acknowledged by means of complete references.

Full name: Tatenda Dzurume Signature: Date: March 2021

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MANUSCRIPTS

The following manuscripts have been submitted and are still under review in international peer-reviewed journals. The manuscripts have also been presented in two conferences. The co-authors played a major role in reviewing and improving the manuscript with me being the main author.

1. **Dzurume, T.,** Dube, T., Thamaga, H., Shoko, C and Mazvimavi, D. Use of multispectral satellite data to assess impacts of land management practices on wetlands in the Limpopo Transfrontier River Basin, South Africa (GIScience & Remote Sensing_TGRS-S-20-00343).
2. **Dzurume, T.,** Dube, T and Shoko, C Remote sensed data in estimating chlorophyll-a concentration in wetlands located in the Limpopo Transboundary River Basin, South Africa (Geocarto International_200979632).

The research was presented at the following online conferences:

1. 21st WaterNet/WARFSA/GWPSA Symposium on the 28th of October 2020, South Africa
2. the Geo-Information Society of South Africa WC AGM on the 12th of November 2020, South Africa

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DEDICATION

To my family (Dzurume & Nhoro Families)

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Isaiah 41 vs 10 *"Do not be afraid, for I am with you. Do not be anxious, for I am your God. I will fortify you, yes, I will help you, I will really hold on to you with my right hand of righteousness."*

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CHAPTER ONE

1.0 Introduction

Wetlands in Sub-Saharan Africa support the livelihoods of many poor communities through the provision of critical ecosystems goods and services, including food (Rebelo et al.,2010). Due to their diversity and high productivity, wetlands are used for harvesting plants used to make mats and baskets among other products (Marambanyika 2015, Kabii 2017, Ondiek et al., 2020). The presence of wetlands in the southern countries such as Botswana creates employment and this creates income for the local communities in return. For example, over 600 people can be employed in the tourist camps in the Okavango Delta alone (Collins and DWAF, 2006). However, their productive is influence by factors within and around their respective catchments. Wetlands are influenced by changes in the composition of land uses due to human activities within their catchments (Haidary et al. 2013). Since most of the services provided by wetland ecosystems have not been traded in the economic market, the value of wetland ecosystems continues to be neglected or underestimated by stakeholders, government, and public and as a results wetlands are increasingly facing degradation (Xu et al. 2019). Numerous studies indicate that the loss and degradation of wetlands have been increasing in the past decades (Yang et al. 2018). In sub-Saharan Africa, certain policies and practices have led to the conversion of wetlands to farmlands for instance agricultural policies have been the main culprit with most policies and practise aimed to drive economic growth and increase food security. However, wetland conversion continues informally, with these systems being used during the dry season for the production of sugarcane, groundnut, vegetables, and fruits, as well as for grazing livestock in western, eastern and southern Africa (Uwimana et al. 2017).

Land use and land cover changes are being recognized as the main factor affecting wetland health (Rashid and Aneaus, 2019). Protecting these resources while maintaining or enhancing the economic and social benefits from their use is a present day challenge. There is therefore a need to understand the pattern and trends of LULC changes on the local, regional and global scales and associated impacts on wetlands (Manandhar et al., 2009). Human activities can influence ecological, environmental integrity and affect natural ecosystems by transforming the structure and pattern of land use and land cover (Zhang et al., 2019). For example, over the last years, there have been drastic land-use changes throughout Israel, previously grazed areas are being converted to irrigated or rain-fed agriculture (Rozenstein and Karnieli, 2011). A land cover

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change assessment that was carried out over a period 10 years (1995–2005) in South Africa showed an increase of 1.2% in transformed land (for example forestry, urban, mining and plantation forestry) and a decrease in cultivated land by 0.5% (Namugize et al., 2018). Some of the main anthropogenic drivers of land use and land cover changes are the over-exploitation of agricultural lands the conversion of natural vegetation to commercial forestry or pasture land and rapid urbanisation (Namugize et al., 2018) and an increase in population growth (Maimaitijiang et al. 2015).

Water quality deterioration is one of the major issues currently faced by sub-Saharan Africa (Dube et al., 2015). Eutrophication is a major cause of excessive aquatic plant production and blooms of harmful algae, impairing water quality (Gönülal and Aslan 2019). Water quality degradation poses a threat to human and aquatic life, which raises serious concerns for the future of water resources (Dube et al. 2015). The influence of land use on water quality has been a concern since the 1970s (Ding et al. 2016). LULC changes also may increase the transference of nutrients to water bodies. For instance, water quality around the globe is degrading primarily due to intense agricultural activities associated with rapid urbanization (Giri and Qiu, 2016).

Understanding the relationships between land use and water quality is of important for wetland management and conservation. Many research studies investigating the linkages between LULC and water quality have concluded that significant relationships exist between land use and water quality parameters at a catchment level (Haidary et al. 2013, Ding et al. 2016, Giri and Qiu 2016, Namugize et al., 2018, Zhang et al. 2019). These studies, concluded that LULC changes have numerous negative impacts on the water quality of a watercourse, as they lead to both increases and declines in the concentration of water quality parameters.

Remote sensing provides a valuable primary source of spatially and temporally explicit information necessary for wetland monitoring and management. Multi-spectral satellite imagery are important resources for obtaining LULC information (Zhang, et al., 2019, Manandhar et al., 2009). Aerial and Landsat satellite images are also frequently used to evaluate land cover distribution and to update existing geospatial features (Rwanga and Ndambuki, 2017). Several studies have identified the potential of satellite remote sensing data and techniques for mapping different types of wetlands at different spatial scales (Ritchie and Das 2015, Sinha et al., 2017). Satellite remote sensing has been used far back as 40 years back to monitor inland water quality inland (Masocha et al. 2018). Remote sensing offers relatively cheap, repetitive and quantitative

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methods to monitor water quality and remote datasets such as Landsat, MODIS and Sentinel-2 provide both spatial and temporal datasets for water quality monitoring. This work therefore seeks to estimate chl-a concentrations and associated dynamics in two wetland systems located in the Limpopo Transfrontier River Basin, Southern Africa.

1.1 Problem Statement

Most of the recent studies done in the LBR have mainly focused on climate such as the studies done by Mosase and Ahiablame (2018) and (Mosase et al., (2019) therefore there is a need to understand LULC changes that are affecting wetlands water quality. Evidence of limited understanding of wetland conditions and their function in the ecosystem particularly in data poor regions and this has led to poor public and national perception of wetlands and the degradation of wetlands (Nhamo et al., 2017).Wetlands are globally amongst the most threatened ecosystems despite their value and importance, especially from the effects of agriculture and water management among other factors (Rebelo et al., 2010). Most people in rural areas of Sub-Saharan Africa depend on wetlands for domestic, agricultural and other uses. Hence, it is of high importance that land use and land cover changes as well as water quality and possible source of contamination are established and monitored. In order to understand the extent at which the water quality is degrading it is of importance to know the degree or extend in which the land use and land cover (LULC) changes are likely to influence these wetlands and as a result affect their water quality. The understanding of the relationship between landscape characteristics and water quality is of great importance in improving water contamination prediction in wetlands that are situated in semi-arid environments and for providing guidelines for catchment land use planning. There is therefore a need to quantify the effect of different land use and land cover changes on water quality to improve water resource management on a regional scale even in cases where wetlands might be considered protected.

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1.2 Aim

To evaluate the impacts of land use and land cover on the water quality of wetlands within the Limpopo Transboundary River Basin using remotely sensed data.

1.3 Objectives

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1. To evaluate the impacts of land use and land cover (LULC) changes on two wetland systems (Makuleke and Nylsvlei Nature Reserve) in the Limpopo Transfrontier River Basin (LTRB) in South Africa between 2014 and 2018.

2. To estimate Chlorophyll-*a* concentrations (water quality) and associated dynamics in two tropical wetland systems (Makuleke and Nylsvlei) located in the Limpopo Transboundary River Basin, South Africa.

1.4 Chapter outline

***Chapter 1: Introduction**:* This chapter provides an overall overview about the background of the research conducted on the subject. It also presents research questions, as well as outlines the main aim and objectives of the study.

***Chapter 2: Study area and the two selected wetlands**:* This chapter provides a detailed description of the study area (two wetlands).

***Chapter 3: Objective one**:* The chapter highlights the impacts of land use and land cover (LULC) changes on two wetland systems (Makuleke and Nylsvlei Nature Reserve) in the Limpopo Transfrontier River Basin (LTRB) in South Africa between 2014 and 2018.

***Chapter 4: Objective two**:* This chapter assess and map chlorophyll-*a* concentration changes in Makuleke and Nylsvlei wetland during the 2018-2019 period and highlight some of the factors that might be contributing to chlorophyll changes in these wetlands.

Chapter 5: Synthesis: This chapter provides a detailed synthesis of the main findings, the major conclusions, recommendations and limitations/challenges drawn from the study.

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CHAPTER TWO

Selected Study Area

2.1 Limpopo Transboundary River Basin

The Limpopo Transboundary River Basin (LTRB) is one of the largest catchment areas in Southern Africa and the basin has a mean altitude of 840 m which is the level above sea level, covering approximately 412 000 km^2 (Figure 2.1) (Sawunyama et al., 2006, Mosase et al., 2019). LTRB is located in the eastern part of Southern Africa approximately between 20°S 26°S and 25°E 35°E at 250 to 2 300m above mean sea level. The basin is shared among four countries namely: Botswana, Mozambique, South Africa and Zimbabwe (Gebre and Getahun, 2016) and the basin has twenty-seven (27) major watersheds (Mosase and Ahiablame, 2018). Limpopo River is the main river in the basin; it stretches over 1 800km, starting in South Africa and flowing north where it creates the South Africa-Botswana border, then east to form the South Africa-Zimbabwe border, and Southeast through Mozambique before ending in the Indian Ocean (Mosase, Ahiablame, and Srinivasan 2019).

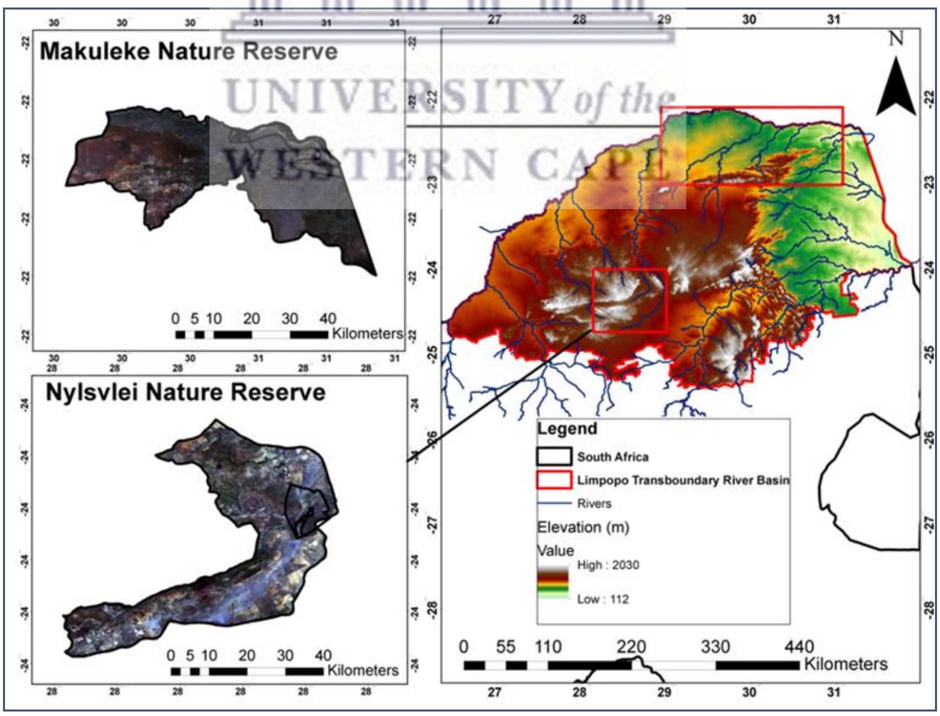

Figure 2. 1: The boundaries of Limpopo Transboundary River Basin and the selected wetlands

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2.1.1 Population growth

The LTRB is the second most populated basin in the Southern African Development Community (SADC) region after the Orange River Basin, which has more than 19 million people. The LRB is home to nearly 17 million people, consisting of 69%, 22%, 10%, and 7% of Botswana, South Africa, Zimbabwe, and Mozambique's population, respectively. The population in the LRB is projected to be 23 million by 2040 (Mosase et al., 2019). In South Africa, Limpopo Province has experienced growth in its population from 5 million in 2002 to 5.8 million in 2017. Limpopo is the 5th largest province in the country in terms of population (StatsSA 2018) and the basin supports a large rural population which relies on rain fed agriculture (Kahinda et al., 2016).

2.1.2 Topography and Geology

The topography of the province is very diverse ranging from bushveld to majestic mountains rich in indigenous forests and unspoilt savanna wilderness. The topography is divided into three distinctive regions which define the climate and vegetation of the province. These include Lowveld region (arid and semiarid),Middle-veld region (semiarid region) and Escarpment region (sub-humid climate with rainfall of over 700 mm per annum) (Cai et al. 2016). However, the topography of LTRB is generally flat to rolling, with the Waterberg on the south and the Soutpansberg in the northeast as the main topographic feature. Sedimentary rocks mostly underline the southern and western parts of the catchment whereas the metamorphic and igneous rocks are found in the northern and eastern part of the Limpopo Transboundary River Basin (LTRB). There are some exception of some alluvium deposits and dolomitise near Mokopane and Thabazimbi these formations are mostly not of high-water bearing capacity. Grasslands and sparse bushveld shrubbery and trees cover most of the terrain. Soils in the LRB consist of moderately deep sandy to sandy-clay loam with deep layers of wind-blown Kalahari sand in the western part of the basin, and sandy soils favourable to hardwood timber production in the east (Mosase et al, 2019).

2.1.3 Climate

The LTRB falls under semi-arid climate regions (Mosase and Ahiablame, 2018). The climate is temperate and semi-arid in the south to extremely arid in the north. The mean annual rainfall ranges from 300mm to 700mm with the potential evaporation as well in excess of the rainfall.

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Rainfall is seasonal with most rainfall occurring in the summer with the thunderstorm. The basin generally experiences short wet seasons with 95 percent occurring between October and April (Kulawardhana et al. 2006). Most of the rainfall in the Limpopo Province occurs during summer (October to March), averaging 500 mm a year whilst the other three seasons are usually dry (Cai et al. 2016). It is a low-lying region characterised with a wet, subtropical climate along the portions of the eastern escarpment to the north and south of the basin (Kahinda et al.,2016) The mean annual temperature ranges from about 18 °C in the mountainous areas to more than 28 °C in the northern and eastern parts of the sub-basin, with an average of about 25.5 °C for the Limpopo Water Management Areas as a whole. Maximum temperatures are experienced in January and minimum temperatures occur on average in July (Mvandaba et al. 2018). The eastern and northern parts are subtropical, with humid and hot summers. The average temperatures in summer are around 27 °C. In winter (May to September), the nights are cold and mostly frost-free, with chilly mornings and dry and sunny days. Still, in the Lowveld it can get very hot with temperatures reaching between 45 and 50 °C (Cai et al. 2016).

2.2 Selected Study Sites

It is estimated that 3% of the total land area is under wetlands in the Limpopo basin. Swamps and floodplains are the most widespread types of wetlands in the region (Jogo and Hassan, 2010). The two wetlands understudy are found in the Limpopo Transboundary River Basin, Makuleke and Nylsvlei Nature Reserve wetlands. These wetlands are both listed under Ramsar Convention on wetlands.

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2.2.1 Makuleke Nature Reserve wetland

Makuleke wetland is located in northern part of LTRB (22°23'S 031°11'E), within the Kruger National Park in the floodplains of Limpopo and Luvhuvhu rivers and bordered by Zimbabwe and Mozambique to the north and east, respectively (Figure 2.2) (Malherbe, 2018, Reid, 2001). The Ramsar area extends from the western Kruger National Park (KNP) border to the Mozambique border on the Limpopo River and from Lanner Gorge on the Luvhuvhu River until the confluence with the Limpopo River at Crooks Corner. The important landscapes of the nature reserves are riparian floodplain forests, floodplain grasslands and flood pans. Floodplains are of great importance in this ecosystem as they hold water right into the dry season, therefore acting

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as a refuge point for wildlife and water birds during both winter and summer months. The wetland area is about 7 700 ha, while the various depressions cover about 350 ha (Malherbe 2018). The Ramsar area consists of about 30–31 floodplain depressions (or pans) that are seasonally filled from the rivers. Some of these pans have their own catchment area and are fed by various streams. The pans are important for the breeding and feeding of various animals and birds that occur within the Makuleke Wetlands. Furthermore, the pans serve as a stopover for several migratory bird species, especially in the Limpopo River's floodplains where the pans hold water longer than in the Luvhuvhu River. The largest pan in the Ramsar area is Banyini, which consists of an area of approximately 162 ha (Malherbe 2018).

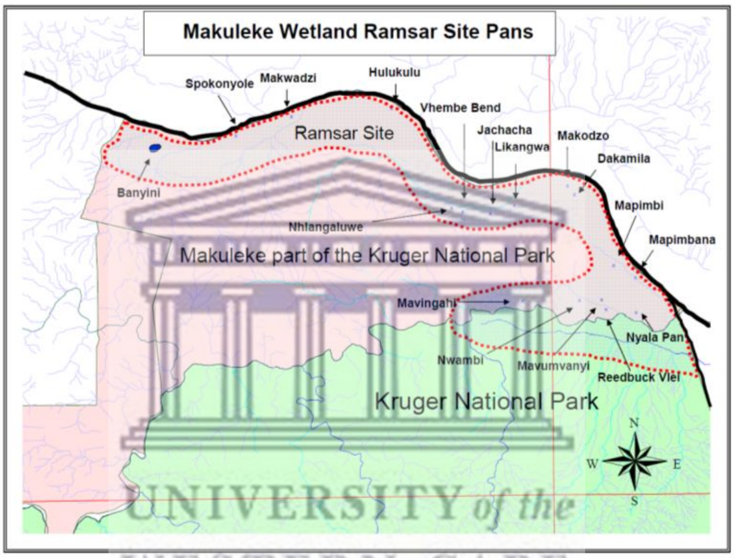

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Figure 2.2: The location of Makuleke Nature Reserve in Limpopo Transboundary River Basin

2.2.1.1 Geology

The diversity of the landscape features and geographic location of the Makuleke Nature Reserve contribute to the high biodiversity of this area (Tinley, 1978). The intrinsic heterogeneity of the area is due to numerous geological features with each characterised by contrasting rock types (Venter, 1990). These rock types include mudstone, basic lavas, quartzite, shale and sandstone (Deacon, 2007; Viljoen, 2015). The Mozambique Plain towards the east is made up of ferricrete, marls, unconsolidated sand, calcrete and boulder beds (Deacon, 2007). Floodplain alluvium occurs at the confluence of the two rivers (Limpopo and Luvuvhu Rivers) to the north (Deacon, 2007). Adjacent floodplains and a well- developed levee characterise the area beside the Limpopo River (Deacon, 2007).

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2.2.1.2 Faunae

There are approximately 33 different amphibian species in the Makuleke Wetlands, of which 28 are tropical species. There is a possibility that more species can be found with further studies as the area is very close to the southern distributions of various amphibians and not many extensive surveys have been completed in the wetlands. Makuleke Wetlands is one of the top birdwatching areas in South Africa. There are approximately 450 species found there, with Pel's fishing owls (*Scotopelia peli*), Pygmy goose (*Nettapus auritus*), Bohm's spinetail (*Neafrapus boehmi*), mottled spinetail (*Telacanthura ussheri*), mountain wagtail (*Motacilla clara*) and Basra reed warbler (*Acrocephalus griseldis*) being more common in the area than in other parts of South Africa. The various pans also have several hippos (*Hippopotamus amphibius*) and crocodiles (*Crocodylus niloticus*), especially in the pans that hold water during the drier winter seasons(Malherbe 2018).

2.2.2 Nylsvlei Nature Reserve wetland

Nylsvlei wetland is one of the largest wetlands along the Nyl River, where Klein Nyl and Groot Nyl are the two main headwaters that arise on the flanks of the Waterberg Range at elevations of approximately 1500m (See Figure 2.3). Below the confluence of these two tributaries, the Nyl flows east-northeast towards and across the northwestern part of the extensive, low-gradient Springbok Flats. South of Naboomspruit, the river enters the Nylsvlei Nature Reserve and is bordered by an extensive 1.8–6.5km wide, 240 km^2 floodplain which hosts the Ramsar-listed Nylsvlei wetland(Tooth and McCarthy, 2007). Nylsvlei wetland is located in the southern part of the LTRB (24°39'S 028°42'E). The main features of the Nylsvlei nature reserve includes riverine floodplains, flooded river basins, and seasonally flooded grassland, with the dominant wetland type being a seasonal river associated with a grassland floodplain (Havenga, Pitman, and Bailey 2007). The wetland has the endangered roan antelope *Hippotragus equis*, and the area serves as a breeding ground for eight South African red-listed water birds (African and Conservation, 1998, McCarthy et al., 2011).

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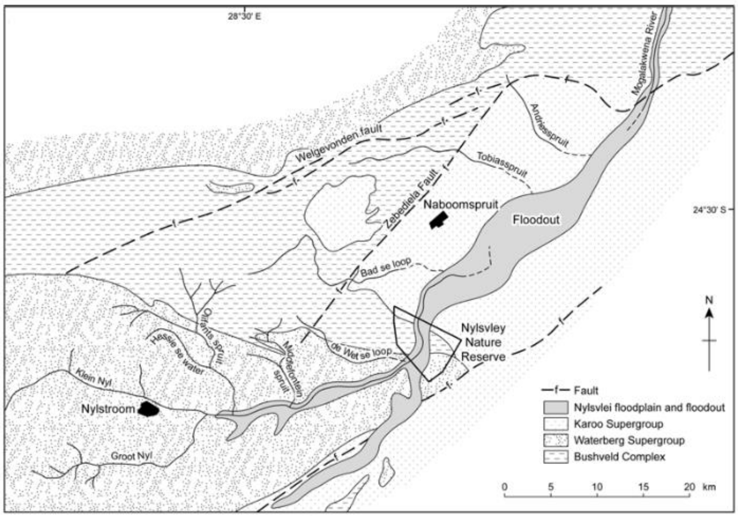

Figure 2. 3: A geomorphology of the Nyl valley showing the major geological features and the location of the major tributaries and the extend of the floodplain wetland (Tooth and McCarthy, 2007)

2.2.2.1 Geology and Climate

The Nyl and its tributaries flow from the resistant quartzite of the Waterberg Range and the igneous rocks of the Swaershoek Range onto the Springbok Flats, which consist of alluvium and regolith that overlies horizon tally layered, Karoo Supergroup sandstones and basalts. Annual precipitation in the Nyl catchment ranges between ~250 and 1100 mm and falls mainly in the austral summer (McCarthy et al. 2011). Annual potential evaporation is high (~2400 mm), and, together with transpiration losses, results in a large annual moisture deficit. As a result, the Nyl River and tributaries are characterized by infrequent flood events, interspersed with longer periods of low or no flow. Flooding usually occurs following early summer rainfall (December to January) and mainly takes place from the southern end of the floodplain, although some downstream sections of the floodplain can flood independently of the upstream sections owing to contributions from individual tributaries arising in the ranges to the west and northwest. Water depths are generally 1m, but the area of inundation sometimes reaches 160 km^2 and, if above average rainfall is sustained, parts of the wet- land may remain inundated for six to eight months. Usually, however, the floodplain and wetland dry out completely by early winter (Havenga et al., 2007, Tooth and McCarthy, 2007).

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CHAPTER THREE

Use of multispectral satellite data to assess impacts of land management practices on wetlands in the Limpopo Transfrontier River Basin, South Africa

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Nysvlei wetland

Abstract

The study sought to assess the impacts of land use and land cover (LULC) changes on two wetland systems (Makuleke and Nylsvlei Nature Reserve) in the Limpopo Transfrontier River Basin (LTRB) in South Africa between 2014 and 2018. To fulfil this objective, multi-date Landsat data images were used to estimate the rate of LULC changes in Makuleke and Nylsvlei wetland ecosystems during the study period. Further, the maximum likelihood classification algorithm was used to identify various land use and land cover classes. The results obtained showed LULC classes were identified with an overall classification accuracy ranging from 80% to 89% for both study areas. The spatial extent of Makuleke declined by 2% between 2014 and 2018, on the other hand, Nylsvlei wetland decreased by 3%. Some of the noticeable changes were that the coverage of natural vegetation tends to increase during wet seasons. Built-up areas

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have slightly increased over the 2014 and 2018 period because of population growth and infrastructure development, which occupy portion of the wetland. In Nylsvlei it was evident that during the 5-year period the cropland areas are progressively increasing. The croplands in the Nylsvlei were found to be the dominant land feature whereas for the Makuleke wetland grasslands are the dominant feature. Overall, the results demonstrated a steady decrease in natural vegetation cover over time. Therefore, the results obtained in this study provide insights and critical information on the state of wetland ecosystems within the Limpopo Transfrontier River Basin. This information can aid in the enforcing of wetland legislation and LULC management practices.

Keywords: Ecological status; multi-date assessment; protected wetlands; spatial characterization; wetland integrity

This chapter is based on the manuscript:

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- the Geo-Information Society of South Africa (GISSA) WC AGM on the 12th of November 2020, South Africa

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3.1 Introduction

Wetlands are unique ecosystems that are considered among the world's most productive and valuable ecosystems (Ollis et al., 2013), and provide several environmental and socio-economic value (Al-Obaid et al., 2017). As delicate as they are, wetlands have historically been the basis for human survival due to the availability of water, biodiversity and sometimes-fertile soils (Marambanyika and Beckedahl, 2016a). In addition, these highly productive ecosystems provide functions such as water security, hydrological regulation and other services (Dixon et al., 2016). Wetlands provide the basis of human livelihoods in Africa through ecosystem services (Rebelo et al., 2010) for example in Western Kenya, rural communities depend on water from the Yala swamp for drinking, cooking and washing purposes and the same has been reported in Southern African countries (Mwita, 2013). Work by Marambanyika et al., (2017) demonstrated the relevance of wetlands on rural livelihoods in rural Zimbabwe. In South Africa, the study done by Adekola et al., (2012) described some of the provisioning services provided by wetlands to the livelihoods of local stakeholders, including monetary values for some services in rural areas. It is, therefore, imperative to routinely assess and monitor the impacts of human developments or land management practices on wetland resources.

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So far, numerous laws and treaties have been introduced to conserve and protect wetlands from degradation and even extinction. These include the 1975 Ramsar Convention, the South African National Environmental Management Act 107 of 1998 (NEMA), the National Water Act 36 of 1998 (NWA) and the environmental provisions of the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA), and the 2002 Environmental Management Act of Zimbabwe that provides for the protection of wetlands. Despite these initiatives, wetland degradation continues at unprecedented rates due to lack of awareness, poor policy implementation and ineffective government policies (Marambanyika and Beckedahl, 2016b, Al-Obaid et al., 2017, Omolo et al., 2018). Wetlands located in semi-arid regions particularly in developing countries are at high risk of exploitation as communities they are in are the main source of productive lands for agriculture. Thus, Land Use and Land Cover (LULC) changes and overexploitation because of unsustainable resources harvesting, agricultural intensification in these wetlands contribute to degradation of wetlands (Mwita, 2013). Lack of information about benefits derived from wetlands results in some wetlands

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being considered as wastelands. Both the natural and anthropogenic forces are responsible for these changes in LULC. These changes not only fragment the landscape but alter biogeochemical cycles, climate, ecosystem processes and resilience, thereby changing the nature of ecosystem services (Namugize et al., 2018). In addition, wetlands are also highly vulnerable to global environmental changes through alterations of hydrological regimes which threaten wetland habitats and their-dependent species (Al-Obaid et al., 2017).

Several methods have been adopted to monitor wetlands conditions. These include traditional and spatial explicit remote sensing techniques (Shuman and Ambrose, 2003). Although, they have received much attention, traditional methods such as field surveys, map interpretation, collations of ancillary and data analysis are reported to be ineffective for routine and spatial explicit monitoring of wetland (Ma et al., 2018). Besides, they are regarded as time consuming, expensive and frequently providing incompatible and inconsistent results. They remain viable in developed and easily accessible areas and this creates spatial irregularities (Masocha et al., 2018). The use of remote sensing is much more effective, cost-effective, and time-effective, as well as has a spatial dimension (Al-doski et al., 2013). The use of satellite data provides a useful tool for monitoring and managing wetland conditions even in remote areas (Mwita, 2013). Some satellites such as Landsat have been providing spatial data for the past 48 years (since 1972) and this makes it advantageous to monitor LULC changes as a proxy for understanding wetland conditions. Landsat data series provide moderate-resolution at 30 m with 15-day revisit time and in addition, of late the 10 – 20 m Sentinel 2 MSI was introduced, with a temporal resolution of 5-days. The two satellite datasets provide complementary advantage that can aid in monitoring and understanding wetland conditions especially for remote and undocumented wetland areas.

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This study sought to assess the impacts of LULC change on protected wetlands in the Limpopo Transfrontier River Basin (LTRB) in South Africa (2014 – 2018), using long term Landsat data. The study period was selected based on the data availability. To achieve the objective, two wetlands namely, Makuleke and Nylsvlei Nature Reserve were selected. These wetlands are protected by law as nature reserves. However, there is a potential that they are being affected by human activities within and outside the protected boundaries.

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3.2 Material and methods

3.2.1 Remote sensing data acquisition

The data used in this research were divided into satellite data and auxiliary data. In total, 12 scenes (See Table 3. 1) of Landsat Images were freely downloaded from the United States Geological Earth Explore (USGS) online portal (https://earthexplorer.usgs.gov/) at < 10% cloud coverage. These images were acquired for two seasons (wet and dry) to assess the impacts of LULC changes on wetland ecosystems from 2014 to 2018. Landsat images with 13 bands were atmospherically corrected using semi-automatic classification tool using QGIS software. Satellite image pre-processing before any detection of change is greatly needed and has a primary unique objective of establishing a more direct relationship between the acquired data and biophysical phenomena (Butt et al., 2015). The data were pre-processed using ArcGIS 10.8 and QGIS software. All 12 images were pre-processed by performing standard pre-processing steps (geo-referencing and atmospheric correction). The images were geometrically corrected based on World Geodetic System (WGS) 84 spheroid and atmospherically corrected using semi-automatic classification tool which implements the Dark object subtraction (DOS1) (the DOS1 atmospheric correction box was checked before the atmospheric correction was run) in QGIS software. Seasonal satellite images the study area image was extracted by clipping the study area using common GIS tools. Auxiliary data include ground truth data for the LULC classes. The ground truth data were in the form of reference data points that were randomly created using GIS tools and used for assessing accuracy of the classified images. These randomly created points consisted of x and y coordinates and they were projected onto the classified maps in ArcGIS 10.8 and exported onto Google Earth to verify the accuracy of the classified maps.

Table 3. 1: Landsat data images used to map the inherent LULC changes

Catchment	Sensor ID	Path/row	Date
Makuleke	LC08_LITP_169076	169_063	08-October-2014
	LC08_LITP_169076	169_063	18-June-2014
	LC08_LITP_169076	169_063	29-October 2016

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	LC08_LITP_169076	169_063	20-April-2016
	LC08_LITP_169076	169_063	16-August-18
	LC08_LITP_169076	169_063	26-April-2018
NyIsvlei	LC08_LITP_170077	170_077	11-July-2014
	LC08_LITP_170077	170_077	16-Jan-2014
	LC08_LITP_170077	170_077	116-July-2016
	LC08_LITP_170077	170_077	05-November-2016
	LC08_LITP_170077	170_077	22-July-2018
	LC08_LITP_170077	170_077	11-November-2018

Table 3.2: Landsat 8 OLI bands

Band	Band Number	µm	Resolution (m)
Coastal	1	0.433–0.453	30
Blue	2	0.450–0.515	30
Green	3	0.525–0.600	30
Red	4	0.630–0.680	30
NIR	5	0.845–0.885	30
SWIR-1	6	1.560–1.660	30
SWIR-2	7	2.100–2.300	30

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3.2.2 Image Classification

In order to determine the main LULC for change detection, a classification scheme was prepared. According to Mwita, (2013) preparation of a scheme is a pre-requisite in the classification process. The scheme of the study was prepared based on the Google Earth observations of the LULC in the Makuleke and Nylsvlei Nature Reserve catchments. Google Earth was used because as stated by Bey et al., (2016) it offer free access to satellite imagery on current and past land dynamics and allows one to zoom land features on any part of the world. The classes were identified and delineated from the satellite images namely, vegetation, built-up areas, forest, grasslands, bare land, shrubs, agricultural areas (farmlands)

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and waterbodies (wetland). Landsat 8 band combinations from (https://landsat.gsfc.nasa.gov/landsat-8/landsat-8-bands/) can be used to identify land features. Band combinations are very useful in visualising features of the earth and they were of great help in identifying LULC classes in the study areas through the images. For each of the classes, training samples were selected by delimiting polygons around the representative sites of the LULC classes. The training data consists of areas of pixels of known classifications and this was done using the on-screen digitizing feature and the created feature called Area of Interest (AOI). The selection of these features was based on areas that are clearly visible on Google Earth in all images that will be classified, for each class 10 training sites were identified because these were the training sites of the known LULC classes that were identified from the high resolution reference imagery (2014 image) and these training sites accurately identified sets of pixels that showed spectral variation. These training samples fully showed the range of variability within each class to allow the software, which was ArcGIS in this case to accurately classify the rest of the image. After the training samples were digitized the next step was to create Signature files for every informational class. Spectral signatures for all LULC derived from satellite imagery were recorded by using pixel enclosed by these polygons. A satisfactory spectral signature is the one ensuring that there is ‘minimal confusion’ among the LULC to be mapped (Gao and Liu, 2010). Confusion might occur between two LULC classes for example, if A is easily misclassified as B, then B could be easily misclassified as C. Therefore, signature files (SIG) were created; these files contain information about the LULC described by the training samples. In classifying the images, Maximum likelihood algorithm (MLC) was used. MLC is based on the probability that a pixel belongs to a particular class (Rawat and Kumar, 2015). The images were classified according to the classes that were selected prior to the classification of the images.

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3.2.3 Accuracy assessment

Assessment of classification accuracy between 2014 and 2018 was carried out to determine the quality of information derived from the classified images. Overlaying 240 unbiased random created points determined the accuracy of the results (40 per class: 40 biased points per classes x six (6) LULC classes per image). Only 240 unbiased points were created per image because the study area is relatively small. The accuracies for the classification results were assessed using confusion matrices, which are user's accuracy, producer's accuracy,

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overall accuracy, omission accuracy and commission accuracy (Olofsson et al., 2013). Figure 3.1 shows a flow diagram presenting a summary of the major steps that were taken.

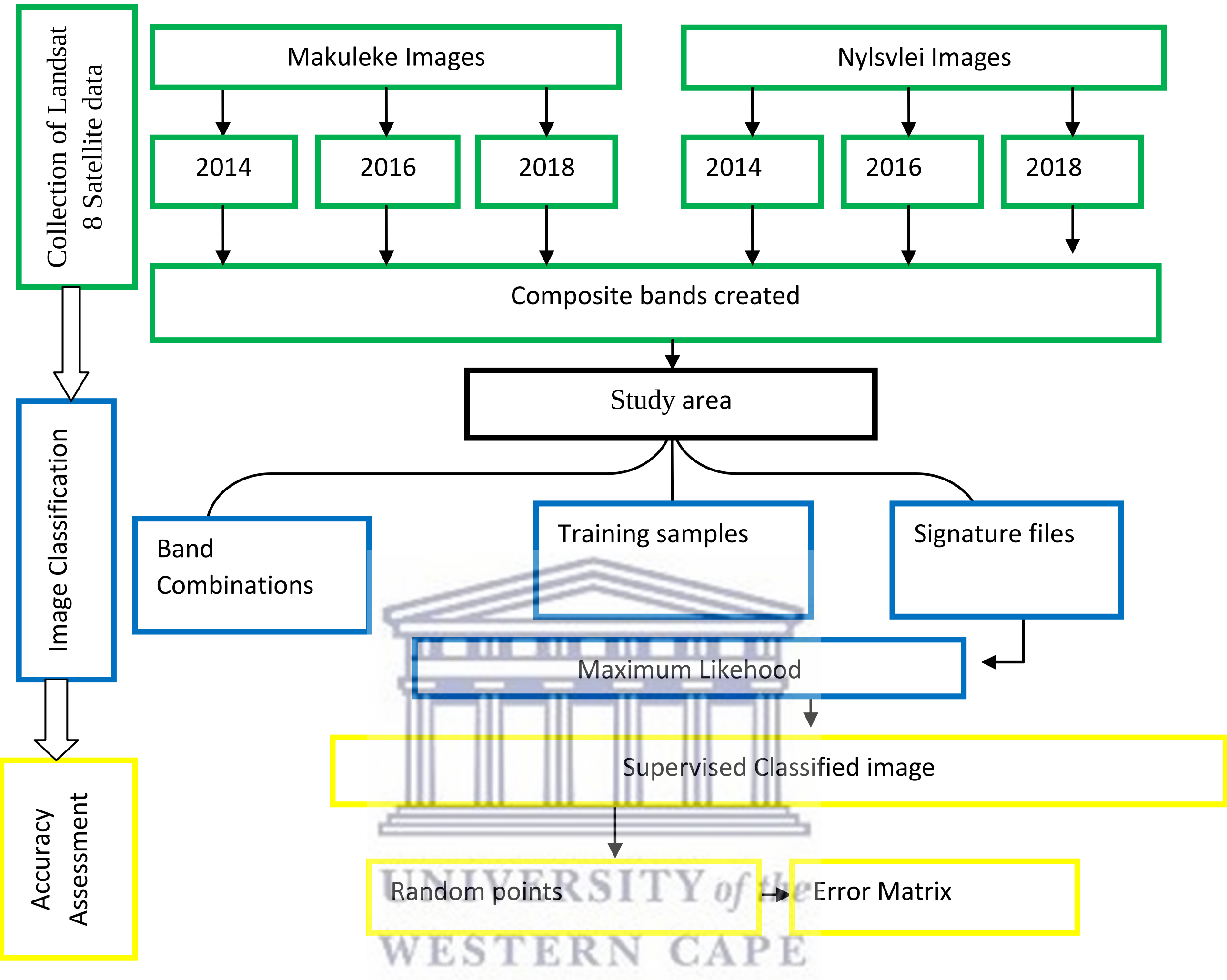

Figure 3. 1: Representation of workflow summary for LULC changes and accuracy assessment used in this study

3.3 Results

3.3.1 Climate Data

Figure 3.2 illustrates the climate variation in the basin during the period of understudy. The climate data was received from South African Weather Services (SAWS). The catchment is characterized by sharp peaks (the highest rainfall average in 2016 of 42.6 mm) and low rainfall amounts (the lowest of 25.79 mm in 2015). The highest temperature experienced in the basin was 26.31 Celsius in 2015 and lowest in 2014 at 11.25 Celsius.

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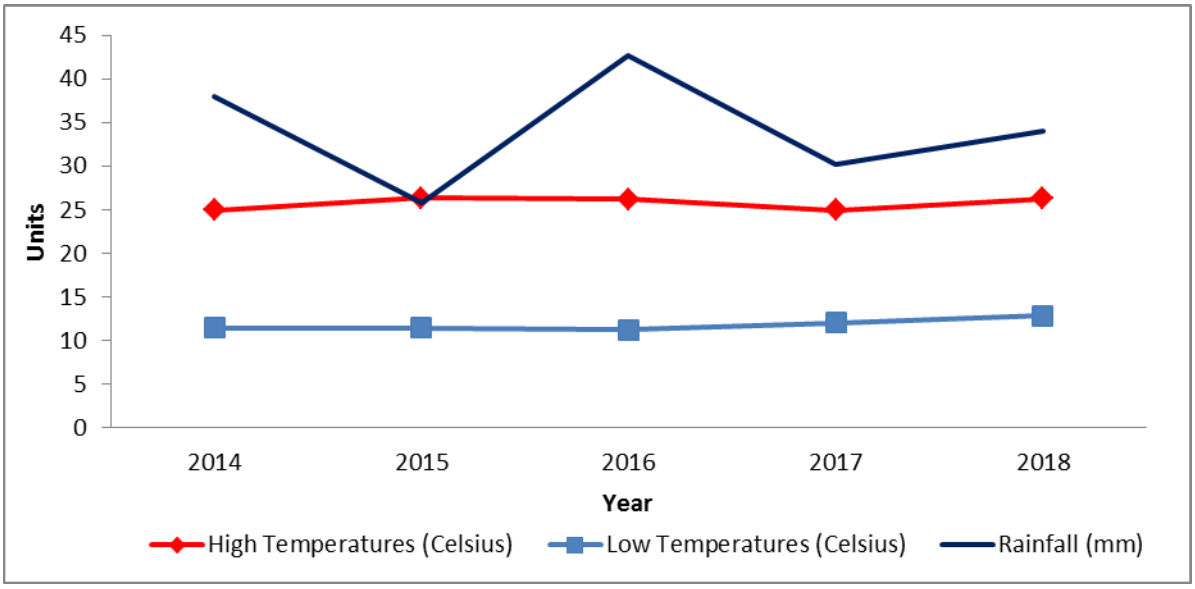

Figure 3. 2: Climate data variation in the Limpopo River Basin between the period of 2014-2018.

3.3.2 Derived classification accuracies

The overall accuracy obtained during classification process is in conformance within the minimum threshold of 65 to 85% suggested by Anderson et al., (1976) for LULC classification. Therefore, the maps produced had an acceptable overall accuracy, with the producer and user accuracies above 70% for most of the classes. Producer's accuracy is the measure of how well real-world land use and land cover classes are classified and the user's accuracy represents the probability of a classified pixel matching the LULC class of its corresponding real-world location (Rwanga and Ndambuki, 2017). Table 3.3(a & b) shows satisfactory LULC classification accuracies achieved for Makuleke with overall accuracy classification ranges between 85% to 89%, with user's and producer's accuracy between 31% and 97% for all six classes during the wet season, whereas during the dry season the overall accuracy was between 80% to 86% with user's and producer's accuracy between 68% and 100%. In Nylsvlei (See Table 3.3(c & d)) the overall accuracy was between 81% to 86% with all class accuracies above 70% during the wet season and had an overall accuracy between 80% and 83% during the dry season, with user's and producer's accuracy between 65% and 98% threshold during the period of study.

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Table 3. 2: Image classification accuracies derived from Landsat data for Makuleke Nature Reserve wetland (a) wet season, (b) dry season and Nylsvlei Nature Reserve wetland (c) wet season and (d) dry season for the period of the study.

[A] Class	**Wet Season – Makuleke**					
	2014		**2016**		**2018**	
	Producer	User	Producer	User	Producer	User
Built-up areas	61	78	81	92	82	80
Vegetation	86	80	91	80	70	76
Water bodies	95	88	90	85	97	80
Forest	70	88	67	80	81	73
Grasslands	65	90	41	88	31	70
Bare land	34	44	44	48	32	42
OA	**88%**		**89%**		**85%**	

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[B] Class	**Dry Season**					
	2014		**2016**		**2018**	
	Producer	User	Producer	User	Producer	User
Water bodies	71	90	79	85	100	82
Vegetation	86	80	71	85	80	75
Built-up areas	80	70	78	70	96	95
Forest	78	73	68	70	75	80
Grasslands	79	85	76	73	87	75
Bare land	86	80	88	75	86	85
OA	**80%**		**81%**		**86%**	

[C] Class	**Wet Season- Nylsvlei**					
	2014		**2016**		**2018**	
	Producer	User	Producer	User	Producer	User
Water bodies	75	92	82	79	85	78
Vegetation	82	82	88	86	82	85
Built-up areas	90	91	92	88	91	95
Agriculture	70	78	76	74	78	74
Shrubs	79	77	70	73	79	72

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Bare land	85	82	81	84	79	82
OA	**81%**		**83%**		**86%**	

[D] Class	**Dry Season**					
	2014		2016		2018	
	Producer	User	Producer	User	Producer	User
Water bodies	92	88	79	89	87	98
Vegetation	85	79	85	78	73	69
Built-up areas	81	84	79	76	76	72
Agriculture	79	75	65	72	98	95
Shrubs	82	79	71	82	81	75
Bare land	76	82	80	79	75	70
OA	**80%**		**81%**		**83%**	

The omission and commission errors of LULC classes are given in Figure 3.3 (a - f) and Figure 3.4 (a - f) for Makuleke and Nylsvlei, respectively. Error of omission refers to reference sites that are left out (omitted) from the correct class in the classified map. Error of Commission refers to sites that are classified as to reference sites that were left out from the correct class in the classified map. For instance, the omission error of bare land is high which means that pixels that belong to this category were not considered in this class in the case of Makuleke. The commission error was high in case of built-up areas which meant that a greater number of pixels which do not fall under this category were classified as built-up areas in the case of Nylsvlei.

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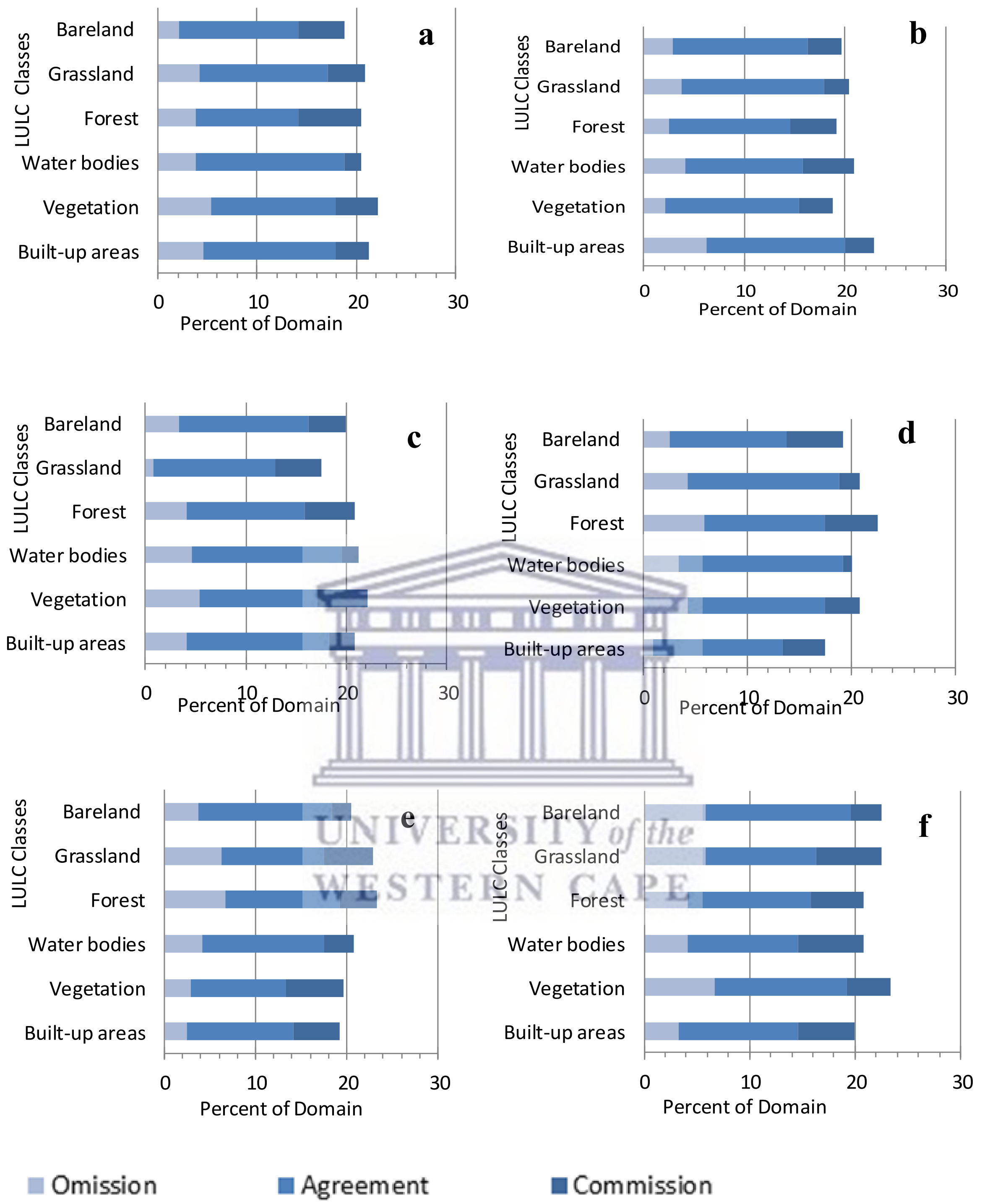

Figure 3. 3: Commission and Omission Error graphs (a - c) 2014, 2016 and 2018 depicting wet season respectively and (d - f) 2014, 2016 and 2018 depicting dry season respectively for Makuleke

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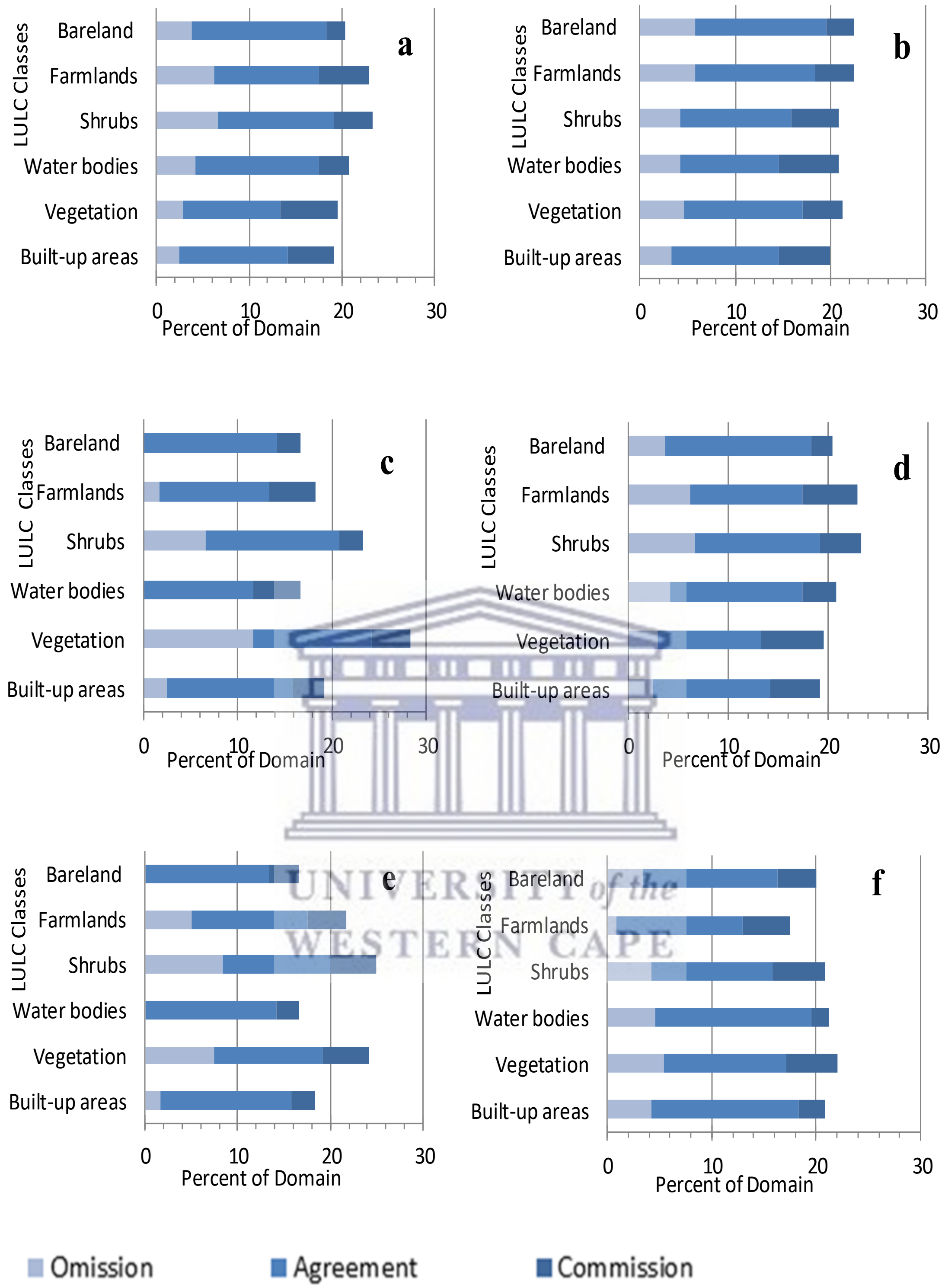

Figure 3. 4: Nylsvlei Commission and Omission Error (a - c) 2014, 2016 and 2018 depicting wet season respectively and (d - f) 2014, 2016 and 2018 depicting dry season respectively

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3.3.3 Spatiotemporal mapping of LULC changes on protected wetlands

Figure 3.5a illustrates LULC changes that occurred around Makuleke Nature Reserve over the 5-year period. The classified images show that most of the Makuleke Nature Reserve catchment was characterised mostly by grasslands especially between 2016 and 2018 in both seasons. During 2014 both in wet and dry season, the catchment was mostly characterised by bare land (See Figure 3.5a). Most of the built-up areas are located to the western part away from the wetland and natural vegetation is mostly located in the northern and eastern part of the catchment. Change is evident in most of the LULC classes. The area occupied mainly by built-up increased from 13%, 17% and 20% of the total area in 2014, 2016 and 2018 respectively for the catchment of Makuleke wetland. The area that is occupied by the forest has fairly remained constant from 2016 to 2018, seasonally. On the other hand, Figure 3.5b shows how Nylsvlei wetland has been changed during the period of study. The area occupied by bare land tends to decrease in wet season and increase in dry season from 11 % in wet season to 17 % in dry season. It can be observed from both seasons since 2014, that the percentage of farmlands has increased from 18%, 24% and 28% of the total area in 2014, 2016 and 2018 respectively compared to other classes such as vegetation. The area covered by built-up area has increased over the years, the area occupied by built-up infrastructure has increased from 5%, 7% and 9% of the total area in 2014, 2016 and 2018 respectively in the catchment of Nylsvlei.

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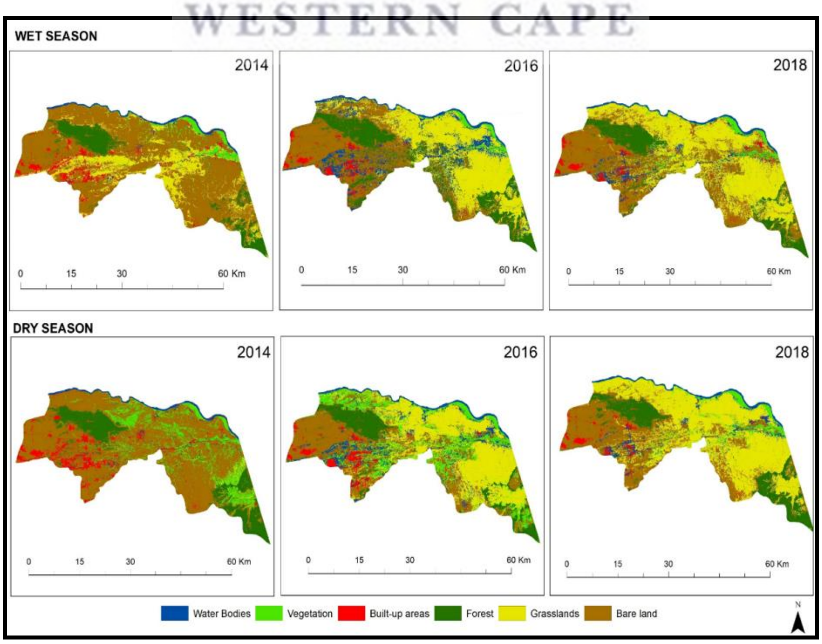

Figure 3. 5a: LULC changes of the Makuleke Basin over the period of 5 year

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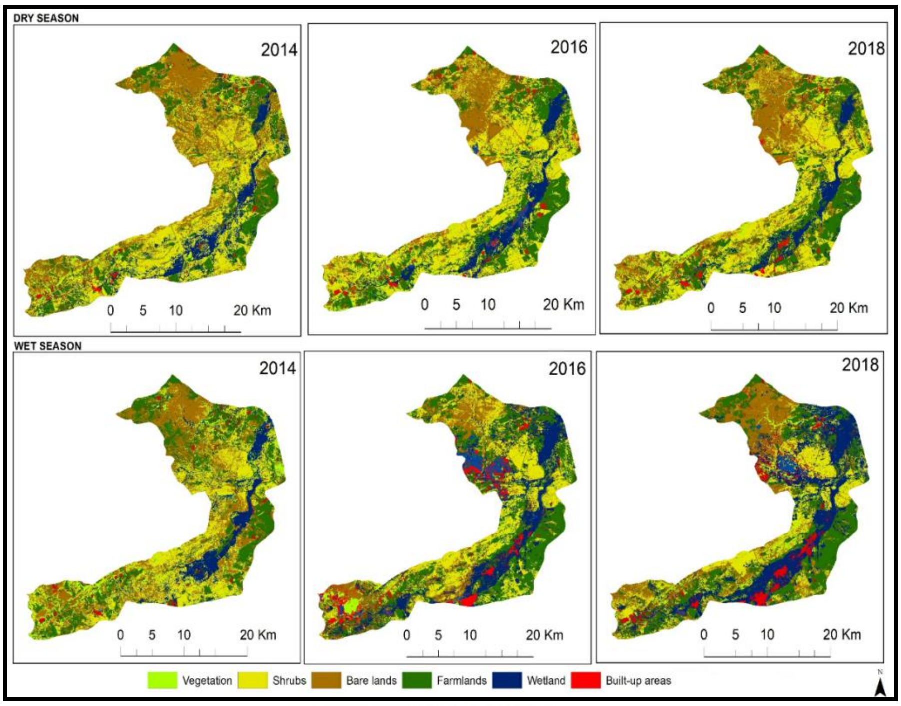

Figure 3.5b: Land use and cover changes in Nylsvlei Basin from 2014 – 2018.

3.3.4 Change detection during the period of study

Change detection is important in understanding how the land features have changed during the period understudy and a summary of changes that occurred during the study period. (See Figure 3.6a) Some changes that were observed for instance were, vegetation has increased from 13% to 20% of the total area during wet seasons. Built-up areas have slightly increased between 2014 and 2018 and this is most likely because of population growth and infrastructure development. Figure 3.5b displays the rate of agriculture (farmlands) has increased around the wetland especially during the 2018 wet season compared to the other years. The increase in wetland farming around the Nylsvlei wetland could be due to LULC changes in the catchment. As illustrated by the graphs (See Figure 3.6a & b), some of the LULC classes can be seen increasing, some declining or remaining stable. In most cases this is seasonal dependent for instance vegetation cover tends to increase during wet seasons and bare lands have fairly remained constant throughout the period under study both in wet and dry seasons.

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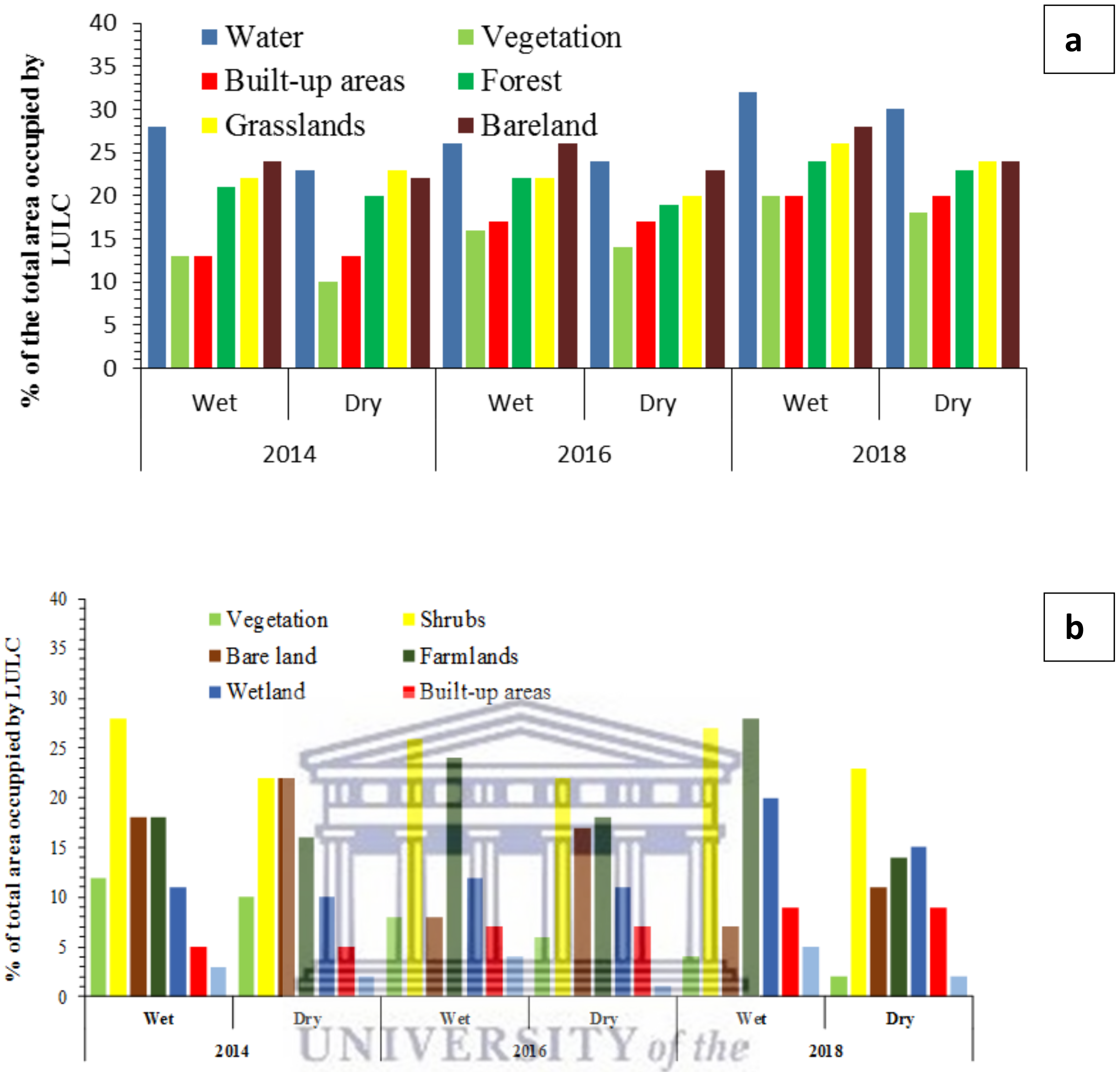

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Figure 3.6: Satellite estimated land cover changes for the (a) Makuleke and (b) Nylsvlei Nature Reserve wetland

3.3.5 Comparison between Makuleke and Nylsvlei

Understanding wetland loss is critical for proper wetland management and decision making. Wetland loss is mainly caused by human activities within their catchments (Hu et al., 2017) and this is also evident in areas under study. Between the year 2014 and 2018, the Makuleke wetland lost its spatial extent by 2% and 3% by Nylsvlei, respectively. Grasslands have occupied some of the wetland areas in Makuleke Nature Reserve with a 4.38% increase from 2014 to 2018, followed by built-up areas with 6.59% change rate percentage between 2014 and 2018. Wetland areas showed a noticeable change during wet and dry seasons. In Nylsvlei, the major LULC classes occupying the wetland area are shrubs (3.8%) and

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farmlands (7.52%) between the years' understudy (See Table 3.4). The results produced showed that farmlands are the dominant feature in the Nylsvlei catchment basin and some of the areas that appear to be built-up areas in the dry years are parts of the wetland. Farmlands and built-up areas are two main human activities that directly causing wetland loss and these activities have a direct impact also on water quality (Rashid and Romshoo, 2013).

Table 3. 3: Change matrix of Makuleke and Nysvlei between 2014 and 2018

LULC	Wetland	Vegetation	Built-up	Bare land	Forest	Grassland	Farmland	Shrub	
Change rate (%)	-1.83	2.35	6.59	2	0.8	4.38	*	*	**Makuleke**
	-2.76	1.82	2.53	1.05	*	*	7.52	3.8	**Nysvlei**

*not applicable

3.4 Discussion

The present study sought to assess LULC change impacts on the protected wetlands (Makuleke and Nylsvlei Nature Reserve) from 2014 to 2018 for two seasons (dry and wet) using Landsat data. The study showed that wetland spatial extents shrank at a faster rate in LRTB mainly due anthropogenic activities such as farming activities, infrastructure development and land conversion affecting wetland ecosystems. Accuracy assessment is an important step in image classification and the quality of the classified maps from satellite images is determined by its accuracy. Information on the accuracy and precision of the classified maps is essential in order for the end-users to use the produced maps efficiently (Manandhar et al., 2009).The results from accuracy assessment of the LULC maps varied among the LULC classes. The overall accuracy statistics obtained in the classification process are in conformance also with the minimum threshold of 65 to 85% suggested by Anderson et al., (1976) for land use and cover classification of both study sites, regardless of some errors which could be attributed to spectral confusion between built-up areas, barren land and farmlands (agriculture land).

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There are significant changes amongst LULC during the 2016 - 2018 period compared to 2014. The LULC classified images of Nylsvlei Nature Reserve suggested that the main threat facing the wetland is the agriculture around the wetland therefore farmlands are the dominant feature. Work done by Mwita, (2013) suggested that one of the major factor that has resulted in intensifying wetland use is climate change. For the past almost three decades, seasons have drastically changed and due to this farmers and livestock farmers have taken advantage of sometimes fertile soil and the availability of water in wetlands. The results showed a decrease in size of the wetland due to parts of the wetland being converted to farmlands and this is in agreement with what was found by Ondiek et al., (2020) who concluded that agricultural expansion through drainage of wetlands has led to loss or reduction of wetlands. Agricultural expansion is the main economic activity taking place in wetlands especially in developing countries. The study done by Van Asselen et al., (2013) showed that globally, results have shown that wetlands have decreased in the past years due to land clearance and drainage as a consequence of urban, agricultural and industrial development activity. The impact of agriculture especially in rural areas can be expected to be more significant than that of urban areas and this can be related to the application of chemical fertilizers within agricultural areas and agricultural lands are permanently changing at various spatial and temporal scales in response to human activity and environmental factors (Giri and Qiu, 2016). With the increasing population and need for food security, pressure on land will force farmers to cultivate more areas of natural ecosystems like forests and wetlands, further degrading water systems (water quantity and quality), livelihoods and economies (Uwimana et al., 2017). The decline in the wetlands and water bodies identified in the study is also seen as a sign that the availability of agriculture land is becoming a challenging issue in the district especially for Nylsvlei wetland. The analysis revealed that wetland is being converted into agricultural land, but this trend is happening at slower rate than other land use change trends identified in this study.

On the other hand, in Makuleke, the increase in bare land during 2014 could be caused by overgrazing done by livestock such as cattle mainly in rural areas around or close to the wetland. This is similar to the findings that of Dahwa et al., (2013) and Morris et al., (2013) who also indicated that increase in livestock grazing leads to treading, soil compaction, a decline in plant species and increase in bare land. The study done by Butt et al., (2015) concluded that this increase in bare land could be due to rapid deforestation in the area which removes vegetation cover from the land and rendered it barren and exposed. There are many

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open spaces categorized as bare land within the Makuleke. Due to that fact that a significant large area of the Makuleke wetland catchment falls under barren landscapes, it becomes vital for wetland managers to increase the green cover in the form of plantation to reduce the influx of sediment that might flow into the wetland, which might result in number of eco-system benefits of the wetland being lost.

There is an increase in built-up areas in Makuleke Nature Reserve basin compared to Nylsvlei Nature Reserve. This is could have been caused by population increase in recent years in the basin. Cristea, (2016) concluded that population growth and associated anthropogenic interferences have the tendency to deplete resources and reduced the rates of flow of ecosystem services. This is also in agreement with what was stated by Mwita, (2013) as the second factor affecting wetlands- rural impoverishment and population growth. These changes have been growing at a faster rate and as a result this will cause a change in land use and cover in most cases affecting wetlands. Increase in built-up areas during the 5-year period used for the study could be attributed to increasing demand for land from the growing population as well as the infrastructure developments that are taking place. In other words, the increase in population implies conversion of other LULC classes into built-up and this could be a reason for the general increase in the built-up area across the basin. In Makuleke Nature Reserve basin there was no any settlement within or close to the wetland as shown in Figure 4a, people are settled far away from the wetland and the wetland is located in a remote area that is far from most social services, whereas in the Nylsvlei, most built up areas are located close to the wetland. A slight increase in built-up areas was expected because because both wetlands (Makuleke and Nylsvlei) are found in nature reserves, therefore it is expected that they will be an increase in tourism and entrepreneurial activities that surround these wetlands will most likely result in slight changes in the spatial distribution of built-up areas.

In both study areas (Makuleke and Nylsvlei) there was decrease in areas covered by vegetation. The decrease in vegetation is related to areas that were converted from either natural vegetation to farmlands. The change was attributed to increased human activities in the wetlands, agriculture during dry season that requires vegetation clearance. The results clearly showed, that there was less percentage of land occupied by vegetation in dry season compared to wet season in both basins. In Nylsvlei basin most of the vegetation is located closer to the built-up areas (western part of the basin) and in Makuleke mostly in the northern and eastern part of the basin.

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The major causes of land use and land cover changes in these catchments can be grouped into natural changes such as climate change and anthropogenic changes such as agricultural activities. The LULC changes in these catchments may be influenced by rainfall trends, due to high rainfall bare lands tends to decrease and grasslands tends to increase. The decrease in rainfall influenced agricultural activities but an increase in bare land. High temperature affected vegetation cover in both study areas, vegetation cover was not constant during the period under study. Anthropogenic activities taking place caused a major change in land use and land cover especially during wet seasons when most of the catchment is covered with crops due to high fertile soil and this was most evident in Nysvlei compared to Makuleke. Another anthropogenic activity that may have affected land use and land cover in the catchment is infrastructure areas (built-up). All these factors have a huge impact of the wetland for example land area impact, environment impact and biodiversity impact.

Wetland and LULC classification using remote sensing data is important, results obtained by different researchers showed different accuracies of different study areas (Melly et al., 2017, Mudereri et al., 2020). The types of data used include historical photography data, medium-resolution images, high-resolution images and hyperspectral images (Ghobadi, 2012, Guo et al., 2017). Many researches used remote sensing data combined with field survey data to carry out many wetland studies (Haidary et al., 2013). Therefore, the combination of in situ data (ground truth) and Landsat would be beneficial in understanding land processes and in making management decisions about wetland management. The advantages of using remote sensed data such as Landsat data in monitoring wetlands dynamics are; the images can be downloaded free of charge, records of the historic data is available on global scale, Landsat TM and Landsat ETM has multispectral bands, with good spatial and temporal resolution and less image processing time is needed (Dube et al., 2015, Grundling et al., 2013).These are some of the few studies that were done by Kulawardhana et al., (2006), Ghobadi et al., (2012), Nhamo et al., (2017) and Ma et al., (2018) that have shown that time series of Landsat data provide very useful information for mapping wetlands and LULC changes. However, they are several limitations such as cloud cover that usually limit the usable of the imagery and that usually affect the reliability of monitoring LULC and wetland.

3.5 Conclusion

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This study focused on assessing the impacts of LULC change dynamics on the protected wetland systems (Makuleke and Nylsvlei) in the Limpopo Transfrontier River Basin in South Africa from 2014 to 2018. Landsat images with its improved capabilities were used to map the spatiotemporal pattern of wetland change of two study sites. From derived results the following conclusions were drawn.

- Landsat data managed to map wetland ecosystems for Makuleke and Nylsvlei with high classification accuracy ranging from 80% to 89% seasonally over the period of 5-years.
- It was observed that major changes in wetland extent decrease in natural vegetation and portion of the area are converted to farmlands.
- Even though these wetlands are protected (Makuleke and Nylsvlei), they are not free from threats which are intensified by the expansion of LULC changes within and around the protected boundaries.

It is therefore conclude and recommend that regularly monitoring of LULC and wetland changes is important for proper management of the wetlands so there is a need to monitor activities that are taking place within the protected boundaries of wetlands in order to safeguard these resources. This study demonstrates the spatial explicit methodology and wetland monitoring frameworks are crucial in determining wetland condition particularly in data limited environments.

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CHAPTER FOUR

Remote sensed data in estimating chlorophyll-*a* concentration in wetlands located in the Limpopo Transboundary River Basin, South Africa

Makuleke wetland

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Abstract

Chlorophyll-*a* concentrations and associated dynamics in two tropical wetland systems were estimated. Makuleke and Nylsvlei wetlands are located in the Limpopo Transboundary River Basin, South Africa. September 2018 and June 2019 Moderate resolution Landsat 8 images and in-situ field measurements were used to estimate and map chlorophyll-*a* concentrations from the two wetlands. Landsat-derived chlorophyll-*a* concentrations were validated using field-derived chlorophyll-*a* measurements. Validation was implemented to assess the consistency of the remotely sensed chlorophyll *a* estimates. The relationship between field measured and Landsat data-derived chlorophyll estimates were determined using the coefficient of determination (r-square: R^2) and the Root Mean Square Error (RMSE). The results show that Makuleke wetland had low estimates during the month of September 2018. The variation of chl-*a* concentration in Makuleke ranged from -0.10 to1.15 µg/L whereas for Nylsvlei wetland the ranges varied between -0.16 and 1.42µg/L, for the period understudy.

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Spatial characterization of Chl-*a* concentrations significantly varied across the two wetlands with much of it concentrated along wetland shorelines. The finding of this study underscores the relevance of remotely sensed data in assessing and routine monitoring wetland water quality- previously challenge task with in-situ measurements.

Keywords: Chlorophyll-*a*; Remote Sensing; Southern African Transfrontier River Basin; Water quality monitoring; Water resources; Protected wetlands

This chapter is based on the manuscript:

Dzurume, T., Dube, T and Shoko, C Remote sensed data in estimating chlorophyll-a concentration in wetlands located in the Limpopo Transboundary River Basin, South Africa (Geocarto International_200979632).

4.1 Introduction

Wetlands in semi-arid regions are highly productive and biologically diverse ecosystems that contribute significantly to livelihood and economic development and play a huge role in sustaining rural livelihoods (Jogo and Hassan 2010, Rebelo et al., 2010). These ecosystems are not only rich in biodiversity but also predominantly valuable in terms of the services that they provide to people including water security, hydrological regulation and other services (Dixon et al. 2016). However, these systems are currently decreasing and degrading at an alarming rate. Agriculture is considered the principal cause of wetland loss worldwide. It has been estimated that South Africa has already lost between 35-50% of its wetlands (Swanepoel and Barnard 2007). In Craigieburn, Mpumalanga, about 70 % of the communities depend on wetlands as the main source of food and income (Scholes and Scholes 2020). The study done by Nyamadzawo et al., (2015) stated that many people in Malawi, Zambia and Zimbabwe use dambos which are seasonal wetlands to provide enough food for the local consumption and also for business purposes. The future of these wetlands is therefore dependent on effective and routine assessment and monitoring initiatives that can inform policy and decision making to promote sustainable management.

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Most of the population in sub-Saharan select wetlands in preference to other areas for their agricultural and fishery activities because of their higher productivity and as result more than half of the wetlands are destroyed through commercial, agricultural and mining practices as

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well as urban development (Greenfield et al., 2007, Swanepoel and Barnard 2007,Mitchell 2013). Southern Africa is rich in mineral resources and some of these mineral mostly occur in areas where there is little water and these activities tend to pollute most of the water resources including wetlands (Mitchell, 2013). Other threats to African wetlands include changes in wetland water quality due to the effects of industrial effluent and agricultural pesticides, siltation from highland catchment areas, and introduction of alien species of flora and fauna leading to colonization by single species and loss of endemic species diversity (Kabii, 2017). Water quality continues to decrease due to an increase in population growth and economic development, especially in developing countries. Degradation of water quality poses a threat to human and aquatic life, which raises concerns for the future of water resources (Dube et al. 2015; Masocha et al., 2018). There is therefore a need to monitor water quality, though, a number of factors in Sub-Saharan Africa makes it difficult to assess water quality due to; limited technical expertise, limited financial resources and accessibility and availability of appropriate remote sensing datasets required for accurate water quality monitoring (Dlamini et al., 2016). The other challenge that makes it difficult to monitor water quality in Southern Africa is that the exact number of wetlands is unknown due to lack of comprehensive national wetland inventories characterising and classifying wetlands in systematic wetland (Jogo and Hassan 2010).

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Chlorophyll-*a* (Chl-*a*) which is a photosynthetic pigment that is found in all green floral components including algae (Patra et al. 2017, Amanollahi et al., 2017) is a critical indicator of wetland health. Chl-*a* has been used as an indicator to identify biomass of the primary conductivity in coastal areas, estuaries, oceanic waters, and lakes. It has also been widely used as an indicator of the water quality because it is possible to estimate algal biomass, which can affect the changes in aquatic environments (Baek et al. 2019; Yin et al. 2016). A considerable concentration of phytoplankton and algae is important for the biological productive and health of a water system however excessive concentration of chlorophyll is not desirable because that will cause an increase in the eutrophic condition of a water body and this will result in increment of phytoplankton of standing crop (Patra et al. 2017). Eutrophication is defined as an aquatic ecosystems response to nutrient loading, the ability to identify important factors and predict subsequent algal blooms with the use of a chl-*a* is very important when it comes to water resources management (Bbalali et al. 2013). High levels of chl-*a* concentration generally indicate a change in trophic status of waterbodies, and it is usually related to reduction in water quality and low biodiversity which severely undermine

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the ecosystem services and functions. In order to restore these services and functions it is of importance to have an understanding of chl-*a* concentrations dynamics (Dalu et al. 2015). High concentrations of chlorophyll may also deteriorates water quality by external and internal nutrient loading, which in most cases leads to disappearance of benthic fauna and greatly affects aquatic organisms (Patra et al. 2016).

So far, different approaches have been developed to estimate and map chl-a concentrations in water bodies. Methods for measuring chlorophyll-*a* can be divided into direct and indirect methods (Baek et al. 2019). Direct methods (such as traditional methods) are based on the use in-situ measurements while indirect methods (such as remote sensing) provide chlorophyll-*a* estimates through the optical water characteristics (Baek et al. 2019). Traditional methods used to assess chlorophyll-a depends on in-situ measurements or laboratory analysis of the samples and although this might provide accurate measurements, it is time consuming and laborious (Abdelmalik, 2018). Field data might be compromised due to inadequate quality control and quality assurance protocols during and after field data collection especially in cases where field samples have to be stored for a certain period of time before they can be analysed (Dube et al. 2015). On the other hand, remote sensing in assessing chlorophyll-a provides information on the physical and chemical properties at temporal and physical scale (Yin et al. 2016).

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The use of remotely sensed data in assessing water quality data dates back to the early 1920s in different parts of the world (Wang et al. 2004), with Landsat Thematic Mapper (TM), which uses the visible and near-infrared spectral bands, being the sensor most widely-used to monitor inland waters. The sensor's spectral characteristics and its 30 m pixel resolution have been used to determine the relationship between the reflectance of waterbodies and their biophysical parameters such as chl-*a* concentration (phytoplankton) and mineral suspended matter in water bodies (Dube et al., 2015). Then recently, the 30 m resolution Landsat 8 Operational Land Imager (OLI) combined with high global data availability, present a unique platform which provide the first and most up-to-date global inventory of the world's lakes and water quality information retrieval at high spatial resolution and positional accuracy using recent Landsat algorithms (Patra et al. 2016). In the last three decades remote sensing has played an increasing role in water quality studies, due to its technological advances including instrument/sensor and algorithm/image processing improvements (Dube et al., 2015). Remote sensing has the potential to present synoptic estimates of chl-*a* concentration in aquatic

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ecosystems as it provides rapid, temporal and synoptic information on the state of the water body, with no interpretive problems associated with under-sampling that are usually experienced through traditional methods (Dalu et al. 2015). Satellite-based remote sensing is increasingly playing a fundamental role in providing value information about chlorophyll in water bodies dominated by cyanobacteria and algal blooms globally (Malahlela et al., 2018).

The aim of the study was to evaluate and map chlorophyll-*a* concentration changes in Makuleke and Nylsvlei wetland during the 2018 and 2019 period. Considering that these wetlands are located in nature reserves so if they are being affected by excessive amounts of chlorophyll this may greatly affect wetland productivity and their recreational use. This will result in the ecosystem value of these wetlands being degraded. Therefore, monitoring of chl-*a* in both unprotected and protected wetlands is of importance because protection of water resources would satisfy the water demand in different sectors, aid in assessing water quality in the unmonitored watershed as monitoring in field is expensive and time consuming and hence, the acquired knowledge would provide guidelines in the management of these water resource.

4.2 Material and methods

4.2.1 Remote sensing data acquisition and pre-processing

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Four medium spatial resolution (30 m) multispectral Landsat 8 OLI images were acquired over the two nature reserves (Makuleke and Nylsvlei) between 2018-2019 and used to derive chlorophyll-*a* estimates. The Landsat 8 OLI exhibits higher radiometric resolution wavelength coverage than the Landsat 7 Enhanced Thematic Mapper plus (ETM+) bands hence the use of Landsat 8 images. These images were downloaded free of change from the National Aeronautics and Space Administration (NASA) and United States Geological Earth Explore (USGS) (https://earthexplorer.usgs.gov/). All image data from the Landsat 8 OLI were in GeoTIFF format provided by the US Geological Survey Earth Explorer. Table 4.1 has the specifics of these images that were used. The selection of Landsat satellite images was influenced by the quality of the images, so only images with < 10% cloud coverage were selected because cloud cover could compromise the accuracy of the classified images and by the month in which field measurements were taken. Landsat 8 bands used in this study are available every 16 days with a spatial resolution of 30m. Satellite image pre-processing

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before any detection of change is greatly needed and has a primary unique objective of establishing a more direct affiliation between the acquired data and biophysical phenomena (Butt et al. 2015). Atmospheric correction is important step in any satellite image that observes the surface of the earth. Therefore, to obtain accurate and precise quantitative data using remote sensing, it is necessary to perform atmospheric correction (Abdelmalik, 2018). In the current study the Landsat 8 images were atmospherically corrected using semi-automatic classification tool using common GIS tools in ArcGIS.

Table 4. 1: Satellite images specifications.

Catchment	Sensor ID	Path/row	Date
Makuleke	LC08_L1TP_169076	169_076	09-2018
	LCO8_L1TP_169076	169_076	06-2019
Nylsvlei	LCO8_LITP_170077	170_077	09-2018
	LCO8_L1TP_170077	**170_077**	**06-2019**

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4.2.2 In-situ measurements of Chlorophyll-*a*

Field data measurements were collected in the month of September 2018 and June 2019 from Makuleke and Nylsvlei wetlands, respectively. On average, five samples (three samples were taken per point for all five sampling points and the average was used as the reading for that specific point). Water samples for chl-*a* concentration determination were collected along the water column during the day at each site and stored on ice for processing in the laboratory. The water samples were used for chlorophyll-*a* extraction in 90% acetone using the spectroscopic method according. This is also the same method that was used by Aminot and Rey (2000) and recently by Dalu et al., (2013) in monitoring chlorophyll-*a* concentration. The acetone method involves the measurement of chl-*a* concentrations by extracting chlorophyll dye from the filter paper using acetone. The chl-*a* concentrations were then calculated by measuring the absorbance of the dye extract at 663, 645, 630, and 750 nm. The

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actual amount of chlorophyll was measured by the subtraction of the absorbance values at 750 nm from the absorbance values of the sample at 663, 645, and 630 nm. This data set was used for validation and for producing the maps.

4.2.3 Mapping of the wetlands

Multi-Landsat images were classified to derive key land cover types such as up-built areas, bare lands, vegetation and other water bodies. The normalised difference water index (NDWI) and Normalized Difference Vegetation Index (NDVI) were also computed to estimate chl-a. The NDWI provides critical water information and effectively extract the water body information from the other land surface features. NDWI is very useful for revealing water-related features of wetlands (Orimoloye et al. 2020). Therefore this index was used to extract and map wetlands before extracting chlorophyll *a* concentrations in both wetlands. The NDWI index, indicate wetness and is used as wetland inundated area proxies. Where a wetland is covered by hydric soils or is dry the NDWI values are expected to be low. On the other hand, NDWI values are expected to increase with increasing moisture presence. NDWI was established by McFeeters (1996) (Equation 1). The NDWI values ranges between -1 to +1 where, positive values predict water and negative value predicts non-water.

$$NDWI = \frac{Green - NIR}{Green + NIR} \quad (1)$$

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Where, NIR is the reflectance in the near-infrared band; Green is the reflectance in the green band.

4.2.4 Chlorophyll-*a* estimation from Landsat data

This study utilized visible bands (blue, green, and red) and a near infrared (NIR) band, to determine chl-*a* concentration because this is where chl-*a* is at peak. The study done by Amanollahi et al., (2017) showed that band 4 with wavelength between 663nm-668nm presents the best results in estimating Chlorophyll-*a*. Normalized Difference Vegetation Index (NDVI) and Chl-*a* have a strong correlation hence both indices are commonly used to measure plant primary productivity and biomass especially in water bodies such as wetlands

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(Kulawardhana et al. 2007). Due to the high NIR reflectance of chlorophyll, NDVI index is used to chl-*a*. NDVI as a commonly used vegetation index, can effectively reflect the vegetation information (Ma et al., 2018) and can be used as an numerical indicator for biomass hence can be used as a proxy for estimating Chl-*a* concentration from remotely sensed data (Dube, 2012). NDVI is considered as one of the most accurate indices (Mwita, 2016). The NDVI was computed using the red and near-infrared bands of the recently launched Landsat 8 multispectral imagery acquired over Makuleke and Nylsvlei wetlands using the atmospherically corrected images of Landsat 8. NDVI was calculated following Tucker (1979) as follows:

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red} \quad (2)$$

Where, NIR is reflectance in the near infrared region of the electromagnetic spectrum (band 5 of Landsat 8) while Red is the reflectance in the red region of the electromagnetic spectrum (Landsat 8 band 4). NDVI is a dimensionless index with values ranging from -1 to +1. In tropical environments, previous research has shown that NDVI values below 0 indicate water, those above 0 but less than 0.1 are associated with bare surfaces while those in the 0.5 to 1 range indicate dense green vegetation (Tucker.1979). However, when wetlands have natural vegetation the NDVI values will differ depending on vegetation density and vigour of each wetland. Chl-a concentration was then derived from the green chlorophyll index (CI_{green})

$$CI_{green} = \frac{\text{NIR}}{\text{green}} - 1 \quad (3)$$

Where, NIR is reflectance in the near infrared region of the electromagnetic spectrum (band 5 of Landsat 8) while Green is the reflectance in the green region of the electromagnetic spectrum (Landsat 8 band 3).

4.2.5 Accuracy Assessment

Landsat-derived chlorophyll-*a* concentrations were validated using field-derived chl-*a* measurements that were taken during sampling. Five sampling points were used to validate the remotely sensed chl-*a* estimates. These samples that were taken in the field were plotted on the classified imagery with the remotely sensed estimates using their GPS coordinates. Validation was implemented to assess the reliability of the remotely sensed chl-*a* estimates. To achieve this objective, the Root Mean Square (RMSE) was used to assess the predictive

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error of the model between what is measured in the field and what is predicted using the Landsat imagery. The RMSE is the measure of the average magnitude of the error. Its values range from 0 to infinity. Low RMSE values indicate accurate model estimation and vice versa (See equation (4)) (Dalu et al. 2015). Figure 4.1 shows a summary of the methods.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(yi - yi^{\wedge})^2} \tag{4}$$

Where, where yi is the measured chlorophyll-a concentrations, yi ^ is Landsat data-derived chlorophyll-a estimates and n are the number of the observations.

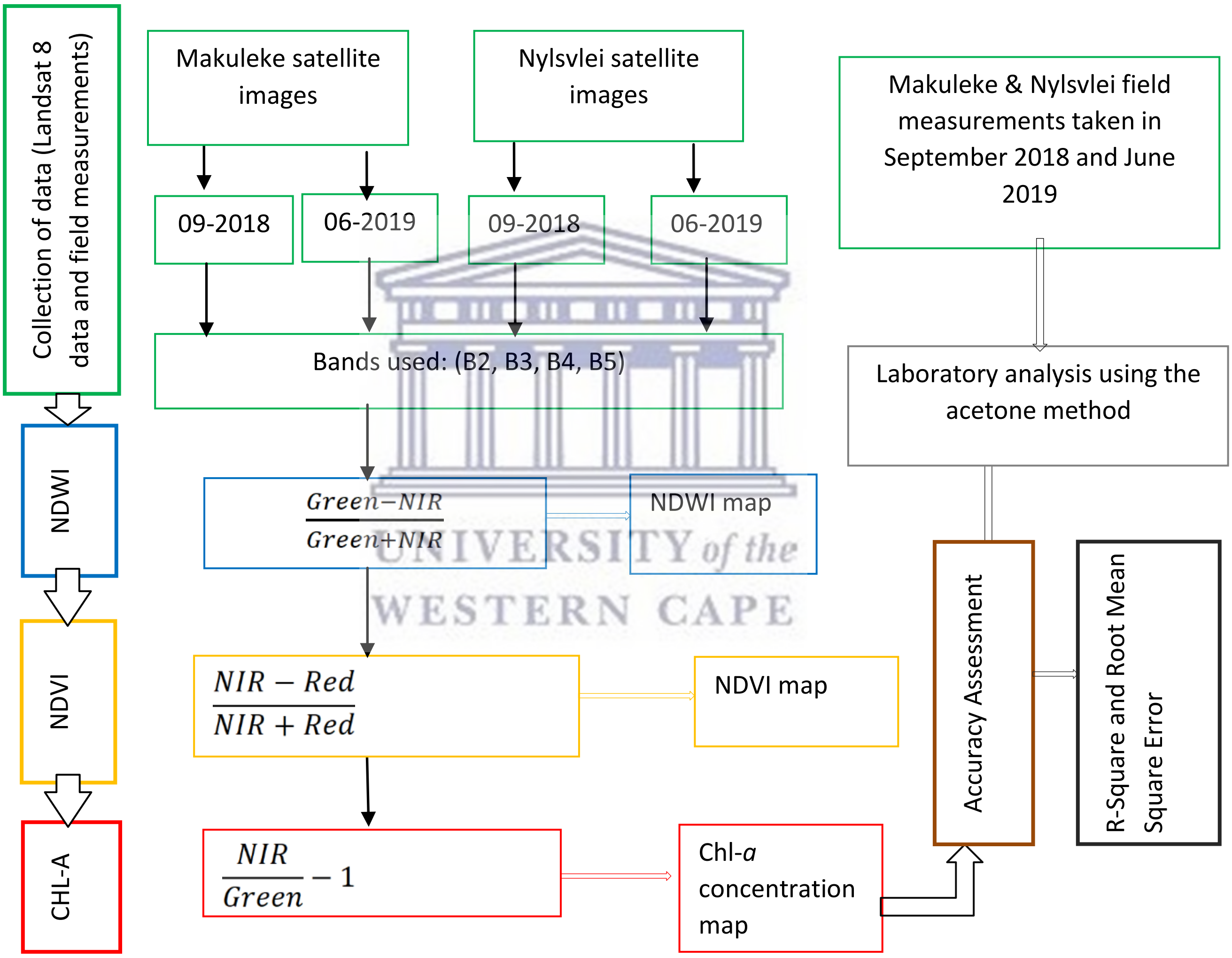

Figure 4. 1: Summary of the methods used

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4.3 Results

4.3.1 Field measurements

In situ chl-*a* concentrations of Nylsvlei and Makuleke varied significantly, ranging from 0 µg/L to 1.42 µg/L. The highest value of chl-*a* concentration was observed in June 2019 in Nylsvlei wetland (1.42µg/L). Chl-*a* concentrations ranged between 0.27 µg/L and 1.39µg/L for during the month of September 2018 with a mean value of 0.48 µg/L. Makuleke wetland in June 2019, chl-*a* had a mean of 0.58 µg/L, and a standard deviation of 0.38 µg/L. During the month of September 2018, the chl-*a* concentration ranged between 0.07 µg/L to 0.64µg/L with a mean value of 0.35 µg/L. During the month of June 2019, chl-*a* ranged between 0 to 1.42 µg/L (mean =0.48 µg/L, standard deviation = 0.49µg/L) for Nylsvlei wetland (See Table 4.2). Chlorophyll-*a* (chl-*a*) levels were generally high during the June and lowest in the months of September.

Table 4. 2: Chl-*a* summary statistics for Makuleke and Nylsvlei wetland (September 2018 and June 2019 period)

Parameter	**Makuleke**		**Nylsvlei**	
	September 2018	June 2019	September 2018	June 2019
Mean	0.48	0.58	0.35	0.48
Median	0.39	0.46	0.4	0.3
Mode	n/a	n/a	0.4	0.16
Standard Dev.	0.21	0.38	0.19	0.49
Range	0.58	1.12	0.52	1.54
Minimum	0.27	0	0.07	0
Maximum	0.85	1.39	0.64	1.42

4.3.2 Chl-*a* concentration predicted using Remote sensed data

The variation of chl-*a* concentration during the study period is shown in Figure 4.2 (a -b) for Makuleke and Figure 4.2 (c-d) for Nylsvlei. Chl-*a* concentration in Makuleke ranged from -0.10 to 1.15 µg/L and for Nylsvlei wetland Chl-a ranged between -0.16 to 1.42 µg/L for the period understudy. The results showed that most of the chl-*a* concentrations are mainly found along the edges of the wetlands.

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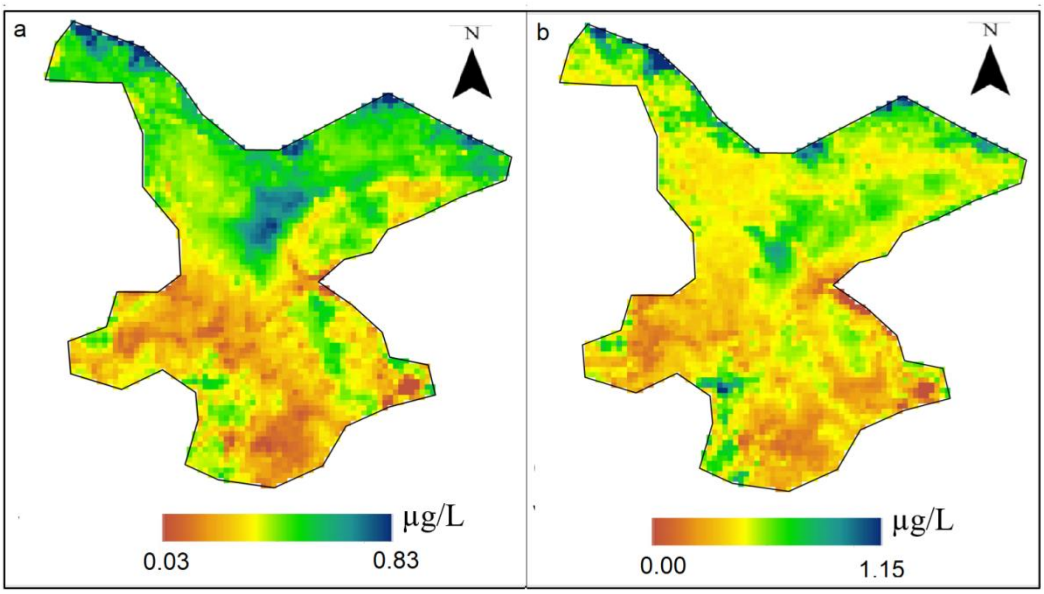

Figure 4. 2 (a-b): Depicts chl-*a* concentrations over the Makuleke wetland during (a) September 2018 and (b) June 2019

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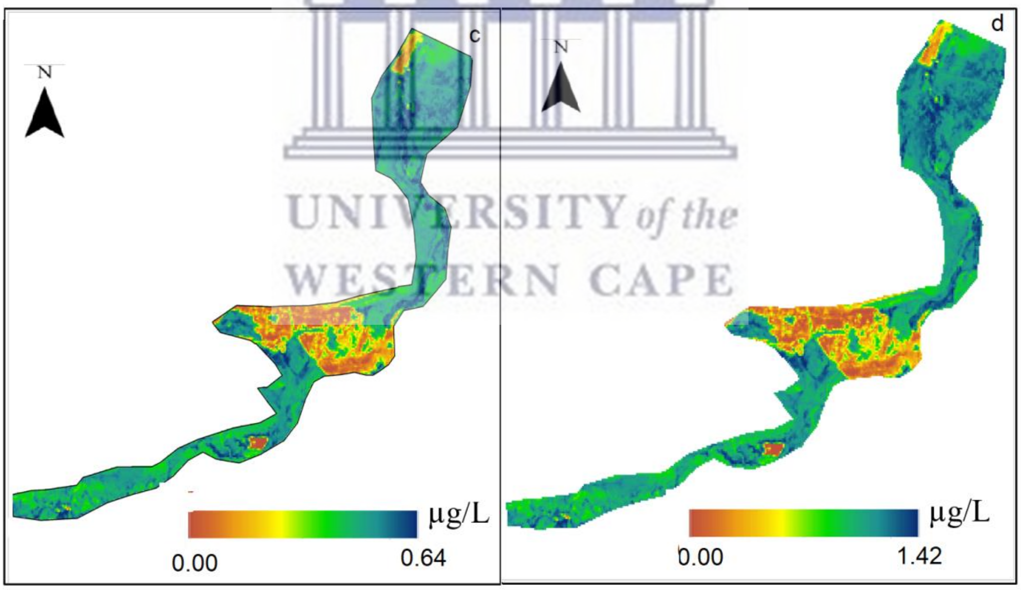

Figure 4.2 (c-d): Landsat derived spatial distribution chl-*a* concentrations over the Nylsvlei wetland during (a) September 2018 and (b) June 2019

4.3.3 Comparison of both field measurements and remote sensed data

Chlorophyll-*a* concentration results for Makuleke and Nylsvlei wetlands in terms of the coefficient of determination (R^2) and root mean square error (RMSE). The results indicate

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that Landsat at some points accurately estimated chlorophyll-*a* concentration and underestimated in some areas when compared to the field measurements. Landsat 8 predicted chl-*a* vs. observed chl-*a* concentrations produced an R^2 value of 0.95 and a root mean error of 0.04 for September 2018 and for June 2019 the R^2 value of 0.97 and a root mean error of 0.16 µg/L for Makuleke (See Figure 4.3a-b). While for Nylsvlei the R^2 value of 0.95 and 0.06 µg/L RMSE for September 2018 and for June 2019 the R^2 value of 0.92 and 0.26 µg/L RMSE (Figure 4.3 (c-d)).

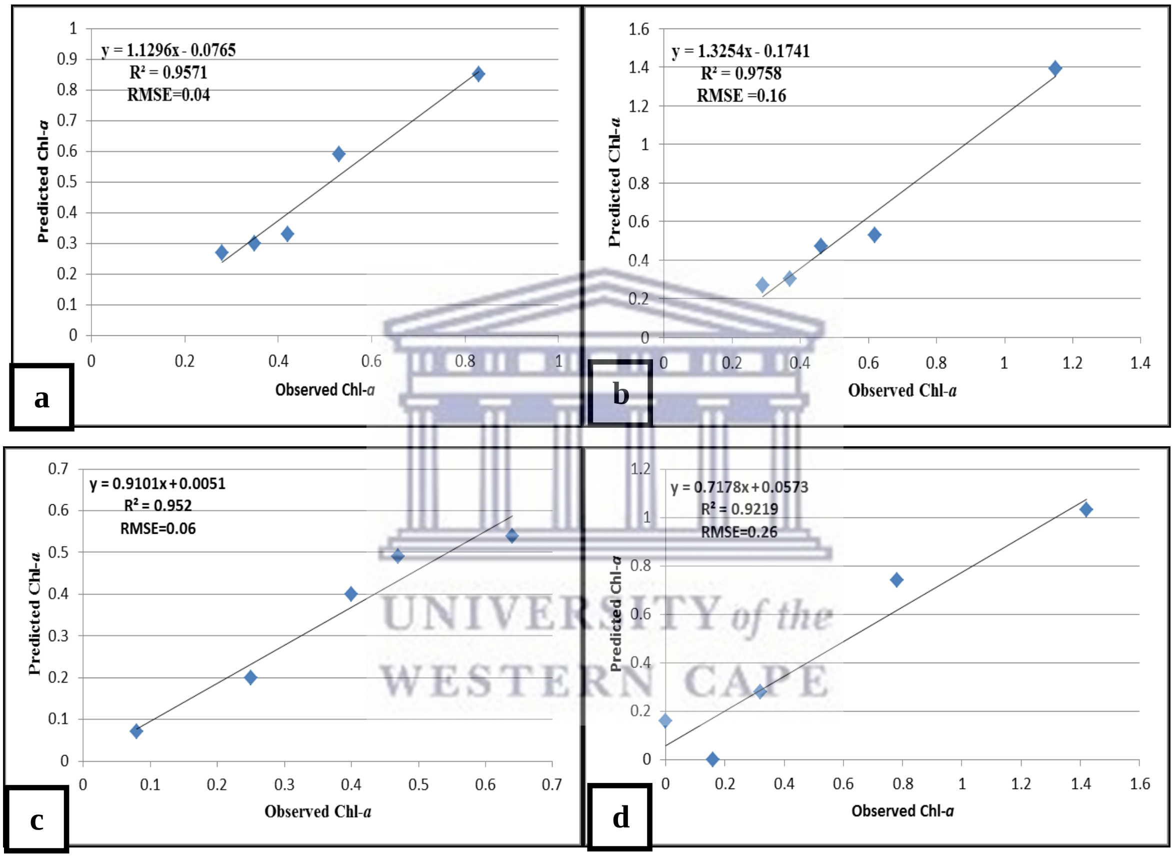

Figure 4. 3 (a-d): Relationships between the observed (field measurements) vs. the predicted (Chl-*a*) values (a) September 2018, (b) June 2019 for Makuleke wetland, (c) September 2018 and (d) June 2019 for Nylsvlei wetland

4.4 Discussion

This present study aimed to investigate chl-*a* concentrations in Nylsvlei and Makuleke Nature Reserve wetlands in the Limpopo Transfrontier River Basin, South Africa. Chl-*a* concentrations were used as an indicator to assess these two wetlands health. This study

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demonstrates the importance of using satellite data in monitoring chlorophyll-*a* variations in wetlands, especially in remote areas. The Normalized Difference Water Index (NDWI) values between September 2018 and June 2019 effectively depicted the depletion of the water in Makuleke and Nylsvlei wetlands which might be as a result of natural or human activities which may include climate change, built-up areas and agricultural activities. In such environments, there will be an increase in algal and this will cause a decline in biodiversity status causing high levels of eutrophication in the environment which will greatly affects the wetland and causing some physiochemical properties in water to change.

Chl-*a* mainly reflects green, absorbs most energy from wavelengths of violet-blue and orange-red light, which causes chlorophyll to appear green in a water body (Gholizadeh et al., 2016). An increase in chl-*a* amounts may lead to a decrease in light permeability in water and thus decrease in oxygen produced by photosynthesis (Gönülal and Aslan 2019). From the Landsat 8 data acquired for both wetlands, high concentrations of chl-*a* were estimated to be in the edges part of the wetlands in comparison to the rest of the wetland. From the analysis of the image, it becomes apparent that wind could be the cause why there is high concentration of chl-*a* especially at the edges of both wetlands. Another factor that could be cause of spatial chlorophyll changes may be a response to seasonal variability. These variations in temperature causes a situation in which the growth rates of freshwater eukaryotic phytoplankton generally stabilise, while growth rates of many cyanobacteria increase, thereby providing a competitive advantage (Paerl and Huisman, 2009). Therefore, as a result, water quality in many wetlands has declined progressively over the past several decades because of the increasing usage of recycled water in wetlands and the inflow of nutrients from agricultural and urban areas (Guo et al. 2017).

The derived chl-*a* estimates demonstrated distinct variations across the two-year period understudy for both wetlands, in some parts of the wetlands the concentration of chl-*a* was considerable low and even non-existent in other parts of the wetlands. Chl-*a* concentration derived from the Landsat satellite images were low for most parts of the wetlands, which could probably be attributed to reduced water levels. Therefore, the spatio-temporal variation in chlorophyll-*a* concentration within the reservoir is most likely due to seasonal changes.

Chl-*a* concentrations were considerable high in June 2019 than in September 2018 for both Nylsvlei and Makuleke wetlands. As shown by Gönülal and Aslan (2019) some factors that

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results in chl-*a* concentration are high concentrations of nitrogen and phosphorus, which are caused by nutrients in aquatic ecosystems. Even though these elements are necessary for the biochemical cycle, are usually incorporated into the water by anthropogenic activities and their excessive amounts lead to eutrophication which causes serious environmental problems in the aquatic ecosystem. Increase in chl-*a* concentrations in most cases indicate a change in tropic status of a water body and it is usually associated with decrease in water quality and low biodiversity which adversely destabilizes the ecosystem services and functions (Dalu et al. 2015). An increase in chl-*a* concentration may lead to decrease in light permeability in water and thus decrease in oxygen produced by photosynthesis and this usually prevent the bacteria that decomposes organic matter in the sediment and restore the ecosystem (Gönülal and Aslan 2019).

The study done by Dalu et al., (2015) showed that low chlorophyll-*a* concentrations could most likely be attributed to dilution due to freshwater inflow and increased sediment loads which would have limited primary production rates. The low chl-a concentration could also be due to a combination of increased water depth and sediment resuspension taking place in the wetlands or could be caused by dilution due to freshwater inflow and increased sediment loads which would have limited primary production rates. Increased water temperature and low water level, may have an effect on dissolved oxygen values, while an increase in chlorophyll-a amounts may lead to a decrease in light permeability in water and thus decrease in oxygen produced by photosynthesis (Gönülal and Aslan 2019). This can be the case for these wetlands considering where these wetlands are located. The other factor that might have contributed to low concentrations of chl-*a* being predicted in both study areas is that even though estimating chlorophyll through remote sensing techniques is possible the use of Landsat 8 might not permit discrimination of chlorophyll in waters with high suspended sediments due to dominance of the spectral signature from the suspended sediments (Ritchie et al., 2003). The study done by Nilsaz et al., (2010) showed that high levels of turbidity affect the predicting of chl-*a* and this is mostly evident during rainy seasons compared to dry seasons. High water suspended solid affects light penetration in the water resulting in low primary production (Ghorbani, 2016). This might have contributed to low levels of chlorophyll-a being predicted in this study.

The concentration changes can be attributed to several factors especially during planting season in the catchment area, and nutrients are washed into the lake with the first rainfall

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(Ndungu et al. 2013). At the same time, the rainfall period leads to clearer water, thereby promoting light penetration into the water column of the lake. These changes are probably attributable to the ever increasing multiple stressors, such as increased agricultural activities, urbanization and climate change. Other studies have stipulated the trophic state is influenced by forcing factors such as eutrophication and sediment loads. The effects of the forcing factors also can be modified by other accompanying factors such as season, agricultural activities in the catchments, algal grazing and mixing depth which, in turn, can play a role in the prevailing water transparency status (Ndungu et al. 2013).Another factor that can affect chl-a concentration in these wetlands is that wetland species appear to vary greatly in chlorophyll and biomass reflectance as a function of plant species and hydrologic regime. Spectral behaviour of wetland vegetation is also influenced by leaf water content which determines the absorption of the mid-infrared region. Red reflectance increases with leaf water stress through an association with a reduction in chlorophyll concentration (Adam et al., 2010).

4.5 Conclusion

The aim of the study was to assess and map chlorophyll-*a* concentration changes in Makuleke and Nylsvlei wetland during the 2018-2019 period. Chlorophyll-*a* is an indicator of the abundance of phytoplankton, which make an important contribution to overall primary productivity of water bodies such as wetlands. Therefore, using remote sensing techniques to predict and map chl-*a* concentration is of important in the monitoring and assessing of water quality in wetlands especially because of remote sensing techniques ability to measure chlorophyll concentration spatially and temporally. The results demonstrate that Landsat 8 OLI data could provide a useful tool for investigating the spatio-temporal variability of chl-*a* in wetlands especially in remote areas that are not easily accessible.

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CHAPTER FIVE

The use of remote sensing data for assessing water quality in wetlands within the Limpopo River Basin South Africa: Synthesis

Typical wetland in the Limpopo Transfrontier River Basin: Photo courtesy Dr. Dalu 2020

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5.1 Introduction

Wetlands are amongst the most productive ecosystems in the world however they are not exempted from factors within and around their catchments.Wetlands are influenced by changes in the composition of land uses due to human activities within their catchments (Haidary et al. 2013). There is a need to understand the pattern and trends of LULC changes and associated impacts on wetlands water quality. Understanding the relationships between land use and water quality is of important for wetland management and conservation. Numerous studies (Haidary et al. 2013, Ding et al. 2016, Giri and Qiu 2016, Namugize et al., 2018, Zhang et al. 2019) have concluded that LULC changes have numerous negative impacts on the water quality of a watercourse. Remote sensed data is useful in mapping land use and land cover changes. Landsat 8 sensor’s spectral characteristics and its 30 m pixel

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resolution have been used to map LULC changes and to determine the relationship between the reflectance of waterbodies and their biophysical parameters such as chl-*a* concentration. Remote sensing has the potential to present synoptic estimates of chl-*a* concentration in aquatic ecosystems as it provides rapid, temporal and synoptic information on the state of the water body. Therefore, the objectives of this study were to:

1. To assess the impacts of land use and land cover (LULC) changes on two wetland systems (Makuleke and Nylsvlei Nature Reserve) in the Limpopo Transfrontier River Basin (LTRB) in South Africa between 2014 and 2018.
2. To estimate Chlorophyll-*a* concentrations (water quality) and associated dynamics in two tropical wetland systems (Makuleke and Nylsvlei) located in the Limpopo Transboundary River Basin, South Africa.

5.2 Findings summary

Landsat 8 images were used to assess and detect LULC changes in the Makuleke and Nysvlei Nature Reserves. In this present study, the results obtained showed the reliability of Landsat 8 images in detecting land use and land cover changes. The overall accuracy obtained during classification process is in conformance within the minimum threshold of 65 to 85% with overall accuracy between 80 to 89%, therefore the maps produced an acceptable overall accuracy, with the producer and user accuracies above 70% for most of the classes. Some of the noticeable changes were that the coverage of natural vegetation tends to increase during wet seasons compared to dry season and the spatial extent of Makuleke declined by 2% between 2014 and 2018, on the other hand, Nylsvlei wetland decreased by 3%.

Remote sensing data showed a great potential in predicting chlorophyll-*a* concentrations and associated dynamics in two tropical wetland systems were estimated. For September 2018 and June 2019 Moderate resolution Landsat 8 images and in-situ field measurements were used to estimate and map chlorophyll-*a* concentrations. The relationship between field measured and Landsat data-derived chlorophyll estimates were determined using the coefficient of determination (r-square: R^2) and the Root Mean Square Error (RMSE). The results show that Makuleke wetland had low estimates during the month of September 2018. The variation of chl-*a* concentration in Makuleke ranged from 0 to1.15 µg/L whereas for Nylsvlei wetland the ranges varied between 0 and 1.42µg/L, for the period understudy. The

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results demonstrate that Landsat 8 OLI data could provide a useful tool for investigating the spatio-temporal variability of chl-*a* in wetlands especially in remote areas.

5.3 Conclusions

This study focused on assessing the impacts of LULC change dynamics on the protected wetland systems (Makuleke and Nylsvlei) water quality (chlorophyll-*a*) in the Limpopo River Basin in South Africa between the periods of 2014 to 2019. Some of the major conclusions were:

- Landsat images with its improved capabilities were used to map the spatiotemporal pattern of wetland change of two study sites.
- Landsat data managed to map wetland ecosystems for Makuleke and Nylsvlei with high classification accuracy ranging from 80% to 89% seasonally over the period of 5-years.
- Even though these wetlands are protected (Makuleke and Nylsvlei) they are not free from threats which are intensified by the expansion of LULC changes within and around the protected boundaries, therefore the importance of monitoring these changes.
- Understanding the spatial and temporal variability in Chl-*a* concentrations at wetland scale is important in the monitoring and assessing of wetland water quality.
- Spatial characterization of Chl-*a* concentration significantly varied across the two wetlands with much concentrated along wetland shorelines.
- Furthermore, results suggest that built-up and agricultural activities around these wetlands are contributing to increase in chl-*a* concentration.
- Increase sediment concentration caused by agricultural activities reduces oxygen level in these wetlands and built-up areas results in more permeable surfaces which contributes to nutrients easily being washed into these wetlands which contributes to chl-*a* concentrations in these wetlands.

The finding of this study can be used in enforcing of wetland legislation and LULC management practices and highlights the relevance of remotely sensed data in assessing and routine monitoring wetland water quality.

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5.4 Recommendations

Based on this present study these are the recommendations recommended:

1. There is a need to monitor activities that are taking place within the protected boundaries of wetlands in order to safeguard these resources.
2. Spatial explicit methodology and wetland monitoring frameworks are crucial in determining wetland condition particularly in data limited and not easily accessible environments.
3. Mapping of chlorophyll-*a* in water bodies especially wetlands should be a consistent procedures especially in areas affected with anthropogenic and natural activities.
4. The government should hold workshops and training on the importance of proper environmental management around wetlands, so that more could be educated about these precious resources.
5. Management agencies should also consider monitoring nitrate and phosphorous more often and incorporate those results in monitoring chl-*a* assessments.

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