ASSESSING CURRENT AND FUTURE RANGELAND RESOURCES USING REMOTE SENSING IN VHEMBE DISTRICT, SOUTH AFRICA

Henry Nuwarinda

(Student N0: 2018712261)

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Geography

at

The Faculty of Natural and Agricultural Sciences, Geography Department

University of the Free State

South Africa

Promoter: Prof Samuel Adelabu,

Co-Promoter: Prof Abel Ramoelo,

29 November 2023

ACKNOWLEDGMENTS

I am indelibly grateful to my supervisors and mentors, Prof. Abel Ramoelo and Prof. Samuel Adelabu. You tirelessly and generously gave me constructive comments and guided me out of the woods. To Prof Abel, thank you for your constant encouragement, and evaluation of my assumptions, and for stretching my capacities despite your busy schedule.

I'm grateful to Dr. Katlego Mashiane for his candid and technical support for pushing me to the limit and for encouraging me to stand strong right through this study. Thank you for your significant statistical contributions and for instilling courage and hope in completing this study.

I am grateful to Azwifaneli Davhula for using his precious time at the inception of this study to encourage me to advance my skills in Remote Sensing and GIS and for crunching the numbers to come up with the very first paper of this study.

I would also like to thank Prof Okello Tom and Dr Matthew Ojelede for always encouraging and supporting me when I needed it the most, especially Prof Okello for his words of wisdom and instilling courage and most importantly giving me hope when I needed it the most.

I thank my wife Kukundakwe and our boys Bakama, Mutahinduka and Mutasingwa who had to tolerate my withdrawal from them for periods of time and for standing in the gap for me.

DEDICATION

This work is dedicated to my dearest mother Mrs. Anna Barugahare (Late) . Mama you will always have a special place in my heart and in our family. Thank you for being a mother to us.

DECLARATION

I, Hery Nuwarinda, declare that the thesis that I herewith submit for the Doctoral Degree in Geography at the University of the Free State, is my independent work, and that I have not previously submitted it for a qualification at another institution of higher education.

--------------------------- --------------------------

Student's Signature Date

Faculty of Natural and Agricultural Sciences,
Geography Department

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

1. Prof Samuel Adelabu Signed ___________________ Date ________________

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

2. Prof. Abele Rameolo Signed _____________________ Date ________________

ABSTRACT

In the Vhembe Biosphere and its surroundings, the problem of natural resource change and biodiversity loss has become an urgent issue. The region is highly dependent on biodiversity resources to meet basic needs for fuelwood, building materials and livestock feed. However, these resources are threatened by ongoing land degradation. Traditional methods of data collection like direct and indirect personal interviews, using questionnaire or an interpreter have proven time-consuming and cumbersome. To address these challenges, this study explores the potential of remote sensing technology to identify key indicators of natural resources, including vegetation cover (i.e., trees, grasses, and shrubs).

This study aimed to assess the condition and changes of natural resources in the Vhembe Biosphere and its immediate surroundings. Understanding these changes is crucial in biodiversity conservation and sustainable resource management. We investigated the factors driving these changes, particularly those related to vegetation cover, a critical factor for ecosystem change or biodiversity loss in Vhembe Biosphere region. Socio-economic factors influence on biodiversity loss were investigated together with the complicated interplay between socio- economic conditions and environmental factors about biodiversity loss.

The study used quantitative research approach to achieve its objectives. A comprehensive analysis of South Africa's national land cover dataset, compiled from multi-year Landsat-5 and Sentinel-2 imagery, served as the central data for assessing changes in natural resources. In addition, a detailed investigation of the factors responsible for these changes was carried out using generalized linear models to identify the most critical factors contributing to vegetation cover change. Socio-economic parameters such as education, employment and income levels were studied to understand their impact on biodiversity loss in the Vhembe Biosphere. Finally the study investigated the dynamic relationship between socio-economic factors and environmental variables and their role in biodiversity loss.

The study revealed the complex relationship between human activities and natural factors in shaping changes in natural resources. The results showed that land use activities, especially bush encroachment, directly threaten natural resource change. At the same time, climate variables were found to be a significant driver exacerbating these changes, further

highlighting the complicated interplay between human activities and environmental influences. In addition, the educational level of the population had a significant impact on biodiversity, highlighting the need for conservation education and outreach to curb the exploitation of biodiversity resources.

The findings underscore the need for a multidisciplinary approach to biodiversity loss that includes scientific measures to reduce the negative impacts of human activities and natural forces. In particular, we highlighted the importance of strategies to mitigate and adapt to unpredictable patterns of climate change. Awareness raising and conservation education in communities around the Vhembe Biosphere were identified as critical elements in promoting positive conservation values and behaviour. In addition, the sharing of indigenous and local knowledge together with scientific knowledge was seen as an effective approach to addressing the challenges of biodiversity loss and developing effective climate change mitigation strategies.

This study has explored the complexity of natural resource changes and causes of biodiversity loss in the Vhembe Biosphere and surrounding areas. It has highlighted the interplay of human activities and environmental factors as the main drivers of natural resource change, emphasizing the role of land use and climate change. It has also highlighted the significant influence of education and socio-economic conditions on biodiversity. These findings highlight the multidimensional nature of biodiversity loss and its causes and underscore the need for comprehensive and integrative strategies to address this problem.

The study makes several recommendations for dealing with biodiversity loss in the region. First and foremost, we suggest that scientific measures like environmental education and awareness, conservation and restoration, sustainable resource management, and climate change mitigation be taken to mitigate the impact of human activities and environmental factors on natural resources. Strategies to adapt to unpredictable climate change should be developed and implemented. Promoting education and awareness of surrounding communities on biodiversity conservation is crucial to promote positive values and behaviour. Promoting the sharing of indigenous and local knowledge together with scientific knowledge can enhance the diversity of perspectives and integrated approaches to addressing the challenges of biodiversity loss and developing effective mitigation strategies.

This study serves as a foundation for future research on biodiversity loss and its management in Vhembe biosphere and similar regions. Further studies could explore a more comprehensive examination of the interactions between human activities and biodiversity, as well as innovative conservation strategies specific to the Vhembe Biosphere and similar regions.

Key Words: *Biodiversity Loss, Natural Resource Change, Vhembe Biosphere, Remote Sensing, Socio-economic Factors, Climate Change, Conservation Education*

TABLE OF CONTENTS

LIST OF FIGURES

List of Tables

CHAPTER ONE

INTRODUCTION

This chapter introduces biodiversity resources its current status and the challenges locally and globally .

1. Background of the study

Biodiversity resources refer to the diversity and variability of natural resources among living organisms (Gaston et al., 2013; Koziell et al., 2001), the ecological complexes in which they naturally occur (Oberle et al., 2019; DeLong 1996), and how they interact with each other and with the physical environment (Yu et al., 2013). Biodiversity resources are natural landscapes that occur in enormous forms (Cantonati et al., 2020). Forests, scrublands, wetlands, deserts in Africa and the rest of the world (Sachs et al., 2022; Friedel, et al., 2000). Biodiversity resources contribute immensely to meeting basic human needs in the form of agricultural land, livestock grazing, building materials and food (Crenna et al., 2019; Sandstrom et al., 2017).

Past and present extraction and processing of materials, including fuel and food, accounts for 90% of biodiversity loss (D'Adamo 2019; Hertwich 2010). Biodiversity loss is cited as one of the triple planetary crisis, including pollution and climate change (Cardinale et al., 2012). Living Planet report, IPBES-IPCC indicate that biodiversity loss is caused by invasive alien species, climate change, pollution, unsustainable utilisation of the natural resources and land use change (Portner et al., 2021; Grooten et al., 2018). Globally and in Africa, biodiversity resources and ecosystems are under threat from human activities (Maximillian et al. 2019; Barlow et al. 2018; Payet et al., 2010), for example deforestation, overfishing, pollution and climate change (Muluneh 2021; Watson et al., 2019; Barlow et al., 2018). The call to protect biodiversity resources, restore terrestrial ecosystems (Sachs et al., 2022) and manage them sustainably (Mbow et al., 2017; Whiting et al., 2004; Aronson et al., 1993) is more important than ever. The complexity of natural resource ecosystems, the current challenges of global climate change and increasing population growth worldwide mean that the sustainability and productivity of biosphere resources is becoming increasingly unsustainable (Kleemann et al., 2017; Clark et al., 2016; Mollinga 2010), which is a problem in Africa and specifically in South Africa.

In South Africa, biodiversity areas are among the ecosystems affected by severe land cover changes (McGranahan, et al., 2013). This is due to uncontrollable land degradation, excessive livestock production, seasonal forest fires, inadequate water sources (Koziell et al., 2001) and limited policy attention to biodiversity management and restoration (McGranahan, et al., 2013; Coetzer, et al., 2012). As a result, there is a decline in certain native plant species and a loss of biodiversity (Coetzer, et al., 2012). Land degradation is exacerbated by the encroachment of development projects that arise due to population growth and economic development, resulting in the need to use more land for infrastructure development (Hoffman 2000). Excessive pressure from urban development, mining and cattle ranching are among the main causes of biodiversity loss and land cover change with the potential to lead to soil erosion, loss of vegetation cover and a decline in biodiversity resources (McGranahan, et al., 2013; Coetzer, et al., 2012; O'Connor, et al., 2009), which has not yet been analysed at a macro level.

However, recent studies on biodiversity loss have shown that this is a serious and urgent problem (Peixoto et al., 2022; Assessment 2005), affecting ecosystem health and functionality, climate and human well-being (Wegner et al. 2011; Biggs et al., 2008;).
Several studies have been conducted on biodiversity loss in southern Africa (Skowno et al, 2021; Mbaiwa et al, 2013; Griffiths et al, 2010). Nevertheless, few studies have been conducted on the causes of biodiversity loss in the Vhembe Biosphere. Moreover, the extent of socio-economic factors causing biodiversity loss in the study area is relatively unknown. In this regard, further studies are needed to fully quantify the impact of biodiversity loss in the Vhembe Biosphere.

1.1.1 Natural Resource Services

Natural resource services contribute significantly to societal welfare (de Groot et al., 2012; The Economics of Ecosystems and Biodiversity TEEB, 2010; Millennium Ecosystem Assessment, 2005; Costanza et al., 1997). Given the enormous contribution that biodiversity resources make to societal well-being (MA, 2005), human activities have put significant pressure on biodiversity resources (Xie et al., 2017; Sutton et al., 2016; Costanza et al., 2014) and threaten the services that this biodiversity provides. However, if biodiversity and its associated ecosystems are well managed, biodiversity in an area can be well protected (Fenta et al., 20202). Despite the enormous contribution of ecosystem services to societal well-being (MA, 2005), anthropogenic activities continue to exert incessant and significant pressure on natural ecosystems (Xie et al., 2017; Sutton et al., 2016; Costanza et al., 2014) and threaten the services that these ecosystems provide. Human-induced pressures on natural ecosystems are partly due to the fact that ecosystem services have long been viewed as inexhaustible public resources that can be exploited without cost (de Groot et al., 2012; Costanza et al., 1997). As a result, the supply of ecosystem services has declined (Li et al., 2019; Sutton et al., 2016; Costanza et al., 2014;), as resources that are not valued are often ignored in management decisions (Costanza et al., 1997).

1.1.2 Biodiversity Loss Risk

Global biodiversity loss remains a major challenge to biodiversity and ecological diversity (Magurran 2021), with human encroachment continuing to be a major factor in biodiversity loss and fragmentation (Wilkinson et al., 2018). Recent assessments of global economic biodiversity losses show that the total value of ecosystem services worldwide is in the tens of trillions of dollars (Costanza et al., 2014). Many of these ecosystem services are underpinned by the risk of biodiversity loss (Vanbergen et al., 2013). Fenta et al. (2020) note that despite repeated international targets, few coordinated actions are currently to halt biodiversity loss (Tittensor et al. 2014). In the midst of current scenarios, restoring biodiversity and habitats and addressing human-induced pressures such as habitat loss, pollution and invasive species is critical, complicated by the opportunity costs of these actions (Jupiter et al., 2014). It is crucial to comprehensively determine the current extent of biodiversity loss and its impacts on ecosystems and human well-being (Newbold et al. 2016) to take practical action to conserve biodiversity. Spangenberg et al., (2012) note that current biodiversity conservation measures do not appear to be sufficient to reverse ongoing losses and suggest developing rational and sustainable strategies that are practically effective in protecting biodiversity.

1.1.3 Implications of Biodiversity Loss Management

The typical disappearance of biodiversity is always associated with damaging ecological changes in ecosystems (Hautier et al., 2015; Pereira et al., 2012) and ecological disasters such as floods, forest fires, volcanic eruptions, which contribute to changes in biodiversity, drastically contribute to the decline of local biodiversity. Conversely, biodiversity loss due to human activities is usually permanent. Human activities such as agriculture, livestock and urbanisation occupy much of the global land area (Gupta 2019). Massive erosion of biodiversity and associated ecosystems has led to an exponential loss of 60% on average in both aquatic and terrestrial ecosystems (Greig et al., 2012).

Biodiversity loss is a global and local problem that is increasing in scope and scale (Young et al., 2006). The solutions proposed so far to protect against biodiversity loss and the measures taken are insufficient to address the increasing scale of biodiversity loss (Pekel et al., 2016; Kremen et al., 2008). Lewciki et al., (2003) suggest that the underlying failure is due to the inability to recognise and understand the fundamental conflict between promoting urbanisation and the use of natural resources on the one hand, and policies and proposals to promote sustainable development and biodiversity conservation on the other. Wood et al., (2013) also believe that this conflict and the strong bias that still exists in Favor of growth and resource use is a major contributor to biodiversity loss. Practical and relevant conservation approaches must begin with an understanding of this conflict and be based on the expectation that the roots of this conflict must be addressed if meaningful and tangible long-term progress in biodiversity conservation is to be achieved (Redpath et al., 2013)

Natural resource management has traditionally focused on maintaining or restoring historic conditions (e.g., National Park System Advisory Board, 2012). While historical context can still serve as a motivation for management decisions, restoring historical baseline conditions may no longer be realistic in the face of climate change (Stein et al., 2014). In some cases, management practices that resist change may be effective; in other cases, managers may choose to accept ecosystem change or modify management practices to accommodate change and minimise the loss of valuable species and services as ecosystems change (Aplet and Mckinley, 2017; Millar et al., 2015; Stein et al., 2013). Nature based solution or ecosystem-based adaptation approaches are needed that are constantly updated to consider emerging and anticipated impacts of climate change (Holsman et al., 2019; Bradford et al., 2018; Stein et al., 2014).

1.2 Problem Statement

Assessing current and future rangeland resources using remote sensing is important in providing data that promotes effective mechanism to accurately assess rangeland vegetation change and other attributes for better and effective sustainable management (Mansour et al., 2012’ Ludwig et al., 2004). Lack of information on rangeland resource change indicators, especially vegetation cover, which includes trees and grass biomass, hinders the development of practical-oriented policies that sustainably promote management of rangeland resources especially in protected and simi-protected biodiversity areas (Roba et al., 2009; Kirki 2004)

Rural and semi-rural communities rely heavily on biodiversity resources to meet their basic needs for fuelwood, building materials and livestock feed (Munthali 2007; Keep et al., 2005). However, these invaluable vegetational resources are threatened by human activities (Dai et al., 2023). The assessment of vegetational natural resource drivers is importantly relevant to quantify the availability and changes of natural vegetation resources and their impact on the surrounding communities. Furthermore, understanding the relationship between socio-economic and environmental drivers of biodiversity has the potential to contribute to practical management policies and plans that support biodiversity management.

Existing literature points to limited data availability on the state of natural vegetation cover and its changes over time, especially in Vhembe District (Jauro et al., 2020; Evan 2007). Analysing changes in the natural vegetation cover and conducting biodiversity loss assessments is therefore proving to be a valuable strategy for assessing natural resource productivity.

In a study curried out by Skowno et al., (2021) the key metrics of habitat loss across South Africa at national and biome levels for the first time was carried out using metrics of habitat loss. Spatial patterns, trends, implication and limitation of the metrics were presented, results indicate general habitat loss in South Africa since arrival of European settlers Skowno et al., (2021), but no specific attention to biodiversity loss in designated biosphere environments and specially Vhembe Biosphere has been carried out.

Studies on the extent and rate of natural vegetation resources loss have been conducted for 458 vegetation types in South Africa Lesotho and Swaziland (Mucina et al., 2006), the study results indicated that the total extent of habitat loss caused by the expansion of each of the six anthropogenic land-cover classes since European settlement was evident from the 2018 data set (Dayaram et al., 2006), these results indicate the extent of the loss but less mention on specific drivers of habitat loss assessment.

The national Biodiversity assessment of 2011 analysed the indicators of ecosystem threat status and protection level enabling comparison between terrestrial, river, wetland, estuarine, coastal and marine ecosystem in South Africa (Driver et al., 2011). The assessment aimed at ascertaining the degree to which ecosystems are still intact or alternatively losing vital aspects of their structure, function and composition, on which their ability to provide ecosystem services ultimately depends, but no assessment has gone further to look at the biodiversity threat status for some of the biosphere reserves in the country.

Protection of biodiversity for the past years has focused on the lower levels of biodiversity, namely species (Coggins, 1974) or populations (Rojas, 1992). Biodiversity loss through land use practices has been recognised as the major threat to biodiversity (Wilcove et al., 1998). Limited replication of such studies has not happened in some of similar and related environments like biosphere reserves that do experience conservation challenges due to their co-existence nature with the surrounding communities. Analysis of biodiversity loss should be assessed as an essential component of biodiversity conservation planning.

Conventional methods of data collection to conduct such analysis and assessments are cumbersome and time-consuming, so, more efficient approaches are needed. Remote sensing is ever proving to be a promising solution to identify these natural resource indicators and provide timely and spatially relevant data. Analysing changes in the natural vegetation cover and conducting biodiversity loss assessments with a particular focus on woody perennials, including trees, shrubs, grasses and grass biomass, is therefore proving to be a valuable strategy for assessing natural resource productivity. These assessments provide indispensable insights for effective biodiversity planning and management.

This study endeavored to assess vegetational natural resources and biodiversity resource loss and drivers in Vhembe Biosphere. We present the first attempt to assess natural resources and subsequent drivers of natural resource loss in Vhembe biosphere where limited attention has been accorded to specify the causes of biodiversity loss.

1.3 Aim of study

The main objective of this study was to contribute to biodiversity conservation management through effective assessment of changes in natural resource condition and their driver in the Vhembe biosphere and adjacent areas.

1.4 Research Objectives

In order to achieve the aim of the study; the following are the objectives are;

1. To assess the changes in natural resources in the Vhembe biosphere and its surroundings.
2. To assess natural resource change drivers in the Vhembe Biosphere and its surroundings.
3. To identify the socio-economic drivers of biodiversity loss in the Vhembe Biosphere.
4. To assess the interaction between socio-economic and environmental drivers towards biodiversity loss in Vhembe Biosphere

1.5 Study Rationale

This study is in line with South Africa's commitment to uphold and implement the National Environmental Management Act: Biodiversity Act (Section 10 of 2004), which serves as a sound basis for the conservation and sustainable management of biodiversity (Driver et al., 2011). Conventional methods of gathering relevant information on natural resources are cumbersome and time-consuming. Remote sensing is proving to be a viable solution for estimating natural resource indicators and providing data in a temporally and spatially explicit manner. Analysis of changes in natural resources serves as a means to quantify the availability, use and management of these resources.

However, existing literature shows a lack of comprehensive data on the status of natural biodiversity resources and land cover changes over time in the Vhembe Biosphere Evans 2017; Jauro et al., 2020). Therefore, this study focuses on assessing changes in natural resources in the Vhembe Biosphere, as these changes are relevant indicators for analysing changes in natural biodiversity resources. The aim is to provide information relevant to the planning and management of biodiversity resources in South Africa.

1.6 Study Area Description

A biosphere region which is comprised of many zones that correspond to various land use patterns (Basane et al., 2016). More so, these zones also serve as a connection between the development and conservation agendas (Griebeler et al., 20222; Price et al., 2013; Foggin 2016). The Vhembe Biosphere (Figure 1-1) lies close to the borders of Zimbabwe, Botswana, and Mozambique along the northeastern part of South Africa (Dombo et al., 2006; https://www.vhembebioshere.org/). and it can be located geographically on 22º051'17 "S 30º06'13 "E and is situated between 22º07'32 "S and 23º34'14 "S latitude 28º39'32 "E and 31º33'49 "E longitude (Hahn 2017; https://www.vhembebiosphere.org/).

Vhembe biosphere is made up of the Makgabeng Plateau (Hahn 2017; Dombo et al., 2006; Van Wyk et al., 2001), the northern portion of the Kruger National Park, is home Mapungubwe World Heritage Site. Several province nature reserves, and two recognized centers of biodiversity and endemism, Soutpansberg and Blouberg (Van Wyk et al., 2001). The biosphere has three biomes, namely savanna, grassland and forest (SAMABNC 2014; Hahn 2006), four bioregions and 23 types of vegetation of biotopes (Dombo et al., 2006, Hahn 2006, Mucina and Rutherford 2006; Van Wyk et al., 2001). South Africa is home to eight of these biotopes (Mucina and Rutherford 2006). The Vhembe Biosphere is also a biogeographical node that includes the Kalahari and Lowveld bioregions, which have temperate and tropical climates (UNESCO 2017; Hahn 2006).

According to the 2011 Limpopo Census report (2012), the Vhembe Biosphere has a relatively large and quickly rising population of 1.5 million individuals scattered throughout four local municipalities (Stats SA 2012). Interestingly, ninety-seven percent of this population lives in rural areas and has a high unemployment rate (Stat SA 2012), moreover, they rely on scarce natural resources in an unsustainable way, which has ramifications for land use and land cover change in the Vhembe Biosphere. Although it is commonly acknowledged that land use activities cause natural resource change, there is little or no information on natural resource change in the Vhembe Biosphere and the surrounding areas. .

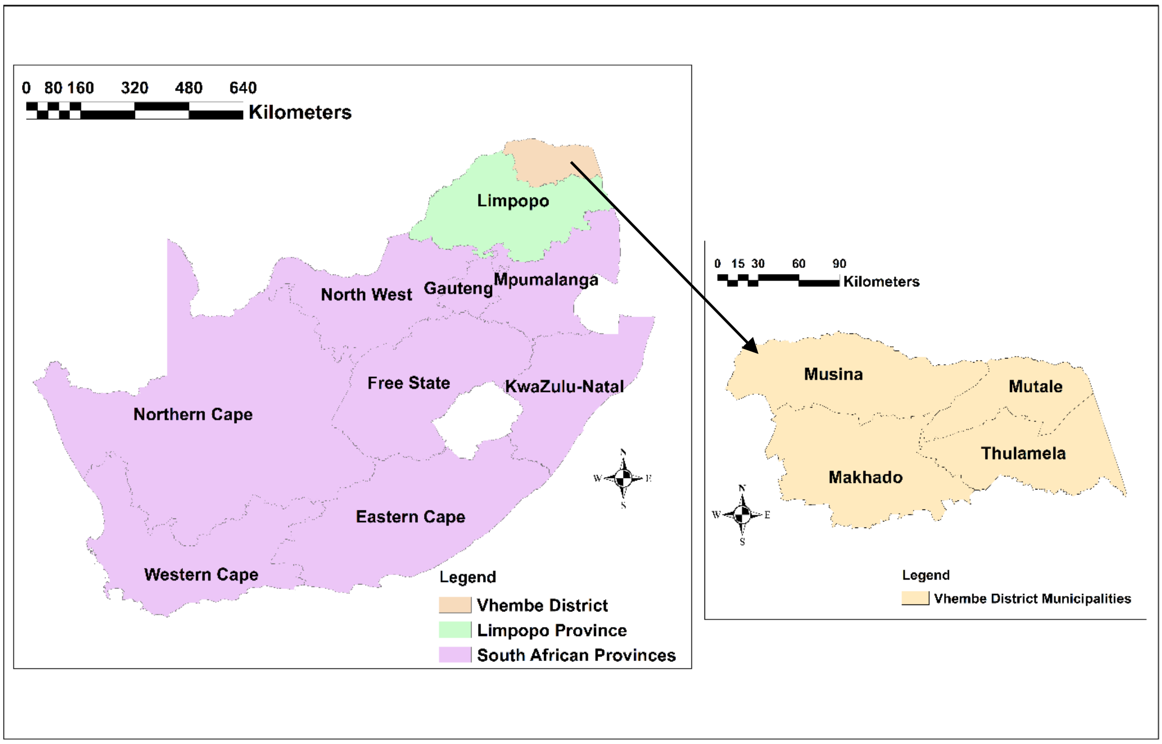

Figure 1-1: Description of Study Area
(Source: Study Author 2023)

1.7 Thesis Outline

In order to achieve the objectives of this study, this thesis is structured as a collection of four research articles submitted to peer-reviewed international journals Two of these articles have already been published in Chapter 3 and 4, while two are currently undergoing the peer review process for journal publication. Each chapter is designed as a stand-alone article that can be read independently but is linked to the overall research objectives. Therefore, there may be some repetition and overlap, especially in the "Introduction" and "Methods" sections of the different chapters. The thesis is divided into seven chapters, each of which contributes to the comprehensive exploration of biodiversity loss and its management:

Chapter 1: Introduction and Background of the Study provides an overview of the study.

Chapter 2: Literature Review conducts a thorough examination of the current state of biodiversity, threats, challenges, opportunities and national conservation efforts.

Chapter 3: Natural Resource Change Assessment addresses the detailed assessment of natural resource change in the Vhembe Biosphere and its surroundings, focusing on the key drivers of change and transformation.

Chapter 4: Assessment of natural resources drivers involves the use of reclassified data to produce a map representing natural resource change with 12 land cover classes. This chapter uses logistic regression analysis to identify drivers of change, using climatic temperatures, topography and edaphic factors as independent variables.

Chapter 5: Socio-economic drivers of biodiversity loss examines the potential contribution of socio-economic factors such as education, employment and income levels to biodiversity loss in the Vhembe biosphere. It uses logistic regression to identify and model socio-economic factors.

Chapter 6: Interactions between environmental and socio-economic drivers examines the complex interplay between environmental and socio-economic factors in biodiversity loss in the Vhembe biosphere.

Chapter 7: Synthesis and Conclusions provides a comprehensive summary of the study's findings and derives conclusions from the previous chapters. It highlights relevant recommendations for future research, sustainable management and restoration related to biodiversity loss. The chapter concludes with an assessment of the contribution of the work to science. A consolidated reference list is provided at the end of the thesis.

CHAPTER 2
LITERATURE REVIEW

This chapter introduces biodiversity resources its current status and the challenges globally and locally.

2. Global Biodiversity Loss

Global biodiversity loss continues to be a crisis (Bang et al., 2020; Singh 2002), whose importance is now well-documented and widely acknowledged (Pecl et al ., 2017). What is also acknowledged is that biodiversity loss at such a global scale requires a global management response (Hooper et al., 2012). Nonetheless, reliance on a methodical approach common to responding to international problems precedes biodiversity loss management (Wood et al., 2013; Martens et al., 2009), for example, the legal framework developed by the Convention on Biological Diversity (Prip 2018), while the Global Environment Facility (GEF) has provided a financial framework (Wood et al., 2013; Perrings et al ., 1997). Such approaches have not only played a role in maintaining the visibility of the issue on the international agenda but have also provided the impetus for activities and programs that have directly contributed to the conservation of biological diversity around the world (Parks et al 2023). Despite encouraging developments that have emerged in biodiversity conservation and management in the past twenty years, Wood et al., (2013) argue that the existing approaches and responses have failed to abate biodiversity loss in any significant way.

Bland et al., (2018) and Gibson et al., (2007) posited that in terrestrial and marine ecosystems continue to show that biodiversity continues to disappear. The root causes of biodiversity loss are complex and versatile including natural calamities, climate change, habitat loss due to man's activities, invasive species and environmental pollution (Cardinale et al., 2012; Hens et al., 2005), while Wood et al., (2013) and Kumar (2012) assume that biodiversity loss will continue unabated until its direct and indirect root causes are understood and addressed. Biodiversity loss, as a global phenomenon, is accelerating in scale and scope (Adger et al., 2003), the solutions proposed and activities undertaken to date have not been sufficient to address the biodiversity loss problem (Barbier et al., 2019). This basic failure stems from an inability to understand and articulate the basic conflict between the promotion of growth and consumption on one side, and activities and incentives promoting sustainable development and conservation of biological diversity on the other (Wood et al., 2013).

Wood et al ., (2013) stipulate that this conflict in tandem with the conceived bias that continues to exist in favor of growth and consumption are the root cause of biodiversity loss, while Heller et al., (2009) and Gladwin et al., (1995) proposes that practical biodiversity management approaches must begin with a comprehension of this conflict and be based on the expectation that the root causes of this conflict must be addressed if they are to succeed in the long run.

2.1 Assessing Biodiversity Loss

Biodiversity loss, management and conservation continues to be inept at alarming level despite its vital role in man's existence (Kothari et al., 2014). High levels of biodiversity loss are experienced in developing countries with limited conservation approaches (Stepping et al., 2018; Hannah 2007). Additionally, Stepping et al., (2018) argue that developing countries will still encounter structural challenges in their efforts to abate biodiversity loss, for, as long as in developing countries, exploitation of biodiversity resources is seen as the first area of call to promote economic development (Stepping et al., 2018; Myers 1988). Further to that, Phang et al., (2020) argues that developing countries are still short of funds, technical, and personal capacities to measure, assess and implement practical solutions to reduce biodiversity loss and foster practical methodologies in biodiversity conservation.

Measuring biodiversity loss is a multi-dimensional concept (Purvis et al., 2000) which is vital in any attempts to assess the effectiveness of existing biodiversity management efforts. There is however, increased but still limited understanding of the relationship between biodiversity and eco-system process toward the assessment and measurement for biodiversity loss at local, national and international levels (Phang, et al., 2020).

Mace et al., 2028, further explain that there is need for a shift away from numerical targets to biodiversity conservation targets and to adopt vectors of change and practical biodiversity management approaches. Moreover, the quantification of change in biodiversity resources at risk of extinction requires robust biodiversity threat assessment and posses implementation challenges in developing countries (Nicholson et al., 2021).

2.2 Biodiversity status in Southern Africa

Southern Africa is one of the highly biodiverse regions of the world (WSMC, 2000), and at present contains some of the most extensive areas outside the artic and dry deserts that have been relatively unimpacted by modern industrial society (Bigs et al., 2008; Dietz et al., 2007). The major drivers underlying loss of biodiversity in Southern Africa are land use change and climate change (MA, 2004a). Climate change is already affecting species distributions around the world (Christensen et al., 2007; Root et al., 2003) and is projected to have considerable further impacts in the 21st century (Thomas et al., 2004; Gitay et al., 2002). Climate models project the rise in degree temperature in southern Africa (Scholes et al., 2021; James et al., 2013), and changes in the seasonality and rainfall distribution, with associated impacts on local ecosystems and species (Broennimann et al., 2006; van Vuuren et al 2006). Nevertheless, land use change is expected to remain a dominant driver of biodiversity loss in southern Africa over the next century (MA, 2005a; van Vuuren et al., 2006).

South Africa like many developing countries is burdened with high and ever-increasing population and unemployment rates and poverty (34.9%) (Statistics South Africa 2021; Shackleton 2020). Additionally, the country continues to experience severe land degradation and poor land productivity especially in rural areas (Kgaphola et al., 2022; Barbier et al. 2018). Hence, a number of the poor people who live in rural areas depend on the provisioning of biodiversity resources (Scheiter et al. 2018; Shackleton 2020). High dependence on biodiversity resources continues to result in a loss of biodiversity (Raven et al., 2020; Loreau 1998). Human dependence on biodiversity resources is considered among the main drivers of biodiversity loss (Ramarumo et al., 2020; Rampheri et al. 2020).

2.3 Vhembe Biosphere

Vhembe's biosphere ecological characteristics are entirely dependent on the specific biome in which it is located (Dalu et al., 2022). Vhembe as one of the largest biosphere reserves in South Africa has a total surface area of 30,700km^2 (Riwanza et al., 2022). The biosphere consists of three biomes: savanna, grassland, and forest with four bioregional homes to 23 different vegetation types or biotopes (Nuwarinda et al., 2021; Evans 2017). Numerous factors continue to influence biodiversity loss in Vhembe Biosphere, ranging from pollution, invasive alien species, climate change to urban development and agricultural expansion with its associated impacts (Edorgan et al., 2021; IPBES 2019). To halt the exponential trend of vegetational natural resource loss, it is essential to address the root causes of biodiversity loss. There is connection between the way natural resources are managed and the impact on the main drivers of ecosystem loss and restoration.

The interconnectedness between humans and natural ecosystems plays out in natural landscapes characterized as socio-ecological systems (Schmitz et al.,2018; Petrosillo et al., 2011). The geographic nature of biodiversity resources is a multi-use landscape (Pool-Stanvliet et al., 2020) managed as an adaptive social-ecological system (Pool-Stanvliet et al., 2019; Schultz et al., 2018). Long-standing relationships exist between populations that live within and around protected biodiversity areas (Xu et al., 2006; Rao et al., 2003; Rao et al., 2000). Biosphere reserve strength lies in the acknowledgment that biodiversity conservation and ecosystems cannot be achieved in isolation from the social, cultural, and economic nexus of issues facing communities who live within and around such biodiversity areas (Perring et al., 2011).

2.4 Key Factors Contributing to Biodiversity Loss

Nature and biodiversity have recently declined faster than at any time in history due to unsustainable use of land and resources (IPBES 2019). Numerous factors continue to influence biodiversity loss in various ecosystems, from pollution, invasive alien species, desertification, climate change to urban development and agricultural expansion with its associated impacts (Edorgan et al., 2021). To halt the exponential trend of vegetational natural resource loss, it is essential to address the root causes of biodiversity loss. The way natural resources are managed has a major impact on the main drivers of ecosystem loss and restoration.

Notwithstanding all the efforts made globally towards tackling environmental challenges, the rate of biodiversity loss is still continuing worldwide. According to the global assessments (MEA 2005), more than a third of the species assessed are facing extinction, and an estimated 60% of the Earth’s ecosystems have been degraded in the last 50 years, with negative consequences for the ecosystem services.

Through the analysis of relevant literatures on biodiversity loss, it is generally agreed that biodiversity loss has four major categories of direct drivers. These are habitat alteration and loss, over-harvesting, species and disease introduction, and pollution and climate change. Of these, habitat alteration is clearly the predominant cause and is a problem that operates at the local scale. The implication of this analysis is the acceptance that factors causing biodiversity loss are amplified by the conditions operating at a defined geographical level.

Jaureguiberry et al., (2022) explain that human welfare globally is supported by ecological systems and the benefits they provide to people (Dasgupta 2021; Díaz et al., 2015;), so anthropogenic impacts on biodiversity are inevitable and of growing scientific and societal concern (Jaureguiberry et al., 2022; Turnhout et al 2006). Knowing which, human pressures contiguously continue to influence biodiversity loss (Xu et al., 2021), subsequently, man's activities as singular direct drivers contribute the most damage to biodiversity worldwide (Jaureguiberry et al., 2022), hence, a necessity for designing practical and relevant systemic policies and action targets to abate and manage local and global biodiversity loss (Balvanera et al., 2019; Turnhout et al., 2016).

Additional climate change has justifiably raised attention as a recent and accelerating direct driver (Malhi et al., 2020; Scheffers 2016), but other direct drivers like exploitation of natural resources, land use change see use change, pollution, and invasive alien species invariably continue to drive widespread biodiversity loss (Maxwell et al., 2016; Huenneke et al., 2000).

Irrespective of other threats contributing to biodiversity loss, climate change still remains the most rapid and worrying threat to biodiversity, and its impacts are increasingly well quantified (IPCC, Climate Change 2022).

Current aggressive efforts to abate and tackle climate change alone will not be sufficient to slow down and prevent further biodiversity loss (Jaureguiberry et al., 2022, Maxwell et al., 2016) unless damaging land use change and direct exploitation of natural resources are also tackled with similar ambition and determination (Maxwell et al 2016; Tingley et al., 2013)

Analysis by Jaureguiberry et al., (2022) indicate that land use change and sea use change in form of extensive cropping or animal husbandry, direct natural resource exploitation mostly through fishing, logging, hunting, and wildlife trade (Balvanera 2019) are still dominant drivers of global biodiversity loss over recent decades.

2.5 Socio-economic Impacts on Biodiversity

Different studies have explored the role of people in shaping the natural environment particularly focusing on vegetation distribution (Locke and Grove 2016; Luck et al., 2009; Grove et al., 2006; Martin et al., 2004), and the diversity of ecosystem species (Kinzig et al., 2005; Melles 2005). These studies are often rooted in the human population density, behavioral change or socio-economic stratification theories that link biodiversity resources distribution and economic growth (Oli et al., 2015; al., 20Smith et al., 2005). Socio-economic factors such as income levels and education are assumed to have a significant impact on biodiversity (Sponsel, 2013; Ayyad, 2003; Turpie 2003). Higher levels of economic development, and human development including income and education levels, tend to have lower biodiversity levels (Singh et al., 2021; Shende et al., 2015). This is because human development often leads to habitat destruction, pollution, and overexploitation of natural resources (Xu et al., 2023), which negatively impact biodiversity (Rajovic et al., 2017; Rawat et al., 2015). Centrally, the low-income population is more likely to be exposed to environmental challenges such as toxic waste dumps, air and water pollution, which negatively impact biodiversity. Consideration of socio-economic factors that contribute to biodiversity loss when developing conservation strategies is important (Prakash et al., 2022).

The loss of biodiversity-dependent ecosystem services underscores the inequality of the most vulnerable population of society (Zamboni et al., 2020; Hooper 2012), through decreased access to basic materials for a healthy life. Socio-economic development that does not consider the impacts on these ecosystem services may decrease the quality of life of these vulnerable populations (Vizzarri 2015; Mace et al., 2012).

2.6 Biodiversity Conservation Strategies

Biodiversity loss is widely considered as the leading challenge in biodiversity conservation efforts (Iritie 2015), understanding and redefining existing biodiversity conservation mechanisms ought to be done as a key step towards any strategy for biodiversity conservation of a country or region (Margules and Pressey, 2000; Barnabe 200 & Ndinga, 2001); this is particularly true in Africa which is rich in biodiversity (Iritie

2015). Understanding how species interact within their environment at the face of increased global warming and climate change threats is crucial in designing appropriate conservation mechanisms to help protect and maintain biodiversity (Oliver et al., 2014; Mackey et al., 2008)

2.7 Vhembe Biosphere

Vhembe's biosphere ecological characteristics are entirely dependent on the specific biome in which it is located (Dalu et al., 2022). Vhembe as one of the largest biosphere reserves in South Africa has a total surface area of 30,700km^2 (Riwanza et al., 2022). The biosphere consists of three biomes: savanna, grassland, and forest with four bioregional homes to 23 different vegetation types or biotopes (Nuwarinda et al., 2021; Evans 2017). Numerous factors continue to influence biodiversity loss in Vhembe Biosphere, ranging from pollution, invasive alien species, climate change to urban development and agricultural expansion with its associated impacts (Edorgan et al., 2021; IPBES 2019). To halt the exponential trend of vegetational natural resource loss, it is essential to address the root causes of biodiversity loss. There is connection between the way natural resources are managed and the impact on the main drivers of ecosystem loss and restoration.

The interconnectedness between humans and natural ecosystems plays out in natural landscapes characterized as socio-ecological systems (Schmitz et al.,2018; Petrosillo et al., 2011). The geographic nature of biodiversity resources is a multi-use landscape (Pool-Stanvliet et al., 2020) managed as an adaptive social-ecological system (Pool-Stanvliet et al., 2019; Schultz et al., 2018). Long-standing relationships exist between populations that live within and around protected biodiversity areas (Xu et al., 2006; Rao et al., 2003; Rao et al., 2000). Biosphere reserve strength lies in the acknowledgment that biodiversity conservation and ecosystems cannot be achieved in isolation from the social, cultural, and economic nexus of issues facing communities who live within and around such biodiversity areas (Perring et al., 2011).

CHAPTER 3

ASSESSING NATURAL RESOURCE CHANGE IN VHEMBE BIOSPHERE AND SURROUNDINGS

This chapter is based on: ***Nuwarinda, H.,*** *Ramoelo, A., & Adelabu, S. (2021). Assessing natural resource change in Vhembe biosphere and surroundings. Environmental Monitoring and Assessment, 193(7), 404.*

Abstract

South Africa is the trustee of Africa's vast natural and biological resources. Natural resources in various South African biospheres are constantly changing due to anthropogenic and non-anthropogenic reasons. Agriculture, cattle cultivation, commercial plantations, urbanization, and mining are among the key drivers of natural resource change and transformation. Land cover change assessment was utilized in this study to analyze natural resource change in the Vhembe biosphere and environs. Land use land cover alteration and natural resource changes evaluation in the Vhembe biosphere was carried out using South Africa's national land-cover dataset, which was derived from multi-seasonal Landsat 5 and Sentinel-2 imagery. In order to meet the study objectives, the 72x class land cover map was reclassified into 12x classes. The natural resources change evaluation for this study was based on eight of twelve classifications quantified in hectares: indigenous forests, thicket/dense brush, natural woodland, shrubland, grassland, water bodies, and wetlands. The assessment findings infers that land use and related activities have significantly contributed to natural resource change, with cultivated commercial, natural woodland, and built-up residential contributing the most significant upward change in hectarage and percentage, from 132,246.9 (ha) to 365,644.92 (ha) - a percentage change of 176%; 94,665.42 (ha) to 257,889.68 (ha) - a percentage change of 172%; and 74,070.27 While shrub-land, thicket/dense bush, and indigenous forests experienced the greatest decreases from 1990 to 2018, they were: 263,070.6(ha) to 977.72(ha), 338,723.7(ha) to 23,166.92, and 13,211.91(ha) to 7,402.92(ha), with percentage changes of -100%, -93%, and -44%, respectively, in the Vhembe biosphere and its surroundings. Lastly, the study showed how natural resources are changing and the use of remote sensing for environmental monitoring and assessment in the Vhembe district.

Key words: *Natural resource change, Biosphere Region, Land cover classes, Land cover change*

3. Introduction

There is a growing need for monitoring pressure on both basic and critical natural resources in both the developing and developed worlds. Furthermore, water scarcity, energy limitations, and other pre-existing problems such as poverty and social inequality pose significant dangers to the already depleted natural resource bases. One of the 21st century development difficulties facing the world is maintaining continual and exponential demand for livelihood survival while maintaining the sustainability foundation of natural resources (Azevedo et al., 2014; Rosegrant et al., 2001). Natural resource depletion discussions currently assume that the world is entering a critical regime of natural resource stressors due to a variety of variables (Mittal et al., 2015; Bengtsson et al., 2018). For the foreseeable future, urbanization and population growth are predicted to double global natural resource demand (Madlener et al., 2011; Rosegrant et al., 2001; Tesfa 2015). These demand trends have significant implications for natural resources, which will continue to support life on earth and economic systems in the future. The global extent and level of natural resource exploitation, use, and management, particularly for vegetation, land, forests, and water, has contributed significantly to natural resource and environmental degradation (Mucova et al., 2019; Cimon-Morin et al., 2016), with serious consequences for ecosystem services and food production (Cimon-Morin et al., 2016; Basane et al., 2016; UNECA, 2011; IPBES 2018). Changes in ecosystems and natural resource base have been associated with extensive land uses resulting from anthropogenic factors such as agricultural intensification, livestock grazing urbanisation, infrastructure development, and deforestation (Halmy et al., 2015; Rawat et al., 2013; Berberoglu et al., 2009; Thomas et al., 2000) and exacerbated by climate change (Warren et al., 2000). Land use have a substantial impact on changes in natural resources (Basane et al., 2016; Dale et al., 1998), especially because climate change increases habitat loss, species extinction and the predominance of invasive species (Brook et al., 2008). Land use activities can significantly alter an area's natural resource base and cause the removal and alteration of indigenous vegetation (Rouget et al., 2003; MA 2005), urbanization and industrialization (McKinney 2008; Marzluff et al., 2001), and related activities (Sultan, 2016; Uttara et al., 2012; Chapin et al,. 2000; Diaz et al., 2006; Dale et al., 1998). These changes have serious implications for global natural resources at multiple spatial scales (Lambin et al., 2006). Climate change, overexploitation, land-use change, alien species, and pollution contribute significantly to biodiversity loss (CBD 2020, WWF 2020, IPBES 2018). Land use changes affect watershed runoff, microclimatic resources, processes of landscape-level biodiversity, soil erosion, and land degradation (Sultan, 2016). These processes affect the capacity to act as indicators of land use change and its effect on natural resource change in a specific biome.

South Africa hosts the widest range of biodiversity resources in the world (Basane et al., 2016; Shackleton, 2009) and is ranked third in the world in terms of biodiversity (Brownlie et al., 2017; Cadman et al., 2010; Wynberg, 2002). These biodiversity resources, for example, natural forests, water, shrub-land, cultivatable land, and natural woodland (Scholes et al., 2008; Biggs, 2004), underlie the creation of products and services (Norris 2012) used by huge populations. Local natural resource extracting affords a wide range of consumable products to the majority of impoverished rural South Africans. (Shackleton, 2009) and income for comparable numbers (Lawes et al., 2004; Twine et al., 2003). Natural resource harvesting and utilization is critical to the well-being of most South African rural communities. (2008); Shackleton et al., 2007). Despite significant electricity provision, most rural South Africans continue to rely on natural forests and woodlands as a source of energy for cooking and construction materials (Madubansi et al., 2006; Von-Maltitz et al., 2004), which contributes to the consumption and degradation of natural resources.

Remote sensing has been used extensively to study land cover and land use (Butt et al., 2015). Several remote sensing techniques have been utilized in land use and land cover change analysis, including supervised (Lillesand et al., 2008, Jansen 1996) and unsupervised (Lillesand et al., 2008, Jansen 1996) classification, as well as parametric and non-parametric classifiers (Laurence 2001). Existing land cover maps where extracted from the South African National Land Cover (SANLC) and will be used for land use Land cover change (LULCC) analysis in this study. This research focused on natural resource change analysis in the Vhembe biosphere during the last 20 years in order to give relevant and scientific information for decision making on the causes of natural resource change and to educate appropriate decision-making strategies. The purpose of this study is not to evaluate the classification capabilities of using remote sensing data to undertake land cover classifications, but rather to analyze natural resource change using an existing and highly accurate land cover product. Given the tremendous demand for such natural resources, it is not surprising that there has been an immense decrease in natural resources at different spatial scales. The overall quantification of natural resource change in most rural regions throughout the world is incomplete, and the Vhembe biosphere and surrounding areas are no exception. The Vhembe biosphere contains a remarkable range of habitats and natural resources (Setshego et al., 2020; Dombo et al., 2006; Hahn 2006) as well as a variety of land use activities. Land use and concomitant land cover change as indicators of natural resource change would be a significant source of knowledge to inform policy and decision making. Land use land cover analysis would aid in understanding why, how, where, and to what extent natural resource change occurs, as well as the consequences. This could be true in the Vhembe biosphere region, where natural resource loss (i.e., vegetation) is influenced by climatic conditions, anthropogenic variables, and processes (Wilson et al., 2005). As a result, remote sensing-derived land cover products will be employed efficiently in assessing natural resource change in the Vhembe biosphere, and the major questions are addressed are: what is the quantification of natural resource distribution in the study area from 1990 to 2018? What was the evolution of natural resources between 1990 and 2018? What was the rate of change in natural resources between 1990 and 2018?

3.1 Data Description

This research paper used; the South African National Land Cover (SANLC) 1990 -72 classes land cover data , with 70% accuracy, produced by GEOTERRAIMAGE obtained from Department of Environmental Affairs-GIS data (Thompson 2019; https://egis.environment.gov.za/gis) Accessed 13 February 2020. This data was generated from digital, multi-seasonal Landsat 5 multispectral imagery acquired between 1989 and 1991 (Thompson 2019). In the excess of 600 Landsat images were used to generate the land-cover information, based on an average of 8 different seasonal image acquisition dates, within each of the 76 x image frames required to cover South Africa (Thompson 2019). The National Land-Cover 2018 dataset was generated from 20-meter multi-seasonal Sentinel 2 satellite imagery. The imagery used represents the full temporal range of available imagery acquired by Sentinel 2. This data is widely used in South Africa for understanding the impact of land cover change on a variety of sectors. The accuracy of both maps is over 80%. The SANLC 2018 dataset is based on the new land-cover classification standard (SANS 19144-2) with 72 classes of information and is comparable with the previous 1990 and 2013-14 SANLC datasets (Thompson 2019). Use of the Department Environment Forest and Fisheries/ Department of Rural Development and Land Reform (DEFF/DRDLR) prescribed Albers Equal Area projection as the definitive map projection format for all change assessment and reporting was applied in the generation of 2018 land cover change for South Africa (Thompson 2019; https://www.egis.environment.gov.za/gis/) Accessed 13 February 2020

3.2 Data Processing

Key data to processing steps taken to generate the 1990 / 2018 and 2013/14 / 2018 SANLC change assessment results were: all geographic coordinate format were converted to SANLC datasets to the new, simplified land-cover change legend format and content (Thompson 2019). Re-projection of the legend modified geographic coordinate for 1990, 2013/14 and 2018 SANLC datasets to Albers Equal Area map projection was done, including a single-step spatial resampling for the SANLC 2018 dataset to a 30 x 30m cell resolution output.

During data processing, the study ensured that, pixel-to-pixel registration between all 30m resolution Albers Equal Area map projection outcomes was done, using the 2018 SANLC as the reference dataset against which the 1990 and 2013/14 datasets are registered. In this process there was limited indicator of error. The measure of the accuracy of image registration Root Mean Square Error (RMSE) had lower values that was below 1 that indicated better alignment with image we delt with. This approach was taken as the precision of the source Sentinel 2 imagery from which the SANLC 2018 was generated and considered superior to the Landsat imagery used in the compilation of the 1990 and 2013/14 SANLC datasets. Pixel-level equivalent extent of land-cover geographic coverage between all SANLC datasets was done so that change assessment results do not include a null class in year-on-year assessments, due to differences in mapped land-cover extents resulting from buffer zone mapping. Generation of a national 30m resolution land-cover class-pair based change-reporting matrix for both 1990 vs 2018 and 2013/14 vs 2018 change comparisons was done so that the data set can easily be tabulated for change analysis.

3.3 Methodology

For proper assessment of natural resources change in Vhembe biosphere, land cover change assessment was conducted using a 72 class national land-cover dataset based on 30x30 raster cells for South Africa generated from multi-seasonal Landsat 5 imagery. The 72 class land cover map was re-classified to twelve classes (Table 1). Of the twelve classes, eight classes quantified in hectares: indigenous forests; thicket/dense bush;

natural woodland; shrubland; grassland; water bodies; and wetlands, were categorised as vegetation natural resources for which the natural resources change assessment for this study was based. From eight categories, grassland was the major dominant natural resource followed by thicket/dense bush and shrubland. Water bodies, wetlands lands natural resources had the least total coverage of the study area in hectares.

Land cover natural resources status maps of Vhembe biosphere for the period under study is given in Figure 3-1, while natural resources change is analysed and discussed based on classes in Table 3-1.

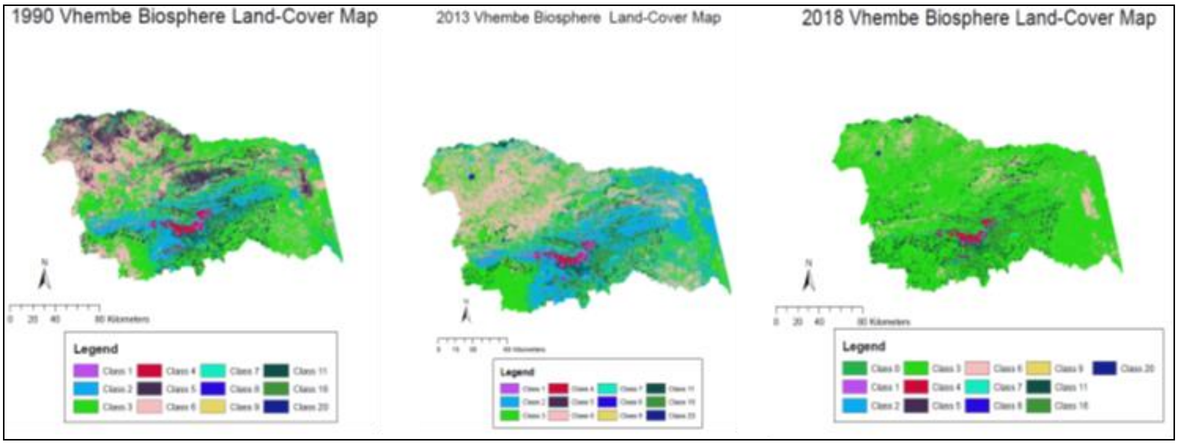

Figure 3-1: Land cover natural resources status maps of Vhembe biosphere
(*Source: Study Author 2021*)

Pre-processing of the acquired land cover data was conducted to ensure that the acquired data has similar and relevant projections clipped to the extent of the study area. Post-classification approach was used to detect and assess natural resource change in the study area based on statistical interpretation and analysis. Initially, the 1990 2018 land cover images were converted from Universal Transverse Mercator (UTM) to GCS_WGS_1984 ALBERS with a spatial resolution of 30m x 30m so that the data can be easily tabulated for change analysis. To identify percentage change of natural resource land cover change for study period - 1990, 2013 and 2018, a table was developed showing the land use land cover classes of study area in hectares and then percentage change measured against each land cover land use classes for each year 1990, 2013, and 2018. Percentage change to determine Land cover and land use change was then calculated.

To compare land cover – natural resource change, statistical analysis was used to calculate and quantify percentage of natural resource change between 1990, 2013 and 2018. To achieve this, the first task was to develop a table showing the area in hectares, then percentage change for each year (1990, 2013 and 2018) was calculated against each land cover/natural resource type. Percentage change to determine the trend of change was then calculated by dividing observed change by the earlier area (hectares) multiplied by 100. The basic procedures employed for data analysis and change detection are shown in Figure 3-2.

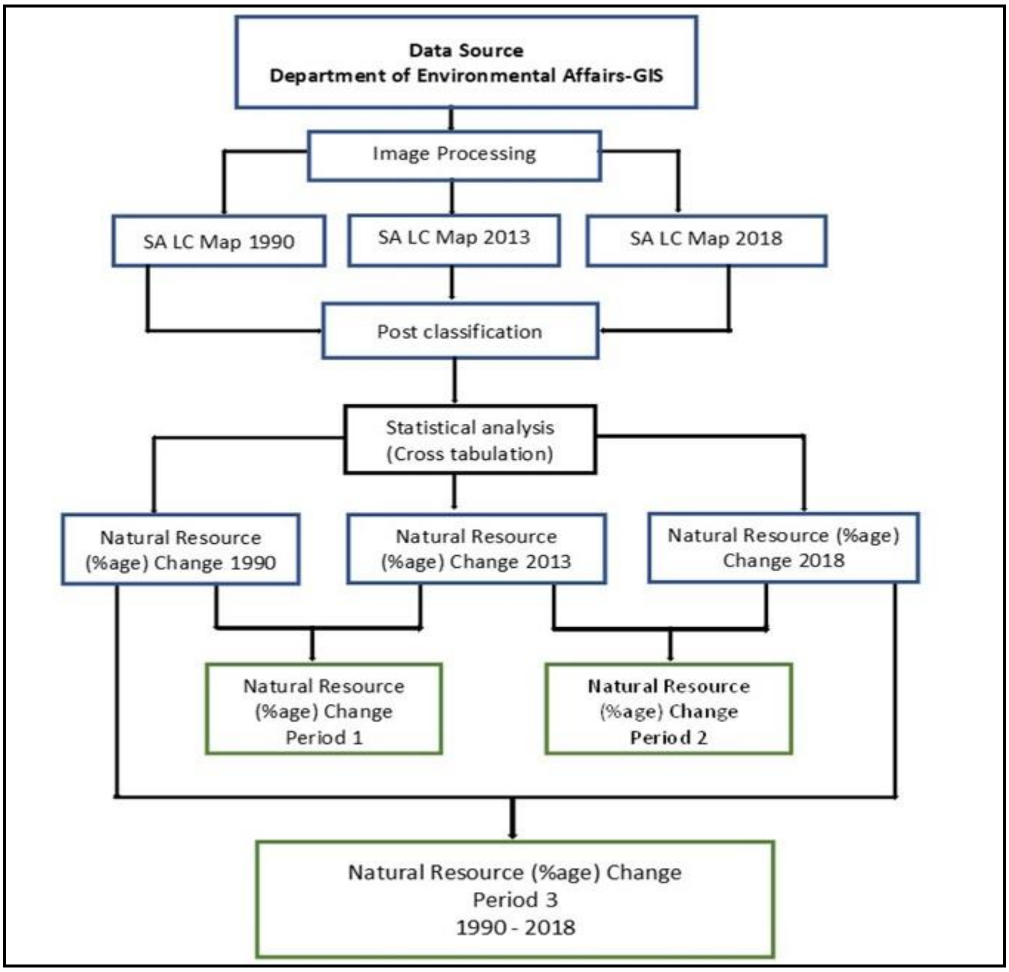

Figure 3-2: Steps taken to detect natural resource change
(*Source: Study Author 2021*)

3.4 Results

3.4.1 Harmonizing land cover classes for 1990, 2013, and 2018

For proper assessment of natural resources change in Vhembe biosphere, land cover change assessment was conducted using a 72 classes land-cover data based on 30x30 raster cells for South Africa generated from multi-seasonal Landsat 5 imagery. The 72 class land cover map was re-classified to twelve classes (Table 1). Land cover natural resources status maps of Vhembe biosphere for the period under study is given in Figure 3, while natural resources change is analysed and discussed based on classes in table 1.

Table 3-1: Land Cover Classes for the study area: 1990, 2013 and 2018

The SANLC 72x class data-set Re-classified to 12x classes or Study Area					
Reclassified Classes	Classes Names (1990)	SANLC 1990 and 2013/14 Classes	Reclassified Classes	Classes Names (2018)	SANLC 2018 Classes
1	Indigenous forest	{4}	1	Indigenous forest	{1}
2	Thicket/Dense bush	{5}	2	Thicket/Dense bush	{2,24)
3	Natural Wood land	{6}	3	Natural Woodland	{3,4,42,43)
4	Planted forest	{32,33,34}	4	Planted forest	{5,6,7}
5	Shrub land	{9}	5	Shrub land	{8}
6	Grasslands	{7}	6	Grasslands	{12,13}
7	Waterbodies	{1,2,}	7	Water bodies	{14,17,18,19,20,21}
8	Wetlands	{8}	8	Wetlands	{22,23)
9	Barren land	{40,41}	9	Barren land	{25,26,27,30,31}
11	Cultivated commercial	{10,11,12,13,14;15,16,17,18,23,24,25}	11	Cultivated	{32,38,39,40,41, 42,43,44,45,46}
16	Built-up residential all	{42, 43,44,45,46,48,49,50,51,52,57, 58,59,60,61,62, ,63,64,65,66,67.68,69, 70,71,72}	16	Built-up	{47,48,49,50, 51,52,53,54,55,56 57,58,59,60,61, 62,63,64,65,66, 67}
20	Mines	35,36,37,38,39	20	Mines	{68,69,71,72}

3.4.1 Natural resource cover maps and statistics

For natural resources area coverage in the study area, grasslands occupied the largest area in 1990 with 562,136.49 hectares, while in 2013 natural woodland was the dominant natural resource land cover with 81,755,37 hectares. In contrast, shrub-land natural resource cover reduced in hectares significantly from 263,070.63 hectares in 1990 to 19,685.43 hectares in 2013 and 977.7 in 2018. Of interest to note is the indigenous forestland natural resource cover, which increased from 13,211.91 in 1990 to 16,880.49 hectares in 2013 and declined sharply in 2018 to 7,402.92 hectares. Natural resource land cover distribution in hectares and percentages for each year is presented in Table 3-2; Figures 3-32 and 3-4.

Table 3-2: Natural resources distribution (ha) in the study area: 1990, 2013 and 2018

Natural resources distribution in hectares (ha) in the study area						
Natural resource share in Hectares/%age	**1990**	**1990**	**2013**	**2013**	**Hectares 2018**	**2018**
Indigenous forest	13 211.91 (ha)	1%	16 880.49 (ha)	5%	7 402.92 (ha)	1%
Thicket/Dense bush	338 723.73 (ha)	22%	63 569.34 (ha)	20%	23 166.92 (ha)	2%
Natural Wood land	94 665.42 (ha)	6%	81 755.37 (ha)	26%	257 889.68 (ha)	21%
Planted forest	28 896.12	2%	23 124.24 (ha)	7%	35 460.12 (ha)	3%
Shrub land	263 070.63 (ha)	17%	19 685.43 (ha)	6%	977.72 (ha)	0%
Grasslands	562 136.49 (ha)	37%	64 506.6 (ha)	20%	326 498.96 (ha)	27%
Waterbodies	2 719.44 (ha)	0%	4 483.71 (ha)	1%	8 953.64 (ha)	1%
Wetlands	5 788.8 (ha)	0%	1 125.27 (ha)	0%	3 561.04 (ha)	0%
Barren land	16 803.09 (ha)	1%	20 340.99	6%	24 971.92 (ha)	2%
Cultivated commercial	132 246.9 (ha)	9%	10 846.8 (ha)	3%	365 644.92 (ha)	30%
Built-up residential all	74 070.27 (ha)	5%	9 220.14 (ha)	3%	147 701.88 (ha)	12%
Mines	3447.09 (ha)	0%	3 183.48 (ha)	1%	2 497.96 (ha)	0%
Totals	1535779.89 (ha)	100%	318721.86 (ha)	100%	1204727.68 (ha)	100%

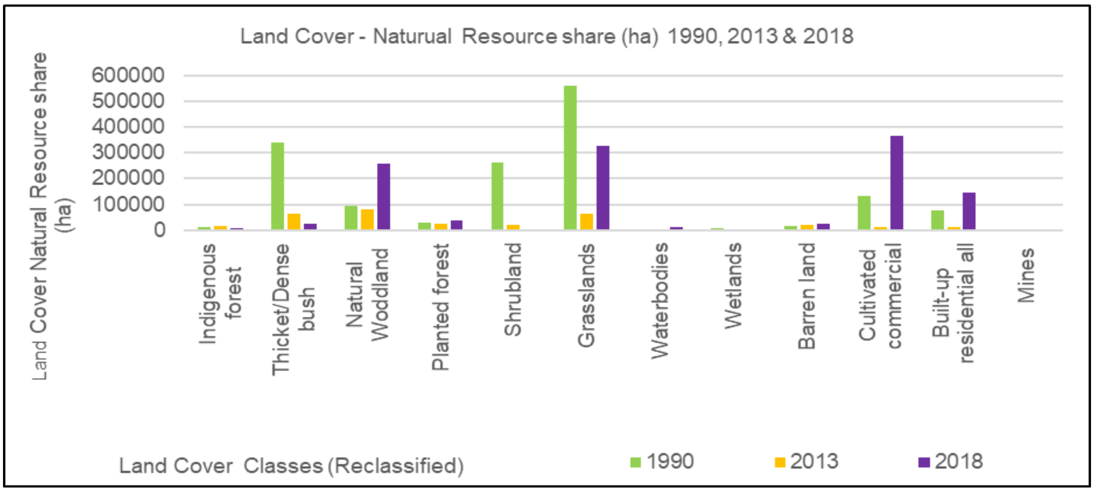

Figure 3-3: Land cover and Natural Resource class status (ha) for 1990, 2013 and 2018
(*Source: Study Author 2021*)

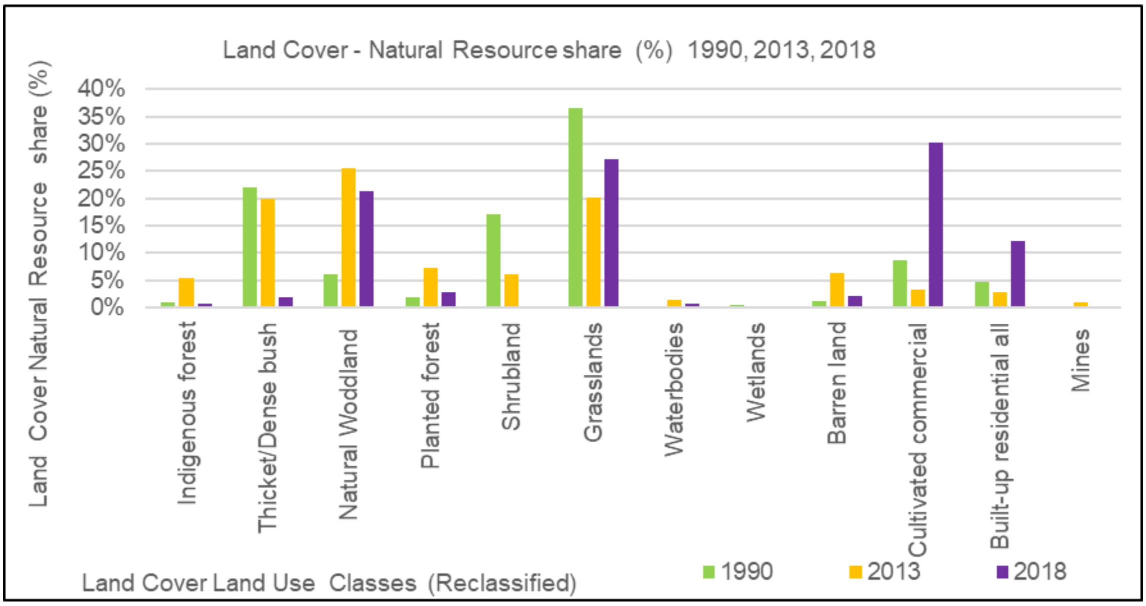

Figure 3-4: Percentage share of Land cover – Natural Resource for 1990, 2013 and 2018
(*Source: Study Author 2021*)

3.4.2 Natural resource change between 1990-2013

Natural resource change assessment based on land cover change in the study area, for 1990 and 2013, indicate that, in 1990, grassland natural resource which was the dominant land cover in Vhembe biosphere; with a total land cover area of 562,136.5 (ha), decreased to 64,506.6 (ha) in 2013 an equivalent of -89% change in natural resource area coverage (Table 3; Figure 6 and Figure 7).

It is also noticed that; thicket/dense bush and shrub land resources decreased from 338,723.7(ha) and 263,070.6(ha) in 1990 to 63,569.34(ha) and 19,685.43(ha) in 2013 at -81% and -93% change respectively. It is anticipated that the three natural resource registered a significant decreased, presumably due to relevant anthropogenic activities like building of residential areas, commercial farming to non-anthropogenic factors like fluctuations in climate and temperature in the study area. Other classes: indigenous forest, planted forests, barren land, wetland land, water bodies and mines remained way below 10% for 1990, 2013 and 2018 and indication of less and insignificant natural resource change during study period.

Table 3-3: Land cover Natural resource change in hectares (**ha**) and percentages (**%ages**) 1990 - 2013/14

Land cover Natural resource change in hectares (ha) and percentages (%ages)				
Land Cover –Natural Resource	**1990**	**2013**	**Hectares Change**	**%age change**
Indigenous forest	13 211.91 (ha)	16 880.49 (ha)	3668.58 (ha)	28%
Thicket/Dense bush	338 723.7 (ha)	63 569.34 (ha)	-275 154.39 (ha)	**-81%**
Natural Woodland	94 665.42 (ha)	81 755.37 (ha)	-12 910.05 (ha)	-14%
Planted forest	28 896.12 (ha)	23 124.24 (ha)	-5 771.88 (ha)	-20%
Shrub land	263 070.6 (ha)	19 685.43 (ha)	-243 385.2 (ha)	**-93%**
Grasslands	562 136.5 (ha)	64 506.6 (ha)	-497 629.89 (ha)	-89%
Waterbodies	2 719.44 (ha)	4 483.71 (ha)	1 764.27 (ha)	65%
Wetlands	5 788.8 (ha)	1 125.27 (ha)	-4 663.53 (ha)	-81%
Barren land	16 803.09 (ha)	20 340.99 (ha)	3 537.9 (ha)	21%
Cultivated commercial	132 246.9 (ha)	10 846.8 (ha)	-121 400.1 (ha)	-92%
Built-up residential all	74 070.27 (ha)	9 220.14 (ha)	-64 850.13 (ha)	-88%
Mines	3 447.09 (ha)	3 183.48 (ha)	-263.61 (ha)	-8%

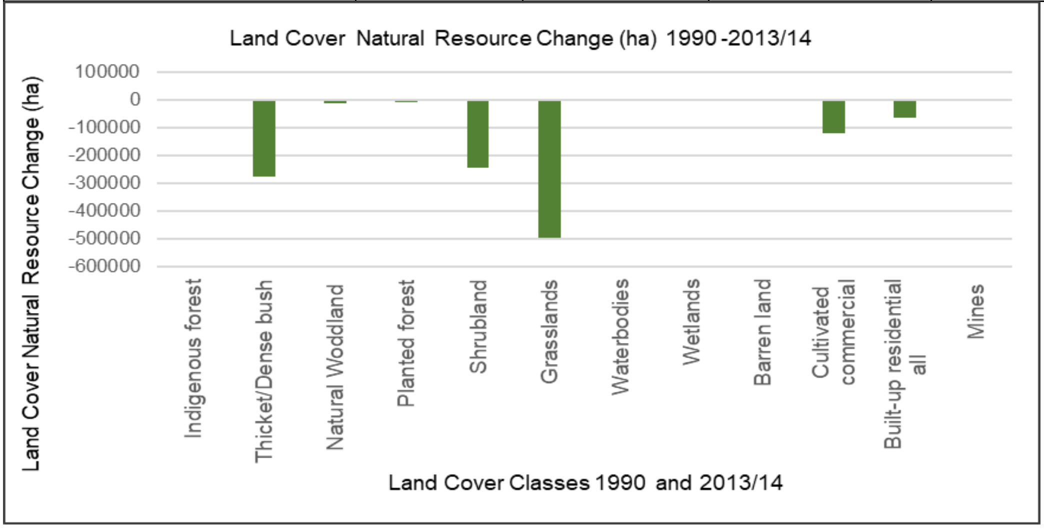

Figure 3-5: Change in Land cover and land use of the study area from 1990 to 2013
(*Source: Study Author 2021*)

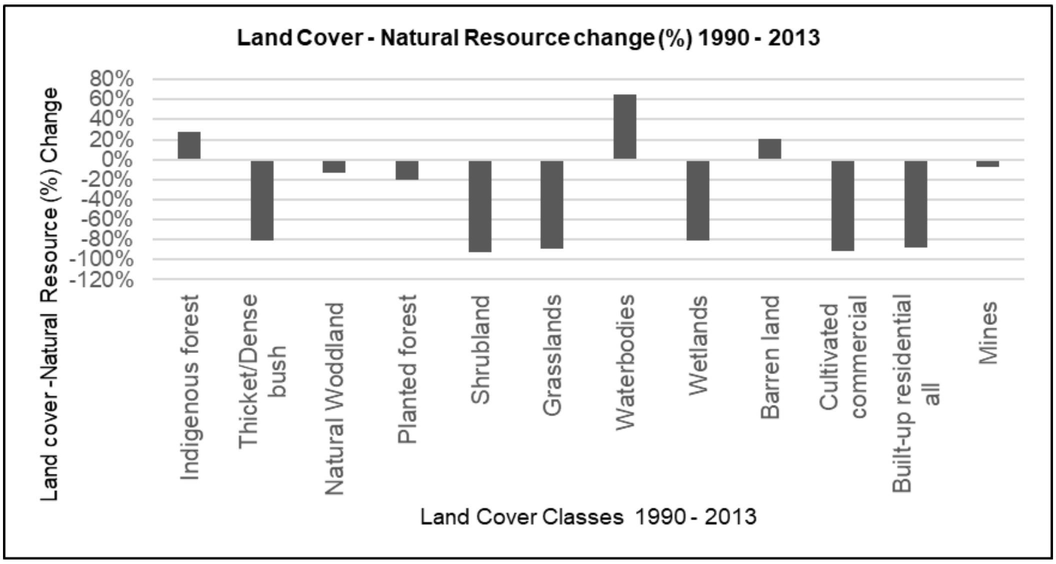

Figure 3-6: Change in Land cover and land use of the study area from 1990 to 2013 (*Source: Study Author 2021*)

3.4.3 Natural resource change between 2013-2018

In 2013 year, thicket dense bush natural resource decreased from 63,569.34 hectares to 23,166.92 hectares in 2018, a -6% decrease (Table 4; Figure 6 and Figure 7). This was followed by shrub land that decreased from 19,685.43 hectares to 977.72 hectares with a percentage change of -9%. It is interesting to note that: while a decrease in shrub land cover natural resource was registered in the study area, for this period, cultivated commercial land and built up residential area registered a drastic increase, as a land cover land use. Cultivated commercial area increased from 10,846.8 hectares in 2013 to 365,644.9 hectares in 2018 with a percentage change of 294%; built up area from 9,220.4 hectares in 2013 to 147,709.9 hectares in 2018 with a percentage change increase of 135% respectively. It can be assumed that, shrub land natural resource decreased at the expense of increased activities in cultivated commercial and build up residential land cover.

Table 3-4: Land cover Natural Resource change (ha) 2013 -2018

Land cover Natural resource Change in hectares (ha) and percentages (%ages)				
Land Cover Land Use Classes	**2013**	**2018**	**Change (Hectares)**	**%age change**
Indigenous forest	16 880.49 (ha)	7 402.92 (ha)	-9 477.57 (ha)	-5%
Thicket/Dense bush	63 569.34 (ha)	23 166.92 (ha)	-40 402.42 (ha)	-6%
Natural Wood land	81 755.37 (ha)	257 889.68 (ha)	176 134.31 (ha)	19%
Planted forest	23 124.24 (ha)	35 460.12 (ha)	12 335.88 (ha)	5%
Shrub land	19 685.43 (ha)	977.72 (ha)	-18 707.71 (ha)	-9%
Grasslands	64 506.6 (ha)	326 498.96 (ha)	261 992.36 (ha)	37%
Waterbodies	4 483.71 (ha)	8 953.64 (ha)	4 469.93 (ha)	9%

Wetlands	1 125.27 (ha)	3 561.04 (ha)	2 435.77 (ha)	19%
Barren land	20 340.99 (ha)	24 971.92 (ha)	4 630.93 (ha)	2%
Cultivated commercial	**10 846.8** (ha)	**365 644.92** (ha)	**354 798.12** (ha)	**294%**
Built-up residential all	**9 220.14** (ha)	**147 701.88** (ha)	**138 481.74** (ha)	**135%**
Mines	3 183.48 (ha)	2 497.96 (ha)	-685.52 (ha)	-2%

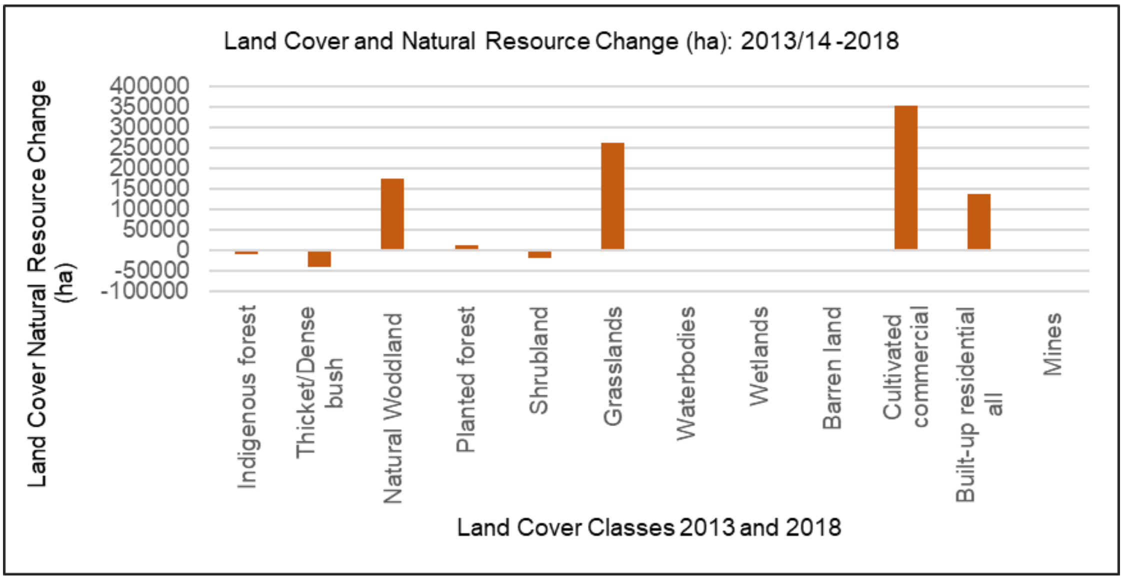

Figure 3-7: Change in Land cover and land use (ha) of the study area from 2013 to 2018 (*Source: Study Author 2021*)

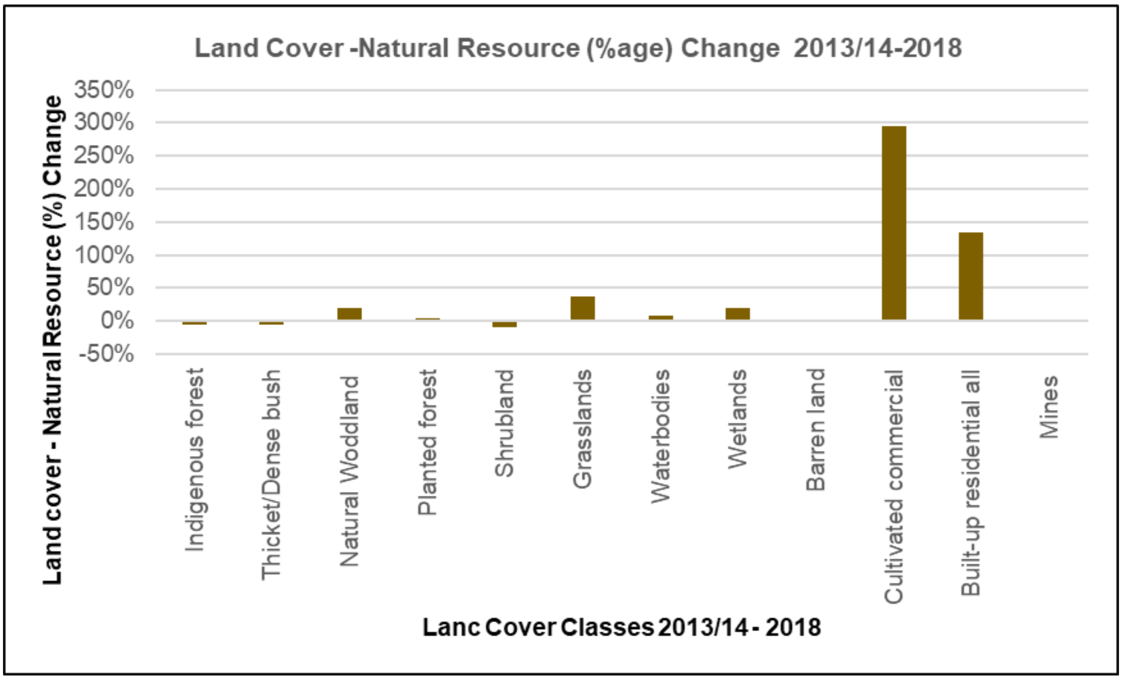

Figure 3-8: Change in Land cover and land use (%) of the study area from 2013/14 to 2018 (*Source: Study Author 2021*)

3.4.4 *Natural resource change between 1990-2018*

Observed natural resource class change analysed for three classes: thicket/dense bush; shrub-land and grass-land; between 1990 to 2018, indicate that: thicket/dense bush resources decreased from 338,723.73 (ha) in 1990 to 23,166.92 (ha) in 2018 by -315,556.81 (ha), a percentage change decrease of -96%, while shrub land natural resource decreased from 263,070.63 (ha) in 1990 to 977.72 (ha) in 2018 by -262,092.91 (ha), a percentage change decrease of -100%; and grass-lands land natural resource decreased from, 562,136.49 (ha) in 1990 to 326,498.96 (ha), a percentage change decrease of -42% in 2018. Cultivated commercial area between 1990 and 2018 increased in hectarage from 132,246.9 (ha) in 1990 to 365,644.9 (ha) in 2018, a percentage change increase of 176%. Built-up residential area increased in hectarage from 74,070.27 (ha) in 1990 to 147,701.88 (ha) in 2018 with a percentage change increase of 99% respectively. The observed changes (hectarage and percentage) in natural resources for cultivated commercial area and built-up residential area can be attributed to encroachment of man's activities on other natural resources like; shrub-land, grass-lands, natural wood land and indigenous forests in the study area.

Table 3-5: Land cover Natural Resource change (ha) 1990 -2018

Land cover Natural Resource Change in hectares (ha) 1990 -2018				
Land Cover Land Use Classes	**1990**	**2018**	**Change (Hectares)**	**%age change**
Indigenous forest	13 211.91 (ha)	7 402.92 (ha)	-5 808.99 (ha)	-44%
Thicket/Dense bush	338 723.7 (ha)	23 166.92 (ha)	-315 556.81 (ha)	-93%
Natural Wood land	94 665.42 (ha)	257 889.68 (ha)	163 224.26 (ha)	172%
Planted forest	28 896.12 (ha)	35 460.12 (ha)	6 564 (ha)	23%
Shrub land	263 070.6 (ha)	977.72 (ha)	-262 092.91 (ha)	-100%
Grasslands	562 136.5 (ha)	326 498.96 (ha)	-235 637.53 (ha)	-42%
Waterbodies	2 719.44 (ha)	8 953.64 (ha)	6 234.2 (ha)	21%
Wetlands	5 788.8 (ha)	3 561.04 (ha)	-2 227.76 (ha)	-38%
Barren land	16 803.09 (ha)	24 971.92 (ha)	8 168.83 (ha)	49%
Cultivated commercial	132 246.9 (ha)	365 644.92 (ha)	233 398.02 (ha)	176%
Built-up residential all	74 070.27 (ha)	147 701.88 (ha)	73 631.61 (ha)	99%
Mines	3 447.09 (ha)	2 497.96 (ha)	-949.13 (ha)	-28%

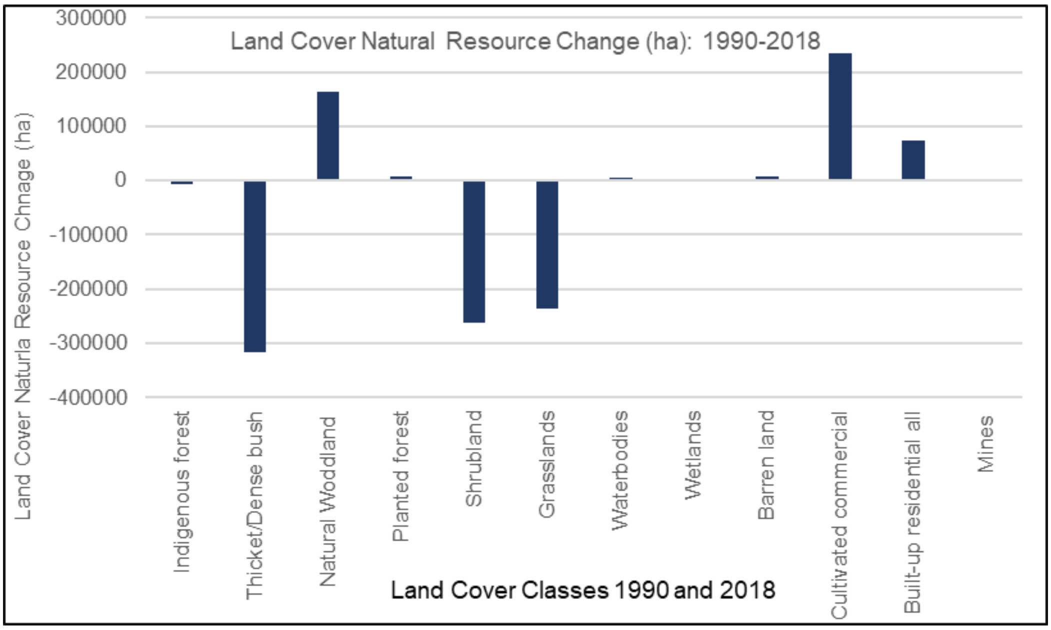

Figure 3-9: Change in Land cover and land use of the study area from 1990 to 2018 (*Source: Study Author 2021*)

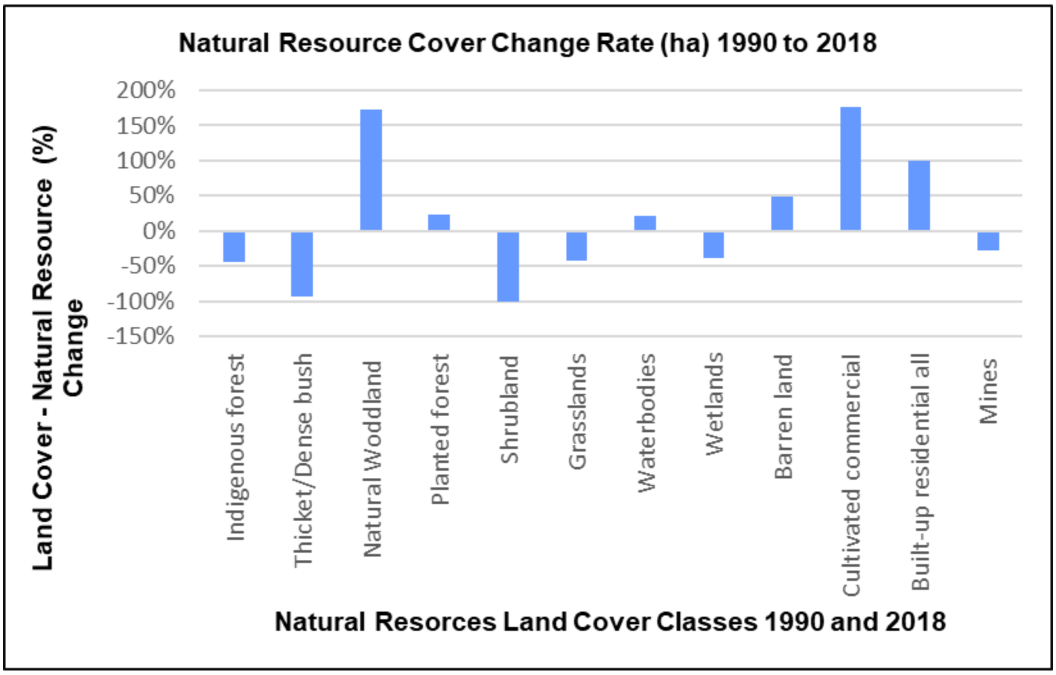

Figure 3-10: Change in Land cover and land use of the study area from 1990 to 2018

3.5 Discussion

Natural resource change driven by human activities and natural factors observed around the world has increasingly contributed to global loss of native biodiversity and the alteration of ecological processes and services across different ecosystems in different parts of the world (Msofe et al., 2019). Land use and its related activities in Vhembe biosphere have a direct influence on natural resource change. Using thicket/dense bushland cover class as an example there was a significant reduction in its area size from 338,727 (ha) in 1990 to 63,569 (ha) in 2013 (Table 3-4), an indication of human activities encroachment on the natural resource. Likewise, natural woodland reduced drastically by -12,910 (ha) from 94,665 (ha) in 1990 to 81,755 (ha) in 2013 (Table 3-4). The sharp reduction of natural woodland registered in this period followed by an increase of barren land from 16,803 (ha) in 1990 to 20,340 (ha) in 2013 (Table 3-4), presupposes increased human activities that could have contributed to the clearance of such a natural resource in search of human survival.

Decrease in grassland resource area cover by -497,627 (ha) from 562,136 (ha) in 1990 to 64,506 in 2013 (Table 3-5) in the study area could be an indication of the importance attributed to utilisation of grassland natural resources by man, like livestock grazing, crop husbandry and other functions they provide for man survival.

This also suggests that climatic variation could be having negative impacts on grassland natural resource, which could significantly be higher than man-induced activities on natural grassland. In this study, we also analysed that, shrub-land natural resource had a steady decline in land use land cover from 263,070 (ha) in 1990 to 19,685 (ha) in 2013 (Table 3-3) the decline continued to 977 (ha) in 2018 with total natural resource decline change of -262,092 ha (Table 3-5) respectively.

This sharp decline over the study period could be attributed to the biotic disturbance in which shrub land struggles to grow or can no longer exist on a piece of land due to anthropogenic causes like livestock grazing and non-anthropogenic causes like climate variation over the study period.

Further data analysis and observation of why the erratic decrease in shrub-land and grassland natural resource cover and usage in the study area indicate that; planted forests could have encroached on both shrub-land and grassland natural resource cover, as planted forest size in hectares increased from 28,896.12 (ha) in 1990 to 35,460.12 (ha) in 2018 (Table 3-5).

Natural woodland resource cover increased by 163 224.26 (ha) from 94,665.42 (ha) in 1990 to 257,889.68 (ha) in 2018, this could be another contributing factor to the decrease in shrub land and grass lands land natural resource coverage in the study area.

Results also indicate that, human induced land use and land cover activities like cultivated commercial activities, ware at a downward trend in land use land cover from 132,246 (ha) in 1990 to 10,846 (ha) in 2013 (Table 3-3). But increased substantially from 10,846 (ha) in 2013 to 365,644 (ha) in 2018 (Table 3-5). This is assumed as an indication of how land use activities have contributed to natural resource land cover change in the study area.

Important to consider is that; natural resources that could have changed due to increase in cultivated land should be investigated further to understand the driver and consequences behind such a change in the study area. The observed decrease in land cover natural resources above could be attributed to; increased land use demand for commercial farming, and urban development as indicated by an erratic increase of cultivated commercial land cover use from; 132 246.9 (ha) in 1990 to 365 644.92 hectares by 233 398 (ha) and built up residential land cover use increase from; 74070.27 (ha) in 1990 to 147 701.88 h (ha) in 2018 by 73 631.61 (ha) as indicated in Table 3-5.

Studies conducted on the impact of land use land cover changes on natural resource (Munthali, et al., 2020) assessment of land use impact on natural resources (Dale et al., 1998), evaluation of ecosystem service and trade off (Xue et al ., 2022; Arunyawat et al,. 2016) using a combination of approaches like remote sensing, household surveys, focus group discussions and GIS with computer models that simulate changes in land cover and land use impact (Munthali, et al., 2020; Dale et al., 1998) concluded that land use land cover changes have led to significant decline in ecosystems, forest cover and agricultural land (Hartemink et al., 2008). In this study, remote sensing and statistical analysis used to assess the drivers of natural resource change in Vhembe biosphere concluded that specific natural resources like; shrub land, indigenous forests, wetlands declined in area size (hectarage) due to natural resources uses in form of urban development, agriculture, plantation farming, mining, animal husbandry.

In Summary, in order to meet developmental and associated requirement, like construction materials and food supply, cultivated land and natural wood plantations have increased at the expense of other vegetation natural resources such as: indigenous forest; natural wood land; thicket/dense bush; shrub land and barren land in the study area, in which, majority of inhabitants depend on the entire Vhembe biosphere resources for their daily survival. Alterations of natural resources to accommodate man's developmental activities like settlement, urbanisation and commercial cultivation as identified, have potential negative conservation implications on natural resources in the study area, either direct or indirect including; biodiversity loss natural resource degradation, pollution and deforestation.

3.6 Conclusion

Natural resource changes in a given environment is an interplay of man's activities and natural causes. In the case of Vhembe Biosphere, natural resources uses in the form of urban development, agriculture, plantation farming, mining, animal husbandry, natural wood land encroachment contributed to decline of different types of natural and biosphere resource. The noticed significant decline in shrub land, grassland and Thicket/dense bush due to potential encroachment by other natural vegetation resources and man's activities presents an opportunity to explore further the drivers of such natural changes and their relevant impact.

Other contributing factors to natural resources change could have been climate patterns that influence the intensity as well as the rate of natural resources change. An assessment of the drivers of natural resource change in the Vhembe biosphere should be undertaken to fully understand the causes behind irreversible natural resources change of the biosphere.

3.7 Study Limitations

Availability of comprehensive data on natural resources, specifically land cover, vegetation was limited. And the determination of the initial state of natural resource was subjective.. However, with this limited data obtained we were able to establish and demonstrate the potential changes natural resource change in Vhembe Biosphere and indicated with the result obtained how this scan significantly contribute understanding such drivers and devise better mitigation measures to abate such changes.

CHAPTER 4

NATURAL RESOURCE CHANGE DRIVERS IN VHEMBE BIOSPHERE AND SURROUNDINGS.

This chapter is based on: ***Nuwarinda*****,** ***H***.*, Ramoelo, A., & Adelabu, S. (2021). Assessing natural resource change drivers in Vhembe biosphere and surroundings. Environmental Monitoring and Assessment,* 193*(7), 404.*

Abstract

Biodiversity loss in terms of habitat changes is occurring at alarming rates throughout the world. This study aimed at assessing the drivers of vegetation cover resources as a major driver of ecosystems change in the Vhembe biosphere. In this study, an analysis of vegetation cover resource change drivers over 28 years (1990-2018) in the Vhembe biosphere was conducted. Twelve (12) land cover classes reclassified from South African National Land Cover (SANLC) of Seventy-two (72) classes data set were used in this assessment, including natural woodland; thicket/dense bush; shrubland; indigenous forests; grassland; water bodies and wetlands; barren land; built-up residential area; cultivated commercial area and mines. This data was reclassified to create a natural resource change map with 12 land cover classes indicating transformation and non-transformation natural resources. The 12 natural resource classes were further reclassified to only 2 classes, where the value of 1 was given to natural resources that changed (transformed), hereafter referred to as loss, and 0 to natural resources that never changed (no transformation). Logistic regression analysis was then used to determine drivers of change (dependent variables) with a set of independent variables such as climatic temperatures, topography, edaphic factors in the study area. The study identified climatic variables such as minimum temperatures, average temperatures, precipitation, and soil chemical and physical properties such as soil pH, nitrogen, soil organic carbon, sand, silt, coarse fragments as the major drivers of vegetation cover natural resources change in Vhembe biosphere.

Key Words: Natural resources, Land use and Land cover change, Driver, Bioclimatic, Transformation, Remote sensing

4. Introduction

Vegetation cover as natural resource usage in ecosystems is one of the contributors of natural resource change globally (Gaitan et al., 2014; Alig et al., 2011). Vegetation cover is a key variable in the ecosystem defining the availability of habitats and land resources (Kim et al., 2019; Francisco et al., 2016). Vegetation cover can be easily measured in the field by assessing the percentage of the ground that is covered by the existing vegetation (Gaitan et al., 2014; Begon et al., 2014; Chiras et al, 2009; Kosmas et al., 2000). Vegetation cover can reflect the conditions of the ecological environment (Cheng et al., 2020; Begon et al., 2014; Chiras et al, 2009;) and the main factors that influence vegetation cover are climate change and human activities (Costanza 1991; Cheng et al., 2020).

The determinants of natural resource change are structured under either socio-economic (Kattumuri 2018) or bio-physical categories (Chiras et al., 2009; Allan et al., 2003;Clark and Munn 1986). Natural resource change occurs when unsustainable resource uses like fuelwood collection (Lampert, 2019; Folke et al 2019; Wessels et el., 2013), conversion of more pristine land into agricultural land, increased settlement (Spierenburg 2020) happen in any given ecosystem. The geographical spread and quality of natural resources has been driven by human activities at local and global scale (Spierenburg 2020; National Research Council, 2010, Stern et al., 1992) in a short time scale leading to major impacts on local and regional ecosystem services and functionalities (Pettorelli et al., 2005; Carlson et al., 1997). Conversely, climate and human activities are among the basic drivers (Wang et al., 2019; Halpern et al., 2005) controlling and affecting the spatial distribution of vegetation and its changes (Wang et al., 2019; Friedl et al., 2002; Cramer et al., 2001). Climatic factors influence the growth processes of natural vegetation on a short to long-term scale (Kim et al., 2021), restrict the geographical distribution of terrestrial vegetation (Zhao et al, et al., 2021; Yunfeng et al., 2019) and determine the type and magnitude of regional ecosystem services (Baojie et al., 2016; Rull et al., 2011).

The combined effects of localized, regional (Terando et al., 2020; Gissi et al., 2018) and global climate change and socio-economic activities (Gissi et al., 2021; Balbi et al., 2019), vegetation resources at different spatial scales (Malhi et al., 2020) are undergoing interconnected change processes (Wang et al., 2019; Cramer et al., 2001). Globally, differentiation of vegetation cover resource and trends are driven by various factors, such as climate (Peng et al., 2012; Gonzalezi et al., 2010), landforms (Corenbit et al., 2009;

Yamaura et al., 2001), land cover types (Eastman et al., 2013), and human activities (Chen et al., 2019; Zhao et al., 2018). For example, de Jong et al., 2012, explained that global terrestrial vegetation activities had substantially declined with variations in climate change from 1982 to 2008.

The latest study by Skowno et al. 2021 highlights that South Africa has lost over 0.24% of natural habitats since 1990. It is estimated by Jewitt 2021; that the highest measure of losses are recorded between the east and southern Africa regional costs (Jewitt 2021), with more significant loss recorded in the in-land non coasts grasslands, and savannas Mpumalanga and Limpopo (Jewitt 2021; Skowno et al., 2021). Natural habitat loss caused by man and his activities such infrastructure development, animal, and crop husbandry (Barger et al 2018) is the leading driver of biodiversity loss in mundane ecosystems in South Africa (Skowno et al 2019; Barger et al 2018),
The increased loss of bionetwork has been recorded in recent years -2014-2018 (Skowno et al., 2019), indicating that; the classic drivers of change for e.g., cropland expansion, human settlements, plantation forestry, and mining are escalating at an increasing rate (Skowno et al., 2019; Barger et al., 2018).

Nature has been degraded by the aggregated drivers of unlimited actions (IPBES 2019) in the drive to meet basic material needs, and due to a growing world population (IPBES 2019). The forest natural resource assessment (FAO, 2010) report stated that on average, 49 countries in sub-Saharan Africa have lost 0.5% of their forest cover resources between 1990’s – 2000 due to a multitude of drivers. Since the 1970's according to IPES 2019, global extraction of biomass, fossil fuels, minerals, and metals increased sixfold because of unlimited actions. Drivers are natural or human-induced factors (Yamaura et al., 2011) that cause changes to ecosystems (Geist et al., 2002) and can either be direct (Yamaura et al., 2011): causing a physical change that can be measured (Lambin et al., 2001) or indirect; change that is less measurable in terms of causality (Nelson et al., 2005, MA.2005). The combined effects of these drivers have resulted in significant changes in our natural resources and ecosystems (Cardinale et al., 2012). A direct driver unequivocally influences ecosystem processes (Nelson et al., 2006) while an indirect driver operates more diffusely, by altering one or more direct drivers (Oesterwind et al., 2016; Nelson et al., 2005;). Examples of driver include predominantly climate change (Cavicchioli et al., 2019), nutrient pollution, land conversions (IPBES 2018; Lorencova 2016) leading to habitat modification (Boris et al., 2020; Brooks et al., 2008; Pimm 2000), overexploitation, and invasive species and associated diseases (Pimm 2000; Nelson et al., 2005). The Millennium Ecosystem Assessment categories of indirect drivers of natural resource change are demographic, economic, socio-political, scientific, and technological, cultural, and religious (MA 2005).

With integrated effects of global climate change, regional and socioeconomic activities (Arnel et al., 2019), vegetation and its associated natural resources at different spatial scales (Yinbing et al., 2019) are undergoing complex change processes (Wang et al., 2018; Crammer et al., 2001). At the regional scale, natural and anthropogenic drivers are strongly coupled (Wang et al., 2014). Identification of natural and anthropogenic drivers of vegetation natural resource changes in any ecosystem is the basis for adapting to climate change and improve human activities (Yinbing et al., 2019). Logically, distinguishing natural and anthropogenic drivers of vegetation natural changes has should be become the basis for ecological restoration (Yinbing et al., 2019). Importantly, changes in the environment due to land use can negatively affect the functioning of the ecosystem (Wang et al., 2019; Mueller et al., 2014). These changes have been mainly driven by the expansion of agricultural activities and human settlements (Zhao et al., 2018).

The interaction of humans with the environment to derive useful resources has altered the structure of the landscape and its natural resource (Zhang et al., 2017; De Jong et al., 2012). Nuwarinda et al. 2021 demonstrated the recurrence of natural resource change in the Vhembe Biosphere. The most evident change based on area size in hectares was thicket/dense bush vegetation, natural woodland, and grassland vegetation. There are a plethora of drivers of vegetation or natural resource change as indicated above. There is a need to determine the most prevalent and significant drivers of change within the Vhembe biosphere to enhance the effectiveness of natural resource management, and such information is limited. The question is, which drivers of change are prevalent and significant in explaining the natural resource or vegetation change in the Vhembe Biosphere? Assessment and understanding the drivers of natural resource changes can provide quantitative data that will potentially assist with the development of natural resource management policies towards natural resource management, planning, and conservation.

4.1 Data Description

The start off point was to pre-process acquired set of land cover dataset (Thompson 2019; https://egis.environment.gov.za/gis) to ensure that it has applicable projections and clipped to properly suit the study area extent (Nuwarinda et al., 2021). Following to this, post-classification approach (Chen et al., 2017) was used to assess and detect natural resource change in the study area based on statistical interpretation and analysis (McCluskey ET AL., 2007). 1990 and 2018 land cover images (Thompson 2019) were obtained and converted from Universal Transverse Mercator (UTM) to GCS_WGS_1984 ALBERS (De-Castro et al., 2012) with a spatial resolution of 30m x 30m so as to easily tabulate data for change analysis (Nuwarinda et al., 2021). To identify the percentage change of natural vegetation resource cover change for study period from1990 to 2013, and 2013 to 2018, able 4-1 adopted and modified from Nuwarinda et al., 2021 was modified to show land use land cover classes for the study area in hectares and percentage change for each year 1990, 2013, and 2018 (Nuwarinda et al., 2021) followed by appropriate calculations to determine percentage change for land cover and land use.

Table 4-1: Natural resources distribution (ha) in the study area: 1990, 2013 and 2018
Source: (Nuwarinda et al., 2021)

Distribution of Natural Resources in hectares (ha) in the study area						
Natural resource distribution in Hectares %age	**1990**	**1990**	**2013**	**2013**	**Hectares 2018**	**2018**
Indigenous forest	13 211.91 (ha)	1%	16 880.49 (ha)	5%	7 402.92 (ha)	1%
Thicket/Dense bush	338 723.73 (ha)	22%	63 569.34 (ha)	20%	23 166.92 (ha)	2%
Natural Wood land	94 665.42 (ha)	6%	81 755.37 (ha)	26%	257 889.68 (ha)	21%
Planted forest	28 896.12	2%	23 124.24 (ha)	7%	35 460.12 (ha)	3%
Shrub land	263 070.63 (ha)	17%	19 685.43 (ha)	6%	977.72 (ha)	0%
Grasslands	562 136.49 (ha)	37%	64 506.6 (ha)	20%	326 498.96 (ha)	27%
Waterbodies	2 719.44 (ha)	0%	4 483.71 (ha)	1%	8 953.64 (ha)	1%
Wetlands	5 788.8 (ha)	0%	1 125.27 (ha)	0%	3 561.04 (ha)	0%
Barren land	16 803.09 (ha)	1%	20 340.99	6%	24 971.92 (ha)	2%
Cultivated commercial	132 246.9 (ha)	9%	10 846.8 (ha)	3%	365 644.92 (ha)	30%
Residential Built-up	74 070.27 (ha)	5%	9 220.14 (ha)	3%	147 701.88 (ha)	12%
Mines	3447.09 (ha)	0%	3 183.48 (ha)	1%	2 497.96 (ha)	0%
Totals	1535779.89 (ha)	100%	318721.86 (ha)	100%	1204727.68 (ha)	100%

In assessing natural resource change drivers, the study used bioclimatic data Table 4-2 (Noce 2022; https://www.worldclim.org/data/bioclim.html) to evaluate and assess natural resource change across multiple natural resources in the Vhembe biosphere. Bioclimatic variables calculated from monthly and precipitation and temperature values from 1990 to 2018 were generated through interpolation (Sluiter, 2009) of average monthly climate data (Table 4-2) at 30 arc-seconds spatial resolution (Fick et al., 2017; Hijmans et al., 2005;), a total of 35 variables were used as dependent variables in the natural resource change analysis (Noce 2022; http://www.worldclim.org/) Accessed 23 July 2020.

Rainfall and mean temperature bioclimatic variables were used in tandem with topographic variables and edaphic factors (Rajakaruna et al., 2008) to predict natural resource change. Bioclimatic variables were obtained from the WorldClim archives (http://www.worldclim.org/) of the global climate conditions. The WorldClim climatic data sets are long-term (30-year) mean annual measurements (Karger et al., 2017) containing grids of rainfall and temperature (Karger et al., 2017) as well as other summarised climatic layers like wettest, driest, coldest, and hottest months and quarters of the year (Karger et al., 2017).

Historical climate data comprising 19 bioclimatic variables were downloaded from the WorldClim website (www.worldclim.org) at 30arc second (approximately 1 Km^2) resolution. Digital elevation model (DEM) (Hawker et al 2018) derived from the Shuttle Radar Topography Mission (SRTM) (Lahsaini et al., 2018) elevation data downloaded from the WorldClim website (www.worldclim.org) was also used to generate slope and aspect using ArcMap.

Edaphic variables used in the study were also drawn from soil attributes from the soil layer map (Cramer et al., 2019), including soil pH, soil organic carbon chemistry, and soil organic carbon, download via www.SoilGrids.org under the Open Database License (ODbL). The variables used in explaining the natural resource change in this study are presented in Table 4-2.

Table 4-2: Variables used to explain natural resource change in the study area

	Variables	Source	Scale/resolution
Climatic			
Bioclimatic	BIO1 = Annual Mean Temperature BIO2 = Mean Diurnal Range (Mean of monthly (max-temp-min temp) BIO3 = Isothermality (BIO2/BIO7) (×100) BIO4 = Temperature Seasonality (standard deviation ×100) BIO5 = Max Temperature of Warmest Month BIO6 = Min Temperature of Coldest Month BIO7 = Temperature Annual Range (BIO5-BIO6) BIO8 = Mean Temperature of Wettest Quarter BIO9 = Mean Temperature of Driest Quarter BIO10 = Mean Temperature of Warmest Quarter BIO11 = Mean Temperature of Coldest Quarter BIO12 = Annual Precipitation BIO13 = Precipitation of Wettest Month BIO14 = Precipitation of Driest Month BIO15 = Precipitation Seasonality (Coefficient of Variation) BIO16 = Precipitation of Wettest Quarter	WorldClim 2.1: (Fick, S. E. and R.J. Hijmans, 2017)	~1Km^2

	BIO17 = Precipitation of Driest Quarter BIO18 = Precipitation of Warmest Quarter BIO19 = Precipitation of Coldest Quarter		
Minimum Temperature	tmin 1-12		
Maximum Temperature	tmax 1-12	WorldClim 2.1: (Fick, S. E. and R.J. Hijmans, 2017)	~1km
Average Temperature	tavg 1-12	WorldClim 2.1: (Fick, S. E. and R.J. Hijmans, 2017)	~1km
Precipitation	prec 1-12	WorldClim 2.1: (Fick, S.E. and R.J. Hijmans, 2017)	~1km
Edaphic			
Topography	Digital Elevation Model (DEM) Slope Aspect	SRTM, https://www2.jpl.nasa.gov/srtm/ Derived from DEM	30m 30M
Soil Chemical Properties	Nitrogen (cg/kg) pH Soil Organic Carbon (dg/kg)	Soilgrid.org (Hengl et al., 2017)	250m
Soil Physical Properties	Sand (g/kg) Silt (g/kg) Coarse Fragments (cm^3/dm^3) Bulk Density (cg/cm^3)	Soilgrid.org (Hengl et al., 2017)	250m

4.1.1 Data Processing

To fully assess natural resource change drivers in the study area, 12 land cover classes (Nuwarinda et al., 2021) that were reclassified from SANLC 72 classes data set (Thompson, 2019) were used in this analysis including; indigenous forests; thicket/dense bush; natural woodland; shrubland; grassland; water bodies; and wetlands, barren land, cultivated commercial, built-up residential and mines (Thompson, 2019; Nuwarinda et al., 2021).

The SANLC 72 classes data was reclassified to create a natural resource change map (Figure 4-2) with 12 classes indicating transformation and non-transformation natural resources. The 12 natural resource classes were further reclassified to only 2 classes, where the value of **1** was given to natural resources that changed (transformed) and **0** to natural resources that never changed (no transformation). The study applied logistic regression, a multivariate analysis model that employs the use of independent variables to predict the probability of a dichotomous event such as **1** = change and **0** = no change (Mousavi et al., 2011; Die et al., 2002). A set of bioclimatic dependent variables were generated and run in a statistical software R-studio for regression analysis. The variables were selected based on their representation of the process believed to be natural resource drivers in the study area.

According to correlation analysis in this study, the correlation coefficient between dependent and independent variables is ranked from the highest to the lowest variable. The results indicate that average temperature (tavg) and minimum temperature are the main drivers of the natural resource change in the Vhembe district. Of all significant variables, tavg4 (6.02) is the highest correlated variable followed by tavg6, tavg10, and tavg5. Other environmental variables with negative estimates in the model are considered to have contributed negatively to the model.

From the results obtained, high average temperature and minimum temperatures registered from 1990 to 2018 in the study area were determined significantly to drive shrubland natural resources in the study area. For example, shrubland reduced in total area from 17% in 1990 to 6% in 2013 and 0% in 2018. This is attributed to the rise in temperature in the study area leading to; (i) shrubs drying off consistently, (ii) encroachment of man to harvest shrubs as firewood for space heating and domestic use leading to bare soils that were easily eroded by rains during the rainy season. High average temperatures registered in the study area that contributed to the drying of shrubs can be assumed to have later contributed to the occurrence of wildfires that destroyed shrubland.

The transformation of Thicket/Dense Bush natural resource to Natural Wooded Land was also recorded in 2013 (20% to 26%) and 2018 (2% to 21%) and indicated by a structural gradient in woody vegetation from open woodland to closed woodland and then to a forest. Important to note is that these two classes are adjacent to one another in the natural vegetation resource distribution table (Table 4-1). However, from a natural resource perspective, the change was seen as an improvement in the original data of 1990 and 2013/14 classification.

4.1.2 Descriptive statistics for all the variable

In this study, we used long-term climatic elements of minimum temperature, maximum temperature, average temperature, and precipitation to determine their contribution to vegetation cover changes in the study area. Historical daily, monthly, and annual precipitation totals, and temperatures observed in Vhembe Biosphere were used between 1990 and 2018. Descriptive statistics were used to analyse the mean, standard error, minimum and maximum temperatures, and precipitation, where the confidence level of 85% of variables was determined.

4.1.3 Generation of Points

Points were generated using the space of 500m and 1000 m and we eventually used the 500m to reduce the effect of spatial auto-correlation. The regression model used is useful for situations that predict the presence or absence of characteristics. The study used logistic regression using R studio wherein the model, probabilities were between 0 and 1, and only significant variables were used to develop the model. In the model, the calculation of R^2 indicates the fitness of the model and its value in logistic regression of the binary response variable. For a very good fit of a logistic regression model, R^2 should have values between 0.2 and 0.4 (Wilson et al, 2005), Z- values are the regression coefficient divided by the standard error. If the value is too big in magnitude, it indicates that the corresponding true regression coefficient is not 0, and the corresponding X-variable matters (Beale et al., 2010; Castellaro et al., 2006).

The P-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect) (Andrade 2019; Favero et al., 2019; Want et al., 2019). A low P-value (<0.05) indicates that you can reject the null hypothesis (Alam 2021, Ferreira et al., 2015). The P-value is used to determine which terms to keep in the regression model (Want et al., 2019; Wasserstein et al 2016). If the P-value is less than or equal to the significant level, it can be concluded that there is a statistical significant association between the response variable and the term (Andrade 2019; Figueiredo et al., 2013). If the P-value is greater than the significance level, it cannot be concluded that there is a statistically significant association between the response variable and the term (Favero et al., 2019; Figueiredo et al., 2013). The model may be fitted without the term. If there are multiple predictors without a statistically significant association with the response, the model must be reduced by removing terms, one at a time Favero et al., 2019; Andrade 2019;).

4.1.4 Logistic regression to determine driver of natural resources change

Logistic regression analysis was used to determine drivers of change (dependent variables) with a set of independent variables such as climatic temperatures, topography, edaphic factors in the study area. Steps taken for logistic regression analysis and model selection are indicated in Figure 4-1 The advantage of using logistic regression as indicated by Mousavi et al 2011, is that; despite making an appropriate link function to the usual linear regression models, logistic regression does not assume linearity between the independent and dependent variable and does not assume variables having equal statistical variances (Wasserstein et al., 2016; Mousavi et al., 2011). In our study, logistical regression was used to analyse natural resource change drivers as the outcomes variable 'natural resource change;' had two categories where **1** (dependent variable) indicated change detected and **0** (independent variable) indicated no changed detected, this assisted in data description and explanation of the relationship between one dependent variable driver and the independent variables. The data mining analysis package “Rattle” (Graham, 2009) was run in a stepwise process within an R-statistical and programming software implemented in R-studio.

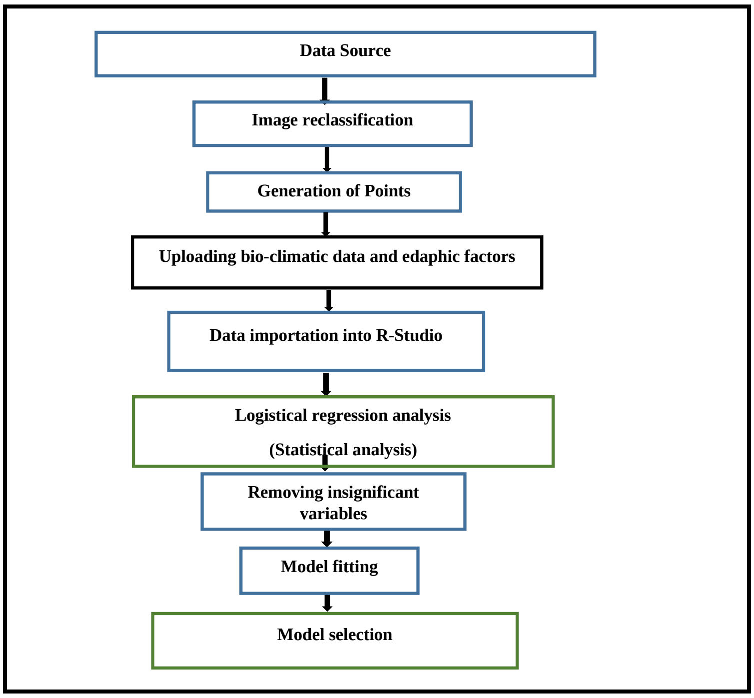

Figure 4-1: Steps taken for logistic regression analysis and model selection

(Source: *Authors)*

4.1.5 Validation of the logistics regression model

To indicate the effectiveness and soundness of the model we used 30% of that data to validate the model using the AUC (Area Under the Curve) ROC (Receiver Operating Characteristics) curve (Favero et al., 2019; Zhou et al., 2007). The coefficient of variation and area-under-the-curve (AUC) was used as indicators of the performance of the logistic regression (Menard 2000; Peng et al. 2002). AUC is a most used indicator for accuracy assessment for probability modelling results (Lobo et al., 2007; Fenlon et al., 2017), with 0 and 1 signifying poor and good performance of the models (Fenlon et al., 2017). The ROC curve has been recommended because it summarises model performance (Fenlon et al., 2017; Zhou et al., 2007) overall conditions a model could operate in (Mohamed et al., 2013 Zhou et al., 2007; Swets, 1988), using all the information provided by the predictive model (Fielding & Bell, 1997), and valid as a single threshold independent measurement of model performance (Thuiller et al., 2005; Brotons et al., 2004). The real value of AUC is that it provides a measure of the degree to which a species is restricted to be a part of the variation range of the modelled predictors (Mohamed et al., 213) so that presences can be told apart from absences (Mohamed et al., 213; Lobo et al., 2008).

4.2 Results

4.2.1 Summary of land cover changes

According to Nuwarinda et al., 2021, natural resource change assessment based on the land cover change in the study area, for 1990 and 2013, indicated that, in 1990, grassland natural resource a dominant land cover in the Vhembe biosphere; with a total land cover area of 562,136.5 (ha), decreased to 64,506.6 (ha) in 2013 an equivalent of -89% change in natural resource area coverage (Nuwarinda et al., 2021). The study also noted that; thicket/dense bush and shrubland resources decreased from 338,723.7(ha) and 263,070.6 (ha) in 1990 to 63,569.34 (ha) and 19,685.43(ha) in 2013 at -81% and -93% change respectively (Nuwarinda et al., 2021).

It is further noted in the study that; during the 2013-year, thicket dense bush natural resources decreased from 63,569.34 hectares to 23,166.92 hectares in 2018, a -6% decrease (Nuwarinda et al., 2021). This was followed by shrubland that decreased from 19,685.43 hectares to 977.72 hectares with a percentage change of -9%. While cultivated commercial area increased from 10,846.8 hectares in 2013 to 365,644.9 hectares in 2018 with a percentage change of 294%; the built-up area from 9,220.4 hectares in 2013 to 147,709.9 hectares in 2018 with a percentage change increase of 135% respectively (Nuwarinda et al., 2021).

The study concluded that the observed changes in natural resources were largely attribute to the encroachment of man's activities on vegetation cover resources like the building of residential areas, commercial farming as a means of meeting developmental and associated requirements in the study area, and non-anthropogenic factors like fluctuations in climate and temperature.

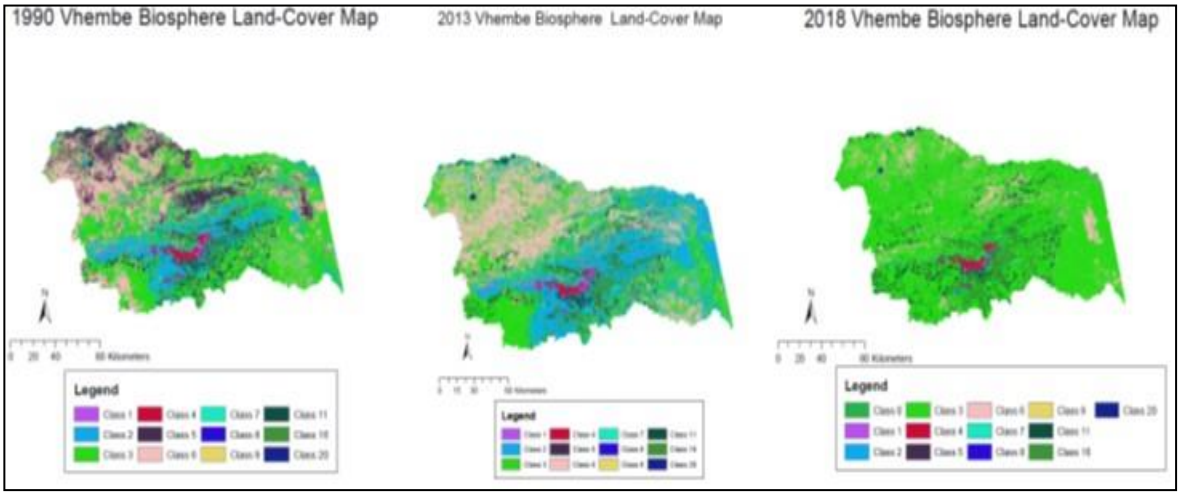

Figure 4-2: Land cover natural resource stamps maps of Vhembe biosphere

(Source: Nuwarinda et al., 2021)

4.2.2 Driver of change using environmental variables

A set of bioclimatic dependent variables were generated and run in a statistical software R-studio for regression analysis. We used all the variables in Table 4-1 using stepwise logistic regression to arrive at the data used in Table 4-2.

All the variables in the Table 4-2 were significant as they were the major drivers of natural resource change in the study area. The variables were selected based on their representation of the process believed to be natural resource drivers in the study area.

Results indicate that average temperature (tavg) and minimum temperature are the main drivers of the natural resource change in the Vhembe district. Of all significant variables, tavg4 (6.02) is the highest correlated variable followed by tavg6, tavg10, and tavg5. Other environmental variables with negative estimates in the model are considered to have contributed negatively to the model.

Logistic regression was done using R-studio with a list of significant environmental variables (Table 4-2) as derived from Hijmans et al., 2005; Fick et al., 2017. The list of variables used to explain natural resource change using stepwise logistic regression to arrive at the data used is presented in Table 4-2.

Table 4-3: List of significant environmental variables used to explain the natural resource change

Variable		Estimates	<0.05

	Intercept	**74.50**	
	Variable description		**P-Value**
Bio_3	Isothemality	-1.04	<0.05
Bio_10	Mean temperature of the warmest quarter	-6.11	<0.05
Bio_13	Precipitation of the Wettest month	-0.05	<0.05
Bio_14	Precipitation of Driest month	-0.11	0.00
Bio_15	Precipitation of Seasonality	-0.32	<0.05
Bio_16	Precipitation of Wettest quarter	-0.13	0.08
Elev	Elevation	0.01	<0.05
Prec_1	Precipitation of January	0.13	<0.05
Prec_2	Precipitation of February	0.06	0.00
Prec_3	Precipitation of March	-0.03	<0.05
Prec_5	Precipitation of May	-0.14	<0.05
Prec_6	Precipitation of June	-0.15	<0.05
Prec_9	Precipitation of September	-0.23	<0.05
Prec_10	Precipitation of October	-0.18	<0.05
tmin_1	Minimum temperature of January	3.55	<0.05
tmin_2	Minimum temperature of February	4.67	<0.05
tmin_5	Minimum temperature of May	-0.85	0.00
tmin_9	Minimum temperature of September	-3.45	<0.05
tmin_10	Minimum temperature of October	-1.99	<0.05
tmin_11	Minimum temperature of November	-3.03	<0.05
tavg_4	The average temperature of April	6.02	<0.05
tavg_5	The average temperature of May	1.25	0.00
tavg_6	The average temperature of June	3.91	<0.05
tavg_8	The average temperature of August	-2.40	<0.05
tavg_9	The average temperature of September	-2.49	<0.05
tavg_10	The average temperature of October	1.59	<0.05
Slope	Slope	-0.01	<0.05
Coarse_F1	Soil properties	-0.14	<0.05
Nitrogen	Soil Nitrogen	-0.01	<0.05
pH	Alkalinity/acidity	-0.14	<0.05
Sand	Soil type	0.00	<0.05
Silt	Soil type	-0.01	<0.05
Soil Class	Soil classes	-0.00	0.00
SOC_Chem	Soil chemical	0.01	<0.05
SOC_Stock	Soil stock	0.16	<0.05

To test the accuracy of the model's binary classifier, a receiver operating characteristic accuracy curve (ROC curve) was generated (Figure 4-3). Because on the high accuracy level of the ROC curve, it is indicates that there was a significant change in natural resources in the study area. The overall performance of the model is measured by the AUC curve (Area under the curve). In our study, the performance of the model based on independent data sets was 85%. Based on the information used, 70% of the points were used for calibration, and 30% of the points were used for validation. ROC at **0** indicates that the model is weak and at **1,** it indicates that the Model is good (at AUC=0.85 signifies the quantity of loss which in this case, indicates high estimates of natural resource loss).

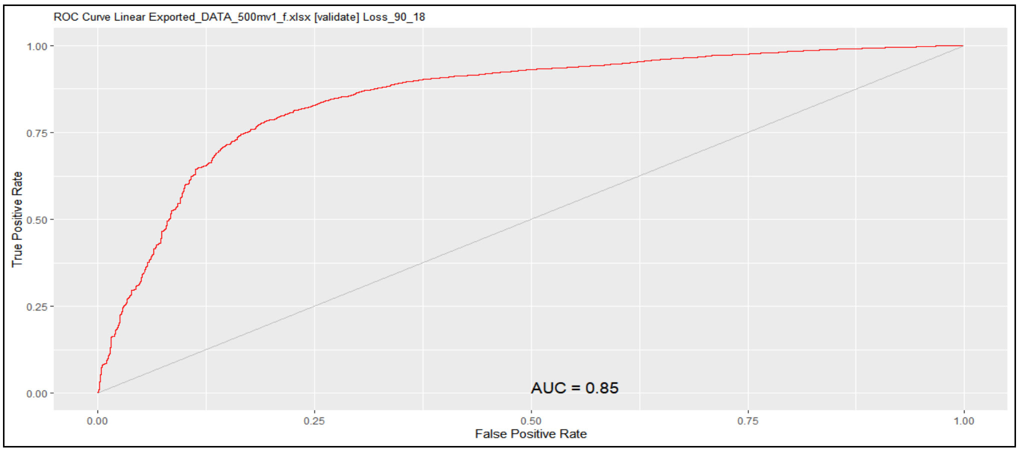

Figure 4-3. ROC Curve

(Source: Nuwarinda et al., 2021)

4.3 Discussion

Variation in bioclimatic factors has the potential to drive every type of vegetation cover resource in any given environment at any given time (Zellweger et al., 2016; Notaro et al., 2012). The distributions of vegetation cover resources will continue to shift as rising temperatures, rainfall variation, change in altitude (Piao et al., 2011; Beniston 2003), and soil properties continue to alter our natural ecosystems and intensify the already existing environmental concerns (Smith et al., 2016; Janzen 2005). Rising temperatures have the potential to affect every type of vegetation cover resources, their distribution, alter natural ecosystems, and amplify the existing environmental concerns (Jain et al., 2005; Baron et al., 1998). The impact of temperature fluctuations in any given ecosystem will include a shift of vegetation cover types and associated impacts on biodiversity, change in forest density and agricultural production, expansion of arid land, and relocations of populations (Li et al., 2021; Franco et al 2014).

Average temperatures recorded during the study period in Vhembe Biosphere seem to have contributed to the vegetation cover shift. Based on incremental high average temperatures recorded from 1990 to 2018, a significant reduction of shrubland vegetation cover resources to grassland natural resources was observed in the study area. This is further compounded by the advancement of barren lands in the area that was predominantly shrubland. Temperature variations also have the potential to increase the risks of drought, forest fires, and invasive species which are additional drivers and stressors to vegetation cover resources in a given biosphere, and this is evident as a case in the Vhembe biosphere.

Furthermore, temperature variations have the potential to influence precipitation wherein our study; lower average precipitation was recorded during the study period in the study area. High average temperatures and lower precipitation are assumed to have practically contributed to the transition of thicket/dense bush to natural woodland between 1990 to 2013 and 1990 to 2018. This relates to revenant study by Werner et al., (2018); Gessner et al (2013) where it was alluded that climate conditions including temperature has a direct influence on vegetation cover. This is evidenced from the observed results obtained where high average temperature and minimum temperatures registered from 1990 to 2018 determined significantly to drive shrubland natural resources in the study area. For example, shrubland reduced in total area from 17% in 1990 to 6% in 2013 and 0% in 2018. This is attributed to the rise in temperature in the study area leading to; (i) shrubs drying off consistently, (ii) encroachment of man to harvest shrubs as firewood for space heating and domestic use leading to bare soils that were easily eroded by rains during the rainy season. High average temperatures registered in the study area that contributed to the drying of shrubs can be assumed to have later contributed to the occurrence of wildfires that destroyed shrubland.

Based on bioclimatic variables assessed, precipitation/rainfall variations in the study area show significant fluctuation during the study period. Compounded by unpredictable estimates of precipitation (Prec: 1 and Prec: 2) of the wettest, month, the driest month, and wettest quarters. Fluctuations in precipitation/rainfall regimes could have led to; (i) transformation/shift from indigenous forest to thicket/dense bush, (ii) barren land to the cultivated commercial and built-up residential area in the study area. The transformation of thicket/dense bush vegetation cover to natural wooded land was also recorded in 2013 (20% to 26%) and 2018 (2% to 21%) and indicated by a structural gradient in woody vegetation cover from open woodland to closed woodland and then to the forest. Important to note is that these two classes are adjacent to one another in the natural vegetation resource distribution table (Table 4-1). However, from a natural resource perspective, the transformation was seen as an improvement in the original data of 1990 and 2013/14 classification.

The most interesting broad transformation to be detected was shrubland vegetation resource moving to grassland vegetation resource in the study area: 17% to 37% in 1990, 6% to 20% in 2013, and 0% to 27% in 2018. The major driving factors for the recorded driver were attributed to the average rainfall (precipitation) recorded in the study area. From further analysis, barren land reduced significantly from 6% in 2013 to 2% in 2018, this was attributed to man's activities like building up of residential areas which are indicated by the increase in built-up residential from 5% in 1990 to 12% in 2018. There was an increase of cultivated commercial area from 9% in 1990 to 30 % in 2018 which could be attributed to consistent average rainfall registered in the study area for the period of study. This is confirmed by analysis of the digital natural resource change map where the original land cover characteristics of 1990 and 2018 can be determined.

From the vegetation cover resource distribution in the study area, it was also observed based on the rate at which natural vegetation cover transformed from one class to another; other factors also contributed to such a shift, including, agriculture expansion with overexploitation of vegetation based natural resources for potential economic purposes including commercial farming and urban development. Of importance to note is that the edaphic factors that were analysed in this study, like elevation, slope, soil properties, type, classes, and chemical composition did not contribute to the transformation of any vegetation cover class to another.

4.4 Conclusion

The impacts of temperatures and rainfall variations on vegetation cover resources vary widely, and can also be compounded by other factors. As temperatures rise, the distribution and composition of vegetation cover resources will continue to shift and transit from one class to another. Practically, based on the assessment results, indigenous forests transformed to thicket/dense bush, shrubland to grassland. However, this transformation is not only affected by temperatures and precipitation but also other contributing factors isothermally, soil organic stock, and soil alkalinity. Vegetation cover resource management in the Vhembe biosphere will need a detailed natural resource management strategy as impact identified drivers continue to increase in the study area.

4.5 Study Limitations

Distinguishing between human-induced and natural drivers of natural resource change were not easy to certain extent based on the interrelatedness role between man and nature in the biosphere. However, we able to use the given set of data explore such drivers in the study area. What was also noted in the study was that natural resource change often results from interaction between multiple factors like land use, invasive species, climate change, and efforts to isolate the effects of a single drive could be a challenge. However, with the given data set we were able to demonstrate the possibility to explore the drivers of natural resource drivers in our study area.

For future studies it was found to be of importance to note that understanding how people perceive and respond to resource use and change is vital, as social-economic and cultural factors influence resource use and management.

CHAPTER 5

ASSESSING THE ROLE OF SOCIO-ECONOMIC FACTORS IN MAINTAINING BIODIVERSITY: A CASE STUDY OF VHEMBE BIOSPHERE, SOUTH AFRICA

This chapter is based on: ***Nuwarinda,*** *H., Ramoelo, A., Adelabu, S., & Mashiane K. (2023). Assessing the role of socio-economic factors in maintaining biodiversity: A case study of Vhembe Biosphere, South Africa. Manuscript submitted @ People and Nature Journal*

Abstract

The recent decline in biodiversity has reached alarming proportions, owing primarily to human activities such as land-use change, pollution, and climate change, and it remains a major conservation concern on local, national, and international levels. Understanding and analysing the drivers of biodiversity loss is critical for investigating potential biodiversity conservation actions. In our study, we hypothesised that socioeconomic factors (education, employment, and income levels) are the primary drivers of biodiversity loss in the study area. Three sets of models were generated: education (AIC=66.33, AUC=1.0), employment (AIC=71.311, AUC = 0.06), and income levels (AIC=74.545, AUC=0.6) and a combination of all the three (AUC = 0.85). The education model shows that biodiversity loss is strongly correlated with the level of education. This could indicate that lower levels of education potentially contribute to biodiversity exploitation and loss in a variety of ways. Lower income levels have the potential to significantly increase biodiversity loss, while higher employment and income levels have the potential to slow the increase in biodiversity loss. An indication that communities surrounding a biosphere with no employment and limited incomes will contribute to biodiversity loss through exploitation of surrounding biodiversity.

Keywords: *Biosphere, Biodiversity loss, Drivers, Income levels, Education level, Employment levels*

5. Introduction

Biospheres are ecosystems that are carefully and cautiously managed (Coleman 1996; Christensen et al 1996) to support numerous ecosystem services (Lavorel et al., 2020; Folke et al., 2021, Lavorel et al., 2020, Alfonso et al., 2017). Their availability contributes to global, national, and local economies (Zoomers 2010; Turner et al., 2007). Their production and usage processes reflect socioecological (Lambin et al., 2010), and economic changes occurring at a larger scale (Lambin et al., 2011; Turner et al., 2007) where economic globalisation and imminent global land scarcity, escalate the management challenges for their future course (Azadi et al., 2022; Lambin et al., 2011; Walker et al., 2002). Zafar et al., 2019; Panayotou 2016; have ardently emphasised that increased social-economic growth requires more resource input and thus more biodiversity and natural resource consumption during production process (Ali, 2021; Harclerode et al., 2016). Therefore, at the early stages of any developmental economy, humans use more biodiversity resources at the expense of resultant environmental consequences that lead to destructive biodiversity effects (Zafar et al., 2019; Wiedmann et al., 2018).

The increased awareness that nature, culture, and economic development are intricately linked (Dessein et al., 2015; Lasco et al., 2010) and that naturally protected areas alone cannot discontinue biodiversity loss is widely acknowledged (Mora and Sale 2011; Mathur and Sinha 2008). More so, the demand for food and other resources globally has been on the rise in the past decades (Harvey et al., 2008), which calls for a more integrated approach to sustainably use and conserve biodiversity (Spake et al., 2017; Harvey et al., 2008; Iftekhar 2006). and The Millennium Ecosystem Assessment MEA 2005 and defined a driver as any natural or human-induced factor or variable that is casually linked directly or indirectly to a measured change in a response variable that directly or indirectly causes a change in an ecosystem, where changes in ecosystem services can feedback to alter biodiversity drivers (Nelson et al., 2015). A direct driver undeniably influences ecosystem processes (Bustamante et al., 2018; MEA 2005; Nelson et al., 2006). Indirect drivers operate more diffusely in adjusting one or more direct drivers (Santos 2021; Bustamante et al., 2018; Rocha et al. 2015).

Some of the biodiversity loss critical drivers in Xu et al., 2004, Sala et al., 2000 are listed as; climate change, agricultural production, fuel-wood collection, nitrogen deposition, livestock grazing, atmospheric carbon dioxide and biotic exchange. It is noted that the consequences of these drivers vary in different ecosystems (Braimoh et al.,2010; Lasco et al., 2010). Different indirect drivers contribute in distinct ways to biodiversity loss in each location (Didham et al., 2012; Maxim et al., 2009; Nelson et al., 2006). Land use activities like deforestation caused by farming expansion, road construction (Barraclough et al., 2013; Freitas et al., 2010), agriculture expansion and fuel wood extraction (Nelson 2008; Nelson et al 2006) are some of the key drivers of biodiversity loss in Africa (Skowno et al., 2021; Norris et al., 2010). It should be noted that specific biospheres provide ecosystem services (Maes et al., 2012; Barbier et al,. 2011) not only for local communities but also for a large population outside their boundaries (Gomez et al., 2013; Zhang et al., 2007;). Indeed, the production and utilisation of biospheres continue to be influenced by intrinsic demands and policy decisions (Seddon et al., 2016; Syrbe et al., 2012) made at local, national, and international levels. Biodiversity loss drivers and consumption of the natural resource capital for economic gains are inextricably linked (Almond et al., 2020; Hajer et al., 2016; UNEP 2011) stemming from utilisation of biodiversity resources for economic advantages (Pearce 2013; Lichtenberg et al., 2010; Taylor 2009). Despite acknowledging the influential role biodiversity plays in supporting terrestrial ecosystems, biodiversity is continuing to decline at an unprecedented rate on earth (Ansari 2021; Harper et al., 2021; Ceballos et al., 2020; IPBES 2019).

Human activities in any given ecosystem, both at the local and commercial scale, contribute majorly to biodiversity loss (Kumar et al., 2022). For example, shifting and extensive agriculture by smallholder and commercial farmers (Patel et al., 2020; Tscharntke et al.,2012), intensification of subsistence and commercial farming in the past four to five decades (Tsiafouli et al., 2015; MEA 2005; Tilman et al.2001), that encourage biomass burning and mono-cropping in given ecosystems (Patel et al., 2020; Zhang et al., 2016), extensive use of synthetic fertilizers, disposal of herbicides and insecticides affect terrestrial ecosystem negatively (Rani et al., 2021; Weldeslassie et al., 2018; Bhandari 2014;) leading to loss of natural and seminatural habitats, and biodiversity loss (Kumar et al., 2021; Foley et al., 2005). Additionally, losses in biodiversity ecosystems are often caused by multiple interacting drivers that work over a period of time (Archer et al., 2017; Wilson et al., 2016), potential increases in temperatures and severe events such as floods, droughts, and heat waves threaten biodiversity (Archer et al., 2017; Mooney et al., 2009; Brook et al., 2008). Biodiversity loss also depends on several economic activities (Barbier et al., 2019; Omann et al., 2009; Bennett et al., 2001), including the location of activities, resource endowments and ecosystem conditions (Polasky et al., 2005; Folke et al., 1996), available technologies and relevant policies (Barro et al., 2004). Incomes derived from economic activities by individuals determine their level and nature of natural resource consumption and associated services (de Vries et al., 2002; Diao et al., 2007).

Zhao et al., (2018); Nelson et al., 2006 postulate that demand for non-agricultural goods and services increases faster than demand for agricultural, which leads to a dramatic change in the structure of economic activities and ecosystem modifications. However, it is noted that; as people's income improves due to economic growth, they tend to shift to non-agricultural goods and services that improves their quality of life (Fischer et al., 2022; Praburaj et al., 2018). While this should be viewed as a positive shift towards pressure reduction on biodiversity ecosystems (Mehrotra et al., 2014; Nelson et al., 2006), it is vital to note that; with economic growth, the industrial and service sectors of an economy grow much faster (Christiaensen et al., 2011; Diao et al., 2010) with significant impact on biodiversity status (Almond et al., 2020; De Ambrosio 2020). In tandem with this, the underpricing and undervaluing of natural resources influence terrestrial biodiversity loss (Barbier 2022; Kusena 2009; Berry et al., 2003) which presupposes that; if natural resources and associated ecosystems are inappropriately priced, converting them to agriculture and other land use forms is less costly than preserving them (Barbier 2022; Newburn et al., 2006).

In Africa, large populations live in rural areas (Kumar and Yashiro 2014; Richardson 2010), and in particular poor households who directly rely on ecosystem services and goods provided by natural resources (Hassan et al., 2016; Robinson 2016; Shackleton et a., 2008) such as livestock production, wild food or wood as energy source for cooking and heating (Adekola et al., 2015; Le Maitre et al., 2007), sequentially this presents progressive effects on biological diversity (Waterehouse et al., 2013; Griffiths et al., 2001). Millennium Assessment Report (Millennium Ecosystem Assessment, 2005) underscores how the intensification of land use has already reduced the flow of biological diversity services in many regions globally and this also manifested on local levels (Socolar, et al., 2016; Coetzer-Hanack et al., 2016).

Vhembe biosphere has a range of bio-diverse ecosystems which support diverse biodiversity (Linen et al., 2014; Driver et al., 2012). Notable ecosystems include indigenous forests, savanna, grasslands, mountain escarpments and a variety of wetlands (Ramarumo et al., 2020; DEA 2011). It experiences enormous pressures from different actors and stressors (Hedden-Dunkhorst & Schmitt 2020; Kasperson et al., 2005), ranging from human settlement expansion, agriculture expansion, mining developments, and other associated land uses (Dalu et al., 2022; SEF 2016; Desmet et al., 2014; DEA 2011) that contribute to biodiversity loss. There is limited and related studies on the quantification of biodiversity loss and analysis of the socio-economic drivers of biodiversity loss in Vhembe Biosphere done before, hence a justification for conducting this study.

Vhembe biosphere has a range of bio-diverse ecosystems which support diverse biodiversity (Linen et al., 2014; Driver et al., 2012). Notable ecosystems include indigenous forests, savanna, grasslands, mountain escarpments and a variety of wetlands (Ramarumo et al., 2020; DEA 2011). It experiences enormous pressures from different actors and stressors (Hedden-Dunkhorst & Schmitt 2020; Kasperson et al., 2005), ranging from human settlement expansion, agriculture expansion, mining developments, and other associated land uses (Dalu et al., 2022; SEF 2016; Desmet et al., 2014; DEA 2011) that contribute to biodiversity loss. There is limited and related studies on the quantification of biodiversity loss and analysis of the socio-economic drivers of biodiversity loss in Vhembe Biosphere done before, hence a justification for conducting this study.

The objective of this study was to analyse how social economic drivers influence biodiversity loss in Vhembe biosphere with the aim of contributing to the understanding and management of biodiversity in the study area and also provide quantitative data that will potentially assist with the development of sustainable biodiversity management practices towards natural resource management, planning, and conservation.

5.1 Data used

5.1.1 Social economic data preparation

To analyse drivers of biodiversity loss in Vhembe biosphere, the study considered three variables of socio-economic data obtained from South Africa Statistics (SA Start 2011) for quantitative analysis: (i) income levels; (ii) employment levels; and (iii) education levels for the population in the study area, between 1990-2014 and 2014-2018, totaling to 29 variables respectively (Table 5-1). Socio-economic variables were selected and used to analyse biodiversity loss in the study area due to that fact that they were assumed to be relevant causes contributing to biodiversity loss. The variables were collected from the Statistics South Africa census data repository (Stats SA 2011). Education levels data comprised of; “Non schooling population”, Some Schooling the population that went to primary school, population that Completed primary school”, some of the population that completed secondary school and Grade 12/Standard 10, based on school going age population per ward resident between 15-64 years of age (Table 5-1). Employment levels were categorized into four categories, (i) employed, (ii) unemployment, (ii) discouraged work seeker and (iv) others not economically active people per household in each ward (Table5-1). For income levels, different income amount totals were considered ranging from 5k -600k; of total monthly incomes of employed population per ward/household residents between 15 to 64 years of age (Table 5-1).

5.1.2 Biodiversity loss data

Biodiversity loss in our study referred to the loss of biological diversity within the Vhembe biosphere at various levels, ranging from loss in gene species, individual organisms and biological communities (Rawat et al., 2015) with the potential to affect the functionality and stability of the ecosystem and the well-being of the surrounding human communities (Rawat et al., 2015; Batisse 1997).

Biodiversity loss data under census classification was acquired through Statistics SA (Statistics SA 201) and used in this study to generate socio-economic variables through the use of statistical software R-Studio for regression analysis. The dependent variable used in the study was biodiversity loss, while the independent variables were education, employment and income levels of the population in the study area. Social economic data variables were selected based on their representative potential as biodiversity loss drivers in Vhembe biosphere.

Social economic data sets were randomly split into 70% calibration and 30% validation for model performance evaluation during logistic regression analysis (Nuwarinda et al 2021; Mourad et al., 2005). In using logistic regression as indicated by Mousavi et al., 2011, the derived advantage was that; despite making an appropriate link function to the usual linear regression models, logistic regression does not assume linearity between independent and dependent variables and does not assume variables having equal statistical variances (Wang et al., 2014).

5.1.3 Social economic drivers for biodiversity loss

To analyse the relationship between social-economic variables and biodiversity loss, logistic regression analysis was used to determine drivers of change (dependent variables) with a set of independent variables split according to education levels, employment level and income levels of the population in the study area.

The advantage of using logistic regression in the analysis of such data is that; it helps in describing the relationship between a response variable and one or more explanatory variables (Fang 2013), where the outcome variable is discrete in taking on two or more possible values (Fang 2013; Ohlmacher & Davis 2003). logistic regression does not assume linearity between independent and dependent variables and does not assume variable having equal statistical variances (Wasserstein et al., 2016; Mousavi et al., 2011).

In our study, logistical regression was used to analyse natural resource change drivers as the outcome's variable 'natural resource change;' had two categories where **1** (dependent variable) indicated change detected and **0** (independent variable) indicated no changed detected, this assisted in data description and explanation of the relationship between one dependent variable driver and the independent variables. The data mining analysis package "Rattle" (Graham, 2009) was run stepwise within an R-statistical and programming software implemented in R-studio.

5.1.4 Validation of the logistical regression model

5.1.4..1 Area Under the Curve

To illustrate the efficacy and integrity of the model we used 30% of the data to validate the model using the Area Under the Curve (AUC) and Receiver Operating Characteristics (ROC) curve (Graham et al., 2009; Andrade 2019). The coefficient of variation and area-under the-curve was used as indicators of logistic regression performance (Zhou et al., 2007; Peng et al., 2012). Area-under the-curve is the most used indicator for accuracy assessment for probability modelling results (Jimenez-Valverde 2012; Pearce et al., 2000) , with **1** and **0** signifying **good** and **poor** performance of the model, respectively (Lobo et al., 2008). The Receiver Operating Characteristics curve has been recommended because it shows the performance of the model's) overall conditions to operate in (Zhao et al., 2018; Graham et al., 2009; Lobo et al., 2008 De Jong et al., 2011), using all the information provided by the predictive model (Mohamed et al., 2013), and valid as a single threshold independent measurement of model performance (Fielding et al., 1997). The factual importance of area-under the-curve is that it provides a measure of degree to which a species is restricted to be a part of the variation range of the modelled predictors (Austin 2007) so that their presences can be told apart from absences (Bahn & McGill 2007; Broton et al., 2004)

5.2 Results

5.2.1 Descriptive statistics for the variables

In this study, we used long-term social economic data variables of education levels, employment levels and income levels for the population in four district municipalities that make up Vhembe biosphere. Historical education, employment, and income levels data for residents in Vhembe Biosphere was downloaded from Statistics SA census data of 2011 (Stat SA, Census 2011). Descriptive statistics were used to analyse minimum and maximum levels of variables, together with the mean and standard error of variables (Table 5-1) based in the number of data samples used from the study area. From the data set used, we looked at the mean, median, minimum, maximum, variance, standard deviation and coefficient of variance to provide variable insights and understand the central tendency, spread and variability of data variables. This helped in interpreting the descriptive statistics variables used. The analysis of the main findings show that biodiversity loss is strongly correlated with the level of education in the study area. "No schooling" emerged as the dominant variable negatively affecting biodiversity levels, reflecting the assertion that limited education levels contribute to biodiversity exploitation and loss in a variety of ways, though lower income levels have the potential to significantly increase biodiversity loss, while higher employment and income levels have the potential to slow the increase in biodiversity loss.

Table 5-1: Descriptive statistics based on employment, income, and education levels in the study area.

Variable Name	N0: of Samples	Minimum	Maximum	Range	Sum	Median	Mean	Variance	Standard deviation	Coefficient of variance
F19 90_2014_change	127	0	1	1	105	1	0.82	0.14	0.37	0.45
F2014_2018_change	127	0	1	1	105	1	0.82	0.14	0.37	0.45
Employment										
Employed	127	306	7294	6988	189368	1074	1491.08	1310080	1144.58	0.76
Unemployed	127	231	1888	1657	119489	932	940.85	130057.1	360.63	0.38

Discouraged work-seeker	127	40	1472	1432	66102	498	520.48	77908.49	279.12	0.53
Other not economically active	127	1331	5171	3840	387001	2978	3047.25	639890.4	799.93	0.26
Income levels										
No income	127	156	1841	1685	93412	702	735.52	81280.98	285.09	0.38
5k	127	74	1343	1269	71570	551	563.54	46424.11	215.46	0.38
5-10k	127	143	3414	3271	185907	1410	1463.83	327627.7	572.38	0.39
10-20k	127	479	3976	3497	266966	2053	2102.09	317511.4	563.48	0.26
20-40k	127	675	4972	4297	332586	2549	2618.78	628476.2	792.76	0.30
40-80k	127	399	2311	1912	140085	990	1103.031	199037.4	446.13	0.40
80-150k	127	216	1812	1596	82169	531	647	129898	360.41	0.55
150-300k	127	91	2173	2082	58386	346	459.73	132632.4	364.18	0.79
300-600k	127	18	1608	1590	30048	148	236.59	79402.83	281.78	1.19
Education										
No schooling	127	193	1872	1679	129697	974	1021.222	104550.1	323.34	0.31
Some primary	127	800	4208	3408	320283	2512	2521.91	370407	608.61	0.24
Completed primary	127	154	1449	1295	65602	489	516.55	26702.03	163.40	0.31
Some secondary	127	1564	5313	3749	375868	2865	2959.59	612038.5	782.32	0.26
Grade 12/Std10	127	406	2806	2400	158046	1155	1244.45	225898.7	475.28	0.38
Higher	127	88	2429	2341	66038	366	519.98	185159.5	430.30	0.82

5.2.2 Model performance presentation

During the statistical analysis, Akaike Information Criterion (AIC) models were generated based on dependent variables data used to compare and understand which of the models generated based on the given variables was the best fit to analyse biodiversity loss drivers in the study area. In our case, the education level AIC model scored the lowest values of 66.333 (Figure 5-1), thus the best performing model while others scored high above the lowest-baseline with; 71.311 employment levels (Figure 5-2), and 74.545-income levels (Figure 5-3), hence presenting the model with the score of 66.333 as the best performing model based on the variables data used.

5.2.3 Social economic drivers of biodiversity

Under the education model, certain variables were significant in explaining the changes in biodiversity loss namely, Some Primary and Some Secondary as indicated in Table 5-2. All the other variables were insignificant (Table 5-2). Amongst the significant variables, "Some secondary" and "Some primary" contributed negatively and positively, respectively. While No schooling was the only variables negatively influencing biodiversity levels, among the insignificant variables.

Table 5-2: Education Variables

Variable	Estimate	Standard Error	Z value	P value	
No Schooling	-0.0028548	0.001572	-1.81	0.06	°
Some Primary	0.0028733	0.0014303	2.00	0.04	*
Completed Primary	0.0080506	0.005229	1.54	0.12	
Some Secondary	-0.0029348	0.0014763	-1.98	0.04	*
Grade 12/Standard	0.0002188	0.0020259	0.10	0.91	
Higher	0.0008569	0.0019546	0.43	0.66	
Significant codes	0 '***'	0.001 '**'	0.01 '*'	0.05 '.'	0.1 ' '1
AIC =66.333					

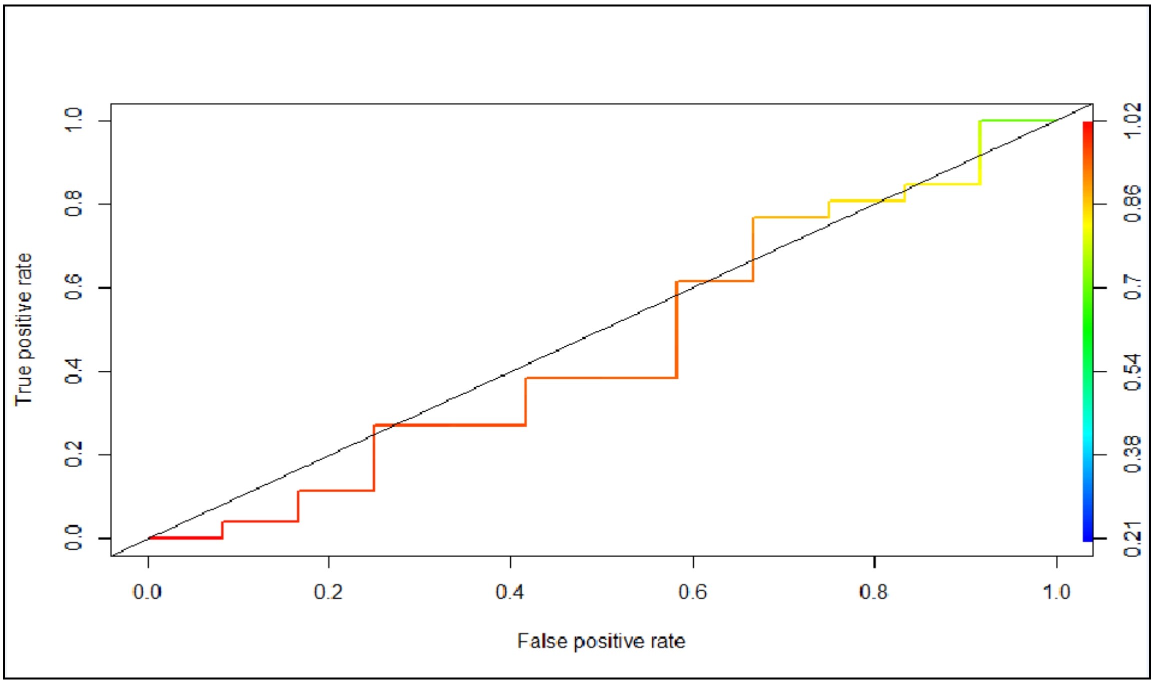

Figure 5-1: Education variables AUC
(Source: Study Author)

Under education model in Figure 5-1, an AUC score of 1.0 was attained, an indication that, the model correctly predicted all education variables and their significant contribution to biodiversity in the study area. It should however be noted that, the score of 1 does not necessarily mean that the model is perfect, it can still have limitations and biases.

5.2.4 Employment

The number of employed people in the study area (Table 5-3) positively and significantly influenced biodiversity, while the discouraged worker-seeker to a smaller extent contributed to biodiversity although not statistically significant. Although not significant, the unemployed and economically in-active people negatively influenced biodiversity although not significantly.

Table 5-3: Employment Variables

Variables	Estimate	Standard Error	Z value	P value	
Employed	6.10	3.91	0.15	0.87	*
Unemployed	-2.90	9.45	-0.30	0.75	
Discouraged work-seeker	1.84	1.35	0.13	0.89	
Others not economically active	-4.35	4.64	-0.93	0.34	
AIC = 71.311					
Significant codes	0 '***'	0.001 '**'	0.01 '*'	0.05 '.'	0.1 "1

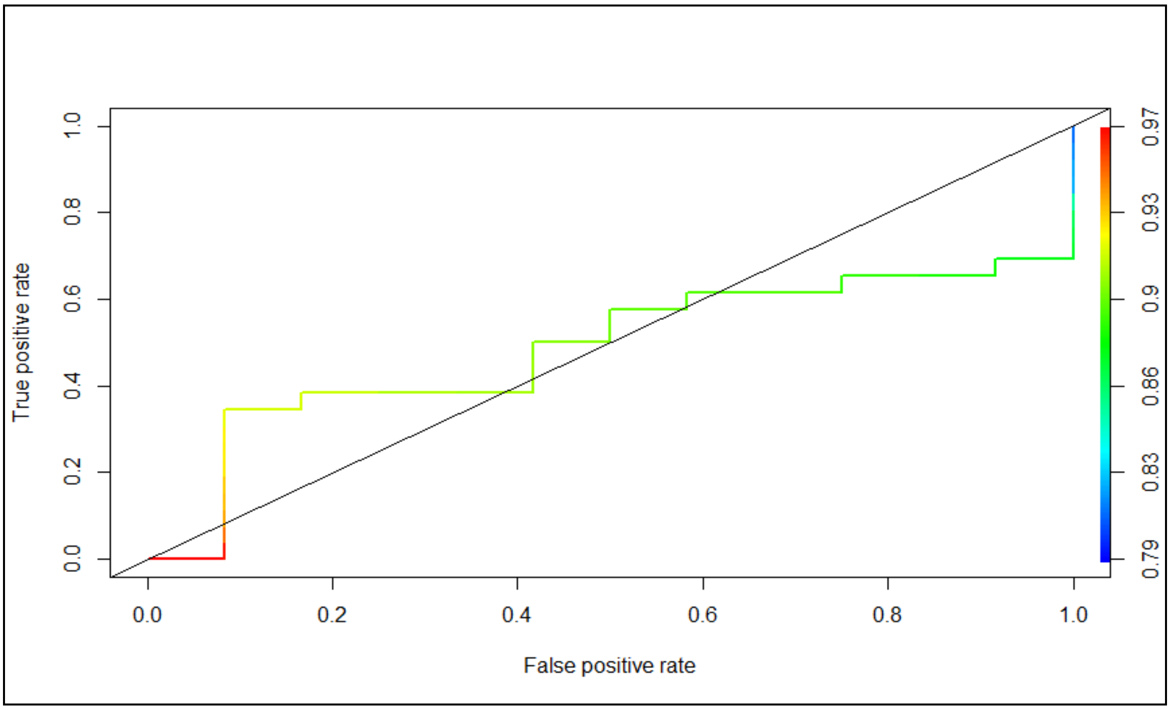

Figure 5-2: Employment variables AUC
(Source: Study Author)

The Area Under the Curve (AUC) as a measure of the accuracy of a model was generated (Figure 5-2) to predict the probable contribution of employment to biodiversity loss. An

AUC score of 0.06 was observed for employment, this score is a poor score for biodiversity loss assessment in the study area.

5.2.5 Income

Our modelling algorithm showed that the income variables investigated in the study (Table 5-4) based on estimates, standard error, Z value and P values had no influence on the levels of biodiversity. Four (4) income levels; 5k, 40-80k, 80-150k and 150-300k negatively influenced biodiversity, while five (5) income levels; No Income, 5-10k, 10-20k, 20-40k and 300-600k positively influenced biodiversity.

Table 5-4: Income Level variables

Variable	Estimate	Standard Error	Z value	P value
No Income	**0.0002179**	**0.0015212**	**0.143**	**0.88**
5k	-0.0007527	0.0044467	-0.169	0.86
5-10k	0.0017471	0.0019013	0.919	0.35
10-20k	0.0010326	0.0019183	-0.538	0.59
20-40k	0.0004397	0.0014327	0.307	0.75
40-80k	-0.0005725	0.00241	-0.238	0.81
80-150k	-0.0034547	0.0033817	-1.022	0.30
150-300k	-0.0013008	0.0049947	-0.26	0.79
300-600k	0.0100561	0.0084491	1.19	0.23
AIC=74.545				

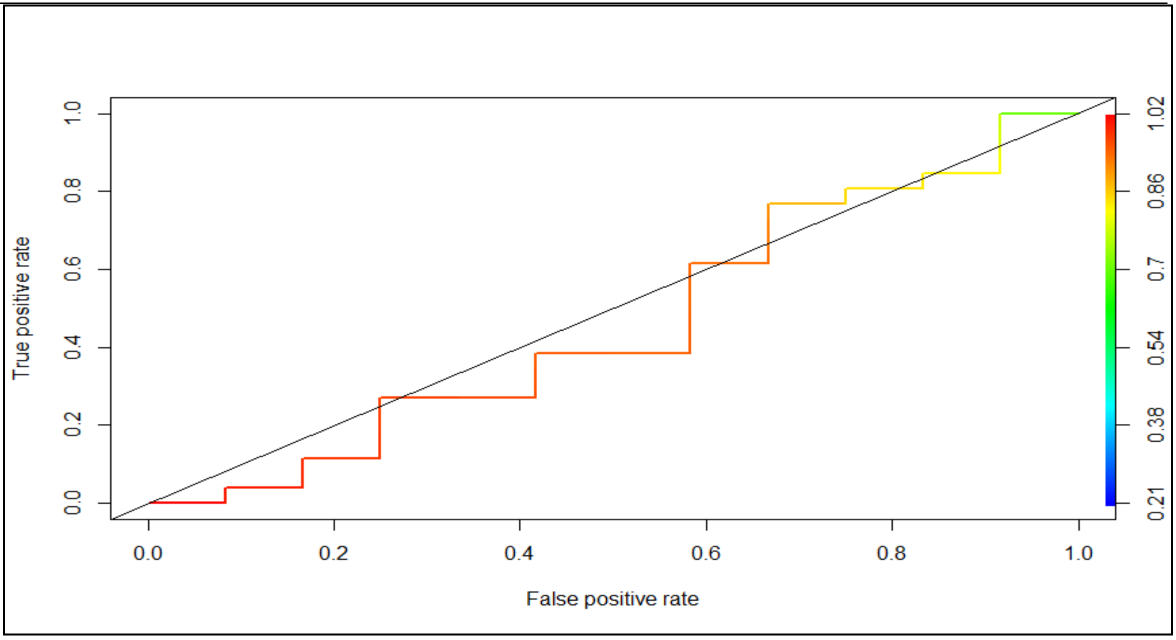

Figure 5-3: Income Levels AUC
(Source: Study Author)

With an AUC score of 0.6 for income levels in our modelling algorithm (Figure 5-3), it was concluded that income variables did not have any significant impact on the levels of biodiversity loss in the study area.

5.2.6 Pooled model

All the social economic variables in the overall model (Figure 5-4) were insignificant. Employment variables were insignificant in influencing biodiversity. The employed positively influenced biodiversity, while the unemployed and job seekers negatively influenced biodiversity. Only three income levels affected biodiversity: No Income; 10-20k; 80-150k; (Table 5-5). Some primary and higher education were the two variables negatively affection biodiversity.

Table 5-5: Combined model variables-Employment, Education and Income Levels

Variable	Estimate	Standard Error	Z value	P value
Employed	0.0013271	0.0016916	0.78	0.43
Unemployed	-0.0004256	0.0024636	-0.17	0.86
Discouraged work-seeker	-0.0010778	0.0032387	-0.33	0.73
Others not economically active	-0.0029526	0.0015533	-1.90	0.05
No Income	-0.0005283	0.0059019	-0.09	0.92
5k	0.0027898	0.0092722	0.30	0.76
5-10k	0.0035607	0.0074885		0.63
10-20k	-0.0020423	0.007471	-0.27	0.78
020-40k	0.0017877	0.0067718	0.26	0.79
40-80k	0.00026873	0.0067727	0.39	0.69
80-150k	-0.0096403	0.0080541	-1.19	0.23
150-300k	0.0011744	0.0110546	0.10	0.91
300-600k	0.0062801	0.012062	0.52	0.60
No Schooling	-0.0042502	0.0074557	-0.57	0.56
Some Primary	0.0057813	0.0091062	0.63	0.52
Completed Primary	0.0021523	0.0123244	0.17	0.86
Some Secondary	-0.0059558	0.0081848	-0.72	0.46
Grade 12/ Standard 10	0.0075999	0.0091792	0.82	0.40
Higher	-0.0008197	0.0085947	-0.09	0.92
Significant codes. 0 '***'	0.001'**'	0.01 '*'	0.05' ° '	0.1 ' ' 1
AIC =107.28				

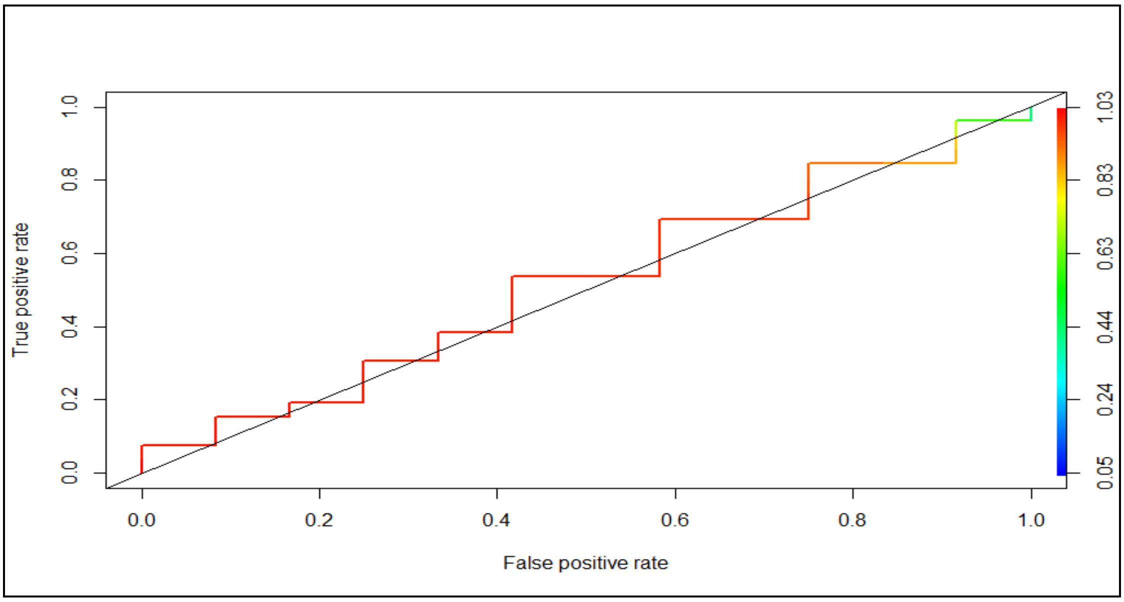

Figure 5-4: Combined model variables: Employment, Education and Income Levels AUC
(Source: Study Author)

To test the accuracy of this model (Figure 5-4), the overall area under the curve receiver operating characteristic accuracy curve (AUC-ROC curve) was generated. Because of the high accuracy level of the AUC-ROC curve, it was concluded that there was a significant driver of biodiversity in Vhembe Biosphere. In our study, the performance of the model based on independent data sets was 85%. Based on the information used, 70% of the points were used for calibration, and 30% of the points were used for validation. ROC at **0** indicates that the model is weak, and at **1** it indicates that the Model is good. At AUC=0.85 indicates high significant quantities of loss which in this case, indicates high estimates of biodiversity loss.

5.3 Discussion

Biodiversity loss is an intricate challenge that is influenced by a nexus of factors, including socioeconomic variables of which no single solution can be approved to address such challenges (Gaston et al., 2003; Sinclair et al., 2002). Education levels of the population in a given biosphere is essential for sustainable and equitable use of biodiversity and its conservation (Rawat et al., 2015; Ericson 2006). Our analysis established that “no schooling” was a dominant variable negatively influencing biodiversity levels in our study area. This is a true reflection of the assertion that; limited education can contribute to biodiversity resource exploitation and loss in many ways (Manzel et al., 2009; Pretty et al 2009). For example, people lacking education may not truly understand the importance of preserving biodiversity resources or even be aware of the consequences of overexploitation of biodiversity resources (Akindele et al., 2021; Claudet et al., 2020; Turner et al., 2006). Moreso, non-educated population are most likely to engage in non-sustainable practices such as deforestation, and biomass burning, because of basic lack of knowledge and skill to engage in sustainable biodiversity resource use practices (Osman 2014; Schroth et al., 2004). It should be emphasised that, other stand-alone variable like climate change has the potential to threaten biodiversity directly through influencing biophysical variables that drive species spatial distribution and indirectly through social economic changes that influence land use and human behaviour.

In the study, it was found that "some primary" contributed to biodiversity levels positively. This justifies the need for education and the fact that higher levels of education are associated with better knowledge and awareness of biodiversity resources and its importance (Aswani et al., 2018; Tonin eta l., 2017; Novacek 2008). With more education levels, people have the opportunity to understand the consequences of their action on biodiversity resources and encourage them to engage in sustainable management practices.

Income inequality have the potential to contribute to unsustainable use of biodiversity resources and overexploitation (Li et al., 2022; Bansard & Schroder 2021), where for example people with high incomes are likely to engage in un-sustainable biodiversity use practices (Bansard & Schroder 2021), like deforestation, overfishing massive urban development because they have greater access to resources to do so and may not likely be dependent on biodiversity for their livelihood. In our study however, income levels had no influence on biodiversity levels in the study area.

Unemployment can contribute to biodiversity loss in any area (Jaureguiberry et al., 2022; Bowler et al., 2020) in several ways. For example, people who are unemployed may turn to unsustainable practices such as deforestation to support themselves and their families (Bowler et al., 2020). In our study the unemployed population and economically in-active population negatively influenced biodiversity levels in the study area. Unemployment can lead to poverty and income inequality, which can also contribute to unsustainable use of natural resources and overexploitation of biodiversity (Chibba et al., 2011). People who are economically in-active may turn to unsustainable practices such as biomass burning, deforestation (Benerjee et al., 2013; Tran et al., 2007) to support themselves and their families.

Alkaike information criterion (AIC) is a mathematical method for evaluating how well a model fits the data it was generated from (Cavanaugh et al., 2019; Bozdogan 1987). In statistics, AIC is used to compare different possible models and determine which one is the best fit for the data (Aho et al., 2014; Mazerolle 2006). The desired result is to find the lowest possible AIC, which indicates the best balance of the model fit with the study assumed variables (Beaujean et al., 2016' Forstmeier et al., 2011; Burnham et al., 2004) . In our study, AIC models were generated based on dependent variables data (education, employment and income levels) used to compare and understand which of the model generated based on the given variables was the best fit to analyze the significant drivers of biodiversity loss in Vhembe biosphere. Education level AIC model scored the lowest values of 66.333 thus the best performing model (Table 5-5), while others scored high above the lowest baseline with; 74.545 income levels (Tables 5-4); and 71.311 employment levels (Tables 5-3), hence the score of 66.333 presented the overall best performing model for the study.

5.3.1 Study implications on society, economy and biodiversity

Biodiversity loss in any given environment significantly impacts its inhabitant communities and other ecosystems (Bommarco et al., 2013; Boulton et al., 2008; Swift et al., 2004). For example, biodiversity loss can lead to the loss of ecosystem services (Harvey et al., 2017; Isbell et al., 2015) such as pollination, nutrient cycling, and water purification (Power 2010; Charlie et al., 2007). Additionally, biodiversity loss can have economic implications (Diaz et al., 2006; Perrings et al., 1992) such as reduced agricultural productivity and increased costs associated with the provision of ecosystem services (Bullock et al., 2011; Dale et al., 2007; Diaz et al., 2006), also biodiversity loss can have social and cultural implications such as the loss of traditional knowledge and practices associated with the use of natural resources (Sillitoe 2017; Hens 2006; Langton and Rhea 2005). Conversely, biodiversity resources potentially promote sustainable development (Roberts et al., 2021). Understanding the causes and consequences of biodiversity loss helps to understand the impact of human activities on ecosystems and the environment. It helps to develop strategies for conserving biodiversity and promoting sustainable development.

5.4 Conclusions

Biodiversity loss was strongly correlated with education levels in the study area, further biodiversity loss seems unavoidable due to low education levels, although lower income levels have the potential to increase biodiversity loss significantly, while higher employment and income levels might decelerate the increase in biodiversity losses. It is pointed out however that, from literature reviewed, other relevant factors like; rural-urban development, mining exploration, and developments, natural resource exploitation, invasive species, climate change are associated drivers for biodiversity loss. Biodiversity loss presents negative footprint on ecosystems and human beings. It is incumbent on relevant policy makers and local municipalities where Vhembe biosphere resides to intensify awareness in prevention of biodiversity loss.

5.5 Study Limitations

Limited data sets, specifically at ward level in the study area on livestock as one of key variables was not accessed and this limited our analysis only to analysing the potential contribution of social and economic variables in biodiversity loss in the study area. However, with this limited data we were able to demonstrate the possibility to understand how socio-economic variables can significantly contribute to biodiversity loss in a given biosphere.

5.6 Study Recommendations

We recommend the establishment of a data collection system on specific ecosystems and socio-economic dynamics at the local municipal level in the case of Vhembe Biospheres to ably aid the understanding of the local challenges and opportunities in managing Vhembe Biosphere Reserve.

We recommend continued consultation and engagement of the local communities and relevant stakeholders in Vhembe biosphere to gain more insights into the local driver of biodiversity loss.

And also the encouragement of local communities involvement in mapping socio-economic activities and biodiversity features for the Vhembe Biosphere would come handy toward the understanding and designing better biospheres management strategies.

CHAPTER 6

ASSESSMENT OF INTERACTION BETWEEN SOCIO-ECONOMIC AND ENVIRONEMNTAL DRIVERS TOWARDS BIODIVESITY LOSS IN VHEMEB BIOSPHERE

This chapter is based on: ***Nuwarinda,*** *H., Ramoelo, A., Adelabu, S., & Mashiane K. (2023). Assessing the relationship between socio-economic factors and environmental drivers toward biodiversity loss in Vhembe Biosphere, South Africa*

Abstract

This study addresses the intricate relationship between socio-economic and ecological factors contributing to biodiversity loss in the South African Vhembe biosphere. Biodiversity loss, once considered solely an ecological problem, has now become an integral part of socio-economic development. Research emphasises the direct impact of biodiversity loss on human well-being, which requires a comprehensive analysis of the socio-economic and ecological factors involved. In the midst of the global environmental crisis characterised by escalating biodiversity loss, there is an urgent need for an in-depth study of the interplay between socio-economic and ecological variables in the unique Vhembe biosphere. This study integrates socio-economic and ecological data and utilizes regression analysis to uncover the intricate relationships that determine biodiversity loss in the Vhembe biosphere.

The Vhembe Biosphere Reserve in South Africa's Limpopo Province is characterised by diverse ecosystems and rich biodiversity. Socio-economic variables, including employment, income and education levels from 1990 to 2018, are analysed for their contribution to biodiversity loss. At the same time, environmental data such as bioclimatic variables, precipitation and maximum temperatures are analysed to assess their impact on biodiversity in this region.

The results of this analysis show complex relationships between socio-economic and environmental factors and their influence on biodiversity loss. Higher levels of education and employment correlate positively with an increase in biodiversity, while regions with a population that has completed only part of primary or secondary education show a higher loss of biodiversity. It is also found that precipitation and maximum temperatures have a negative impact on biodiversity, while certain bioclimatic variables contribute positively to an increase in biodiversity.

This study offers invaluable insights for policy makers and conservationists and provides guidance for the development of effective biodiversity conservation and management strategies in the Vhembe biosphere.

The study emphasises the complex interplay between socio-economic and ecological factors and their role in the loss of biodiversity in the Vhembe biosphere. It emphasises the importance of tailored approaches to address the causes of biodiversity loss and highlights the importance of local education and awareness-raising initiatives. Despite its limitations, this study serves as a valuable resource for mitigating the impact of human activities on biodiversity and lays the foundation for future research on the relationship between employment and income levels and their impact on biodiversity in this dynamic region.

Keywords: *Biodiversity Loss, Socio-Economic Factors, Environmental Variables, Vhembe Biosphere, Regression Analysis, Education Levels, Employment Levels.*

6. Introduction

Recent research and publications have increasingly emphasized the intricate relationship between biodiversity loss and human livelihoods (Wu et al., 2020; Nguyen et al., 2017). This relationship emphasizes the inescapable fact that the fate of our natural environment is closely linked to the well-being of human society. It has been shown that biodiversity conservation is not only an ecological concern, but also a crucial component of socio-economic development (Miller et al., 2011; Roe, 2008; Sunderland et al., 2007). Romanelli et al. (2015) emphasize that the loss of biodiversity has a significant, direct impact on humanity if the ecosystem services it provides can no longer adequately meet societal needs.

Biodiversity loss has become a global environmental crisis with far-reaching consequences for human society (Thakur et al., 2014; Alcamo, 2003). Curbing biodiversity loss is now both a local and international imperative (Bax et al., 2016; Sengupta, 2016; Chandra et al., 2011). The development of robust and scientifically validated indicators to assess biodiversity loss is essential to understand its causes and challenges and to formulate effective mitigation strategies (Hobohm, 2021).

Africa is a unique harbour of diverse biodiversity and provides a rich array of ecosystem services (Egoh et al., 2011). However, the continent is struggling with alarmingly high rates of biodiversity loss (Van Jaarsveld et al., 2005). According to projections, land and lake productivity could decline by 20 to 30 % by 2100 (Dziba et al., 2018). This unprecedented loss of biodiversity poses a threat to livelihoods and undermines resilience to extreme events, particularly among rural populations, who are often the most vulnerable and poor (Sibiya et al., 2022; Sidle et al., 2013).

Despite concerted efforts to study the interplay between human activities and conservation measures in high biodiversity regions, there is a conspicuous lack of systematic assessments of the intricate relationship between socio-economic and ecological factors contributing to biodiversity loss. Therefore, there is an urgent need for a comprehensive analysis that assesses the interplay of these factors in the context of the Vhembe biosphere and ultimately provides valuable insights for biodiversity management.

This study attempts to present an integrated, data-driven analysis of the interplay between socio-economic and environmental drivers of biodiversity loss. It sheds light on how socio-economic factors interact with environmental variables and contribute to biodiversity loss in the Vhembe biosphere. Data and statistical analyses are at the heart of this study. Regression analysis, a powerful statistical tool for assessing the relationships between variables, is the main method used in this study. It aims to uncover the intricate relationships between socio-economic and ecological factors that jointly influence biodiversity loss in the Vhembe biosphere.

6.1 Materials and Methods

6.1.1 Study Area

The study was conducted in the enchanting landscape of the Vhembe Biosphere Reserve in the South African province of Limpopo. This unique biosphere reserve covers an area of approximately 30,700 square kilometers and is home to a population of approximately 1.5 million people, more than 95% of whom live in rural areas (Ruwanza et al., 2022).

The climate in this region is distinctly tropical and is characterised by sultry summer temperatures averaging around 28°C, followed by mild winter temperatures of around 18°C (Evans, 2017; Ruwanza et al., 2020). The area receives an average annual rainfall of around 1,052 millimetres. The soils are particularly acidic and have a high clay content, originating from the basalt and quartzite sandstone formations of the Soutpansberg Ruwanza et al., 2020; (Mucina and Rutherford, 2006).

The Vhembe biosphere is known for its rich and diverse ecosystems that provide a refuge for a variety of species (Linen et al., 2014; Driver et al., 2012). Notable ecosystems include indigenous forests, extensive savannahs, lush grasslands, dramatic mountain slopes and a variety of wetlands (Ramarumo et al., 2020; DEA, 2011). While these diverse ecosystems are teeming with life, they are also subject to significant pressures and threats from various actors and stressors (Hedden-Dunkhorst & Schmitt, 2020; Kasperson et al., 2005).

Challenges facing the Vhembe biosphere include the relentless expansion of human settlements, the encroachment of agriculture into its territories, the ongoing development of mining and other land uses associated with these activities (Dalu et al., 2022; SEF, 2016; Desmet et al., 2014; DEA, 2011). Together, these pressures contribute to the worrying problem of biodiversity loss in this remarkable region.

.

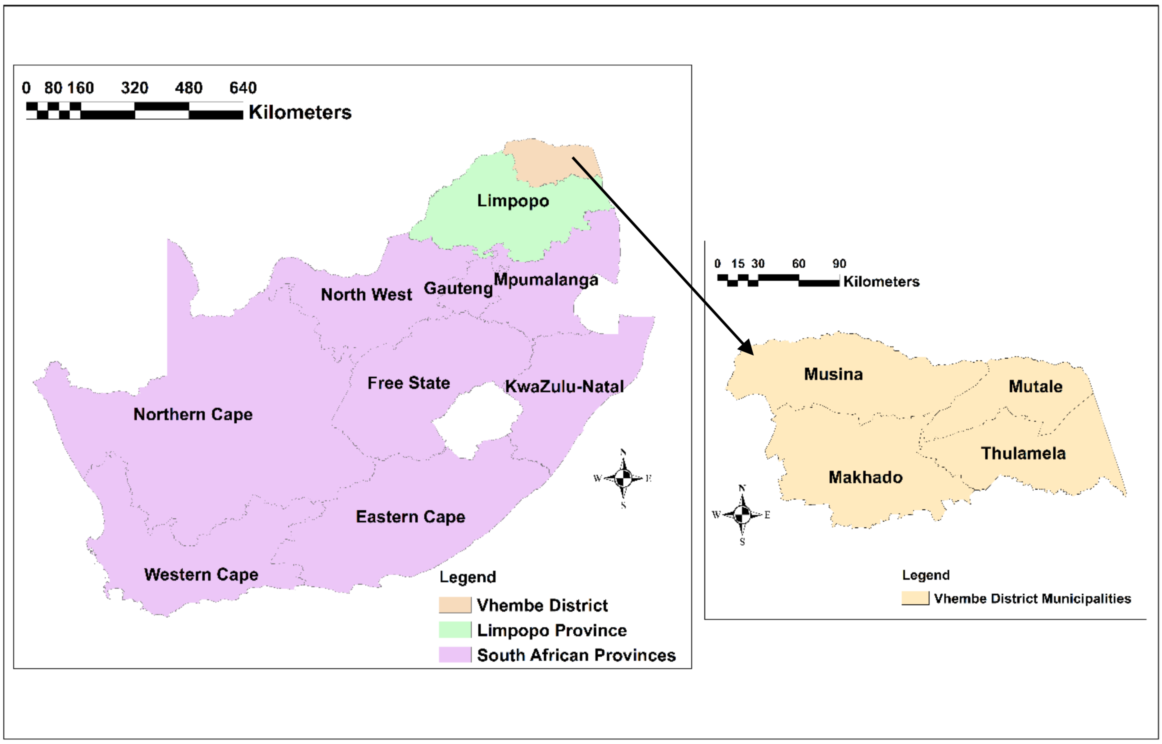

Figure 6-1: Study area Location: Vhembe District Biosphere
(Source: Study Author)

6.2 Data used and preparation

6.2.1 Social economic data and its preparation

Three key socio-economic data variables were used to quantitatively analyse the loss of biodiversity in the Vhembe biosphere. These variables included (i) employment levels, (ii) income levels and (iii) education levels in the study area for the years 1990-2014 and 2014-2018, as shown in Table 1 (Nuwarinda et al., 2023). The main objective was to analyse the causes of biodiversity loss in the Vhembe biosphere. The selection of these socio-economic variables was underpinned by the assumption that they play a central role in biodiversity loss (Nuwarinda et al., 2023; Stats SA, 2011).

In the area of educational attainment, the data comprised various categories, including "population with no schooling'," "some schooling'," "population who attended primary school'," "population who successfully completed primary school" and "proportion of population who completed secondary school and Grade 12/Standard 10" This segmentation was based on the age of the population attending school and focused on individuals aged between 15 and 64 years, as shown in Table 14.

For employment status, the data were divided into four different categories, namely (i) employed, (ii) unemployed, (iii) discouraged job seekers, and (iv) other individuals who were not employed. These categorisations were determined for each household in each district, as shown in Table 6-1.

In terms of income levels, the study covered a wide range of income amounts between 5,000 and 600,000, reflecting the total monthly income of the employed population per district and household residents aged 15-64 years, as shown in Table 6-1. These carefully prepared socio-economic data variables served as the basis for the comprehensive analysis of the causes of biodiversity loss in the Vhembe biosphere.

Table 6-1: Descriptive statistical data based on employment, income, and education levels in the study area.

(*Source Nuwarinda et al., 2023*)

Variable Name	N0: of Samples	Minimum	Maximum	Range	Sum	Median	Mean	Variance	Standard deviation	Coefficient of variance
F19 90_2014_change	127	0	1	1	105	1	0.82	0.14	0.37	0.45
F2014_2018_change	127	0	1	1	105	1	0.82	0.14	0.37	0.45
Employment										
Employed	127	306	7294	6988	189368	1074	1491.08	1310080	1144.58	0.76
Unemployed	127	231	1888	1657	119489	932	940.85	130057.1	360.63	0.38
Discouraged work-seeker	127	40	1472	1432	66102	498	520.48	77908.49	279.12	0.53
Other not economically active	127	1331	5171	3840	387001	2978	3047.25	639890.4	799.93	0.26
Income levels										
No income	127	156	1841	1685	93412	702	735.52	81280.98	285.09	0.38
5k	127	74	1343	1269	71570	551	563.54	46424.11	215.46	0.38
5-10k	127	143	3414	3271	185907	1410	1463.83	327627.7	572.38	0.39
10-20k	127	479	3976	3497	266966	2053	2102.09	317511.4	563.48	0.26
20-40k	127	675	4972	4297	332586	2549	2618.78	628476.2	792.76	0.30
40-80k	127	399	2311	1912	140085	990	1103.031	199037.4	446.13	0.40
80-150k	127	216	1812	1596	82169	531	647	129898	360.41	0.55
150-300k	127	91	2173	2082	58386	346	459.73	132632.4	364.18	0.79
300-600k	127	18	1608	1590	30048	148	236.59	79402.83	281.78	1.19
Education										
No schooling	127	193	1872	1679	129697	974	1021.222	104550.1	323.34	0.31
Some primary	127	800	4208	3408	320283	2512	2521.91	370407	608.61	0.24
Completed primary	127	154	1449	1295	65602	489	516.55	26702.03	163.40	0.31
Some secondary	127	1564	5313	3749	375868	2865	2959.59	612038.5	782.32	0.26
Grade 12/Std10	127	406	2806	2400	158046	1155	1244.45	225898.7	475.28	0.38
Higher	127	88	2429	2341	66038	366	519.98	185159.5	430.30	0.82

6.2.2 *Environmental data and its processing*

In this study, environmental data based on bioclimatic variables, as shown in Table 6-2 and extracted from https://www.worldclim.org/data/bioclim.html, were used to investigate the intricate relationship between socioeconomic and environmental drivers of biodiversity loss in the Vhembe biosphere. The bioclimatic variables derived from the interpolation of the average monthly climate data from 1990 to 2018 were calculated by merging the monthly precipitation and temperature values (Nuwarinda et al., 2022; Sluiter, 2009). These calculations were performed with a spatial resolution of 30 arcseconds, as defined in previous studies (Nuwarinda et al., 2022; Fick et al., 2017).

A total of 35 dependent variables, forged from the bioclimatic variables and in conjunction with the socioeconomic variables in Table 6-1, were used in this study to assess the intricate relationship between the environmental and socioeconomic drivers of biodiversity change. These carefully prepared environmental datasets, together with their associated socioeconomic counterparts, formed the core of the analysis and provided a comprehensive perspective on the multiple factors influencing biodiversity loss in the Vhembe biosphere.

Table 6-2: Variables used to explain natural resource change in the study area
(Source Nuwarinda et al., 2022)

	Variables	Source	Scale/resolution
Climatic			
Bioclimatic	BIO1 = Annual Mean Temperature BIO2 = Mean Diurnal Range (Mean of monthly (max-temp-min temp) BIO3 = Isothermality (BIO2/BIO7) (×100) BIO4 = Temperature Seasonality (standard deviation ×100) BIO5 = Max Temperature of Warmest Month BIO6 = Min Temperature of Coldest Month BIO7 = Temperature Annual Range (BIO5-BIO6) BIO8 = Mean Temperature of Wettest Quarter BIO9 = Mean Temperature of Driest Quarter BIO10 = Mean Temperature of Warmest Quarter BIO11 = Mean Temperature of Coldest Quarter BIO12 = Annual Precipitation BIO13 = Precipitation of Wettest Month BIO14 = Precipitation of Driest Month BIO15 = Precipitation Seasonality (Coefficient of Variation) BIO16 = Precipitation of Wettest Quarter BIO17 = Precipitation of Driest Quarter BIO18 = Precipitation of Warmest Quarter BIO19 = Precipitation of Coldest Quarter	WorldClim 2.1: (Fick, S. E. and R.J. Hijmans, 2017)	~1Km²
Minimum Temperature	tmin 1-12		
Maximum Temperature	tmax 1-12	WorldClim 2.1: (Fick, S. E. and R.J. Hijmans, 2017)	~1km
Average Temperature	tavg 1-12	WorldClim 2.1: (Fick, S. E. and R.J. Hijmans, 2017)	~1km
Precipitation	prec 1-12	WorldClim 2.1: (Fick, S.E. and R.J. Hijmans, 2017)	~1km
Edaphic			

Topography	Digital Elevation Model (DEM) Slope Aspect	SRTM, https://www2.jpl.nasa.gov/srtm/ Derived from DEM	30m 30M
Soil Chemical Properties	Nitrogen (cg/kg) pH Soil Organic Carbon (dg/kg)	Soilgrid.org (Hengl et al., 2017)	250m
Soil Physical Properties	Sand (g/kg) Silt (g/kg) Coarse Fragments (cm^3/dm^3) Bulk Density (cg/cm^3)	Soilgrid.org (Hengl et al., 2017)	250m

6.3 Results

6.3.1 Logistic Regression to determine the correlation between socio-economic and environmental drivers of biodiversity loss

In this study, a multivariate logistic regression analysis was used to model and predict the complex relationship between multiple predictor variables that include social, economic and environmental factors in their contribution to biodiversity loss. The results of this analysis are presented in Table 6-3 They show the coefficient estimates for each independent variable within the model along with their respective significance levels in relation to biodiversity loss. The main objective of this analysis was to find the best fitting model that describes the relationship between these independent variables and biodiversity loss.

The estimated coefficient for the variable 'No schooling' was determined to be 1.103 (Tabel 6-3), which is a positive estimate. This indicates that an increase in the level of education is associated with a higher probability of an increase in biodiversity in the study area. Conversely, estimates of -4.31 and -2.94 were determined for the variables 'Some Primary' and 'Some Secondary' respectively, which indicates a negative correlation with the loss of biodiversity. The variable 'Completed Primary' yielded a positive estimate of 2.48, indicating a contribution to biodiversity gain.

In addition, the coefficient estimates for 'Precipitation' (Prec12) and 'Maximum temperatures' (tmax-12) were found to be -9.644 and -6.460 respectively, indicating a negative impact on biodiversity and thus contributing to its loss. In contrast, the bioclimatic variable (bio16) recorded a positive estimate of 3.22, indicating a positive correlation with biodiversity gain.

In the socio-economic domain, an estimate of -3.66 was calculated for the coefficient 'discouraged job seekers', indicating its contribution to biodiversity loss. On the other hand, the variable 'employed persons' yielded a coefficient estimate of 1.362, indicating a positive impact and contribution to biodiversity gain.

These coefficient estimates provide valuable insights into the complex relationship between socio-economic and ecological factors and their respective roles in biodiversity loss in the Vhembe biosphere. The analysis serves as an important tool for understanding and quantifying the various factors influencing biodiversity dynamics in the study area.

Table 6-3: Combined model for Socio-economic and environmental variables

Variable	Estimate	Standard Error	Z value	P value	
Intercept	**-6.314e+08**	**6.833e+07**	**-9.241**	**<2e-16**	***
Employed	1.362e+05	1.410e+04	9.66	<2e-16	***
Unemployed	1.736e+05	3.805e+04	4.562	5.07e-06	***
Discouraged -work- seeker	-3.66E+04	4.479e+04	-8.171	3.06e-16	***
No schooling	1.103e+06	5.300e+04	20.812	<2e-16	***
Some Primary	-4.31E+05	3.092e+04	-10.209	<2e-16	***
Completed-Primary	2.48E+06	1.328e+05	18.673	<2e-16	***
Some Secondary	-2.947e+05	3.092e+04	-9.529	<2e-16	***
Elevation	4.009e+06	80223e+04	4.875	1.09e-06	***
Prec -12	-9.644e+06	1.395e+06	-6.914	4.71e-12	***
tmax-12	-6.460e-02	7.308e-03	-8.839	<2e-16	***
tmin-12	-2.526e-01	1.464e-02	-17.258	<2e-16	***
tavg 12	8.721e-02	6.567e-03	13.279	<2e-16	***
bio16	3.221e+06	3.541e+05	9.098	<2e-16	***
AIC= 28					

In this model, a P-value of <0.05 was achieved, indicating a statistically significant relationship between the independent variables, which include socioeconomic and environmental factors, and the dependent variable, biodiversity loss. Consequently, all variables, except for "Other - not economically active" with a P-value of less than 0.005, show their statistical significance as predictors of the dependent variable. This statistical result emphasises the significant and influential role of these variables in explaining the loss of biodiversity in the study area.

6.3.2 Validation of multivariate logistic regression model.

Validation of the multivariate logistic regression model (Figure 6-2) was performed using 40% of the data, and the Akaike Information Criterion (AIC) was used to assess the goodness of fit of the model (Ripplinger et al., 2008). AIC is a widely recognised tool for comparing different models and determining the best fit to the data (Ward 2008; Aho et al., 2014). It is calculated based on the number of independent variables used to construct the model and the maximum likelihood estimate of how well the model fits the data (Burnham et al., 2011; Anderson et al., 1994). The AIC model attempts to identify the model that explains the greatest amount of variation while using the fewest independent variables (Bevan 2023; Wagenmakers et al., 2004).

The advantage of using AIC in multivariate regression analysis is that you can select the best fitting model for your data by comparing different potential models and selecting the one that offers the greatest explanatory power with the least number of independent variables (Johnson et al., 2004; Posada et al., 2004). This approach ensures that the chosen model is both effective and efficient in explaining the relationship between socioeconomic and ecological variables and biodiversity loss in the Vhembe biosphere.

6.3.3 Model Performance Presentation: Akaike Information Criterion (AIC)

The Akaike Information Criterion (AIC) serves as a mathematical tool for assessing how effectively a model aligns with the data from which it was derived (Cavanaugh et al., 2019). In statistical analysis, AIC is utilized to compare various potential models and pinpoint the one that best matches a specific dataset (Wang et al., 2006). The goal is to minimize the AIC value, signifying the optimal balance between the model's fit and the variables assumed in the study (Beaujean et al., 2016; Forstmeier et al., 2011).

In our investigation, the Akaike Information Criterion (AIC) was employed to gauge the model's accuracy. A combined multivariate regression analysis yielded an AIC score of 32, indicating that the model provides a strong fit to the data and is a promising candidate for further analysis. This analysis allowed us to ascertain the positive and negative contributions of each socio-economic and environmental variable to biodiversity loss.

This study investigated the complex relationship between socio-economic data variables, including education levels, employment levels and income levels of the population in and around the Vhembe biosphere, extracted from the South African statistical dataset. It also investigated how environmental variables such as bioclimatic data, topography, soil chemical properties and soil physical properties contribute to biodiversity loss in the Vhembe biosphere.

The most striking result was found when analysing the variable 'discouraged job seekers' with an estimated coefficient of -3.66. This indicates a negative relationship with biodiversity loss, meaning that a decrease in discouraged job seekers is associated with a positive impact on biodiversity. On the other hand, the variable 'Employed' yielded an estimated coefficient of 1.362, indicating a positive relationship with biodiversity gain. This means that an increase in the level of employment is positively correlated with an improvement in biodiversity.

In addition, the variable 'Completed primary school' had an estimated coefficient of 2.48, which shows a positive correlation with biodiversity gain. This indicates that a higher level of education is associated with a higher probability of an improvement in biodiversity. Conversely, the variables 'Some Primary' and 'Some Secondary' had estimated coefficients of -4.31 and -2.94 respectively, indicating a negative correlation with biodiversity loss. This means that regions with a higher percentage of people who have only completed some primary or secondary education tend to have a greater loss of biodiversity.

In addition, the coefficient estimates for 'precipitation' (Prec12) and 'maximum temperatures' (tmax-12) were -9.644 and -6.460, respectively, reflecting a negative relationship with biodiversity. This means that an increase in precipitation and maximum temperatures is associated with a decrease in biodiversity. In contrast, the bioclimatic variables (bio16) had an estimated coefficient of 3.22, indicating a positive correlation with an increase in biodiversity. Biodiversity tends to thrive better in areas with higher bio16 values.

These results shed light on the complex interplay between socio-economic and ecological factors that influence biodiversity loss in the Vhembe biosphere. They provide valuable insights for policy makers and conservationists seeking to implement effective strategies for the conservation and management of biodiversity in the region.

6.4 Discussion

In this study, the population with a good level of primary education was found to be more likely to understand the challenges of biodiversity loss and the need for appropriate biodiversity management in the Vhembe biosphere, whereas the population with partially completed primary or secondary education was negatively correlated with biodiversity loss, suggesting that limited education and awareness have a negative impact on biodiversity conservation and management. The estimated correlation coefficients of maximum temperatures and precipitation were found to be negatively correlated with biodiversity loss.

The highlight of the study results was that the estimated coefficient for ‘discouraged job seekers’ was estimated to be -3.66, indicating a negative association with the contribution to biodiversity loss. In contrast, a value of 1.362 was found for 'employed people', indicating a positive relationship with biodiversity gain.

These findings suggest that the relationship between social, economic, and environmental factors and their impact on biodiversity is multifaceted (Kumari et al., 2021; Rawat et al., 2015). Social and economic factors such as education levels, population growth, education and employment levels, income and poverty, and urbanisation have progressive and significant impacts on biodiversity by driving habitat destruction and fragmentation (Numbere et al., 2022; Verma 2020). The reason for this could be as argued by Waldron et al. (2017) that; education plays an important role in promoting sustainable practices and reducing the impact of human activities on biodiversity. It is therefore important to note that populations with higher levels of education are more likely to be aware of the opportunities and challenges of biodiversity and more likely to be committed to the sustainable management of biodiversity (Willis et al., 2007).

Scher et al. (2008) point out that the working population in each ecosystem has the potential to contribute to biodiversity conservation by adopting sustainable biodiversity management practices. They can reduce their carbon footprint in a variety of ways (Boiral et al., 2019), such as carpooling or cycling to and from work, reducing energy consumption by installing renewable energy systems at home and at work, and reducing water consumption by collecting rainwater and supporting local biodiversity conservation efforts (Charnley et al., 2007).

In addition, environmental factors such as climate change also have a significant impact on biodiversity (Prakash et al., 2021; Schweiger et al., 2010) by altering ecosystems and disrupting the natural balance of species (Gasper et al., 2011; Fankhauser et al., 1997). In our study, the estimated correlation coefficients of maximum temperatures and precipitation were found to be negatively correlated with biodiversity loss. Sattar et al. (2021) and Prakash et al. (2021) argue that the rise in temperature over the last decade has led to changes in the timing of seasonal events such as migration, which affects the availability of food and other natural resources for the species that depend on them (Pimm 2009). Changes in precipitation patterns affect the distribution of species and alter the structure of ecosystems. Changes in precipitation and temperature have a significant impact on biodiversity by altering ecosystems and disrupting the natural balance of species (Thuiller et al., 2007).

To address the impact of social, economic and environmental factors on biodiversity resources, it is important to adopt a holistic approach that considers the complex interactions between different factors (Lindenmayer et al., 2000). This includes implementing existing policies that regulate pollution control, protection against habitat loss and addressing socio-economic challenges such as unemployment, limited education and awareness raising (Bennett et al., 2015; Daramola et al., 2010).

6.5 Conclusions

Analysing a combination of socio-economic and environmental variables revealed a positive relationship to understand their contribution to biodiversity loss in the Vhembe biosphere. The population that had completed primary education and found employment showed greater openness to sound environmental management practices than the discouraged job-seeking population. This emphasises the importance of focusing on environmental education in primary school, laying the foundation for developing an awareness and understanding of biodiversity conservation and management among the population in the Vhembe biosphere. It is important to recognise that the relationship between socio-economic and ecological variables and the management of biodiversity loss is complex and multi-faceted. Effective management of biodiversity loss requires a customised approach to tackle the causes of biodiversity loss. Therefore, it is the responsibility of local and provincial decision makers in Vhembe Municipality to intensify education and awareness of the need for biodiversity management at the local level.

6.6 Study Limitations

A limitation of this study was the limited availability of community-level data on income levels of the working population, which is a key variable. This limitation restricted our ability to fully assess the potential impact of employment and education levels in conjunction with environmental variables on biodiversity in the study area. However, even with this limitation, the study was able to show how the relationship between socioeconomic and environmental factors can significantly influence biodiversity loss in each biosphere.

6.7 Recommendation

The results of our study emphasise the importance of understanding how socio-economic and ecological parameters can complement each other to contribute to either biodiversity gain or loss. Promoting education and environmental awareness at the grassroots level is crucial to mitigate the impact of human activities on biodiversity. In addition, our study results provide a promising avenue for further research on how sustainable employment and income generation in the Vhembe Biosphere can impact biodiversity in the Vhembe Biosphere Reserve, an area characterised by a relatively large and rapidly growing human population with a high unemployment rate.

6.8 Practical Suggestion to Improve Study Results

Going forward, in the bid to improve the results of this study and other related studies and achieve directive, practical and relevant outcomes in the study area, there is need for collaboration across potential disciplines like social scientists, ecologists and economists, local communities and policy makers in gathering relevant local content data.

More focused local content study will be much more meaningful going forward in understanding the wider biodiversity challenges, risks and designing potential mitigations measure.

Further practical work can be done in aligning biodiversity conservation with economic policies and explore provision of incentives for promoting biodiversity conservation sustainable practices.

CHAPTER 7

SUMMARY, CONCLUSION AND RECOMMENDATIONS

In this chapter, synthesis of the thesis is presented with overall conclusions from the objectives of the study, as well as recommendations. The recommendations forfuture studies are also presented.

7. Overall Summary, Conclusion and Recommendation

7.1 Summary

Biodiversity loss, a global and local challenge, continues to increase in scope and scale and requires immediate attention and action (Young et al., 2006; Assessment 2005). The implications of biodiversity loss go beyond ecological concerns and underscore the urgency of finding effective solutions (Magurran, 2021; Gaston, 2000).

This study focused on assessing changes in natural resources and their drivers in the Vhembe Biosphere. The main objective of Chapter 3 was to assess natural resource change in Vhembe biosphere. Chapter 4 focused on the drivers of change in natural resources, while Chapter 5 examined the role of socio-economic factors in biodiversity conservation. Chapter 6 examined the interaction between socio-economic and ecological factors that contribute to biodiversity loss in Vhembe biosphere. The major aim of the study was to contribute to the existing knowledge on how to sustainably manage and mitigate biodiversity loss.

The assessment of natural resource change in Chapter 3 showed that land use activities, including cultivated commercial areas, natural forests and built-up residential areas, have contributed most to natural resource change in the Vhembe Biosphere between 1990 and 2018. What was evident from the objective analysis results, was that given the analysed limited data on natural resource change causes, the need to develop practical, sustainable strategies for dealing with natural resource loss specifically in the Vhembe biosphere was crucial. This study advocates for on-the-ground data collection to support the formulation of relevant and sustainable management strategies.

Chapter 4 of the study assessed the drivers of vegetation cover resources in the Vhembe biosphere to understand what the potential drivers are, so as to contribute to the existing biodiversity loss knowledge and practical mitigation measures. Having identified that climatic variables such as: minimum temperatures, average temperatures, precipitation, are some of the major drivers of vegetation cover natural resources change in Vhembe biosphere. It became evident that the need to understand and be aware of the impacts such environmental factors have on rangeland biodiversity resources is needed to promote practical planning and mitigation measures for biodiversity loss management.

In chapter 5 we hypothesised that socio-economic factors (education, employment, and income levels) as the primary drivers of biodiversity loss in the study area. The analysed data presented a compelling evidence that biodiversity loss is strongly correlated with the level of education, income and employment levels, which was premised that lower levels of education do potentially contribute to biodiversity exploitation and loss in a variety of ways. likewise, lower income and employment levels have the potential to significantly exacerbate biodiversity loss, while higher employment and income levels have the potential to slow the increase in biodiversity loss. Presented with such results, motivating communities around Vhembe biosphere to co-exist with biosphere resources make sense as a starting point. The need for awareness about the crucial importance of managing biosphere resources and its impact on man survival takes the center stage of recommendations.

Chapter 6 explored the relationship between socio-economic and environmental factors contributing to biodiversity loss in Vhembe biosphere. The study outcomes indicates that biodiversity is an integral part of socio-economic growth and development and it emphasises the direct impact of biodiversity loss on human well-being, which requires a comprehensive analysis of the socio-economic and ecological factors involved. The study outcomes further highlighted the intricate relationship between low education and employment level with biodiversity loss. This is true based on that fact that communities with limited education and employment opportunities will resort to over-exploitation of biodiversity resources (Maffi et al., 2012) perpetuating a vicious cycle of biodiversity loss

This study contributes to the growing body of knowledge on biodiversity loss and its management. Existing literature suggests that conservation initiatives to-date are inadequate to address the escalating scale of biodiversity loss (Pekel et al., 2016; Kremen et al., 2008). This inadequacy is rooted in the challenge of reconciling the conflicting drivers of biodiversity loss, particularly between urbanisation, land use and resource use on the one hand, and sustainable development and biodiversity conservation on the other (Lewciki et al., 2003; Bridgwater et al., 2002). Wood et al. (2013) also emphasize that these conflicting factors and the prevailing tendency towards growth and resource consumption are the main causes of biodiversity loss.

Effective biodiversity management must recognise that conflict plays an important role in resource use and conservation (Bennett et al., 2017; Young et al., 2010). It should be based on the premise that addressing the root causes of such conflicts is essential for tangible progress in biodiversity conservation (Redpath et al., 2013; Mora et al., 2011).

Biodiversity loss continues in different African biospheres and is caused by various factors, including both anthropogenic and non-anthropogenic causes (Hanski 2015; Assessment 2005). Land use activities, which are among the main causes of biodiversity loss and natural resource change, have significant impacts on the study area (Assede et al., 2023; Degife 2019

Natural resource use and management are influenced by the drivers that alter natural resources within an ecosystem (George et al., 2015; Williams, 2011). These drivers can be within or outside the natural resource system and include social, economic, political or environmental factors (Allison & Hobbs, 2006). Chapter 3 focuses on assessing the factors influencing natural resource change in the Vhembe biosphere and aims to provide quantitative data that can contribute to the development of natural resource management strategies. The analysis includes changes in land cover, natural resources and environmental variables and highlights significant changes and their interplay.

7.2 Conclusion

This study research undertook to assess current and future rangeland resources to explore the causes of natural resource change and the contributing factors to biodiversity loss in Vhembe biosphere and the surroundings. We identified the drivers of biodiversity loss and assessed how these factors interact to drive the loss of biodiversity in the biosphere. The study has developed several biodiversity loss analysis models that will be useful in defining measures to address and mitigate biodiversity loss.

The interplay of human activities and natural factors significantly influences natural resource change. Land use activities, especially bush encroachment, pose a direct threat to natural resource change. Climate change has been identified as a major factor exacerbating natural resource change. These interactions create feedback loops in which human activities influence natural forces and vice versa.

Variations in temperature and precipitation are major contributors to biodiversity loss. Their effects vary greatly depending on species, ecosystem, exposure and sensitivity to climate change, leading to a decline in biodiversity in the Vhembe Biosphere.

The link between biodiversity loss and education in the study area is primarily related to lower levels of education. The level of education is crucial for the sustainable and equitable use of biodiversity.

Low level of education contributes to unsustainable exploitation of biodiversity, while a higher level of education is associated with better knowledge and awareness of biodiversity resources.

Income inequality and unemployment also contribute to biodiversity loss, highlighting the importance of education. Education not only promotes awareness, but also increases employment opportunities and income levels, which promotes a positive perception of biodiversity conservation (Navaro et al., 2012). In addition, variables such as climate change can threaten biodiversity by affecting the biophysical factors that determine the distribution of species and by leading to socio-economic changes that affect land use and human behaviour.

The study climax investigated the complex relationship between socio-economic drivers of education, employment and income levels for the population in and around the Vhembe biosphere and environmental drivers of bioclimatic aspects, topography, soil chemical properties and soil physical properties and their contribution to biodiversity loss in the Vhembe biosphere. Investigation outcomes revealed a negative relationship between discouraged job seekers and biodiversity loss, which affirms the assumption that a decrease in discouraged job seekers is associated with a positive impact on biodiversity.

The population classified as Employed revealed a positive relationship with biodiversity gain, indicating that an increase in the level of employment is positively correlated with an improvement in biodiversity (Dogan et al., 2022). Based on this analysis it is possible that a decrease in unemployment levels could lead to a positive impact on biodiversity. If more people are employed, they may have more resources to invest in conservation efforts, which could help protect and preserve natural habitats and ecosystems (Miller et al., 2002). Additionally, if more people are employed, they may be less likely to engage in activities that could harm biodiversity, such as illegal logging, poaching, or pollution (Pretty and Smith 2024). However, it is important to note that this inference is based on our analysis results and there may be other factors that could impact biodiversity as well.

7.3 Recommendations

Several recommendations can be derived from the results of the study to help environmental managers, policy makers and communities deal with biodiversity loss and natural resource management:

- Conservation efforts should focus on scientific interventions like environmental education and awareness; conservation and restoration; sustainable resource management; and climate change mitigation; that mitigate the negative impacts of human activities and natural forces on natural resources. Further studies should assess the interactive impacts of human activities and biodiversity in the Vhembe biosphere and investigate best practises to protect and restore natural resource loss.
- Climate change scenarios are likely to exacerbate biodiversity loss in the Vhembe biosphere. Mitigation and adaptation measures should be considered.
- be considered by policy makers and environmental managers to effectively address these challenges.

- Basic biodiversity conservation education and awareness programmes should be implemented in the communities surrounding Vhembe biodiversity. These programmes can promote positive values and behaviour for biodiversity conservation and instill a sense of responsibility for biodiversity management.
- Education and awareness-raising initiatives can promote the exchange of indigenous and local knowledge with scientific knowledge, thus improving the diversity of perspectives and integrated approaches to biodiversity loss.
- Our study outcomes on biodiversity loss based on socio-economic variables, offers a good starting point for biodiversity conservationists the opportunity to intensify community awareness and training on biodiversity loss and conservation in Vhembe biosphere reserve, a largest biosphere reserve in South Africa. It also presents a good case for further exploratory studies on how the interaction between socio-economic factors and environmental factors contribute to biodiversity loss in Vhembe biosphere

7.4 Contribution to Science, Local Knowledge, and Novelty of Thesis

As an objective in this study, the following contributions are derived from the results obtained during literature review, data collection, analysis, and interpretation. These contributions would guide environmental managers in the local municipality to adopt additional best practices for biodiversity loss restoration that are threatened by man's activities, encourage the adoption of sustainable consumption model that reduce pressure on biodiversity in the Vhembe biosphere, and awareness raising of the surrounding communities about the benefits and cost of biodiversity.

- Assessment of natural resources change and biodiversity loss drivers in Vhembe biosphere has not been previously done despite data being available. This study thus contributed to the local knowledge and can be replicated elsewhere in South Africa and Africa understanding biodiversity loss .

- Investigation of how socio-economic drivers contributes to biodiversity loss in the study area has not been done and indeed in South Africa. The study provides crucial information on how such factors contribute to biodiversity loss and how it can be used elsewhere.

- Although different studies have been conducted in Vhembe biosphere reserve, no such study has been done to explore the role of environmental factors and socio-economic factors in biodiversity loss in Vhembe biosphere.

- Assessment of relationship between socio-economic and environmental driver towards biodiversity loss was the first of its kind to be done in Vhembe Biosphere and surroundings.

7.5 Recommendations for future research

Although this study was limited in scope, several areas remain unexplored and should be considered for future research. These areas include:

- Further studies to assess the interactive impacts of human activities and biodiversity loss.

- Exploration of best practices and approaches to protect and restore natural resources that are lost or changing.

- In-depth study of the effects of temperature and precipitation variability on vegetation cover resources in different environmental contexts.

- Investigate the role of socio-economic factors in biodiversity conservation in different biospheres.

References

Adekola, O., Mitchell, G., & Grainger, A. (2015). Inequality and ecosystem services: the value and social distribution of Niger Delta wetland services. *Ecosystem Services*, *12*, 42-54.

Aho, K., Derryberry, D., & Peterson, T. (2014). Model selection for ecologists: the worldviews of AIC and BIC. *Ecology*, *95*(3), 631-636.

Akindele, E. O., Ekwemuka, M. C., Apeverga, P., Amusa, T. O., Olajuyigbe, S., Coker, O. M., ... & Kolawole-Daniels, A. (2021). Assessing awareness on biodiversity conservation among Nigerians: the Aichi Biodiversity Target 1. *Biodiversity and Conservation*, *30*, 1947-1970.

Alberti, M., & Marzluff, J. M. (2004). Ecological resilience in urban ecosystems: linking urban patterns to human and ecological functions. *Urban ecosystems*, *7*, 241-265.

Alcamo, J. (2003). *Ecosystems and human well-being*.

Ali, A. (2021). Natural resources depletion, renewable energy consumption and environmental degradation: A comparative analysis of developed and developing world. *International Journal of Energy Economics and Policy*, *11*(3), 251-260.

Alig R.J., Mercer, E. (2011). Effects of climate change on natural resources and communities: a compendium of briefing papers. Gen. Tech. Rep. PNW-GTR-837. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 169 .

Allan, C., Curtis, A. (2003). Regional scale adaptive management: lessons from the Northeast Salinity Strategy (NESS). Australasian Journal of Environmental Management. 10 (6): 76–84.

Allison, H. E., & Hobbs, R. J. (2006). *Science and policy in natural resource management: Understanding system complexity*. Cambridge University Press.

Almond, R. E. A., Grooten. M, & Peterson, T. (2020). *Living Planet Report 2020-Bending the curve of biodiversity loss*. World Wildlife Fund.

Anderson, D. R., Burnham, K. P., & White, G. C. (1994). AIC model selection in over dispersed capture-recapture data. *Ecology*, *75*(6), 1780-1793.

Andrade, C. (2019). The P Value and Statistical Significance: Misunderstandings, Explanations, Challenges, and Alternatives. Indian journal of psychological medicine, 41(3), 210–215. *https://doi.org/10.4103/IJPSYM.IJPSYM_193_19*

Andrade, C. (2019). The P Value and Statistical Significance: Misunderstandings, Explanations, Challenges, and Alternatives. Indian journal of psychological medicine, 41(3), 210–215.

Andreae, M. O. (1991) *Global Biomass Burning Atmospheric Climate and Biospheric Implications*, MTI Press, Cambridge, U.K., pp. 233-236.

Anne, E. and T. Robin (1994) The Hard Pressed Researcher, Longman, New York.

Ansari, N. A., Agus, C., Nunoo, E. K., Ansari, N. A., Agus, C., & Nunoo, E. K. (2021). Plausible Solutions with Reference to 'SDG15–Life on Land' Towards an Effective Biodiversity Management.

Arnell, N.W., Lowe, J.A., Challinor, A.J. et al. (2019). Global and regional impacts of climate change at different levels of global temperature increase. Climatic Change 155 (3)377–391 (2019). *https://doi.org/10.1007/s10584-019-02464-z*

Arunyawat, S., Shrestha, R. (2016). Assessing land use change and its impact on ecosystem services in Northern Thailand. *Sustainability*. *8* (8), 768. https://doi.org/10.3390/su8080768

Assede, E. S., Orou, H., Biaou, S. S., Geldenhuys, C. J., Ahononga, F. C., & Chirwa, P. W. (2023). Understanding drivers of land use and land cover change in Africa: a review. *Current Landscape Ecology Reports*, 1-11.

Assessment, M. E. (2004). *Millennium ecosystem assessment*. Millennium Ecosystem Assessment.

Assessment, M. E. (2005). *Ecosystems and human well-being* (Vol. 5, p. 563). Island Press, Washington, DC.

Aswani, S., Lemahieu, A., & Sauer, W. H. (2018). Global trends of local ecological knowledge and future implications. *PLoS One*, *13*(4), e0195440.

Austin, M. (2007). Species distribution models and ecological theory: a critical assessment and some possible new approaches. *Ecological modelling*, *200*(1-2), 1-19.

Azadi, H., Bocquet, E., Hugé, J., Jacobs, S., Janssens de Bisthoven, L., Janssens, I., ... & Verbist, B. (2022). *Guidance for the assessment of ecosystem services in African Biosphere Reserves: A way forward to sustainable development*. UNESCO Publishing.

Azevedo, L. B., Verones, F., Henderson, A. D., Zelm, R. V., Jolliet, O. (2014). Freshwater eutrophication, (8) 1–14.

Bahn, V., & McGill, B. J. (2007). Can niche‐based distribution models outperform spatial interpolation?. *Global Ecology and Biogeography*, *16*(6), 733-742.

Baiser, B., Olden, J. D., Record, S., Lockwood, J. L., McKinney., M. L. (2012). Pattern and process of biotic homogenization in the New Pangaea. Proceedings of the Royal Society B: Biological Sciences, *279* (1748), 4772 - 4777.

Balbi S., Selomane. O., Sitas, N., Blanchard R., Kotze, I., O'Farell, P., Villa, F. (2019). Human Development on natural resources in rapidly urbanizing South Africa, *Environ, Res Lett* (14) 044008

Banerjee, A., & Madhurima, C. (2013). Forest degradation and livelihood of local communities in India: A human rights approach. *Journal of horticulture and forestry*, *5*(8), 122-129.

Bansard, J., & Schroder, M. (2021). The sustainable use of natural resources: the governance challenge.

Baojie, L., Dong X.C., Shaohua, W., Shenglu, z., Teng, W., Chen, H. (2016). Spatio-temporal assessment of urbanisation impacts on ecosystem services: Case study of Nanjing City, China. *Ecological Indicators*; 2016;71:416–427.https://doi.org/10.1016/j.ecolind.2016.07.017

Barbier, E. B. (2022). The Policy Implications of the Dasgupta Review: Land Use Change and Biodiversity: Invited Paper for the Special Issue on "The Economics of Biodiversity: Building on the Dasgupta Review" in Environmental and Resource Economics. *Environmental and Resource Economics*, 1-25. doi: 10.1007/s10640-022-00658-1

Barbier, E. B., & Hochard, J. P. (2018). Land degradation and poverty. *Nature Sustainability*, *1*(11), 623-631.

Barbier, E. B., Barbier, J. C. B., & Folke, C. (Eds.). (2019). *Paradise Lost?: the ecological economics of biodiversity* (Vol. 2). Routledge.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological monographs*, *81*(2), 169-193.

Barger, N.N., Gardner, T.A., Sankaran, M., Belnap, J., Broadhurst. L., Brochier, V., et al. (2018). Direct and indirect drivers of land degradation and restoration. In: Montanarella L, Scholes R, Brainich A, (Eds). The IPBES assessment report on land degradation and restoration. Bonn: *Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; 2018. p. 198–314. https://www.ipbes.net/systems/tdf.ipbes/*

Barnabe, G., Universitede Montpellier, I. I., Doumenge, F. F., & de Monaco, M. O. (2001). Mariculture of Mediterranean species.

Baron, J. S., Hartman, M. D., Kittel, T. G., Band, L. E., Ojima, D. S., & Lammers, R. B. (1998). Effects of land cover, water redistribution, and temperature on ecosystem processes in the South Platte Basin. *Ecological Applications*, *8*(4), 1037-1051.

Barraclough, S. L., & Ghimire, K. B. (2013). *Agricultural expansion and tropical deforestation: International trade, poverty and land use*. Routledge.

Barro, R. J., & Sala-i-Martin. X. (2004). Economic growth. Second edition. MIT Press, Cambridge, Massachusetts, USA.

Bartelmus, P. (2002). *Environment, growth and development: The concepts and strategies of sustainability*. Routledge.

Basane, C,N., Gambiza, J. (2016). Habitat assessment for ecosystem services in South Africa, *International Journal of Biodiversity Science, Ecosystem Services & Management*, *12* (4), 242-254.

Batisse, M. (1997). Biosphere reserves: a challenge for biodiversity conservation & regional development. *Environment: Science and Policy for Sustainable Development*, *39*(5), 6-33.

Bax, N. J., Cleary, J., Donnelly, B., Dunn, D. C., Dunstan, P. K., Fuller, M., & Halpin, P. N. (2016). Results of efforts by the Convention on Biological Diversity to describe ecologically or biologically significant marine areas. *Conservation Biology*, *30*(3), 571-581.

Beale, C. M., Lennon, J. J., Yearsley, J. M., Brewer, M. J., & Elston, D. A. (2010). Regression analysis of spatial data. *Ecology letters*, *13*(2), 246-264.

Beaujean, A. A., & Grant, M. B. (2016). Tutorial on using regression models with count outcomes using R. *Practical Assessment, Research, and Evaluation*, *21*(1), 2.

Begon, M., Howorth, R.W. Townsend, C.R. (2014). *Essentials of Ecology*. 4th ed. Wiley, Cambridge, UK.

Bengtsson, M., Alfredsson, E., Cohen, M., Lorek, S,. Schroeder, P. (2018). Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency. *Sustainability Science. 13* (9) 1533–1547.

Beniston, M. (2003). Climatic change in mountain regions: a review of possible impacts. *Climatic change*, *59*(1-2), 5-31.

Bennett, E. M., Carpenter, S. R., & Caraco N. F. (2001). Human impact on erodible phosphorus and eutrophication: a global perspective. *BioScience, 51*(3):227-234.

Bennett, E. M., Cramer, W., Begossi, A., Cundill, G., Díaz, S., Egoh, B. N., ... & Woodward, G. (2015). Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. *Current opinion in environmental sustainability*, *14*, 76-85.

Bennett, N. J., Roth, R., Klain, S. C., Chan, K. M., Clark, D. A., Cullman, G., ... & Veríssimo, D. (2017). Mainstreaming the social sciences in conservation. *Conservation Biology*, *31*(1), 56-66.

Berberoglu, S., Akin, A. (2009). Assessing different remote sensing techniques to detect land use/cove r changes in the eastern Mediterranean. Applied Earth Observation and Geoinformation, 11, 46-53.

Berhe, A. A. (2019). Drivers of soil change. In *Developments in Soil Science* (Vol. 36, pp. 27-42). Elsevier.

Berry, L., Olson, J., & Campbell, D. (2003). Assessing the extent, cost and impact of land degradation at the national level: *findings and lessons learned from seven pilots*. World Bank.

Bevans, R. (2023, June 22). *Akaike Information Criterion | When & How to Use It (Example).* Scribbr. Retrieved October 27, 2023,

Bhandari, G. (2014). An overview of agrochemicals and their effects on environment in Nepal. *Applied Ecology and Environmental Sciences*, *2*(2), 66-73.

Bhattacharya, T.R., & Managi, S. (2013). Contributions of the private sector to global biodiversity protection: case study of the Fortune 500 companies, International Journal of Biodiversity Science, Ecosystem Service and Management *9*(1), 65-86.

Biggs, R., Simons, H., Bakkenes, M., Scholes, R. J., Eickhout, B., van Vuuren, D., & Alkemade, R. (2008). Scenarios of biodiversity loss in southern Africa in the 21st century. *Global Environmental Change*, *18*(2), 296-309.

Boiral, O., Heras-Saizarbitoria, I., & Brotherton, M. C. (2019). Improving corporate biodiversity management through employee involvement. *Business Strategy and the Environment*, *28*(5), 688-698.

Bommarco, R., Kleijn, D., & Potts, S. G. (2013). Ecological intensification: harnessing ecosystem services for food security. *Trends in ecology & evolution*, *28*(4), 230-238.

Boris, R., and Gavrilovic, S. (2020). Natural Habitat Loss: Causes and Implications of Structural and Functional Changes. 10.1007/978-3-319-71065-5_6-1.

Boulton, A. J., Fenwick, G. D., Hancock, P. J., & Harvey, M. S. (2008). Biodiversity, functional roles and ecosystem services of groundwater invertebrates. *Invertebrate Systematics*, *22*(2), 103-116.

Bowler, D. E., Bjorkman, A. D., Dornelas, M., Myers-Smith, I. H., Navarro, L. M., Niamir, A., ... & Bates, A. E. (2020). Mapping human pressures on biodiversity across the planet uncovers anthropogenic threat complexes. *People and Nature*, *2*(2), 380-394.

Bridgewater, P. B., & Arico, S. (2002, August). Conserving and managing biodiversity sustainably: The roles of science and society. In *Natural Resources Forum* (Vol. 26, No. 3, pp. 245-248). Oxford, UK and Boston, USA: Blackwell Publishers Ltd.

Broennimann, O., Fitzpatrick, M. C., Pearman, P. B., Petitpierre, B., Pellissier, L., Yoccoz, N. G., ... & Guisan, A. (2012). Measuring ecological niche overlap from occurrence and spatial environmental data. *Global ecology and biogeography*, *21*(4), 481-497.

Brook, B, W., Sodhi, N, S., Bradshaw, C, J, A. (2008). Synergies among extinction drivers under global change, *Trends in Ecology and Evolution*, Volume *23*, (8), 453-460, ISSN 0169-5347, https://doi.org/10.1016/j.tree.2008.03.011.

Brook, B., Sodhi. N., Bradshaw, C. (2008). Synergies among extinction drivers under global change. *Trends in Ecology & Evolution* 23(8): 453-460.

Broton, L., Thuiller, W., Araujo, M., Hirzel, A., (2004). Presence –absence versus presence-only modeling method for predicting bird habitat suitability. *Ecography* 27 (4), 437-448.

Brotons, L., Thuiller, W., Araújo, M. B., & Hirzel, A. H. (2004). Presence-absence versus presence-only modelling methods for predicting bird habitat suitability. *Ecography*, *27*(4), 437-448.

Brown, C. D., & Davis, H. T. (2006). Receiver operating characteristics curves and related decision measures: A tutorial. *Chemometrics and Intelligent Laboratory Systems*, *80*(1), 24-38.

Brownlie, S., Amrei V.H., Botha, M., Manuel, J., Balmforth, Z., Jenner, N., (2017) Biodiversity offsets in South Africa – challenges and potential solutions, *Impact Assessment and Project Appraisal* 35:3, 248-256,

Bullock, J. M., Aronson, J., Newton, A. C., Pywell, R. F., & Rey-Benayas, J. M. (2011). Restoration of ecosystem services and biodiversity: conflicts and opportunities. *Trends in ecology & evolution*, *26*(10), 541-549.

Burgi, M., Hersperger, A.M., Schneeberger, N. (2005). Driving forces of landscape change-current and new directions. Landscape Ecology, (19), 857-868.

Burnham, K. P., & Anderson, D. R. (2004). Multimodel inference: understanding AIC and BIC in model selection. *Sociological methods & research*, *33*(2), 261-304.

Burnham, K. P., Anderson, D. R., & Huyvaert, K. P. (2011). AIC model selection and multi-model inference in behavioral ecology: some background, observations, and comparisons. *Behavioral ecology and sociobiology*, *65*, 23-35.

Bustamante, M., Helmer, E. H., Schill, S., Belnap, J., Brugnoli, E., Compton, J. E., Richard, H., Brown, L. K., & Couple … (2018). Direct and indirect drivers of change in biodiversity and nature’s contributions to people. *The IPBES regional assessment report on biodiversity and ecosystem services for the Americas*.

Butchart, S. H. M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J. P. W., Almond, R. E. A., Baillie, J. E. M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K. E., Carr, G. M., Chanson, J., Chenery, A. M., Csirke, J., Davidson, N. C., Dentener, F., Foster, M., Galli, A., Watson, R. (2010). Global Biodiversity: indicators of recent declines. *Science*, *328* (5982), 1164 - 1168. https://doi.org/10.1126/science.1187512

Butt, A., Shabbir, R., Ahmad, S.S., Aziz, N. (2015). Land use change mapping and analysis using Remote Sensing and GIS: A case study of Simly watershed, Islamabad, Pakistan. *The Egyptian Journal of Remote Sensing and Space Science. 18*: 251-259

Byerlee, D., De Janvry, A., & Sadoulet, E. (2009). Agriculture for development: Toward a new paradigm. *Annu. Rev. Resour. Econ.*, *1*(1), 15-31.

Cadman, M., Petersen C., Driver A., Sekhran N., Maze K., Munzhedzi S., (2010). Biodiversity for development: South Africa’s landscape approach to conserving biodiversity and promoting ecosystem resilience. Pretoria: South African National Biodiversity Institute.

Campbell, B. M., Beare, D. J., Bennett, E. M., Hall-Spencer, J. M., Ingram, J. S., Jaramillo, F., ... & Shindell, D. (2017). Agriculture production as a major driver of the Earth system *exceeding planetary boundaries. Ecology and Society, 22(4).*

Cardinale, B., J. Duffy, J., Gonzalez, A., Hooper, D. (2012). Biodiversity loss and its impact on humanity. *Nature*, 486 (7401), 59-67.

Carter, N. H., Viña, A., Hull, V., McConnell, W. J., Axinn, W., Ghimire, D., Liu, J. (2014). Coupled human and natural systems approach to wildlife research and conservation. *Ecology and Society*, *19*(3).

Castellaro, S., Mulargia, F., & Kagan, Y. Y. (2006). Regression problems for magnitudes. *Geophysical Journal International*, *165*(3), 913-930.

Cavanaugh, J. E., & Neath, A. A. (2019). The Akaike information criterion: Background, derivation, properties, application, interpretation, and refinements. *Wiley Interdisciplinary Reviews: Computational Statistics*, *11*(3), e1460.

Cavicchioli, R., Ripple, W.J., Timmis, K.N. et al. (2019). Scientists' warning to humanity: microorganisms and climate change. *Nature Reviews Microbiology* (17)**,** 569–586. https://doi.org/10.1038/s41579-019-0222-5.

Chandra, A., Idrisova, A. (2011). Convention on Biological Diversity: a review of national challenges and opportunities for implementation. *Biodiversity and Conservation*, *20*, 3295-3316.

Chapin III F, S., Zaveleta E.S., Eviner V.T., Naylor R.L., Vitousek P.M., Lavorel S., Reynolds H.L., Hooper D.U., Sala O.E., *International Journal of Biodiversity Science , Ecosystem Services and Management* 251

Chapin, F. S., Zavaleta, E. S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., Hooper, D. U., Lavorel, S., Sala, O. E., Hobbie, S. E., Mack, M. C., Díaz, S. (2000). Consequences of changing biodiversity. *Nature*, *405* (6783), 234-242. https://doi.org/10.1038/35012241

Charles, H., & Dukes, J. S. (2007). Impacts of invasive species on ecosystem services. *Biological invasions*, 217-237.

Charnley, S., Fischer, A. P., & Jones, E. T. (2007). Integrating traditional and local ecological knowledge into forest biodiversity conservation in the Pacific Northwest. *Forest ecology and management*, *246*(1), 14-28.

Chen, C., Park, T., Wang, X., Piao, S., Xu, B., Chaturvedi, R.K., Fuchs, R., Brovkin, V., Ciais, P., Fensholt, R. et al. (2019). China and India lead in the greening of the world through land-use management. *Natural Sustainability*. (2), 122–129.

Chen, W., Bo, D., Xiaohui, C., Zhang, L., (2017). A post-classification change detection method based on iterative slow feature analysis and Bayesian soft fusion, *Remote Sensing of Environment*, Cheng, L., Zhang, Y., Sun, H. (2020). Vegetation Cover Change and Relative Contributions of Associated Driving Factors in the Ecological Conservation and Development Zone of Beijing, China. *Polish Journal of Environmental Studies*, 29 (1), 53-65.

Chibba, M., & Luiz, J. M. (2011). Poverty, inequality, and unemployment in South Africa: Context, issues and the way forward. Economic Papers: *A journal of applied economics and policy*, *30*(3), 307-315.

Chiras, D.D., Reganold, J.P. (2009). Natural Resource Conservation: Management for a Sustainable Future. 10th ed. Prentice-Hall, Upper Saddle River, NJ.

Christensen, J. H., & Christensen, O. B. (2007). A summary of the PRUDENCE model projections of changes in European climate by the end of this century. *Climatic change*, *81*(Suppl 1), 7-30.

Christensen, N. L., Bartuska, A. M., Brown, J. H., Carpenter, S., d'Antonio, C., Francis, R., ... & Woodmansee, R. G. (1996). The report of the Ecological Society of America committee on the scientific basis for ecosystem management. *Ecological applications*, *6*(3), 665-691.

Christiaensen, L., Demery, L., & Kuhl, J. (2011). The (evolving) role of agriculture in poverty reduction—An empirical perspective. *Journal of development economics*, *96*(2), 239-254.

Cimon-Morin, J., Darveau, M., Poulin, M. (2016). Consequences of delaying conservation of ecosystem services in remote landscapes prone to natural resource exploitation. *Landscape Ecology, 31*, 825–842.

Clark, W.C., and R.E. Munn (eds.) (1986). Sustainable Development of the Biosphere. Cambridge University Press, New York, NY.

Claudet, J., Bopp, L., Cheung, W. W., Devillers, R., Escobar-Briones, E., Haugan, P., ... & Gaill, F. (2020). A roadmap for using the UN decade of ocean science for sustainable development in support of science, policy, and action. *One Earth*, *2*(1), 34-42.

Coleman, W. G. (1996). Biodiversity and industry ecosystem management. *Environmental Management*, *20*, 815-825.

Corenblit, D., Steiger, J. (2009). Vegetation as a major conductor of geomorphic changes on the Earth surface: Toward evolutionary geomorphology. *Earth Surface Processing and Landforms*, (34) 891–896.

Costanza, R. (1991). Ecological Economics: The Science and Management of Sustainability. Columbia University Press, New York, NY.

Cramer, M., & Wootton, L., & van Mazijk, R., & Verboom, G. (2019). New regionally modelled soil layers improve prediction of vegetation type relative to that based on global soil models. *Diversity and Distributions*. 25. 10.1111/ddi.12973.

Cramer, W., Bondeau, A., Woodward, F.I., Prentice, I.C., Betts, R.A., Brovkin, V.. Cox, P.M., Fisher, V., Foley, J.A., Friend, A.D., et al. (2001). Global response of terrestrial ecosystem structure and function to CO2 and climate change: Results from six dynamic global vegetation models. *Global Change Biology*, *4* (7) 357–373.

Crenna, E., Sinkko, T., & Sala, S. (2019). Biodiversity impacts due to food consumption in Europe. *Journal of cleaner production*, *227*, 378-391.

Cruz, M., Foster, J., Quillin, B., & Schellekens, P. (2015). Ending extreme poverty and sharing prosperity: Progress and policies. *Policy Research Note*, *15*(03).

Dai, Y., & Li, D. (2023). Climate change and anthropogenic activities shrink the range and dispersal of an endangered primate in Sichuan Province, China. *Environmental Science and Pollution Research*, 1-13.

Dale, V. H., & Polasky, S. (2007). Measures of the effects of agricultural practices on ecosystem services. *Ecological economics*, *64*(2), 286-296.

Dale, V.H., King, A.W., Mann, L.K., Washington-Allen, R.A., McCord, R.A. (1998). Assessing land-use impacts on natural resources. *Environmental Management*, *22* (2), 203-211.

Dalu, T., Mwedzi, T., Wasserman, R. J., Madzivanzira, T. C., Nhiwatiwa, T., & Cuthbert, R. N. (2022). Land use effects on water quality, habitat, and macroinvertebrate and diatom communities in African highland streams. *Science of the Total Environment*, *846*, 157346.

Daramola, A., & Ibem, E. O. (2010). Urban environmental problems in Nigeria: Implications for sustainable development. *Journal of Sustainable Development in Africa*, *12*(1), 124-145.

De Ambrosio, M. (2020). Nature losses threaten emerging economies. *SciDev. net-Enterprise*.

De Castro, A., Expósito, J.M., Peña-Barragán, J.M., Francisca, L.G., (2012). Airborne multi-spectral imagery for mapping cruciferous weeds in cereal and legume crops. *Precision Agriculture*. 13. 302-321. 10.1007/s11119-011-9247-0.

De Groot, R. S., Fisher, B., Christie, M., Aronson, J., Braat, L., Haines-Young, R., ... & Ring, I. (2010). Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. In The economics of ecosystems and biodiversity (TEEB): *ecological and economic foundations* (pp. 9-40). Earthscan, Routledge.

De Jong, R., Verbesselt, J., Schaepman, M.E., de Bruin, S. (2012). Trend changes in global greening and browning: Contribution of short-term trends to longer-term change. *Global Change Biology, 2* (18) 642–655.

De Jong, R., Verbesselt, J., Schaepman, M.E., de Bruin, S. (2012). Trend changes in global greening and browning: Contribution of short-term trends to longer-term change. *Global Change Biology, 2* (18) 642–655.

de Vries, B., and J. Goudsblom, editors. 2002. Mappae mundi: humans and their habitats in a long-term socio-ecological perspective. Amsterdam University Press, Amsterdam, The Netherlands.

Degife, A., Worku, H., Gizaw, S., & Legesse, A. (2019). Land use land cover dynamics, its drivers and environmental implications in Lake Hawassa Watershed of Ethiopia. *Remote sensing applications: society and environment*, *14*, 178-190.

Department of Environmental Affairs (2011). National list of ecosystems that are threatened and in need of protection. Government Gazette No. 34809, Notice No. 1002, 9 December 2011.

Desmet, P. G., Cloete, J., Mphapuli, D., Skowno, A., & Holness, S. (2014). Making the case for Protected Areas in Limpopo. *Contract Number EDET/QUT/2371/13. Report for Limpopo Department of Economic Development, Environment & Tourism (LEDET) by ECOSOL GIS*, Port Elizabeth, 3.

Diao, X., Fekadu, B., Haggblade, S., Taffesse, A. S., Wamisho, K., & Yu, B. (2007). Agricultural growth linkages in Ethiopia: Estimates using fixed and flexible price models (No. 589-2016-39785).

Diao, X., Hazell, P., Thurlow, J. (2010). The role of agriculture in African development. *World development*, *38*(10), 1375-1383.

Díaz, S., Fargione J., Chapin III F.S., Tilman D., (2006). Biodiversity loss threatens human well-being. *PLoS Biol*. 4:e277.

Dietz, T., Rosa, E. A., & York, R. (2007). Driving the human ecological footprint. *Frontiers in Ecology and the Environment*, *5*(1), 13-18.

Dogan, E., Majeed, M. T., & Luni, T. (2022). Revisiting the nexus of ecological footprint, unemployment, and renewable and non-renewable energy for South Asian economies: Evidence from novel research methods. *Renewable Energy*, *194*, 1060-1070.

Dombo, L., Crafford, J., Fouche, P., Gaigher, *et al.*, (2006). The Biosphere Reserve Nomination to the United Nations Educational Scientific and Cultural Organisation (UNESCO) Man and the Biosphere (MaB) Programme. Limpopo Province Department of Economic Development. Republic of South Africa: Environment and Tourism. https://www.environment.gov.za/projectsprogrammes/mab Accessed 10 March 2020

Driver A., Sink, K. J., Nel, J. L., Holness, S., Van Niekerk, L., Daniels, F., ... & Maze, K. (2012). National Biodiversity Assessment 2011: an assessment of South Africa's biodiversity and ecosystems. South African National Biodiversity Institute and Department of Environmental Affairs, Pretoria.

Driver, A., Maze, K., Rouget, M., Lombard, A. T., Nel, J., Turpie, J. K., ... & Strauss, T. (2005). National spatial biodiversity assessment 2004: priorities for biodiversity conservation in South Africa. Strelitzia 17, South African National Biodiversity Institute, Pretoria.

Driver, A., Sink, K.J., Nel, J.L., Holness, S., van Niekerk, L., Daniels, F. Jonas, Z., Majiedt, P.A., Harris, L., Maze, K., (2012). National Biodiversity Assessment 2011: An assessment of South Africa's biodiversity and ecosystems. SANBI & DEA, Pretoria

Duraiappah, A. (1996). Poverty and environmental degradation: a literature review and analysis.

Dziba, L., Archer, E., & Mulongoy, J. (2018). Regional Assessment Report on Biodiversity and Ecosystem Services: Africa.

Eastman, J.R., Sangermano, F.., Machado, E.A., Rogan, J., Anyamba, A. (2013). Global Trends in Seasonality of Normalized Di_erence Vegetation Index (NDVI), 1982–2011. *Remote Sensing*,*5*(10 4799–4818.

Egoh, B. N., Reyers, B., Rouget, M., & Richardson, D. M. (2011). Identifying priority areas for ecosystem service management in South African grasslands. *Journal of environmental management*, *92*(6), 1642-1650.

Eiter, S., and Potthoff K. (2016). Landscape changes in Norwegian mountains: increased and decreased accessibility, and their driving forces. *Land Use Policy* (54) 235-245.

Elliott, J.A, Burnside, N.G, Broomhead, T., Kinsey, B.H., Kwesha, D., (2006) The nature and extent of landscape change under land resettlement programs in Zimbabwe. *Land Degradation Dev* (17) 495-508.

Enuoh, O. O. O., & Bisong, F. E. (2014). Global sustainable development agenda: An implication for conservation challenges in cross river state, Nigeria. *Journal of Sustainable Development*, *7*(4), 211.

Ericson, J. A. (2006). A participatory approach to conservation in the Calakmul Biosphere Reserve, Campeche, Mexico. *Landscape and Urban Planning*, *74*(3-4), 242-266.

Evans, S. W. (2017). An assessment of land cover change as a source of information for conservation planning in the Vhembe Biosphere Reserve. *Applied Geography*, *82*, 35-47

Fang, J. (2013). Why logistic regression analyses are more reliable than multiple regression analyses. *Journal of Business and Economics*, *4*(7), 620-633.

Fankhauser, S., & Tol, R. S. (1997). The social costs of climate change: the IPCC second assessment report and beyond. *Mitigation and adaptation strategies for global change*, *1*(4), 385-403.

FAO. 2010b. Global Forest Resources Assessment (2010). Main report. FAO Forestry Paper No. 163. Rome. www.fao.org/docrep/013/i1757e/i1757e00.htm.

Favero, L. P., Belfiore, P. (2019). Simple and Multiple Regression Models. In L.P Favero and P Belfiore (Ed), Data Science for Business and Decision Making (pp.443-438). Academic Press, https://doi.org/10.1016/B978-0-12-811216-8.00013-6

Fenlon, C., O'Grady, L., Butler, S., Doherty, M., Dunnion, J. (2017). The creation and evaluation of a model to simulate the probability of conception in seasonal-calving pasture-based dairy heifers. *Irish Veterinary Journal.* (70), 32. DOI 10.1186/s13620-017-0110-0

Fenoglio, M. S., Calviño, A., González, E., Salvo, A., & Videla, M. (2021). Urbanisation drivers and underlying mechanisms of terrestrial insect diversity loss in cities. *Ecological Entomology*, 46(4), 757-771.

Ferreira, J.C., and Patino, C M. (2015). What does the p value really mean? *The Brazilian Journal of Pulmonology*, *41* (5), 485-485

Fick, S.E. Hijmans, R.J. (2017). WorldClim 2: new 1km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37* (12) 4302-4315.

Fielding, A., and Bell, J. (1997). A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental conservation*, (24), 38-49.

Figueiredo, D.B.F., Paranhos, P., Da Rocha, E.C., Batista, M., et al. (2013). When is statistical significance not significant, *Brazilian Political Science Review* 7 (1), 31-35 https://www.scielo.br/j/bpsr/a/

Filler, G., & Mai, I. (2000). Limited sampling strategy for mycophenolic acid area under the curve. *Therapeutic drug monitoring*, *22*(2), 169-173.

Finer, M., & Orta-Martínez, M. (2010). A second hydrocarbon boom threatens the Peruvian Amazon: trends, projections, and policy implications. *Environmental research letters*, *5*(1), 014012.

Fischer, J, David J. Abson, Ine Dorresteijn, Jan Hanspach, Tibor Hartel, Jannik Schultner & Kate Sherren (2022) Using a leverage points perspective to compare social-ecological systems: a case study on rural landscapes, *Ecosystems and People*, 18:1, 119-130, DOI: 10.1080/26395916.2022.203235

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, l., Holling, C.S. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review. Ecology. *Evolution and Systems*. 35, 557–581.

Folke, C., Holling, C. S., & Perrings, C. (1996). Biological diversity, ecosystems, and the human scale. *Ecological applications*, *6*(4), 1018-1024.

Forstmeier, W., & Schielzeth, H. (2011). Cryptic multiple hypotheses testing in linear models: overestimated effect sizes and the winner's curse. *Behavioral ecology and sociobiology*, *65*, 47-55.

Fossi, M. C., Pedà, C., Compa, M., Tsangaris, C., Alomar, C., Claro, F., ... & Baini, M. (2018). Bioindicators for monitoring marine litter ingestion and its impacts on Mediterranean biodiversity. *Environmental Pollution*, *237*, 1023-1040.

Francisco, D. L. B., Rubio, P., Banzhaf, E., (2016). The value of vegetation cover for ecosystem services in the suburban context. *Urban Forestry & Urban Greening*. 16. 10.1016/j.ufug.2016.02.003.

Franco, A. C., Rossatto, D. R., de Carvalho Ramos Silva, L., & da Silva Ferreira, C. (2014). Cerrado vegetation and global change: the role of functional types, resource availability and disturbance in regulating plant community responses to rising CO 2 levels and climate warming. *Theoretical and Experimental Plant Physiology*, *26*, 19-38.

Freitas, S. R., Hawbaker, T. J., & Metzger, J. P. (2010). Effects of roads, topography, and land use on forest cover dynamics in the Brazilian Atlantic Forest. *Forest ecology and management*, *259*(3), 410-417.

Friedl, M.A., McIver, D.K., Hodges, J.C.F., Zhang, X.Y., Muchoney, D., et al. (2002).

from https://www.scribbr.com/statistics/akaike-information-criterion/

Fuller, R. A., Irvine, K. N., & Gaston, K. J. (2010). Interactions between people and nature in urban environments. *Urban ecology*, 134-171.

Gaitan, J.J., Oliva, E.G., Bran, E D., Maestre, F.T., Aguiar, M.R., Jobbagy, E.G., Buono, G.G., et al., (2014) Vegetation structure as important as climate for explaining ecosystem function across Patagonia rangelands. *Journal Ecology*, (102) 1419-1428

Gaodirelwe, I., Masunga, G.S., Motsholapheko, M.R., (2018) Community-based natural resource management: a promising strategy for reducing subsistence poaching around protected areas, northern Botswana, Environment, Development and Sustainability: A Multidisciplinary Approach to the Theory and Practice of Sustainable development, *Springer* vol 22 (3) N0 28,2269-2287

Gasparatos, A., Doll, C. N., Esteban, M., Ahmed, A., & Olang, T. A. (2017). Renewable energy and biodiversity: Implications for transitioning to a Green Economy. *Renewable and Sustainable Energy Reviews*, *70*, 161-184.

Gaston, K. J. (2000). Global patterns in biodiversity. *Nature*, *405*(6783), 220-227.

Gaston, K. J., Blackburn, T. M., & Goldewijk, K. K. (2003). Habitat conversion and global avian biodiversity loss. Proceedings of the Royal Society of London. Series B: *Biological Sciences*, *270*(1521), 1293-1300.

Geist, H. J., and Lambin E.F**.** (2002). Proximate causes and underlying driving forces of tropical deforestation. *BioScience, 52* (2), 143-150.

George, G., Schillebeeckx, S. J., & Liak, T. L. (2015). The management of natural resources: An overview and research agenda. *Academy of Management Journal*, *58*(6), 1595-1613.

Gessner, U., Naeimi, V., Klein, I., Kuenzer, C., Klein, D., & Dech, S. (2013). The relationship between precipitation anomalies and satellite-derived vegetation activity in Central Asia. *Global and Planetary Change*, *110*, 74-87.

Gissi, E. J., McGowan, C., Venier, D., Di Carlo, F., Musco, S., et al. (2018), Addressing transboundary conservation challenges through marine spatial prioritization *Conservation Biology* 10.1111/cobi.13134

Gissi, L., Manea, E., Mazaris, A, D., Fraschetti, S., Vasiliki, A., et al. (2021). A review of the combined effects of climate change and other local human stressors on the marine environment, *Science of The Total Environment,* 755, (*1*), https://doi.org/10.1016/j.scitotenv.2020.142564.

Gitay, J. (2002). Rhetoric and truth: The south African scene. *An African Journal of Philosophy, Xvi, 2,* 1-2

Global land cover mapping from MODIS: Algorithms and early results. *Remote Sens. Environ*, (83), 287–302.

Godoy, C.D. Dewbre. J. (2010) Economic Importance of Agriculture for Poverty Reduction. OECD Food, Agriculture and Fisheries Working Paper, N0 23, OECD Publishing.

Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological economics*, *86*, 235-245.

Gonzalez, A., Mouquet, N., & Loreau, M. (2009). Biodiversity as spatial insurance: the effects of habitat fragmentation and dispersal on ecosystem functioning. *Biodiversity, ecosystem functioning and ecosystem services*, 134-146.

Gonzalez, P,; Neilson, R.P., Lenihan, J.M., Drapek, R.J. (2010). Global patterns in the vulnerability of ecosystems to vegetation shift due to climate change. *Glob. Ecol. Biogeogr*. (19) 755–768.

Graham, J. W. (2009). Rattle: A Data Mining GUI for R. *The R Journal*, *1* (2), 45-55.

Griebeler, J. S., Brandli, L. L., Salvia, A. L., Leal Filho, W., & Reginatto, G. (2022). Sustainable development goals: a framework for deploying indicators for higher education institutions. *International Journal of Sustainability in Higher Education*, *23*(4), 887-914.

Griffiths, B. S., Ritz, K., Wheatley, R., Kuan, H. L., Boag, B., Christensen, S., ... & Bloem, J. (2001). An examination of the biodiversity–ecosystem function relationship in arable soil microbial communities. *Soil Biology and Biochemistry*, *33*(12-13), 1713-1722.

Grooten, M., & Almond, R. E. (2018). *Living planet report-2018: aiming higher*. WWF international.

Guo, Q., Fu, B.H., Shi, P.L., Cudahy, T., Zhang, J., Xu, H. (2017). Satellite Monitoring the Spatial-Temporal Dynamics of Desertification in Response to Climate Change and Human Activities across the Ordos Plateau, China. *Remote Sens*. 9.

Hahn, N. (2006). Floristic diversity of the Soutpansberg, Limpopo Province, South Africa. PhD thesis, University of Pretoria.

Hajer, M. A., Westhoek, H., Ingram, J., Van Berkum, S., & Özay, L. (2016). Food systems and natural resources. United Nations Environmental Programme.

Halmy, M, W, A., Gessler, P, E., Hicker, J, A., Salem, B, B. (2015). Land use/land cover change detection and prediction in the north-western coastal desert of Egypt using Markov-C. *Applied Geography* Volume 63, 101-112.

Halpern, B., Frazier, M., Potapenko, J. *et al.* Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nat Commun* 6, 7615 (2015). https://doi.org/10.1038/ncomms8615

Hannah, L. (2010). A global conservation system for climate-change adaptation. *Conservation Biology*, *24*(1), 70-77.

Hanski, I. (2005). Landscape fragmentation, biodiversity loss and the societal response: The long term consequences of our use of natural resources may be surprising and unpleasant. *EMBO reports*, *6*(5), 388-392.

Harclerode, M. A., Lal, P., & Miller, M. E. (2016). Quantifying global impacts to society from the consumption of natural resources during environmental remediation activities. *Journal of Industrial Ecology*, *20*(3), 410-422.

Harper, M., Mejbel, H. S., Longert, D., Abell, R., Beard, T. D., Bennett, J. R., ... & Cooke, S. J. (2021). Twenty-five essential research questions to inform the protection and restoration of freshwater biodiversity. Aquatic Conservation: *Marine and Freshwater Ecosystems*, *31*(9), 2632-2653.

Hartemink, A. E., Veldkamp, T., & Bai, Z. (2008). Land cover change and soil fertility decline in tropical regions. *Turkish Journal of Agriculture and Forestry*, *32*(3), 195-213.

Harvey, E., Gounand, I., Ward, C. L., & Altermatt, F. (2017). Bridging ecology and conservation: from ecological networks to ecosystem function. *Journal of Applied Ecology*, *54*(2), 371-379.

Hassan, M. M., & Nazem, M. N. I. (2016). Examination of land use/land cover changes, urban growth dynamics, and environmental sustainability in Chittagong city, Bangladesh. *Environment, development and sustainability*, *18*, 697-716.

Hautier, Y., Tilman, D., Isbell, F., Seabloom, E. W., Borer, E. T., & Reich, P. B. (2015). Anthropogenic environmental changes affect ecosystem stability via biodiversity. *Science*, *348*(6232), 336-340.

Hawker, L., Bates, P., Neal, J., Rougier, J. (2018). Perspectives on Digital Elevation Model (DEM) Simulation for Flood Modelling in the Absence of a High-Accuracy Open Access Global DEM. 241-255, https://doi.org/10.1016/j.rse.2017.07.009.

Hedden-Dunkhorst, B., & Schmitt, F. (2020). Exploring the potential and contribution of UNESCO Biosphere Reserves for landscape governance and management in Africa. *Land*, *9*(8), 237

Heller, N. E., & Zavaleta, E. S. (2009). Biodiversity management in the face of climate change: a review of 22 years of recommendations. *Biological conservation*, *142*(1), 14-32.

Hens, L. (2006). Indigenous knowledge and biodiversity conservation and management in Ghana. *Journal of Human Ecology*, *20*(1), 21-30.

Hijmans, R., Cameron, S., Parra, J., Peter J., Andy, J. (2005). Very high resolution interpolated climate surfaces of global land areas. *International Journal of Climatology*. (25), 1965-1978. 10.1002/joc.1276 .

Hobohm, C. (2021). Environmental Indicators and Biodiversity Conservation Strategies. *Perspectives for Biodiversity and Ecosystems*, 159-180. https://f.hubspotusercontent20.net/hubfs/4783129/LPR/PDFs/ENGLISH-FULL.pdf

Ikendi, S. (2022). Ecological conservation, biodiversity, and agricultural education as integrated approaches for envisioning the future of sustainable agriculture in North America. *International Journal of Sustainable Development & World Ecology*, 1-12.

IPBES (2018): The IPBES regional assessment report on biodiversity and ecosystem services for Africa. Archer, E. Dziba, L., Mulongoy, K. J., Maoela, M. A., and Walters, M. (eds.). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany.

IPBES *(*2019*)* Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services *(ed. by* S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, *et al.), p.* 56. *IPBES Secretariat*, Bonn, Germany.

IPBES. (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Version 1). Zenodo. https://doi.org/10.5281/zenodo.3831674

Iritié, B. G. J. J. (2015). Economic growth and biodiversity: An overview. Conservation policies in Africa. *Journal of Sustainable Development*, *8*(2), 196-208.

Isbell, F., Tilman, D., Polasky, S., & Loreau, M. (2015). The biodiversity-dependent ecosystem service debt. *Ecology letters*, *18*(2), 119-134.

Jain, A. K., & Yang, X. (2005). Modeling the effects of two different land cover change data sets on the carbon stocks of plants and soils in concert with CO2 and climate change. *Global Biogeochemical Cycles*, *19*(2).

James, R., & Washington, R. (2013). Changes in African temperature and precipitation associated with degrees of global warming. *Climatic change*, *117*, 859-872.

Janzen, H. H. (2005). Soil carbon: a measure of ecosystem response in a changing world?. *Canadian Journal of Soil Science*, *85*(Special Issue), 467-480.

Janzen, H. H. (2005). Soil carbon: a measure of ecosystem response in a changing world?. *Canadian Journal of Soil Science*, *85*(Special Issue), 467-480.

Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D. E., Coscieme, L., Golden, A. S., ... & Purvis, A. (2022). The direct drivers of recent global anthropogenic biodiversity loss. *Science advances*, *8*(45), eabm9982.

Jauro, T. I., Tesfamichael, S. G., & Rampedi, I. T. (2020). Tracking conservation effectiveness in the Vhembe Biosphere Reserve in South Africa using Landsat imagery. *Environmental Monitoring and Assessment*, *192*, 1-22.

Jensen, J.R. (1996). Introductory Digital Image Processing: A Remote Sensing Perspective. 2nd Edition, Prentice Hall, Inc., Upper Saddle River, New Jersey.

Jewitt, Debbie. (2021). Rates and patterns of habitat loss across South Africa's vegetation biomes. *South African Journal of Science*. 10.17159/sajs.2921/8182.

Jianchu, X. (2002). People and ecosystems in mountain landscape of Northwest Yunnan, Southwest China: causes of biodiversity loss and ecosystem degradation. *Global Environmental Research Journal*, *special*, 103-110.

Jiménez-Valverde, A. (2012). Insights into the area under the receiver operating characteristic curve (AUC) as a discrimination measure in species distribution modelling. *Global Ecology and Biogeography*, *21*(4), 498-507.

Jobson, J. D. (2012). *Applied multivariate data analysis: regression and experimental design.* Springer Science & Business Media.

Johnson, J. B., & Omland, K. S. (2004). Model selection in ecology and evolution. *Trends in ecology & evolution*, *19*(2), 101-108.

Johnson, M. C., Poulin, M., & Graham, M. (2003). Towards an integrated approach to the conservation and sustainable use of biodiversity: lessons learned from the Rideau River Biodiversity Project. *Human Ecology Review*, 40-55.

Jones, C. M., & Athanasiou, T. (2005). Summary receiver operating characteristic curve analysis techniques in the evaluation of diagnostic tests. *The Annals of thoracic surgery*, *79*(1), 16-20.

Kabanda, T. A,. (2004). Climatology of Long term drought in the Northern region of the Limpopo Province of South Africa. Unpublished Ph.D. thesis. The University of Venda. Kattumuri, R., (2018). Sustaining natural resources in a changing environment: evidence, policy and impact, Contemporary Social Science, 13:1, 1-16, DOI:10.1080/21582041.2017.1418903.

Kabanda, T. A., Munyati, C. (2010). Anthropogenic-induced climate change and the resulting tendency towards land conflict; the case study of the Soutpansberg region, South Africa. In A. Mwiturubani and J van Wyk (eds). Climate change and Natural Resources Conflicts in Africa. Monograph No. 170, Institute for Security Studies.

Karger, D., Conrad, O., Böhner, J. *et al.* (2017). Climatologies at high resolution for the earth's land surface areas. *Scientific Data* 4, 170122. https://doi.org/10.1038/sdata.2017.122

Karki, K. B. (2004). Research direction on soil sustainability in Nepal. *Green field-journal of Agriculture, Veterinary and Food Sciences*, *2*(2).

Kasperson, Roger E., Kristin Dow, Emma Archer, Daniel Cáceres, Thomas Downing, Tomas Elmqvist, Siri Eriksen et al. "Vulnerable peoples and places." *Ecosystems and human wellbeing: Current state and trends* 1 (2005): 143-164.

Kepe, T., Wynberg, R., & Ellis, W. (2005). Land reform and biodiversity conservation in South Africa: complementary or in conflict?. *The International Journal of Biodiversity Science and Management*, *1*(1), 3-16.

Kgaphola, M. J., Ramoelo, A., Odindi, J., Mwenge Kahinda, J. M., Seetal, A. R., & Musvoto, C. (2023). Impact of land use and land cover change on land degradation in rural semi-arid South Africa: case of the Greater Sekhukhune District Municipality. *Environmental Monitoring and Assessment*, *195*(6), 710.

Kim, I., Kwon, H. (2021). Assessing the Impacts of Urban Land Use Changes on Regional Ecosystem Services According to Urban Green Space Policies Via the Patch-Based Cellular Automata Model. *Environmental Management*, (67**),** 192–204. https://doi.org/10.1007/s00267

Kim, Y.J., Song, Y.K., Lee, D.K. (2019).Understanding the Critical Impact Path on Vegetation Growth under Climate Extremes and Human Influence. *Forests*, (*10)*, 947. https://doi.org/10.3390/f10110947

Knop, E. V. A. (2016). Biotic homogenization of three insect groups due to urbanization. *Global Change Biology*, 22(1), 228-236.

Kothari, A., Corrigan, C., Jonas, H., Neumann, A., & Shrumm, H. Secretariat of the Convention on Biological Diversity, 2014. *Recognising and supporting territories and areas conserved by indigenous peoples and local communities: Global overview and national case studies*.

Kumar, A., Ekka, P., Patra, S., Kumar, G., Kishore, B. S., Kumar, R., & Saikia, P. (2022). Geospatial Perspectives of Sustainable Forest Management to Enhance Ecosystem

Services and Livelihood Security. *Advances in Remote Sensing for Forest Monitoring*, 10-42.

Kumar, R., Sankhla, M. S., Kumar, R., & Sonone, S. S. (2021). Impact of pesticide toxicity in aquatic environment. *Biointerface Research in Applied Chemistry*, *11*(3), 10131-10140.

Kumari, R., & Deepali, B. (2021). Biodiversity Loss: Threats and Conservation Strategies. *International Journal of Pharmaceutical Sciences Review and Research*, *68*, 242-254.

Kusena, K. (2009). Land cover change and its impact on human-elephant conflicts in the Zimbabwe, Mozambique and Zambia (ZiMoZa) Transboundary Natural Resource Management Area.

Lahsaini, M., Tabyaoui, H., Mounadel, A., Nouzha, B., Ferdaous. L. (2018). Comparison of SRTM and ASTER Derived Digital Elevation Models of Inaouene River Watershed. *Journal of Geoscience and environmental Protection,* (6). 141-156. https://doi.org/10.4236/gep.2018.69011

Lambin, E. F., Turner B. L., Geist, H. J., Agbola, S. B., ...*et al.*, (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change 11*(4), 261-269

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., ... & Xu, J. (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global environmental change*, *11*(4), 261-269.

Lambin, E.F., Geist, H.J. (2006). Land use and land cover change: Local processes and global impacts. *Environmental Science* 1, 1-8.

Lampert, A. (2019). Over-exploitation of natural resources is followed by inevitable declines in economic growth and discount rate. *Nature Communication* (10) 1419. https://doi.org/10.1038/s41467-019-09246-2

Langton, M., & Rhea, Z. M. (2005). Traditional indigenous biodiversity-related knowledge. *Australian Academic & Research Libraries*, *36*(2), 45-69.

Lasco, R. D., UEBELHöR, K., & Follisco J.R. (2010). Facing the challenge of biodiversity conservation and climate change in Southeast Asia. *Climate and Development*, *2*(3), 291-294.

Laurance, W. F., Goosem, M., & Laurance, S. G. (2009). Impacts of roads and linear clearings on tropical forests. *Trends in ecology & evolution*, *24*(12), 659-669.

Laurence, H. R. 2001. A Comparison of Parametric Classification Procedures of Remotely Sensed Data Applied on Different Landscape Units. *Remote Sensing of Environment 75*:174-187

Lawes, M.J., Obiri, J.A.F., Eeley, H.A.C., (2004). The uses and value of indigenous forest resources in South Africa. In: M.J. Lawes, H.A.C. Eeley, C. M. Shackleton, B.G.S., Geach, (Eds). *Indigenous Forests and Woodlands in South Africa*: (pp227-235) Policy, People and Practice. University of KwaZulu-Natal Press. Scottsville, South Africa.

Lehohla, P. (2015). Census (2011). population dynamics in South Africa. *Statistics South Africa*, 1-112.

Leviston, Z., Walker, I., Green, M., & Price, J. (2018). Linkages between ecosystem services and human wellbeing: A Nexus Webs approach. *Ecological indicators*, *93*, 658-668.

Li N., Ulucak, R., & Danish, K. (2022). Turning points for environmental sustainability: the potential role of income inequality, human capital, and globalization. *Environmental Science and Pollution Research*, *29*(27), 40878-40892.

Li, C., Fu, B., Wang, S., Stringer, L. C., Wang, Y., Li, Z., ... & Zhou, W. (2021). Drivers and impacts of changes in China's drylands. *Nature Reviews Earth & Environment*, *2*(12), 858-873.

Lichtenberg, E., Shortle, J., Wilen, J., Zilberman, D. (2010). Natural resource economics and conservation: contributions of agricultural economics and agricultural economists. *American Journal of Agricultural Economics*, *92*(2), 469-486.

Lillesand, T.M., Kiefer, R.W., Chipman, J.W., (2008). *Remote Sensing and Image Interpretation*, 6th ed. United States: Wiley, p. 545.

Linden, J., & Hahn, N., & Taylor., P. (2014). Conservation planning in the Vhembe Biosphere Reserve, Limpopo Province.

Linden, J.D., Hahn, N., and Taylor, P, J., (2014). Conservation planning in the Vhembe Biosphere Reserve, Limpopo Province. https://www.researchgate.net/publication/277006421

Lindenmayer, D. B., Margules, C. R., & Botkin, D. B. (2000). Indicators of biodiversity for ecologically sustainable forest management. *Conservation biology*, *14*(4), 941-950.

Liu, H.Y., Zhang, M.Y., Lin, Z.S., Xu, X.J. (2018). Spatial heterogeneity of the relationship between vegetation dynamics and climate change and their driving forces at multiple time scales in Southwest China. *Agriculture and Forest Meteorology*, (256), 10–21.

Lobo, J., Jiménez-Valverde, J.A., Raimundo, R. (2008). AUC: A misleading measure of the performance of predictive distribution models. *Journal of Global Ecology and Biogeography*. (17), 145-151.Lobo, J.M., Valverde, A. J., Raimundo, R. (2007). AUC: a misleading measure of the performance of predictive distribution models. *Global Ecology and Biogeography*, DOI: 10.1111/j.1466-8238.2007.00358.x www.blackwellpublishing.com/geb

Loreau, M. (1998). Biodiversity and ecosystem functioning: a mechanistic model. *Proceedings of the National Academy of Sciences*, *95*(10), 5632-5636.

Lorencova, K,E., Harmackova, Z,V., Landoza, L., Parl, A., Vackar, D. (2016). Assessing impact of land use and climate change on regulating ecosystem services in the Czech Republic, Ecosystem *Health and Sustainability*, **2**:3, DOI: 10.1002/ehs2.1210

Ludwig, J. A., Tongway, D. J., Bastin, G. N., & James, C. D. (2004). Monitoring ecological indicators of rangeland functional integrity and their relation to biodiversity at local to regional scales. *Austral ecology*, *29*(1), 108-120.

Luvuno L.B, Kotze D.C, Kirkman K.P. (2016). Long-term landscape changes in vegetation structure: fire management in the wetlands of Kwa-Mbonambi, South Africa. *African Journal of Aquatic Science,* (41) 279-288.

MA (Millennium Ecosystem Assessment). 2005. Ecosystems and Well-being: biodiversity synthesis. World Resources Institute, Washington D.C., USA. pp. 86

Mace, G. M., Barrett, M., Burgess, N. D., Cornell, S. E., Freeman, R., Grooten, M., & Purvis, A. (2018). Aiming higher to bend the curve of biodiversity loss. *Nature Sustainability*, *1*(9), 448-451.

Mackey, B. G., Watson, J. E., Hope, G., & Gilmore, S. (2008). Climate change, biodiversity conservation, and the role of protected areas: an Australian perspective. *Biodiversity*, *9*(3-4), 11-18.

Madlener, R., Yasin, S. (2011). Impacts of urbanization on urban structures and energy demand: What can we learn for urban energy planning and urbanization management. *Sustainable Cities and Society*, *1* (1), 45-53

Madubansi, M., Shackleton, C.M. (2006). Changing energy profiles and consumption patterns following electrification in five rural villages, South Africa. *Energy Policy 34* (18), 4081-4092.

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J. P., ... & Bidoglio, G. (2012). Mapping ecosystem services for policy support and decision making in the European Union. *Ecosystem services*, *1*(1), 31-39.

Maffi, L., & Woodley, E. (2012). *Biocultural diversity conservation: a global sourcebook*. Routledge.

Magurran, A. E. (2021). Measuring biological diversity. *Current Biology*, *31*(19), R1174-R1177.

Malhi, Y., Franklin, J., Seddon, N., Solan, M., Turner, M. G., Field, C. B., & Knowlton, N. (2020). Climate change and ecosystems: Threats, opportunities and solutions. *Philosophical Transactions of the Royal Society B*, *375*(1794), 20190104.

Manson, S.M, Kernik, M. (2018). Human–environment interactions and scalable remote sensing A2 — Liang, Shunlin. *Comprehensive Remote Sensing*. Elsevier; 4-16.

Mansour, K., Mutanga, O., & Everson, T. (2012). Remote sensing based indicators of vegetation species for assessing rangeland degradation: Opportunities and challenges. *Afr. J. Agric. Res*, *7*(22), 3261-3270.

Margules, C. R., & Pressey, R. L. (2000). Systematic conservation planning. *Nature*, *405*(6783), 243-253.

Marzluff, J.M., McGowan K.J., Donnelly R., Knight R.L. (2001). Causes and consequences of expanding American crow populations. In: Marzluff JM, Bowman R, Donnelly R, editors. Avian ecology and conservation in an urbanizing world. *Kluwer Academic*; 333–365.

Maxim, L., Spangenberg, J. H., & O'Connor, M. (2009). An analysis of risks for biodiversity under the DPSIR framework. *Ecological economics*, *69*(1), 12-23.

Mazerolle, M. (2006). Improving data analysis in herpetology: using Akaike's Information Criterion (AIC) to assess the strength of biological hypotheses. *Amphibia-Reptilia*, *27*(2), 169-180.

McCluskey, A., Lalkhen, A, G., (2007). Statistics IV: Interpreting the results of statistical tests, *Continuing Education in Anaesthesia Critical Care & Pain*, (7), *6*, 208–212 https://doi.org/10.1093/bjaceaccp/mkm042

McKinney M. L.& Lockwood J. L.. 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. *Trends Ecol. Evol*. 14, 450–453.doi:10.1016/S0169-5347(99)01679-1 (doi:10.1016/S0169-5347(99)01679-1).

McKinney, M. L., & Lockwood, J. L. (1999). Biotic homogenization: a few winners replacing many losers in the next mass extinction. *Trends in ecology & evolution*, *14*(11), 450-453.

McKinney, M.L. (2008). Effects of urbanization on species richness diversity: a review of plants and animals. *Urban Ecosystems*. (11) 161–176.

Mehrotra, S., Parida, J., Sinha, S., & Gandhi, A. (2014). Explaining employment trends in the Indian economy: 1993-94 to 2011-12. Economic and Political Weekly, 49-57.

Menard, S. (2000). Coefficient of determination for multiple logistic regression analysis. *American Statistician*, (54), 17-24

Menzel, S., & Bögeholz, S. (2009). The loss of biodiversity as a challenge for sustainable development: How do pupils in Chile and Germany perceive resource dilemmas?. *Research in Science Education*, *39*, 429-447.

Millennium ecosystem assessment, M. E. A. (2005). *Ecosystems and human well-being* (Vol. 5, p. 563). Washington, DC: Island press.

Millennium Ecosystem Assessment. 2003. Ecosystems and their services. Pages 49-70 in Millennium Ecosystem Assessment. *Ecosystems and human well-being*. Island Press, Washington, D.C., USA.

Millennium Ecosystem Assessment. 2005a. Ecosystems and human well-being. Volume 1. Current state and trends. Island Press, Washington, D.C., USA.

Mittal, I., Kumar, R,G. (2015). Natural Resources Depletion and Economic Growth in Present Era *Journal of Science & Technology 10* (3) 24-28 https://ssrn.com/2920080 Accessed 21 March 2020

Mohamed, B., Hassiba, D., Alitouche, T.A.. (2013). Evaluation measures for models assessment over imbalanced data sets. *Journal of Information Engineering and Applications*, (3), 27-38.

Mohamed, B., Hassiba, D., Alitouche, T.A.. (2013). Evaluation measures for models assessment over imbalanced data sets. *Journal of Information Engineering and Applications*, (3), 27-38

Mora, C., & Sale, P. F. (2011). Ongoing global biodiversity loss and the need to move beyond protected areas: a review of the technical and practical shortcomings of protected areas on land and sea. *Marine ecology progress series*, *434*, 251-266.

Morgado, R. G., Loureiro, S., & González-Alcaraz, M. N. (2018). Changes in soil ecosystem structure and functions due to soil contamination. In *Soil pollution* (pp. 59-87). Academic Press.

Mourad, Mohammad & Bertrand-Krajewski, Jean-Luc & Chebbo, Ghassan. (2005). Calibration and validation of multiple regression models for stormwater quality prediction: Data partitioning, effect of dataset size and characteristics. *Water Science & Technology*. 52. 45-52. 10.2166/wst.2005.0060.

Msofe, N.K., Sheng, L., Lyimo, J. (2019). Land Use Change Trends and Their Driving Forces in the Kilombero Valley Floodplain, South-Eastern Tanzania. *Sustainability*, (11) 505-523

Mucina L. & Rutherford, M.C., (eds) (2006). The Vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* 19. South African National Biodiversity Institute, Pretoria

Mucina, L., Jurgens, N., le Roux, A., Rutherford, M.C., *et al.*, (2006c). Succulent Karoo Biome. In: Mucina, L. and Rutherford, M.C. (eds). The Vegetation of South Africa, Lesotho, and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Mucina, L., Rutherford, M.C., Powrie. L.W. (2006). Vegetation Atlas of South Africa, Lesotho and Swaziland. In: L. Mucina and M.C Rutherford, (Eds). *The Vegetation of South Africa, Lesotho and Swaziland*, (pp. 748-789). South African Biodiversity Institute, Pretoria. ISBN: 978-1919976-21-1 https://www.sanbi.org/documents/the-vegetation-of-south-africa-lesotho-and-swaziland-strelitzia-19/ Accessed 27 May 2020

Mueller, T., Dressler,G., Tucker,C.J., Pinzon, J.E., Leimgruber, P., Dubayah, R.O., Hurtt, G.C., Bohning-Gaese, K., Fagan, W.F. (2014). Human Land-Use Practices Lead to Global Long-Term Increases in Photosynthetic Capacity. *Remote Sensing*, **(**60), 5717–5731.

Mulugisi, A. (2015). The impact of Heavy rains on the Vegetation cover in the Limpopo Province of South Africa Unpublished Master's thesis. University of Venda

Munthali, M. G., Davis, N., Adeola, A. M., Botai, J. O. (2020). The impacts of land use and land cover dynamics on natural resources and rural livelihoods in Dedza District, Malawi. *Geocarto International*, 1-18. DOI: 10.1080/10106049.2020.1791978

Munthali, S. M. (2007, February). Trans‐frontier conservation areas: Integrating biodiversity and poverty alleviation in Southern Africa. In *Natural resources forum* (Vol. 31, No. 1, pp. 51-60). Oxford, UK: Blackwell Publishing Ltd.

Myers, N. (1988). Threatened biotas:" hot spots" in tropical forests. *Environmentalist*, *8*, 187-208.

National Research Council (2010). Understanding the Changing Planet: Strategic Directions for the Geographical Sciences. Washington, DC: The National Academies Press. https://doi.org/10.17226/12860.

Navarro-Perez, M., & Tidball, K. G. (2012). Challenges of Biodiversity Education: A Review of Education Strategies for Biodiversity Education. *International Electronic Journal of Environmental Education*, *2*(1), 13-30.

Ndinga, A. (2001). Forest conservation in Central Africa and international politics: the failure of the Brazzaville Process. *Forest conservation in Central Africa and international politics: the failure of the Brazzaville Process.*

Nelson, G. C. (2005). Drivers of ecosystem change. Ecosystems and human wellbeing Current state and trends findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment.

Nelson, G. C., Bennett, E., Berhe, A. A., Cassman, K., DeFries, R., Dietz, T., Dobermann, A., Dobson, A., Janetos, V., Levy, M., Marco, D., Nakicenovic, N., O'Neill, B., Norgaard, R., Petschel-Held, G., Ojima, D., Pingali, P., Watson, R., and Zurek. M. (2006). Anthropogenic drivers of ecosystem change: an overview. *Ecology and Society* 11 (2), 29. http://www.ecologyandsociety.org/vol11/iss2/art29

Nelson, G. C., Bennett, E., Berhe, A. A., Cassman, K., DeFries, R., Dietz, T., ... & Zurek, M. (2006). Anthropogenic drivers of ecosystem change: an overview. *Ecology and Society*, 11(2).

Nelson, G. C., Bennett, E., Berhe, A. A., Cassman, K.G., & … Zurek, M. (2005). Drivers of change in ecosystem condition and services. Ecosystems and Human Well-being: Scenarios. (eds S.R.Carpenter, P.L. Pingali, E. Bennett, & M. Zurek). Island Press, Washington D.C., USA. pp. 173–222.

Nethengwe, S. N., (2007). Integrating Participatory GIS and Political Ecology to study Flood Vulnerability in the Limpopo Province of South Africa. Dissertation submitted to the Eberly College of Arts & Sciences at West Virginia University in partial fulfillment of the requirements for Ph.D. Geography.

Newburn, D. A., Berck, P., & Merenlender, A. M. (2006). Habitat and open space at risk of land-use conversion: Targeting strategies for land conservation. *American Journal of Agricultural Economics*, 88(1), 28-42.

Nguyen, H. H., Dargusch, P., Moss, P., & Aziz, A. A. (2017). Land-use change and socio-ecological drivers of wetland conversion in Ha Tien Plain, Mekong Delta, Vietnam. *Land Use Policy*, *64*, 101-113.

Nicholson, E., Watermeyer, K. E., Rowland, J. A., Sato, C. F., Stevenson, S. L., Andrade, A., ... & Watson, J. E. (2021). Scientific foundations for an ecosystem goal, milestones and indicators for the post-2020 global biodiversity framework. *Nature Ecology & Evolution*, *5*(10), 1338-1349.

Noce, S., Caporaso, L. and Santini, M. (2020). A new global dataset of bioclimatic indicators. *Scientific Data* 7, 398. https://doi.org/10.1038/s41597-020-00726-5

Norris, K. (2012). Biodiversity in the context of ecosystem services: the applied need for systems approaches. Philosophical transactions of the Royal Society of London. Series B, *Biological sciences*, *367* (1586), 191–199. https://doi.org/10.1098/rstb.2011.0176

Norris, K., Asase, A., Collen, B., Gockowksi, J., Mason, J., Phalan, B., Wade, A. (2010). Biodiversity in a forest-agriculture mosaic–The changing face of West African rainforests. *Biological conservation*, 143(10), 2341-2350.

Notaro, M., Mauss, A., & Williams, J. W. (2012). Projected vegetation changes for the American Southwest: combined dynamic modeling and bioclimatic-envelope approach. *Ecological applications*, *22*(4), 1365-1388.

Novacek, M. J. (2008). Engaging the public in biodiversity issues. *Proceedings of the National Academy of Sciences*, *105*(1), 11571-11578.

Numbere, A. O., & Maduike, E. M. (2022). The impact of unsustainable exploitation of forest and aquatic resources of the Niger Delta, Nigeria. In *Biodiversity in Africa: potentials, threats and conservation* (pp. 239-265). Singapore: Springer Nature Singapore.

Oberle, B., Bringezu, S., Hatfield-Dodds, S., Hellweg, S., Schandl, H., & Clement, J. (2019). *Global resources outlook: 2019*. International Resource Panel, United Nations Envio, Paris, France.

Oesterwind, D., Zaiko, A. (2016). Drivers and pressures – Untangling the terms commonly used in marine science and policy, *Journal of Environmental Management*, 181, 8-15 https://doi.org/10.1016/j.jenvman.2016.05.058.

Ohlmacher, G. C., & Davis, J. C. (2003). Using multiple logistic regression and GIS technology to predict landslide hazard in northeast Kansas, USA. *Engineering geology*, *69*(3-4), 331-343.

Olden, J. D., Poff, N. L., Douglas, M. R., Douglas, M. E., & Fausch, K. D. (2004). Ecological and evolutionary consequences of biotic homogenization. *Trends in ecology & evolution*, *19*(1), 18-24.

Oliver, T. H., & Morecroft, M. D. (2014). Interactions between climate change and land use change on biodiversity: attribution problems, risks, and opportunities. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(3), 317-335.

Omann, I., Stocker, A., & Jäger, J. (2009). Climate change as a threat to biodiversity: An application of the DPSIR approach. *Ecological Economics*, *69*(1), 24-31.

Osman, K. T. (2014). *Soil degradation, conservation and remediation* (Vol. 820). Dordrecht: Springer Netherlands.

Otegbulu, A. C., & RSV, F. (2011). Economics of green design and environmental sustainability. *Journal of Sustainable Development*, *4*(2), 240.

Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development.

Patel, S. K., Sharma, A., & Singh, G. S. (2020). Traditional agricultural practices in India: an approach for environmental sustainability and food security. *Energy, Ecology and Environment*, 5(4), 253-271.

Pawar, P. R. (2016). Anthropogenic threats to coastal and marine biodiversity: a review. *Int J Mod Biol Res*, *4*, 35-45.

Pearce, D., & Moran, D. (2013). *The economic value of biodiversity*. Routledge.

Pearce, J., & Ferrier, S. (2000). Evaluating the predictive performance of habitat models developed using logistic regression. *Ecological modelling*, *133*(3), 225-245.

Peng, D.L., Zhang, B., Liu, L.Y., Fang, H.L., Chen, D.M., Hu, Y., Liu, L.L. (2012). Characteristics and drivers of global NDVI-based FPAR from 1982 to 2006. *Glob. Biogeochem. Cycle*, 26.

Peng, D.L., Zhang, B., Liu, L.Y., Fang, H.L., Chen, D.M., Hu, Y., Liu, L.L. (2012). Characteristics and drivers of global NDVI-based FPAR from 1982 to 2006. Glob. Biogeochem. *Cycle*, 26.

Pereira, H. M., Navarro, L. M., & Martins, I. S. (2012). Global biodiversity change: the bad, the good, and the unknown. *Annual Review of Environment and Resources*, *37*, 25-50.

Pereira, H. M., Navarro, L. M., & Martins, I. S. (2012). Global biodiversity change: the bad, the good, and the unknown. *Annual Review of Environment and Resources*, *37*, 25-50.

Petrie, B., chapman, A., Midgley, A. Parker, R. (2014) Risk, vulnerability and Resilience in the Limpopo River Basin system: climate change, water and biodiversity – a synthesis. For the USAID Southern Africa “Resilience in the Limpopo River Basin” (Resilim) program. OneWorld sustainable investments, cape town, South Africa. https://www.climatelinks.org/

Pettorelli, N., Vik, J.O., Mysterud, A., Gaillard, J.M., Tucker, C.J., Stenseth, N.C. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends *Ecol. Evol.* (20) 503–510.

Petz, K., Glenday, J., Alkemade, R. (2014). Land management implications for ecosystem services in a South African rangeland. *Ecological indicators*, *45*, 692-703.

Phang, S. C., Failler, P., & Bridgewater, P. (2020). Addressing the implementation challenge of the global biodiversity framework. *Biodiversity and conservation*, *29*(9-10), 3061-3066.

Piao, S., Cui, M., Chen, A., Wang, X., Ciais, P., Liu, J., & Tang, Y. (2011). Altitude and temperature dependence of change in the spring vegetation green-up date from 1982 to 2006 in the Qinghai-Xizang Plateau. *Agricultural and Forest Meteorology*, *151*(12), 1599-1608.

Pimm, S. L. (2009). Climate disruption and biodiversity. *Current biology*, *19*(14).

Pimm, S., and Raven, p., (2000). Extinction by numbers. Nature 403: 843-845. https://doi.org/10.1038/35002708

Plieninger, T., Draux, H., Fagerholm, N., Bieling, C., Burgi, M., Kizos, T., Kuemmerle, T., Primdahl, J., Verburg, P.H. (2016). The driving forces of landscape change in Europe: a systematic review of the evidence. *Land Use Policy*, (57), 204-214.

Polasky, S., Nelson, E., Lonsdorf, E., Fackler, P., & Starfield, A. (2005). Conserving species in a working landscape: land use with biological and economic objectives. *Ecological applications*, *15*(4), 1387-1401.

Pongsiri, M. J., Roman, J., Ezenwa, V. O., Goldberg, T. L., Koren, H. S., Newbold, S. C., ... & Salkeld, D. J. (2009). Biodiversity loss affects global disease ecology. *Bioscience,* 59(11), 945-954.

Pörtner, H. O., Scholes, R. J., Agard, J., Archer, E., Arneth, A., Bai, X., ... & Ngo, H. T. (2021). IPBES-IPCC co-sponsored workshop report on biodiversity and climate change. *IPBES and IPCC*, *10*.

Posada, D., & Buckley, T. R. (2004). Model selection and model averaging in phylogenetics: advantages of Akaike information criterion and Bayesian approaches over likelihood ratio tests. *Systematic biology*, *53*(5), 793-808.

Power, A. G. (2010). Ecosystem services and agriculture: tradeoffs and synergies. *Philosophical transactions of the royal society B: biological sciences*, *365*(1554), 2959-2971.

Praburaj, L., Design, F., & Nadu, T. (2018). Role of agriculture in the economic development of a country. *Shanlax International Journal of Commerce*, *6*(3), 1-5.

Pretty, J., & Smith, D. (2004). Social capital in biodiversity conservation and management. *Conservation biology*, *18*(3), 631-638.

Pretty, J., Adams, B., Berkes, F., De Athayde, S. F., Dudley, N., Hunn, E., ... & Pilgrim, S. (2009). The intersections of biological diversity and cultural diversity: towards integration. *Conservation and Society*, *7*(2), 100-112.

Prip, C. (2018). The Convention on Biological Diversity as a legal framework for safeguarding ecosystem services. *Ecosystem services*, *29*, 199-204.

Purvis, A., Gittleman, J. L., Cowlishaw, G., & Mace, G. M. (2000). Predicting extinction risk in declining species. *Proceedings of the royal society of London. Series B: Biological Sciences*, *267*(1456), 1947-1952.

Rajakaruna, N., & Boyd, R.S. (2008). Edaphic Factor. In S. E. Jørgensen, B. D. Fath (Ed). Encyclopaedia of Ecology, (pp.1201-1207, Academic Press. https://doi.org/10.1016/B978-008045405-4.00484-5

Ralph A.J., Mercer E., (2011). Effects of climate change on natural resources and communities: a compendium of briefing papers. General. Technical. Report. PNW-GTR-837. Portland, OR: U.S. Department of Agriculture, Forest Service, *Pacific Northwest Research Station* 169

Ramarumo, L. J., & Maroyi, A. (2020). An inventory of useful threatened plant species in vhembe biosphere reserve, Limpopo Province, South Africa. *Biodiversitas Journal of Biological Diversity*, 21(5).

Rampheri, M. B., Dube, T., Shoko, C., Marambanyika, T., & Dhau, I. (2022). Local community attitudes and perceptions towards benefits and challenges associated with biodiversity conservation in Blouberg Nature Reserve, South Africa. *African Journal of Ecology*, *60*(3), 769-779.

Rani, L., Thapa, K., Kanojia, N., Sharma, N., Singh, S., Grewal, A. S., ... & Kaushal, J. (2021). An extensive review on the consequences of chemical pesticides on human health and environment. *Journal of Cleaner Production*, *283*, 124657.

Raven, P., & Wackernagel, M. (2020). Maintaining biodiversity will define our long-term success. *Plant Diversity*, *42*(4), 211-220.

Rawat, J.S., Biswas, V., Kumar, M. (2013). Changes in land use/cover using geospatial techniques-A case study of Ramnagar town area, district Nainital, Uttarakhand, India. *Egypt Journal of Remote Sensing and Space Science*. *16*, 111–117.

Rawat, U. S., & Agarwal, N. K. (2015). Biodiversity: Concept, threats and conservation. *Environment Conservation Journal*, *16*(3), 19-28.

Richardson, R. B. (2010). Ecosystem services and food security: Economic perspectives on environmental sustainability. *Sustainability*, *2*(11), 3520-3548.

Ripplinger, J., & Sullivan, J. (2008). Does choice in model selection affect maximum likelihood analysis?. *Systematic biology*, *57*(1), 76-85.

Roba, H. G., & Oba, G. (2009). Efficacy of integrating herder knowledge and ecological methods for monitoring rangeland degradation in northern Kenya. *Human Ecology*, *37*, 589-612.

Roberts, L., Hassan, A., Elamer, A., & Nandy, M. (2021). Biodiversity and extinction accounting for sustainable development: A systematic literature review and future research directions. *Business Strategy and the Environment*, *30*(1), 705-720.

Robinson, E. J. (2016). Resource-dependent livelihoods and the natural resource base. *Annual Review of Resource Economics*, *8*, 281-301.

Rocha, J., Yletyinen, J., Biggs, R., Blenckner, T., & Peterson, G. (2015). Marine regime shifts: drivers and impacts on ecosystems services. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1659), 20130273.

Rodríguez-Caballero, E., Cantón, Y., Chamizo, S., Lázaro, R., & Escudero, A. (2013). Soil loss and runoff in semiarid ecosystems: a complex interaction between biological soil crusts, micro-topography, and hydrological drivers. *Ecosystems*, *16*, 529-546.

Romanelli, C., Cooper, D., Campbell-Lendrum, D., Maiero, M., Karesh, W. B., Hunter, D., & Golden, C. D. (2015). Connecting global priorities: biodiversity and human health: a state of knowledge review. World Health Organistion/Secretariat of the UN Convention on Biological Diversity.

Rondinelli, D. A., Johnson Jr, J. H., & Kasarda, J. D. (1998). The changing forces of urban economic development: Globalization and city competitiveness in the 21st century. *Cityscape*, 71-105.

Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C., & Pounds, J. A. (2003). Fingerprints of global warming on wild animals and plants. *Nature*, *421*(6918), 57-60.

Rosegrant, M., Paisner, S., Meijer, S., Witcover. J. (2001). Global food projections to 2020: Emerging trends and alternative futures. Washington, DC: *International Food Policy Research Institute*. https://www.ifpri.org/publication/global-food-projections-2020. Accessed 8 August 2020.

Rouget, M., Richardson D.M., Cowling R.M., Lloyd J.W., Lombard A.T. (2003). Current patterns of habitat transformation and future threats to biodiversity in terrestrial ecosystems of the Cape floristic region, South Africa. *Biological Conservation*. *112* 63–85.

Rull, V., Sampériz, G. P., Corella, J.P. *et al.* (2011).Vegetation changes in the southern Pyrenean flank during the last millennium in relation to climate and human activities: the Montcortès lacustrine record. *J Paleolimnol* 46, 387–404 https://doi.org/10.1007/s10933-010-9444-2

Ruwanza, S., & Thondhlana, G. (2022). People's perceptions and uses of invasive plant Psidium guajava in Vhembe Biosphere Reserve, Limpopo Province of South Africa. *Ecosystems and People*, *18*(1), 64-75.

Sala, O. E., Stuart Chapin, F. I. I. I., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., ... & Wall, D. H. (2000). Global biodiversity scenarios for the year 2100. *science*, *287*(5459), 1770-1774.

SAMABNC (South African Man and Biosphere National Committee). (2014). National report on the implementation of Madrid action plan. 26th Session UNESCO Man and Biosphere Programme ICC International Coordinating Council; Sweden; 2014 Jun 10–13. Pretoria: Department of Environmental Affairs.

Sánchez-Bayo, F. (2011). Impacts of agricultural pesticides on terrestrial ecosystems. *Ecological impacts of toxic chemicals*, *2011*, 63-87.

Sanderson, S. E., & Redford, K. H. (2003). Contested relationships between biodiversity conservation and poverty alleviation. *Oryx*, *37*(4), 389-390.

Sandström, V., Kauppi, P. E., Scherer, L., & Kastner, T. (2017). Linking country level food supply to global land and water use and biodiversity impacts: The case of Finland. *Science of the Total Environment*, *575*, 33-40.

Santos, A. R. (2021). *Ecosystem services and drivers of change in mangroves and seagrasses in Maputo Bay, Mozambique* (Doctoral dissertation).

Sarkar, S. K., & Bhattacharya, A. K. (2003). Conservation of biodiversity of the coastal resources of Sundarbans, Northeast India: an integrated approach through environmental education. *Marine pollution bulletin*, *47*(1-6), 260-264.

Sattar, Q., Maqbool, M. E., Ehsan, R., Akhtar, S., Sattar, Q., Maqbool, M. E., ... & Akhtar, S. (2021). Review on climate change and its effect on wildlife and ecosystem. *Open J Environ Biol*, *6*(1), 008-014.

Scheiter, S., Kumar, D., Corlett, R. T., Gaillard, C., Langan, L., Lapuz, R. S., ... & Tomlinson, K. W. (2020). Climate change promotes transitions to tall evergreen vegetation in tropical Asia. *Global Change Biology*, *26*(9), 5106-5124.

Scherr, S. J., & McNeely, J. A. (2008). Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'eco-agriculture' landscapes. Philosophical Transactions of the Royal Society B: *Biological Sciences*, *363*(1491), 477-494.

Scholes, R., & Engelbrecht, F. (2021). Climate impacts in southern Africa during the 21st Century. *Report for Earthjustice and the Centre for Envrionmental Rights. Global Change Instiute, University of Witwatersrand*.

Scholes, R.J., Mace, G.M., Turner, W., Geller, G.N, Jürgens, N., Larigauderie, A., Muchoney, D., Walther, B.A., Mooney, H.A. (2008). Toward a global biodiversity observing system. *Journal Science, 321* (5892), 1044-1045.

Schroth, G., da Fonseca, G. A., Harvey, C. A., Gascon, C., Vasconcelos, H. L., & Izac, A. M. N. (Eds.). (2004). *Agroforestry and biodiversity conservation in tropical landscapes*. Island press.

Schweiger, O., Biesmeijer, J. C., Bommarco, R., Hickler, T., Hulme, P. E., Klotz, S., ... & Settele, J. (2010). Multiple stressors on biotic interactions: how climate change and alien species interact to affect pollination. *Biological Reviews*, *85*(4), 777-795.

Secretariat of the Convention on Biological Diversity (CBD) (2020) Global Biodiversity Outlook 5. Montreal., https://www.cbd.int/gbo/gbo5/publication/gbo-5-en.pdf

Secretariat of the Convention on Biological Diversity. (2001). *Handbook of the convention on biological diversity*. Earthscan.

Seddon, N., Mace, G. M., Naeem, S., Tobias, J. A., Pigot, A. L., Cavanagh, R., ... & Walpole, M. (2016). Biodiversity in the Anthropocene: prospects and policy. *Proceedings of the Royal Society B: Biological Sciences*, *283*(1844), 20162094.

SEF (2016): Vhembe Biosphere Reserve Initial Strategic Environmental Management Plan (SEMP), Status Quo Report, SEF Report No. 506567, Prepared for the Vhembe Biosphere Reserve Committee by Strategic Environmental Focus.

Semenya, S. S., Tshisikhawe, P,. Potgieter, M.T. (2013). Invasive alien plant species: A case study of their use in the Thulamela Local Municipality, Limpopo Province, South Africa, *Scientific Research and Essays*, 7 (27), 2363-2369.

Sengupta, M. (2016). The sustainable development goals: An assessment of ambition. *E-International Relations*, *18*.

Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PloS one*, *6*(8), e23777.

Setshego, M.V., Aremu, A.O., Mooki, O. (2020). Natural resources used as folk cosmeceuticals among rural communities in Vhembe district municipality, Limpopo province, South Africa BMC Complementary Medicine and Therapies *20*, 81.

Shackleton, C, M., Pasquini, M.W., Drescher, A.W. (2009). *African indigenous vegetables in urban agriculture.* Earthscan, London. (p298) ISBN 978-18440-771-5-1

Shackleton, C. M., Shackleton, S. E., Buiten, E., Bird, N. (2007). The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. *Forest policy and economics*, *9* (5), 558-577.

Shackleton, C., Shackleton, S., Gambiza, J., Nel, E., Rowntree, K., Urquhart, P. (2008). Links between ecosystem services and poverty alleviation. *Situation analysis for arid and semi-arid lands in southern Africa*. Rhodes University, for Ecosystem Service and Poverty Reduction Research Programme: DFID, NERC, ESRC, https://aridareas.co.za/links-between-ecosystem-services-and-poverty-alleviation/. Accessed 08 August 2020. Southern Europe. Wageningen: Wageningen Academic Publishers.

Shackleton, R. T. (2020). Loss of land and livelihoods from mining operations: A case in the Limpopo Province, South Africa. *Land Use Policy*, *99*, 104825.

Sibiya, N., Sithole, M., Mudau, L., & Simatele, M. D. (2022). Empowering the Voiceless: Securing the Participation of Marginalised Groups in Climate Change Governance in South Africa. *Sustainability*, *14*(12), 7111.

Sidle, R. C., Benson, W. H., Carriger, J. F., & Kamai, T. (2013). Broader perspective on ecosystem sustainability: Consequences for decision making. *Proceedings of the National Academy of Sciences*, *110*(23), 9201-9208.

Sillitoe, P. (Ed.). (2017). *Indigenous knowledge: Enhancing its contribution to natural resources management*. CABI.

Sinclair, A. R., Mduma, S. A., & Arcese, P. (2002). Protected areas as biodiversity benchmarks for human impact: agriculture and the Serengeti avifauna. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *269*(1508), 2401-2405.

Singh, J. S., Singh, K. P., Agrawal, M. (1991). Environmental degradation of the Obra-Renukoot-Singrauli area, India, and its impact on natural and derived ecosystems. *Environmentalist*, *11*(3), 171-180.

Skowno, A. L., Jewitt, D., & Slingsby, J. A. (2021). Rates and patterns of habitat loss across South Africa's vegetation biomes. *South African Journal of Science*, *117*(1-2), 1-5.

Skowno, A. L., Poole, C. J., Raimondo, D. C., Sink, K. J., Van Deventer, H., Van Niekerk, L., ... & Driver, A. (2019). National biodiversity assessment 2018: the status of South Africa's ecosystems and biodiversity. *Synthesis Report. South African National Biodiversity Institute, Pretoria*, *201*.

Skowno, A.L, Poole, C.J, Raimondo, D.C, Sink, K.J, Van Deventer, H., Van Niekerk, L., *et al.*, (2018). National Biodiversity Assessment. The status of South Africa's ecosystems and biodiversity – synthesis report. Pretoria: South African National Biodiversity Institute. http://opus.sanbi.org/ handle/20.500.12143/6362.

Skowno, A.L., Jewitt., D, Slingsby, J.A. (2021). Rates and patterns of habitat loss across South Africa's vegetation biomes. South A Journal of Science. 117 (1/2). https://doi. org/10.17159/sajs.2021/8182

Sluiter, R. (2009). Interpolation methods for climate data. *KNMI* The Netherlands.

Smith, P., House, J. I., Bustamante, M., Sobocká, J., Harper, R., Pan, G., ... & Pugh, T. A. (2016). Global change pressures on soils from land use and management. *Global change biology*, *22*(3), 1008-1028.

Socolar, J. B., Gilroy, J. J., Kunin, W. E., & Edwards, D. P. (2016). How should beta-diversity inform biodiversity conservation?. *Trends in ecology & evolution*, *31*(1), 67-80.

Sodhi, N. S., & Brook, B. W. (2006). *Southeast Asian biodiversity in crisis*. Cambridge University Press.

Song, M., Cen, L., Zheng, Z., Fisher, R., Liang, X., Wang, Y., & Huisingh, D. (2017). How would big data support societal development and environmental sustainability? Insights and practices. *Journal of Cleaner Production*, *142*, 489-500.

Spake, R., Lasseur, R., Crouzat, E., Bullock, J. M., Lavorel, S., Parks, K. E., ... & Eigenbrod, F. (2017). Unpacking ecosystem service bundles: Towards predictive mapping of synergies and trade-offs between ecosystem services. *Global Environmental Change*, *47*, 37-50.

Spierenburg, M. (2020). Living on Other People's Land; Impacts of Farm Conversions to Game Farming on Farm Dwellers' Abilities to Access Land in the Eastern Cape, South Africa, Society & Natural Resources, (33): *2*, 280-299, DOI: 10.1080/08941920.2019.1584342

Stat SA, Census 2011 Municipal report – Limpopo (2012). Statistics South Africa, Pretoria http://www.statssa.gov.za/census/census_2011/census_products/LP_Municipal_Report.pdf

Stats, S. A. (2011). Statistics South Africa. *Formal census*.

Stepping, K. M., & Meijer, K. S. (2018). The challenges of assessing the effectiveness of biodiversity-related development aid. *Tropical Conservation Science*, *11*, 1940082918770995.

Stern, P.C., Young, O, R., Druckman, D., (Ed). 1992. Global Environmental Change: Understanding the Human Dimensions. Washington, DC: The National Academies Press.https://doi.org/10.17226/1792.

Streiner, D. L., & Cairney, J. (2007). What's under the ROC? An introduction to receiver operating characteristics curves. *The Canadian Journal of Psychiatry*, *52*(2), 121-128.

Sultan, R.M. (2016). The impacts of agricultural expansion and interest groups on deforestation: An optimal forest control model. *International Journal of Agricultural Resources, Governance and Ecology*". *12* (2), 137-154.

Swets, J.A., (1988) Measuring the accuracy of diagnostic systems. *Science* (240) 1285-1293.

Swift, M. J., Izac, A. M., & Van Noordwijk, M. (2004). Biodiversity and ecosystem services in agricultural landscapes are we asking the right questions? *Agriculture, ecosystems & environment*, *104*(1), 113-134.

Syrbe, R. U., & Walz, U. (2012). Spatial indicators for the assessment of ecosystem services: providing, benefiting and connecting areas and landscape metrics. *Ecological indicators*, *21*, 80-88.

Tan, X., Liu, B., & Tan, X. (2020). Global changes in baseflow under the impacts of changing climate and vegetation. *Water Resources Research*, *56*(9), e2020WR027349.

Terando, A., Reidmiller, D., Hostetler, S.W., Littell, J.S., Beard, T.D., Jr., Weiskopf, S.R., Belnap, J., Plumlee, G.S., (2020) Using information from global climate models to inform policymaking—The role of the U.S. Geological Survey: U.S. Geological Survey Open-File Report. 1058, 25 p., https://doi.org/10.3133/ofr20201058.

Thakur, B. K., Rout, H. S., & Chakraborty, T. (2014). Environmental degradation, sustainable development and human well-being: evidence from India. Manthan: *Journal of Commerce and Management*, *1*(1), 101-120.

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., ... & Williams, S. E. (2004). Extinction risk from climate change. *Nature*, *427*(6970), 145-148.

Thomas, D. S. G., Sporton, D., Perkins, J. (2000). Environmental impact of livestock ranches in the Kalahari, Botswana: Natural resource use, ecological change and human response in a dynamic dryland system. Land Degradation and Development, *11* (4), 327-341.

Thompson, M. (2019). 2013, 2014 vs 2018 South African National Land-Cover Change Assessments: Core Metadata Elements-SANS1878. https://www.geoterraimages.com/ Accessed 24 Oct 2020

Thuiller, W., Richardson, D. M., & Midgley, G. F. (2007). 12 Will Climate Change Promote Alien Plant Invasions?. *Ecological Studies, Vol. 193*, 197.

Tonin, S., & Lucaroni, G. (2017). Understanding social knowledge, attitudes and perceptions towards marine biodiversity: The case of tegnùe in Italy. *Ocean & coastal management*, *140*, 68-78.

Tran, P., & Shaw, R. (2007). Towards an integrated approach of disaster and environment management: A case study of Thua Thien Hue province, central Viet Nam. *Environmental Hazards*, *7*(4), 271-282.

Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I., Perfecto, I., ... & Whitbread, A. (2012). Global food security, biodiversity conservation and the future of agricultural intensification. *Biological conservation*, *151*(1), 53-59.

Turner, N. J., & Berkes, F. (2006). Coming to understanding developing conservation through incremental learning in the Pacific Northwest. *Human ecology*, *34*, 495-513.

Twine, W., Moshe, D., Netshiluvhi, T., Siphugu, V. (2003). Consumption and direct-use values of savannah bio-resources used by rural households in Mametja, a semi-arid area of Limpopo province, South Africa. *South African Journal of Science*, *99* (9), 467-473.

UNECA (2011) Minerals and Africa's development. United Nations Economic Commission for Africa (UNECA), Addis Ababa. https://www.uneca.org/publications/minerals-and-africas-development/ Accessed 12 February 2020

UNESCO 2017: Ecological Sciences for Sustainable Development:http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/africa/south-africa/vhembe/ Accessed 04 March 2020

United Nations Environment Programme. International Resource Panel, United Nations Environment Programme. Sustainable Consumption, & Production Branch. (2011). *Decoupling natural resource use and environmental impacts from economic growth*. UNEP/Earthprint.

Usman, M., Balsalobre-Lorente, D., Jahanger, A., & Ahmad, P. (2022). Pollution concern during globalization mode in financially resource-rich countries: do financial development, natural resources, and renewable energy consumption matter?. *Renewable Energy*, *183*, 90-102.

Uttara, S., Bhuvandas N., Aggarwal V. (2012). Impacts of urbanization on the environment. *International Journal of Research in Engineering and Applied Sciences*. *21* 637–1645.

Van Jaarsveld, A. S., Biggs, R., Scholes, R. J., Bohensky, E., Reyers, B., Lynam, T., ... & Fabricius, C. (2005). Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SA MA) experience. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1454), 425-441.

Van Weelie, D., & Wals, A. (2002). Making biodiversity meaningful through environmental education. *International Journal of science education*, *24*(11), 1143-1156.

Van Wyk, A.E., Smith, G, F. (2001) Regions of Floristic endemism in Southern Africa; a review with emphasis on succulents. Umdaus Press

Verma, A. K., Rout, P. R., Lee, E., Bhunia, P., Bae, J., Surampalli, R. Y., ... & Chen, Y. (2020). Biodiversity and sustainability. *Sustainability, Fundamentals and Applications*, 255-275.

von Maltitz, G.P., Shackleton, S.E. (2004). Use and management of forests and woodlands in South Africa: Stakeholders, institutions and processes from past to present. In: Indigenous forests and woodlands in South Africa, In: M. J. Lawes, H. A. C. Ealey, C. M. Shackleton, and B. G. S. Geach (Eds). *Policy, People and Practice* (pp.129-148). Scottsville, South Africa: University of KwaZulu-Natal Press.

Vuuren, D. V., Eickhout, B., Lucas, P. L., & Elzen, M. D. (2006). Long-term multi-gas scenarios to stabilise radiative forcing-exploring costs and benefits within an integrated assessment framework. *The energy journal*, *27*(3_suppl), 201-234.

Wagenmakers, E. J., & Farrell, S. (2004). AIC model selection using Akaike weights. *Psychonomic bulletin & review*, *11*, 192-196.

Waldron, A., Miller, D. C., Redding, D., Mooers, A., Kuhn, T. S., Nibbelink, N., ... & Gittleman, J. L. (2017). Reductions in global biodiversity loss predicted from conservation spending. *Nature*, *551*(7680), 364-367.

Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., ... & Pritchard, R. (2002). Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conservation ecology*, *6*(1).

Wang, B., Zhou, V., Wang, H,. et al., (2019). The p-value and model specification in statistics. *General Psychiatry*, (32), e100081. doi:10.1136/gpsych-2019-100081

Wang, L.H., Tian, F., Wang, Y.H., Wu, Z.D., Schurgers, G., Fensholt, R. (2018). Acceleration of global vegetation green-up from combined effects of climate change and human land management. *Global Change Biology*, (24) 5484–5499.

Wang, S.J., Ma, H.T., Zhao, Y.B. (2014). Exploring the relationship between urbanization and the eco-environment A case study of Beijing-Tianjin-Hebei region. *Ecological Indicators* (45) 171–183. www.SoilGrids.org

Wang, Y., & Liu, Q. (2006). Comparison of Akaike information criterion (AIC) and Bayesian information criterion (BIC) in selection of stock–recruitment relationships. *Fisheries Research*, *77*(2), 220-225.

Ward, E. J. (2008). A review and comparison of four commonly used Bayesian and maximum likelihood model selection tools. *Ecological Modelling*, *211*(1-2), 1-10.

Warren, R., VanDerWal, J., Price, J., Welbergen, J. A. (2013). Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. *Nature Climate Change, 3* (7): 678-682.

Wasserstein, R.L, Lazar NA. (2016). The ASA's Statement on p -Values: Context, Process, and Purpose. *American Statistician*, 70 (2), 129 – 133, DOI:10.1080/00031305.2016.1154108

Wasserstein, R.L, Lazar NA. (2016). The ASA's Statement on p -Values: Context, Process, and Purpose. *American Statistician*, 70 (2), 129 – 133, DOI:10.1080/00031305.2016.1154108

Waterhouse, J. B., & Shi, G. R. (2013). Climatic implications from the sequential changes in diversity and biogeographic affinities for brachiopods and bivalves in the Permian of eastern Australia and New Zealand. *Gondwana Research*, *24*(1), 139-147.

Weldeslassie, T., Naz, H., Singh, B., & Oves, M. (2018). Chemical contaminants for soil, air and aquatic ecosystem. *Modern age environmental problems and their remediation*, 1-22.

Werner, C., Schmid, M., Ehlers, T. A., Fuentes-Espoz, J. P., Steinkamp, J., Forrest, M., ... & Hickler, T. (2018). Effect of changing vegetation and precipitation on denudation–

Part 1: Predicted vegetation composition and cover over the last 21 thousand years along the Coastal Cordillera of Chile. *Earth Surface Dynamics*, *6*(4), 829-858.

Werner, M. (2001). Shuttle Radar Topography Mission (SRTM) Mission Overview. Frequenz - Journal of Telecommunications. 55. 75-79. 10.1515/FREQ.2001.55.3-4.75.

Wessels, K.J., Colgan, M.S., Erasmus, B.F.N., Asner, G.P., Twine, W.C., Mathies, R., et al., (2013). Unsustainable fuelwood extraction from South African Savannas. Environmental Research Letters (8) 1 014007

Wiedmann, T., & Lenzen, M. (2018). Environmental and social footprints of international trade. *Nature Geoscience*, *11*(5), 314-321.

Wigley, B. J., Bond, W. J., & Hoffman, M. T. (2010). Thicket expansion in a South African savanna under divergent land use: local vs. global drivers?. *Global Change Biology*, *16*(3), 964-976.

Williams, B. K. (2011). Adaptive management of natural resources framework and issues. *Journal of environmental management*, *92*(5), 1346-1353.

Willis, K. J., Araujo, M. B., Bennett, K. D., Figueroa-Rangel, B., Froyd, C. A., & Myers, N. (2007). How can a knowledge of the past help to conserve the future? Biodiversity conservation and the relevance of long-term ecological studies. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*(1478), 175-187.

Wilson, G.A. Juntti, M. (2005). Unravelling desertification: policies and actor networks in Southern Europe. (Eds). Wageningen Press, (pp 245) EU 49, ISBN 90-86998-42-46.

Wilson, M. C., Chen, X. Y., Corlett, R. T., Didham, R. K., Ding, P., Holt, R. D., ... & Yu, M. (2016). Habitat fragmentation and biodiversity conservation: key findings and future challenges. *Landscape Ecology*, *31*, 219-227.

Wood, A., Stedman-Edwards, P., & Mang, J. (2000). *The Root Causes of Biodiversity Loss* (1st ed.). Routledge. https://doi.org/10.4324/9781315071688

Wood, E.C., Tappan, G.G., Hadj, A. (2004). Understanding the drivers of agricultural land use change in central Senegal. *Journal of Arid Environments 59* 565–582.

Wu, J., Guo, Y., & Zhou, J. (2020). Nexus between ecological conservation and socio-economic development and its dynamics: Insights from a case in China. *Water*, *12*(3), 663.

WWF (2020) Living Planet Report 2020 - Bending the curve of biodiversity loss. Almond, R.E.A., Grooten M. and Petersen, T. (Eds). WWF, Gland, Switzerland;

Wynberg, R. (2002). Institutional responses to benefit-sharing in South Africa. In Biodiversity and Traditional Knowledge: In: S.A. Laird, (Eds). *Equitable Partnerships*

Practice, (pp. 60–70), WWF/UNESCO/Kew People and Plants Conservation Manual. Earthscan, London.

Xu, J., & Wilkes, A. (2004). Biodiversity impact analysis in northwest Yunnan, southwest China. *Biodiversity & Conservation*, *13*, 959-983.

Xue, Z., & Ding, G. (2023). Evaluation of ecosystem services from 2000 to 2020 and their trade-offs/synergies in a coalfield: a case study in the Pingshuo mining area of the Loess Plateau, China. *Environmental Science and Pollution Research*, *30*(13), 36680-36691.

Yamaura, Y., Amano, T., Kusumoto, Y., Nagata, H., Okabe, K. (2011). Climate and topography drive macroscale biodiversity through a land-use change in a human-dominated world. *Oikos,* (120) 427–451.

Yan H, Y., Nix, H. A., Hutchinson, M. F., Booth, T. H., (2005). Spatial interpolation of monthly mean climate data for China. *International Journal of Climatology*, (25), 1369 – 1279. DOI: 10.1002/joc.1187

Yang, G. H, Bao, A. M, Chen, X., et al. (2010). Vegetation cover change with climate and land use variation along main stream of Tarim River. Journal of Desert Research, 30(6): 1389–1397.

Yinbing, Z., Ranhao S., Zhongyun., N. (2019). Identification of Natural and Anthropogenic Drivers of Vegetation Change in the Beijing-Tianjin-Hebei Megacity Region *Remote Sensing*, (11), 12-24; doi:10.3390/rs11101224

Young, J. C., Marzano, M., White, R. M., McCracken, D. I., Redpath, S. M., Carss, D. N., ... & Watt, A. D. (2010). The emergence of biodiversity conflicts from biodiversity impacts: characteristics and management strategies. *Biodiversity and Conservation*, *19*, 3973-3990.

Yunfeng H., Dao, R., Yang, H., (2019). Vegetation Change and Driving Factors: Contribution Analysis in the Loess Plateau of China during 2000–2015. *Sustainability*, (11), 1320; doi:10.3390/su11051320.

Zellweger, F., Baltensweiler, A., Ginzler, C., Roth, T., Braunisch, V., Bugmann, H., & Bollmann, K. (2016). Environmental predictors of species richness in forest landscapes: abiotic factors versus vegetation structure. *Journal of Biogeography*, *43*(6), 1080-1090.

Zhang, B. Y., Yu, Z. Z., Liu, L. Y., et al. (2008). Study on the vegetation coverage changes monitoring of Beijing city by remote sensing. *Areal Research and Development*, 27(1): 108–112.

Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., & Swinton, S. M. (2007). Ecosystem services and dis-services to agriculture. *Ecological economics*, *64*(2), 253-260.

Zhang, Y., Song, C., Band, L.E., Ge, S., Li, J. (2017). Reanalysis of global terrestrial vegetation trends from MODIS products: Browning or greening?. *Remote Sensing of Environment*, (191), 145–155.

Zhang, Z., Qiang, H., McHugh, A. D., He, J., Li, H., Wang, Q., & Lu, Z. (2016). Effect of conservation farming practices on soil organic matter and stratification in a mono-cropping system of Northern China. *Soil and Tillage Research*, *156*, 173-181.

Zhao, J., & Tang, J. (2018). Understanding agricultural growth in China: An international perspective. *Structural Change and Economic Dynamics*, *46*, 43-51.

Zhao, L., Dai, A.G., Dong, B. (2018). Changes in global vegetation activity and its driving factors during 1982–2013. *Agriculture and Forest Meteorology,* (249), 198–209.

Zhou, K.H., O'Malley, A. J., Mauri, L. (2007). Receiver-Operating Characteristics Analysis for Evaluating Diagnostic Tests and Predictive Models. *Circulation*, 115: 654-657 https://doi.org/10.1161/CIRCULATIONAHA.105.594929