Land Degradation and Its Impacts on Ecosystem Services in the Nigerian Guinea Savannah: Implications for Sustainable Land Management

Inaugural dissertation of the Faculty of Science

University of Bern

Presented by

Ademola Andrew Adenle

from Nigeria

Supervisor of the Doctoral Thesis:

Prof. Dr. Chinwe Ifejika Speranza
Dr. Sébastien Boillat
Dr. Sandra Eckert

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Summary

Land degradation is a major environmental concern. Globally, land degradation directly impacts about 1.5 to 3.2 billion people by affecting water and nutrient cycles, reducing food and biomass production, and adversely affecting livelihoods that are dependent on land and natural resources. Land degradation, its drivers, and its impacts manifest differently depending on the social and ecological contexts. Thus, attention to the context in analysing land degradation and its proximate and underlying causes will yield insights to foster sustainable land management (SLM). Although land degradation has been implicated in various environmental and development challenges in Africa, knowledge about land degradation in some regions remains inadequate to support the identification of SLM practices.

The Guinea savannah zone in Nigeria is one such region, facing widespread and severe land degradation. The region has lost much of its native vegetation due to the combined effects of land degradation, deforestation, and land use changes. Land degradation has been associated with farmer–herder conflicts, communal clashes, out-migration, and food insecurity. These impacts are likely to worsen as climate change progresses and in the absence of SLM.

Thus, the overarching aim of this study is to improve understanding of the spatial distribution of land degradation in the Nigerian Guinea Savannah (NGS) and its drivers and thus derive insights into the sustainable management of its land resources. The insights will also help inform pathways to achieving land degradation neutrality (LDN), a global environmental goal. Its objectives are to (1) assess human-induced biomass loss as a proxy for land degradation in the NGS; (2) identify characteristic patterns of social and ecological factors associated with land degradation in the region and analyse their implications for land governance and SLM; (3) examine land users' perceptions of land degradation and its implications for SLM, using Niger state as a case study; and (4) examine the potentials for operationalizing LDN in Nigeria. These four objectives were addressed in four studies. The research questions were investigated with a mixed-methods approach combining satellite remote sensing data and analysis and geographic information systems (GIS) with field surveys, focus group discussions, key informant interviews, and a review of environmental policies in Nigeria.

Results from assessing human-induced biomass loss, as a proxy for land degradation (Study 1) showed a declining trend in annual mean normalized difference vegetation index (NDVI) and annual NDVI anomalies observed in the NGS between 2003 and 2018. The indices were from the Moderate Resolution Imaging Spectroradiometer (MODIS). Overall, the study revealed that 38% (251K km^2) of the NGS experienced degradation, 14% (91K km^2) experienced improvement, and the remaining 48% (320K km^2) was stable. Land degradation is mostly evident in states bordering the northwest to the central and northeast of the NGS, such as Niger state. These results show that land degradation affects a substantial part of the study area.

Thus, identifying characteristic patterns of social and ecological factors associated with land degradation in the region and analysing their implications for land governance and SLM (Study 2) provided further insights. The archetype analysis identified nine archetypes dominated by (1) protected areas; (2) very high-density population; (3) moderately high information and knowledge access; (4) low literacy levels and moderately high poverty levels; (5) rural remoteness; (6) remoteness from a major road; (7) very high livestock density; (8) moderate poverty level and nearly level terrain; and (9) very rugged terrain remote from a major road. Among these archetypes, four archetypes characterized by very high-density population, moderately high information and knowledge access, and moderately high poverty level, as well as remoteness from a major town, were associated with 61.3% large-area degradation. The other five archetypes, covering 38.7% of the area, were associated with small-area degradation.

Although the MODIS satellite analysis (Study 1) and the archetype analysis of spatial data on land degradation drivers, hint at the different types of land use and management including the ecological aspects of land degradation (Study 2), Study 3 examines the perspectives of land users on land degradation. A questionnaire survey was used to capture local land users' perceptions of land degradation. The assessment of local land users' perceptions of land degradation in predominantly rural remote farming communities was necessary to provide insights to further guide land governance and management. Thus, focused on the rural remote archetypes and its analysed communities far from major towns but with a moderately low prevalence of land degradation drivers such as population density, protected areas, and flat terrain. Using a case study on Niger state, an administrative unit in the NGS and a Principal Component Analysis, Study 3 identified key components in land users' perceptions of land degradation characteristics and drivers and SLM. They include (1) four perception dimensions of land degradation characteristics: (2) two perception dimensions of land degradation drivers, and (3) six perception dimensions of sustainable land management. The four major dimensions of perceptions of land degradation in the study context include vegetation-condition-dominated characteristics, soil-condition-dominated characteristics, and vegetation with Sudano-Sahelian characteristics as well as land use land cover (LULC) with the prevalence of drier conditions. The two categories of land degradation drivers are human-activity-dominated drivers at a smaller scale and nature-dominated drivers at a larger scale. The two categories of land degradation drivers are human activities dominated drivers at a smaller scale and larger-scale drivers (nature-driven). The dimensions of SLM identified include institutional actors' effect; natural resources management and environmentally friendly agricultural practices as well as tree-based initiatives; conservation initiatives and policy initiatives. The study showed that land degradation in Niger State is due to land use pressure from within the state and from migrant resource users with limited cultural attachments to local land management approaches. A spatial differentiation in dependence on natural resources showed that of the three geopolitical zones in Niger State, the zone with more diversified livelihood alternatives from agriculture, B, has less degradation than the other two zones, A and C.

The archetypes approach (Study 2) identified policies and practices addressing increasing population in combination with other socio-economic factors such as poverty reduction as important. Other strategies include creating awareness about land degradation, the promotion of sustainable practices, and various forms of land restoration, such as tree planting, as ways of progressing towards LDN. In addition, Study 3 on key dimensions based on land users' perceptions identified environmentally friendly agriculture initiatives such as farmer-managed natural regeneration and a bottom-up approach involving traditional village heads to tackle land degradation. Ranking of SLM using the relative importance index (RII) (Study 3) showed that land users perceive institutional actors (70.0%), technological practices (67.6%), conservation practices (66.8%), and policy initiatives (66.5%) as effective SLM.

Connecting the insights from the three previous studies on land degradation in the NGS, Study 4 examined ways to operationalize LDN in Nigeria. Study 4 reviewed literature, assessed spatial datasets, and analysed national policies to examine the need to contextualize LDN according to the main agro-ecological zones in Nigeria, which include the NGS. The study also identified two promising entry points for operationalizing LDN; these are incentivizing and promoting SLM practices among local resource users and mainstreaming SLM initiatives in sectors such as

agriculture and the environment. To support SLM measures, reform of national land use policy is needed to address the current limitations of land tenure in Nigeria.

In conclusion, this study has identified large areas of the NGS affected by land degradation and identified the typologies of degradation extent, thus making it easier to target SLM measures. Because land degradation depends on land users' perceptions and contexts, knowledge gained can inform approaches to motivate the land users themselves to address land degradation. Insights gained from the focus on the NGS have informed contributions to examine how changes in land use affect biodiversity and ecosystem services in the Río de la Plata grasslands (RPG), one of the most modified savannah biomes in the world, managed by Argentina, Brazil, and Uruguay. Results showed that a strict regulation of LULC change in the RGP is required to address land degradation. Studies in both contexts thus show the importance of appropriate policies to support SLM. These studies also highlight further research questions, such as what the key socio and economic determinants shaping land users' perceptions of land degradation are and how land users prioritize ecosystem services, as additional pathways to align SLM practices to the social and ecological context.

Keywords: Archetypes, Land degradation, Savannah, Sustainable Land Management, Nigeria.

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Preface

This PhD thesis was conducted at the Institute of Geography at the University of Bern. This thesis was supported by scholarship funding from the UniBE International 2021 initiative of the Vice-Rectorate Development, University of Bern, Switzerland, and a small grant from the Rufford Foundation, United Kingdom, I.D. 27153-1. This study aims to provide knowledge on how to address land degradation through sustainable land management in Nigeria, which is one of the targets of the Sustainable Development Goal 15. The research outputs are to serve as strategic insights into sectoral implementation in Nigeria within the framework of national sustainable development plans and actions.

The thesis content stems from my research findings, which I produced as first author of three peer-reviewed research papers and as co-author of two other articles. This research synthesis is arranged into three main parts, with each chapter detailing the distinct and unifying themes relating to the research topic specified in the title 'Land Degradation and Its Impacts on Ecosystem Services in the Nigerian Guinea Savannah: Implications Sustainable Land Management'. The overview introduces the main topic, a description of the methodology, an outline of the key insights and discussions, synthesis, and the conclusions and recommendations. The annexed section comprises the required declaration of consent and my curriculum vitae.

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List of Abbreviations

CILSS	Comité Permanent Inter Etats de lutte contre la Sécheresse dans le Sahel
FCT	Federal Capital Territory
FMNR	farmer-managed natural regeneration
GDP	gross domestic product
IPCC	Intergovernmental Panel on Climate Change
LGAs	local government areas
LD	land degradation
LDN	land degradation neutrality
LDNW	land degradation neutral world
LUA	Land Use Act
LULC	land use land cover
LCC	land cover change
MEA	Millennium Ecosystem Assessment
MODIS	Moderate Resolution Imaging Spectroradiometer
NBSAP	National Biodiversity Strategies and Action Plan
NDVI	normalized difference vegetation index
NGS	Nigerian Guinea Savannah
NGSA	Nigerian Guinea Savannah archetypes
UN	United Nations
UNCBD	United Nations Convention on Biological Diversity
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
NTFPs	nontimber forest products
RESTREND	residual trend analysis
RII	relative importance index
RPG	Río de la Plata grasslands
SDGs	Sustainable Development Goals
SESs	Social and ecological systems
SLM	sustainable land management

SOM	self-organizing map
SSA	Sub-Saharan Africa
TAMSAT	Tropical Applications of Meteorology using SATellite data
WOCAT	World Overview on Conservation Approaches and Technologies

Chapter 1

1.0 Introduction

1.1 Background

Land degradation manifests in a reduction or loss in the capacity or quality of land resources to provide ecosystem services (UNCCD, 2016b). It affects about 1.5 to 3.2 billion people, with estimates of the spatial distribution of degraded land varying from less than 1 billion Ha to over 6 billion Ha (Earthscan, 2011; Gibbs & Salmon, 2015)**.** Affected regions include Africa, Central Asia, and Latin America; (Cherlet et al., 2018; Gibbs & Salmon, 2015). Currently, about 5% of the reduction in total global net primary productivity is attributed to land degradation, and 8% of global losses in soil organic carbon, which indicates healthy soil, are linked to activities involving land conversion and unsustainable land management practices (Enang et al., 2017; Matano et al., 2015). The estimated ecosystem service deficit due to land degradation is between USD 6.3 and 10.6 trillion annually, ranging from 10% to 17% of the world's gross domestic product (GDP) (Cherlet et al., 2018; ELD Initiative & UNEP, 2015). Land degradation thus has social, economic, and environmental impacts that affect global governance of sustainability issues (Cherlet et al., 2018; Olsson, et al., 2019)**.**

Land degradation is a challenge of foremost concern due to its complex nature and the many forms it can take (Kust et al., 2017; Olsson, et al., 2019). Land degradation affects vegetation quality and soil fertility and causes changes in land use and land cover (Kust et al., 2017). It thus threatens the livelihoods of millions, triggers global food insecurity, hunger, and higher food prices, and drives environmental hazards caused by the reduction and loss of biodiversity and ecosystem services (Nkonya, Mirzabaev, et al., 2016; Olsson, et al., 2019). Similar to climate change, whose impacts transcend countries, large-scale land degradation cannot be resolved by a single country or region acting alone due to its transnational impacts (Gibbs & Salmon, 2015; Nkonya, Johnson, et al., 2016). Thus, combating land degradation and attaining land degradation neutrality (LDN) remain key goals in global environmental conventions (Cowie et al., 2018; Kust et al., 2017)

Reducing land degradation remains a major goal in Africa, where 83% of livelihoods are tied to land-based primary extractive and agricultural activities (Liniger et al., 2019; Nkonya, Johnson, et al., 2016). About 40% of Africa's total landmass, and in some countries, over 65% of their landmass, are degraded, thus reducing income and food security (ELD Initiative & UNEP, 2015;

Igbatayo, 2018; Tully et al., 2015) and resilience against natural hazards such as climate change (Akhtar-Schuster et al., 2017; Chasek et al., 2015).

In Sub-Saharan Africa (SSA), a consistent decline in agricultural yield prevails (Schlenker & Lobell, 2010) despite efforts to increase agricultural output. For instance, in 2014, the average cereal production for Africa was 1.5 ton/ha while the global average was 3.6 ton/ha (Zhou, 2016). Declining agricultural productivity and other ecological crises are vital signs of land degradation in Africa (Pingali et al., 2014; Tully et al., 2015). Although efforts and debate continue on how to increase Africa's productivity, the downside is that the growth in African agriculture has largely been through the conversion of other land use to agriculture (Akinyemi & Ifejika Speranza, 2022). The low agricultural productivity prevalent in Africa has been associated with poor soil management practices (Zingore et al., 2015). Therefore, addressing land degradation remains critical (Cherlet et al., 2018; Igbatayo, 2018).

The Sustainable Development Goals (SDGs) provide a timely opportunity to respond to threats confronting human wellbeing and the environment (Costanza et al., 2016). Nigeria, as a member of the United Nations (UN) framework, is compelled to put in place mechanisms for addressing land degradation as part of its SDG commitments. With research into sustainable land management (SLM) as a response to land degradation (Giger et al., 2018; Liniger et al., 2019), identifying essential policy reforms will yield options to strengthen the implementation of the SDGs (Costanza et al., 2016). Goal 15, 'Life on Land', in particular acknowledges the need to 'protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss' to achieve sustainable development (UN, 2015; UNCCD, 2016b). Achieving the SDGs requires up-to-date reliable information and research that support the monitoring and characterization of land conditions at all scales (Cowie et al., 2018; UNCCD, 2016b). Therefore, to successfully implement SLM in regions threatened with land degradation while taking steps to achieve LDN, shared knowledge is critical (Liniger et al., 2019; Studer et al., 2016). Although many African countries are vulnerable to the impacts of land degradation and climate change (Igbatayo, 2018; Mbow, 2020), little research has been done to operationalize SDG 15 and LDN, including the adoption and assessment of SLM (Kust et al., 2017; Liniger et al., 2019). Studies have shown that global investments and efforts at poverty alleviation, food, water and energy security, human health, migration, conflict, and biodiversity loss will yield more progress if land degradation is halted(Mbow, 2020; Scholes et al., 2018; UNCCD, 2019). According to the World Overview on Conservation Approaches and Technologies (WOCAT), implementing SLM in Africa has more potential to halt land degradation than the cost of not taking action against land degradation (Liniger et al., 2019; Studer et al., 2016).

1.2 Scientific gaps in studies of land degradation in the Nigerian Guinea Savannah

The Nigeria Guinea savannah (NGS) occupies 49% of the country's landmass and is a major crop and livestock production region. However, land degradation has reduced the capacity of this savannah ecosystem to provide ecosystem services (ES) and goods such as food, nontimber forest products, and fodder (Arowolo et al., 2018; Zhang et al., 2016). Various social and ecological drivers such as fire, topography, grazing, and farming activities interact to shape its productivity (Arowolo & Deng, 2018; Osunmadewa et al., 2018). Given the dependence of livelihoods on its land resources, the reduction and loss of ecosystem services further impoverish the land users (Arowolo et al., 2018; Zhang et al., 2016).

Several studies have implicated both human activities and rainfall variability as causes of land degradation (Macaulay, 2014; Olsson, et al., 2019), but no consistent account is available of the spatiotemporal, long-term trend of land degradation caused by human activities and rainfall variability in Nigeria. Similarly, baseline information on current land use or and projections of future land use and potential insights for addressing land degradation through SLM are still lacking. The few studies conducted are carried out at a very coarse resolution that provides too little detail to identify responses to land degradation (Gibbs & Salmon, 2015; Ibrahim et al., 2015).

In addition, archetypes that can highlight the constellation and interplay of land degradation drivers and thus guide an integrative response to land degradation are poorly researched and understood (Lohmann et al., 2012; Sietz et al., 2017). Archetype analysis identifies recurrent patterns among cases where general similarity or resemblance cannot be expected (Eisenack et al., 2019). To promote decisive action to address land degradation, understanding the archetypical pattern of degradation drivers is essential. An archetype analysis can involve a geospatial clustering technique that produces a two-dimensional map of factors. Archetype research has been adopted by the United Nations Environment Programme (UNEP, 2007) Global Environmental Outlook 4, to examine issues such as agro-food systems (Sietz et al., 2012), institutional analysis, climate change (Sietz et al., 2012), ecosystem services (Dittrich et al., 2017), and water resources (Oberlack & Eisenack, 2018). Therefore, contextualization archetypes of land degradation types and drivers in the NGS offer the potential to improve understanding of its causes.

Further, perceptual experiences of land degradation, ecosystem services, and SLM in the NGS have not been well understood. Conflicts among various resource users such as farmers and herders in the NGS (Fasona et al., 2016; Majekodunmi et al., 2014; Olagunju et al., 2021) will also be minimized if land degradation, SLM, and land governance are better understood (Ifejika Speranza et al., 2019; Mrabure & Awhefeada, 2020). Capturing local knowledge through community and land users' perspectives of land degradation to better connect science and policy with local practice is grossly neglected (Crossland et al., 2018; Mortimore, 2016). Thus, participatory integration of land users' knowledge is needed to better target SLM responses
(Mashi & Shuaibu, 2018; Mortimore, 2016).

1.3 Aim and Objectives

1.3.1 Aim

The main aim of this thesis is to improve understanding of land degradation in the Nigerian Guinea Savannah and to provide insights on sustainable management of its land resources.

1.3.2 Objectives

This thesis therefore pursues the following objectives and sub objectives:

1) Assess human-induced biomass loss in the NGS at a medium resolution spatial scale between the years 2003 and 2018 as a proxy for land degradation (Study 1/Paper 1);

(a) provide empirical insights into current vegetation status and trends from the analysis of medium resolution satellite data;
(b) control for climate variability, in particular, change in rainfall, which is generally considered strongly correlated with vegetation, thereby separating rainfall changes from other factors affecting increasing degradation of the savannah; and
(c) characterize the extent, severity, and location of human-induced degradation across the NGS and identify degradation hotspots.

2) Identify characteristic patterns of social-ecological factors associated with land degradation in the NGS and the implications for land governance and SLM in the region (Study 2/Paper 2);

(a) categorize and link archetypes according to state administrative boundaries and land degradation status;
(b) characterize the archetypes in terms of large- and small-area degradation; and
(c) draw policy and SLM conclusions insights from archetypes patterns.

3) Examine land users' perceptions of land degradation and implications for SLM in Niger state, Nigeria (Study 3/Paper 3);

(a) examine the land degradation situations in the three geopolitical zones, namely zones A, B, and C, of Niger state;
(b) assess land users' perceptions of the distinctive characteristics and indicators of land degradation in Niger state;
(c) examine how land users perceive the drivers of land degradation in the NGS; and
(d) examine land users' preferences for specific SLM practices and strategies to address land degradation.

4) Contribute insights for operationalizing LDN in Nigeria (Study 4/Paper 4);

(a) assess the status of LDN indicators in relation to land governance across Nigeria.
(b) examine the current land management and governance environment in Nigeria; and
(c) investigate the level of engagement of Nigeria's land management and governance policies with LDN.

Chapter 2

2.0 Methodology

This chapter deals with the study context, scientific concepts, framework, and analytical approaches for achieving the aim and objectives of the study. The approaches are mostly from the fields of land degradation, SLM, ecosystem studies, and remote sensing applications.

2.1 Context

2.1.1 Study area

The study area (Fig. 1), the NGS, lies between 6.50°N and 9.62°N, 2.7°E and 13.20°E, is bordered by the rainforest in the south and the Sudan Savannah in the north (Iloeje, 2001). Agro-ecologically, the NGS is in a zone with favourable ecological and climatic conditions of mean annual rainfall of 782–1250 mm and a mean temperature of about 27.7ºC (FGN, 2003, 2014). In Nigeria, the subnational administrative units are called states, and the geographical area covered by states in this zone is regarded as the 'middle belt' of the country. It is the largest agro-ecological zone in the country, covering about 49% of the country's landmass and 25 of its 36 states (NBSAP, 2015). The belt is traditionally divided into two regions, the Northern and Southern Guinea Savannah, due to differences in vegetation composition (Wakawa et al., 2016). In the southern region, the vegetation is characterized by a mix of trees and tall grasses, with shorter grasses and fewer trees in the north (FGN, 2003; Wakawa et al., 2016). Common trees include the Shea butter tree (*Vitellaria paradoxa).* It is a crucial habitat for threatened fauna, such as chimpanzees (*Pan troglodytes*), and flora, such as bear's creeper family (*Acanthaceae)* (Borokini, 2014). A distinct montane vegetation characterizes the central and eastern regions of the NGS (Iloeje, 2001).

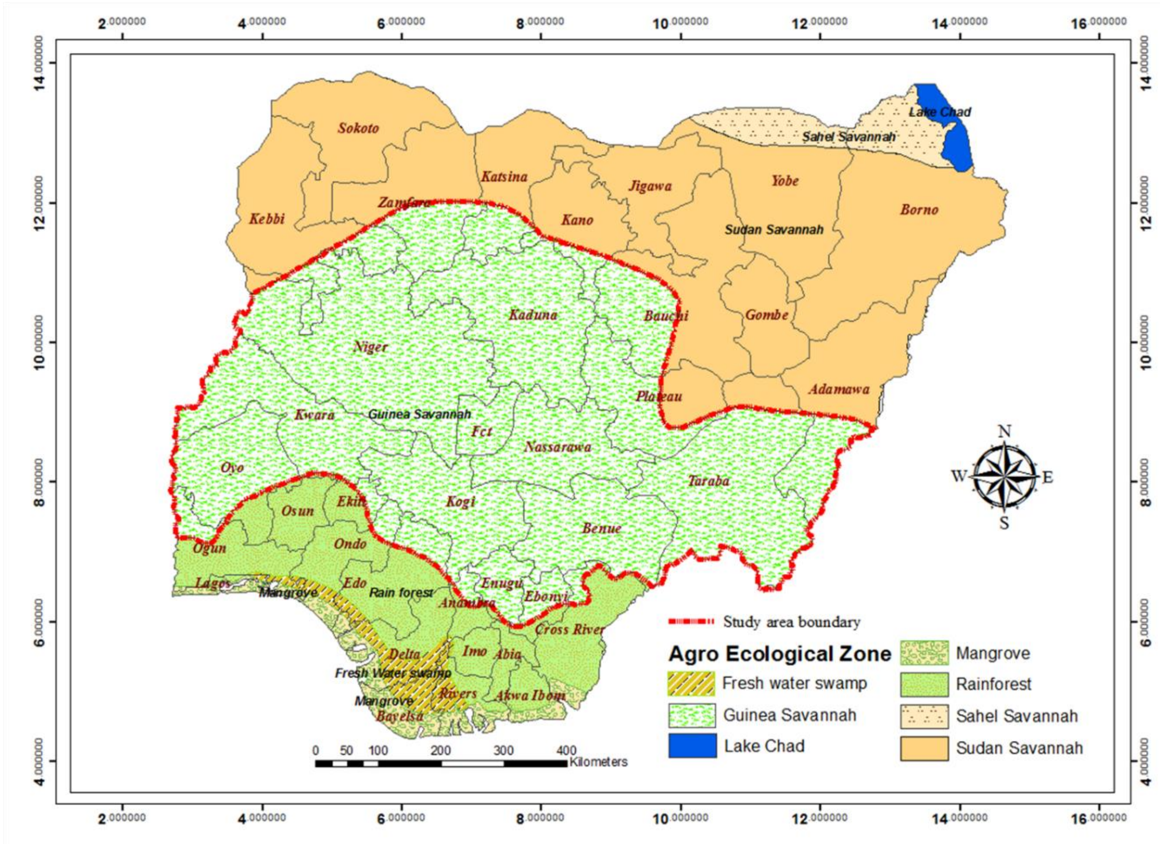

Fig.1: Agro-ecological zones of Nigeria, with the boundary of NGS (adapted from Iloeje, 2001).

The NGS encompasses the stretches of the two major rivers, the Niger and the Benue, their basins, and their confluence. The location of the two major national hydropower stations at Kainji and Shiroro have been determined by the location of these two rivers in the zone. Several protected areas are also located in the NGS, such as the Foge Islands and Kainji Lake National Park, which are designated wetland sites under the Ramsar Convention(Ayanlade & Proske, 2016). This fertile region is known as a major food basket of the country, with most production of crops such as yam being rain-fed. The NGS also provides grazing resources for livestock, of which a large proportion belongs to transhumance systems involving seasonal nomadism. Its inhabitants belong to diverse ethnic and religious groups (FGN, 2003). Various major towns and urban centres are in the NGS, including Abuja, the capital of Nigeria. With population growth and heavy dependence on natural resources, maintaining land quality is increasingly challenging, and conflicts over access to and control of land often occur (Alhaji et al., 2018; Fasona et al., 2016).

To assess perceptions of land degradation (Fig 3 and 4), I carried out fieldwork in Niger state (Fig. 2). Niger state is located within the NGS, between 8.02˚N and 10.20˚N and 3.38˚E and 7.03˚E (Fig.

2). It is in the north-central part of Nigeria and is the largest of the 36 states, covering 9.3% of the country's landmass. Niger state shares an international boundary with the Republic of Benin on its western border around Borgu Local Government Area (LGA) and subnational boundaries with Kaduna, Kebbi, Abuja, Kwara, and Kogi states.

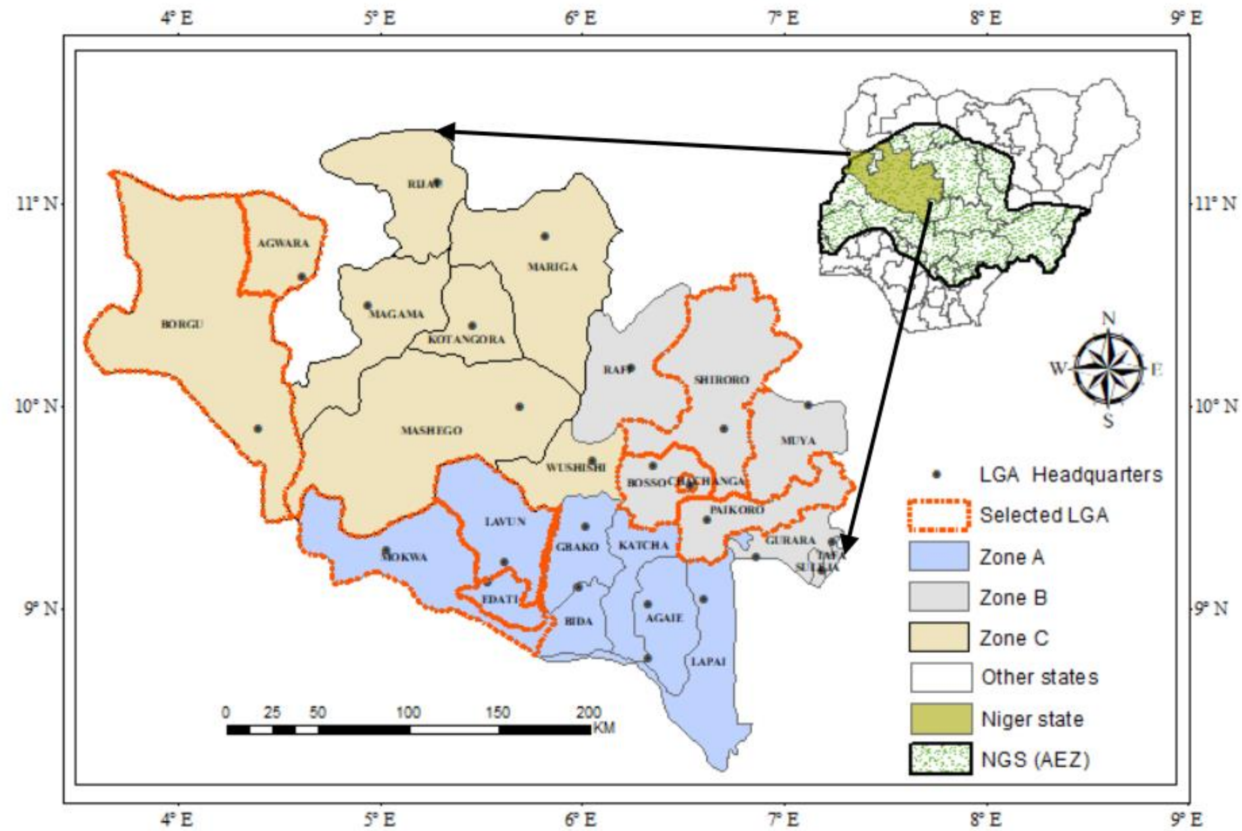

Fig. 2: Map of Niger State, showing the three geopolitical zones with the selected LGAs

With a total of 25 LGAs and its administrative capital in Minna (Fig. 2), Niger state is divided into three geopolitical zones, named A, B, and C, which also represent the agricultural zones for agricultural development purposes with headquarters in Bida, Kuta, and Kontagora, respectively (Alhaji et al., 2018). The state had 5,550,000 inhabitants in 2016 (NBC, 2017) comprising mostly rural dwellers who engage in farming, with extensive cultivation of maize, rice, yam, and groundnuts for both export and domestic consumption (Iloeje, 2001), and livestock such as cattle, goats, sheep, poultry, and guinea fowl for meat production (Alhaji et al., 2018). The State has diverse ethnic groups including the Nupes', who are the majority, the Gwaris', the Kambaris', the Bisasan, and the nomadic Fulani pastoralists (Alhaji et al., 2018). Apart from the state capital Minna and major towns such as Suleja and Bida, most settlements are remote villages inhabited by poor subsistence farmers.

Fig.3a: Degradation in Lavun Niger state

Fig.3b: Degraded savannah land in Agwara

(Source: Own fieldwork, 2019)

Fig.4a: Savannah in Boss LGA, zone B

Fig.4b: Assessing degradation of Savannah in Niger state

(Source: Own fieldwork, 2019)

2.2 Concepts and framework

2.2.1 Social and Ecological System and Land degradation

A social and ecological system (SES) is 'an integrated complex system that includes social (human) and ecological (biophysical) subsystems in a two-way feedback relationship' (Berkes, 2011). This research concept has become prominent in understanding changes and dynamics of coupled systems over space and time because it captures the interconnectedness and relationships between society and ecosystems (Fisher & Rucki, 2017). SES thinking was developed from general systems theory (Checkland, 1981) and applied to ecology (Biesbroek et al., 2017; Gunderson & Holling, 2002) before being extended to focus on both social and ecological factors (Berkes & Folke, 2002; McGinnis & Ostrom, 2014). In this study, land degradation as a social-ecological case focuses on the human–nature interactions in the NGS (Okpara et al., 2018). The SES interactions provide an understanding of the spatiotemporal status of the savannah ecosystem as a biophysical unit interacting with human-induced land degradation after adjusting for rainfall effects. Drivers such as topographic features, fire, and livestock intensity were used for the archetype analysis, which captures the prevailing human dynamics influencing the status of the savannah. The need to understand the feedback in the coupled system led to the framing of the study to include land users, their contributions, and their perceptions of the degradation of the savannah ecosystem (Aíza et al., 2021; Herrmann et al., 2020).

The SES framework is a construct of assumptions, concepts, values, and practices that establishes a perspective view of the reality of human–nature connectedness. For this study, the SES framework (McGinnis & Ostrom, 2014) was useful for conceptualizing land degradation in the NGS (Fig. 5). The framework provides a common language to understand the issues of land degradation in terms of resource system (RS), resource units (RU), governance system (GS), and actors (A) within a social, political, and economic setting (S) (McGinnis & Ostrom, 2014; Ostrom, 2009). For this study, the RS is the Nigerian Guinea Savannah (NGS) land system with several resource components, such as interactions between soil, climate, and vegetation, co-developing into SESs. In Study 1 and its objectives, human impacts causing land degradation were examined across the NGS as an agro-ecological zone. The RU of interest is the parts of the resource systems – the savannah ecosystem, a subsystem of the SESs in the NGS – that are used or experience degradation, leading to the loss of their ecosystem services. The GS from Study3 and its objectives involve the various land users, actors, and factors whose actions can govern and address savannah land degradation through their perceptions and adoption of SLM actions. The A are the local communities and land users selected from archetype characterization of the drivers of land degradation (Study 2 and objectives). The S is Niger state in North-Central Nigeria (see study context) comprising three geopolitical zones with an extensive rural agricultural landscape. The SES framework provided the basis for exploring the long-term effects of land degradation and SLM in relation to biomass changes, drivers, and impacts on ecosystem services in the NGS.

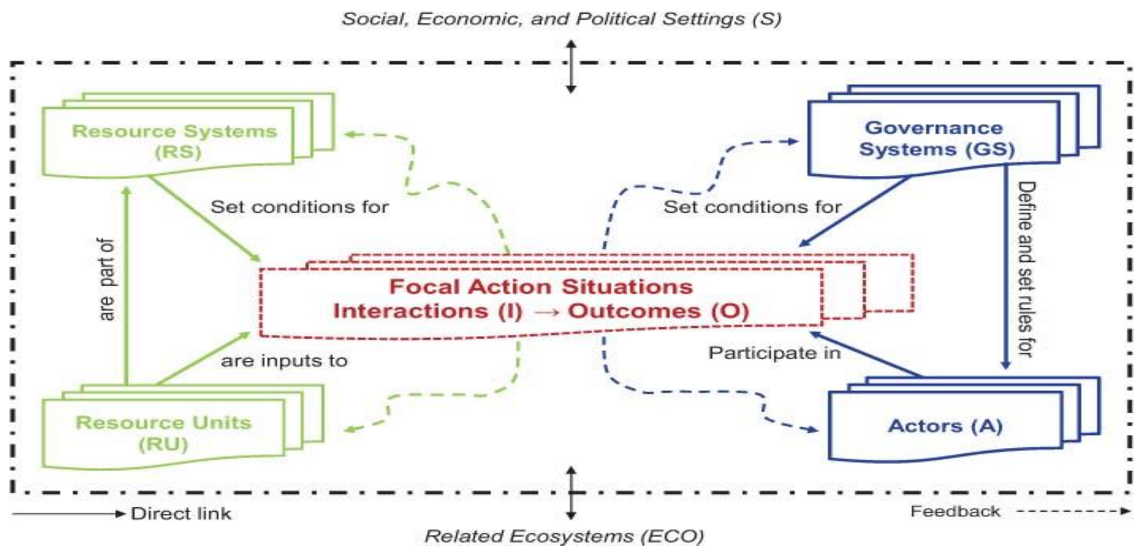

Fig. 5: Social and Ecological Systems Framework (SESF) (McGinnis & Ostrom, 2014).

2.2.3 Land Degradation in Savannah

Within the scope of debate over what constitutes a true savannah (Bond & Parr, 2010; Veldman, 2016), degradation of savannah is usually investigated through the anthropogenic reduction of savannah biomass and configuration without the impacts of rainfall or temperature on the process (Li et al., 2020; Osborne et al., 2018). Thus, the assessment of land degradation of savannah ecosystems usually centres on the conversion of savannah to other Sahelian ecosystems (Bond & Parr, 2010) and the effects of LULC (Briassoulis, 2019; CILSS, 2016), including historical changes and decline causing biomass loss (Le et al., 2014). The main indicators for monitoring and assessing land degradation are (1) land cover, with the metric of land cover change (LCC); (2) land productivity, with the metric of net primary productivity; and (3) carbon stocks above and below ground, with the metric of soil organic carbon (Cowie et al., 2018; Kust et al., 2017). These indicators are prescribed by the UNCCD for assessing progress towards LDN (Cowie et al., 2018; Kust et al., 2017). Thus, savannah degradation in this study was considered as the reduction in vegetation greenness (NDVI) while excluding rainfall influence.

2.2.4 Ecosystem Services

The consequences of land degradation include the loss of ecosystem services. Thus, we understand biomass or NDVI as capturing ecosystem services (Baniya et al., 2019). The Millennium Ecosystem Assessment (MEA) describes ecosystem services (ES) as the benefits humans derive from nature. Thus, land degradation in the context of MEA is the long-term loss of ES (MEA, 2005). According to MEA, land degradation threatens the four key categorizations of ecosystem services: provision, regulating, cultural, and supporting services. This is valid because savannah ecosystems are disturbed through human activities such as crop cultivation and expansion, grazing activities, and other poor land management activities (Arowolo & Deng, 2018; Osborne et al., 2018). For the core part of the study (Study1), land degradation was framed as a loss or decline in land productivity, and by extension ecosystem services, and was assessed by analysing biomass status (Baniya et al., 2019). The co-authored paper on the Río de la Plata grasslands (Study5) framed land degradation as a loss of ecosystem services but built on the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) nature's contributions to people, which builds on the MEA (Díaz et al., 2015).

2.2.5 Normalized Difference Vegetation Index (NDVI)

Remote sensing is a technique for observing features from a distance and gathering data that enable the assessment of environmental change. The normalized difference vegetation index (NDVI) is a remote sensing measure for assessing the difference between near infrared, which vegetation strongly reflects, and red light, which it strongly absorbs. Thus, NVDI has several environmental applications. The NDVI is obtained by Equation I:

$$\mathrm{NDVI} = \frac{\mathrm{NIR}-\mathrm{R}}{\mathrm{NIR}+\mathrm{R}}, \quad \text{………Equation I}$$

where NIR is the near-infrared reflectivity and R corresponds to the red region of the electromagnetic spectrum.

The state of NDVI from most sensors is a known proxy for understanding healthy vegetation conditions, which provides into assessing land degradation, desertification, and ecosystem changes (Akinyemi & Kgomo, 2019; Zoungrana et al., 2018). NDVI is useful for land degradation and ecosystem services assessment because this study conceived land degradation as the condition of biomass or land productivity status, which is linked to vegetation health (Baniya et al., 2019; Eckert et al., 2015). In this research, I combined several remote sensing techniques with statistical techniques to exclude rainfall effect from NDVI and thus determine the extent, severity, and geography of human-induced land degradation across the NGS (Objective 1).

2.2.6 Archetypes

Understanding the increasing impacts of human–nature interconnectedness is critical for solving complex sustainability problems. Analysing such interactions with the archetypical approach to land degradation is promising sustainable solutions (Lohmann et al., 2012; Sietz et al., 2017). Archetypes are patterns, sequences, and processes that persist over space and time due to specific factor combinations and interactions (Eisenack et al., 2019). As such, an archetype is a useful tool for identifying, mapping, and reflecting cases with shared similar and dissimilar occurrences, impacts, and syndromes (Eisenack et al., 2019). The archetype analysis was adopted in this study because (1) land degradation drivers cannot be explained by a single factor and (2) the factors that can occur in different combinations, including the need to interface degradation solutions with science, policy, and practice (Gilbey et al., 2019; Sietz et al., 2017). Archetype analysis enabled the study to achieve its aim of advancing insights into land degradation in the NGS (Study2, Objective c). It also provides the opportunities to link the mapped land degradation status (after excluding the rainfall effect from the NDVI (Paper 1, Objective b) with the archetype's outcomes (Study 2) and by extension examine perceptions of land degradation by land users (Study 3).

2.2.7 Land users' perceptions

The participatory assessment was guided by the nature of land degradation as an instance of social–ecological interactions (Batunacun et al., 2019; Okpara et al., 2018). Thus, we adopted Shackleton et al.'s (2019), framework (Fig.6f) to capture the perceptions of land degradation in selected villages and LGAs across the three zones in Niger State, where the archetypes of rural remoteness were identified (Objective 2). The framework was applied (in Study 3) as follows: The socioeconomic attributes of the various land users were summarized to understand the relationship of land users' attributes such as age and education with land degradation as primary factors (Fig.6a). The elements of the study are the savannah lands in Niger state (Fig. 6 b1& b2). Effects of land degradation were captured by the land users' perceptions of land degradation characteristics and drivers (Fig.6b2) (Study 3). The three geopolitical zones, A, B, and C, represent agricultural areas with different socioeconomic, cultural, and institutional developments (Fig.6c). The landscape context is the NGS agro-ecological zone, (Fig.6d). The institutional, governance, and policy context (Fig.6e) involves SLM initiatives and strategies for land degradation management (Fig. 6g). The framework supports Objective 2 of this study to unravel the perception of land users that are associated with rural remote archetypes as a form of large-area degradation, where socioeconomic, policy, and institutional determinants are significant for land degradation management and SLM decisions (Nkonya et al., 2011).

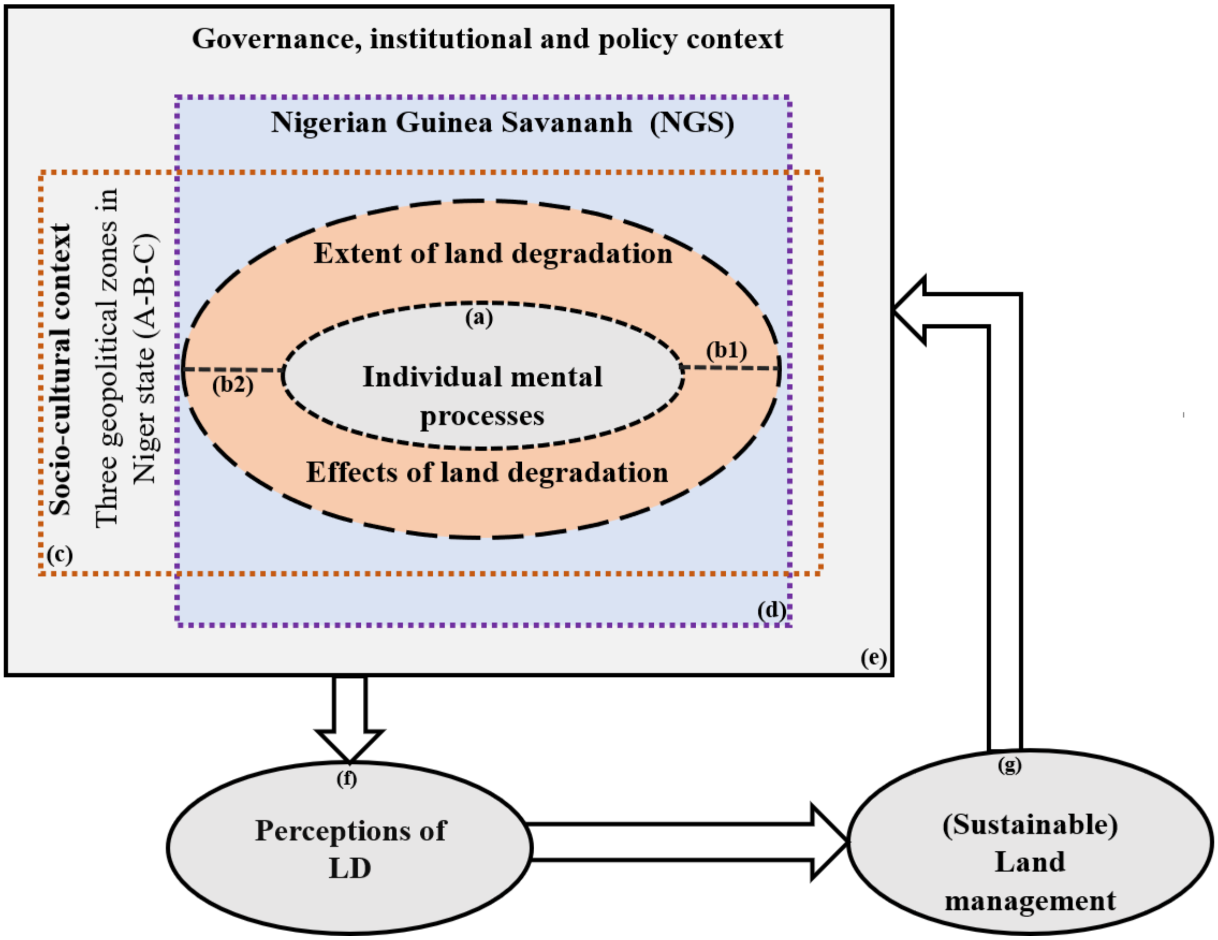

Fig.6: Conceptual approach for linking land users perceptual experience for LD.

Adapted from Shackleton et al. (2019)

Accordingly, the archetype of rural remoteness driving land degradation is dominated by land-use management practices that occur far away from major towns and roads (Objective 2). The research questions for Objective 3 connect with the framework (Fig.6) as follows: (i) what is the spatial extent and status of land degradation in the selected LGA and the three geopolitical zones of Niger state? (Fig. 6b) (ii) What are the perceptions of people towards the distinctive characteristics and indicators of land degradation in Niger state? (Fig. 6f) (iii) How do land users perceive land degradation drivers in the NGS? (Fig. 6f) (iv) Lastly, what SLM practices do land users find relevant to address land degradation? (Fig. 6g).

2.2.8 Sustainable Land Management (SLM)

Sustainable land management refers to practices that conserve land resources such as soil, water, vegetation, and biodiversity to ensure the maintenance or improvement of a healthy and functioning landscape (Liniger et al., 2011). SLM thus aims to maintain landscape long-term productive potential by neutralizing the effects of land degradation while enhancing the economic and social benefits of land (Liniger et al., 2019; Sietz et al., 2017). In this study, SLM includes technologies, policies, approaches, and activities for preventing, reducing, and reversing land degradation and for achieving LDN (Liniger et al., 2011). From the baseline information of human impact as the cause of land degradation in the NGS (Study 1), Study 2 Objective (c), Study 3 Objective (d), and Study 4 Objective (c) of this study, identify the SLM practices for addressing land degradation in the NGS.

2.2.9 Land Degradation Neutrality (LDN)

The effects of land degradation have triggered a continuous search for ways of identifying and implementing interventions to minimize degradation, especially in threatened environments (Gibbs & Salmon, 2015; UNCCD, 2015). Consequently, LDN as a new concept is a promising instrument for achieving the Sustainable Development Goals (SDGs) that focus on land degradation. LDN is defined as ‘a state whereby the amount of healthy and productive land resources necessary to support ecosystem services, remains stable or increases within specified temporal and spatial scales’ (UNCCD, 2016a). LDN was conceptualized by the UN Convention to Combat Desertification (UNCCD) as a mechanism for reviving and protecting degraded landscapes. LDN thus involves the systematic application of measures to avoid, reduce, and reverse land degradation (Cowie et al., 2018; Kust et al., 2017). The adoption of various SLM insights from this study (Study 2, Objective and Study 3, Objective Study 4, Objective c in chapter 1.5.2.) will contribute to informing policies to restore the productivity of degraded lands (Study 4). In Nigeria, LDN is particularly important because people’s economic development depends mostly on the use of land resources (Fasona et al., 2016; Macaulay, 2014). Although land degradation and its neutrality pose methodological, data, governance, and other challenges (Ifejika Speranza et al., 2019; Wessels, 2009; Wessels et al., 2012), these issues interact in various ways to enable or hinder the operationalization of LDN (Kust et al., 2017).

2.3 Methods and data

The specific procedures for collecting and analyzing data for this thesis are presented in Fig. 7

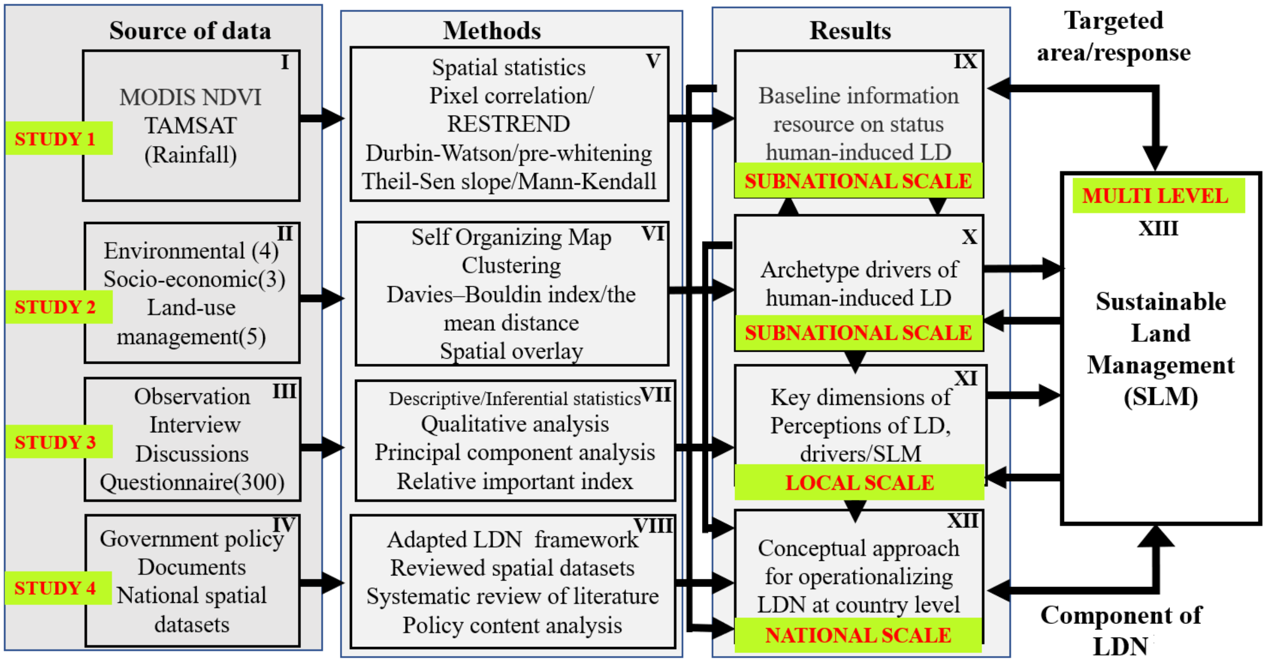

Fig.7: Research workflow

2.3.1 Satellite remote sensing data analysis

Analysis of satellite remote sensing imagery through the residual trend analysis (RESTREND) method enables to adjust and control rainfall effects from the NDVI time-series data (Burrell et al., 2017; Zhuge et al., 2019). Based on RESTREND, Study 1 provided (Fig. 7), among other insights, spatially explicit information about the extent and geographical distribution of degraded lands, and land status (Fig. 7, V & IX). Accordingly, this study separated the effect of rainfall over the NGS between 2003 to 2018 from human-induced effects, because rainfall is the chief determinant of vegetation dynamics in Nigeria(Areola & Fasona, 2018). Furthermore, human-induced land degradation can be better managed through SLM than nonhuman-induced land degradation (Fig.7, IX). RESTREND was applied to the long-term time series of vegetation and rainfall satellite data, from MODIS and TAMSAT to provide information such as the extent, distribution and status of land for tracking previous and present land use activities and land degradation (Fig. 7, I).

2.3.2 Archetype analysis

Archetype analysis was adopted to enable the representative mapping of land degradation drivers within the NGS. The idea is useful for providing an overview of patterns, and it is useful for understanding characteristics of land systems and their governance (Lohmann et al., 2012; Sietz et al., 2011, 2017). Archetype analysis in this study used a self-organizing map (SOM) (Fig. 7 VI), an unsupervised machine learning technique that produces representative clusters, which can be interpreted as Nigerian Guinea Savannah archetypes (NGSA). This study developed 12 drivers (Fig. 7, III & VI) of land degradation into spatial clusters through SOM. The drivers included three environmental ones: soil bulk density, elevation, and slope; four socioeconomic ones: population density, poverty, and female and male illiteracy); and five land-use management ones: fire-occurrence density, livestock grazing intensity, distance from a major road in 2016, distance from major towns, protected area polygon for Nigeria). The clusters were thereafter interpreted as archetypes (Fig. 7, X) and were linked to the land degradation status (Study 1; Fig. 7, IX) and the state administrative boundary of the NGS to support the drawing of SLM insights for the NGS (Study 2; subnational scale).

2.3.3 Participatory assessment

In line with the research objectives and design of Study 3, focus group discussion (FGD) and key informant interviews were organized in each zone among the land users and stakeholders (Fig .8 and Fig. 9), where rural remote archetypes were identified in Study 2. The FGDs in this thesis involved groups of seven selected land users (not more than 15 people) who are farmers willing to discuss their views and share their experiences on land degradation. Key informant interviews are qualitative in-depth interviews with knowledgeable individuals about occurrences related to land issues. Both were necessary to gather information about people’s perspectives on degradation characteristics, drivers, and SLM practices. These research activities were combined to deepen the understanding of the research questions and assist in designing the questionnaire and interpreting the research findings. These activities were carried out in the selected LGAs across the three zones.

Fig.8a: Focus group discussion in Mokwa LGA

Fig.8b: Focus group Discussion in Kudugi, Niger state

Fig.9a: Key informant interaction at Borgu land Zone C

Fig.9b: After discussion session with staff of the National Park Service, Kanji Lake National Park (Source: Own fieldwork, 2019)

The participatory nature of Study 3 enabled the adoption of the framework in section 2.2.7. This also facilitates the gathering of data through questionnaires, FDG and the use of key informant interviews (local scale Fig.7, III). The questionnaire draws on literature review, one FGDs in each geopolitical zone in Niger state, the LDN workshop report on Nigeria, and the World Overview of Conservation Approaches and Technologies (WOCAT). The data were gathered through questionnaire administration to 300 respondents determined purposively from three communities in each geopolitical zone. The questionnaire consisted of four sections, which helped, in addressing the research objectives in Study 3 (Fig. 7, III). The first section of the questionnaire gathered sociodemographic information on the land users such as age, education level, and years of living in the area. The second and third sections focused on land users' perception of the listed land degradation characteristics and drivers while the last section was on SLM categories: institutional actors and technological, conservation, and policy practices. A comprehensive analysis of responses from questionnaires was carried out using Statistical Package for Social Sciences (SPSS ®) descriptive and inferential analysis with principal component analysis (PCA), the RII, and qualitative interpretation of responses from key informants (Fig. 7,VII).

2.3.4 Policy analysis

From Fig. 7(IV), we reviewed spatial datasets and literature relating to the three main parameters of the LDN framework (LCC, NDVI, and SOC), plus land pollution and gully erosion based on the country's land cover types and agro-ecological zones (Fig. 7,VIII). Although the LDN framework guides countries to implement LDN according to specific national circumstances, our approach also integrates literature review and policy analysis to analyse the prospects, entry points, and limitations for LDN engagement. A policy (in Study 4) refers to a government's vision and course of action, which can include legislation, regulations, and plans guided by principles to achieve specific goals (Ifejika Speranza et al., 2019). The proposed conceptual approach enables LDN operationalization and can be applied to other developing countries and regions threatened by land degradation (Fig. 7,(XII)).

Chapter 3

3.0 Overview of research papers

The research output includes five peer-reviewed papers (Table 1 and Fig. 10) the author of this thesis served as first author on three of these and as co-author on the other two. Three of the paper addresses the research objectives as described in Chapter 1 while the last papers are collaborative works on LDN and insights for policy-based conservation strategies through the IPBES framework.

Table 1: Overview of research papers

Studies	Authors	Title	Status
Study 1	**Ademola .A. Adenle**, Sandra Eckert, Oluwatola I. Adedeji, David Ellison, Chinwe Ifejika Speranza	Human-induced land degradation dominance in the Nigerian Guinea Savannah between 2003-2018	Published in Remote Sensing Applications: Society and Environment 2020. Vol 19 (2020):100360 doi.org/10.1016/j.rsase.2020.100360
Study 2	**Ademola .A. Adenle** & Chinwe Ifejika Speranza	Social-ecological archetypes of land degradation in the Nigerian Guinea Savannah: Insights for Sustainable Land Management	Published in Remote Sensing 2021, Vol 13(1), 32 doi.org/10.3390/rs13010032
Study 3	**Ademola. A.Adenle**, Sébastien Boillat & Chinwe Ifejika Speranza.	Key dimensions of land users' perceptions of land degradation and sustainable land management in Niger State, Nigeria	Submitted to the Journal of Environmental Challenges manuscript number: ENVC-D-22-00042.
Study 4	Chinwe Ifejika Speranza, **Ademola.A. Adenle,** & Sébastien Boillat	Land Degradation Neutrality - Potentials for its operationalization at multi-levels in Nigeria	Published in Environmental Science & Policy 2019, Vol 94 (1): 63-71 doi.org/10.1016/j.envsci.2018.12.018
Study 5	Gorosábel, Antonella, Estigarribia, Lucrecia, Lopes, Luis Filipe, Martinez, Ana Maria, Martínez-Lanfranco, Juan Andrés, **Ademola. A.Adenle**, Rivera-Rebella, Carla, & Oyinlola, Muhammed A.	Insights for policy-based conservation strategies for the Rio de la Plata Grasslands through the IPBES framework	Biota Neotropica,2020, 20(1), pp. 1-17. Departamento de Biologia Vegetal Campinas 10.1590/1676-0611-bn-2019-0902

Study 1 analyses human-induced land degradation in the Nigerian Guinea Savannah between 2003 and 2018. The output from this study part of the research provides a baseline for Study 2 and Study 3. Further, Study 2 identifies the socio-ecological archetypes of land degradation for SLM insights and recommendations.

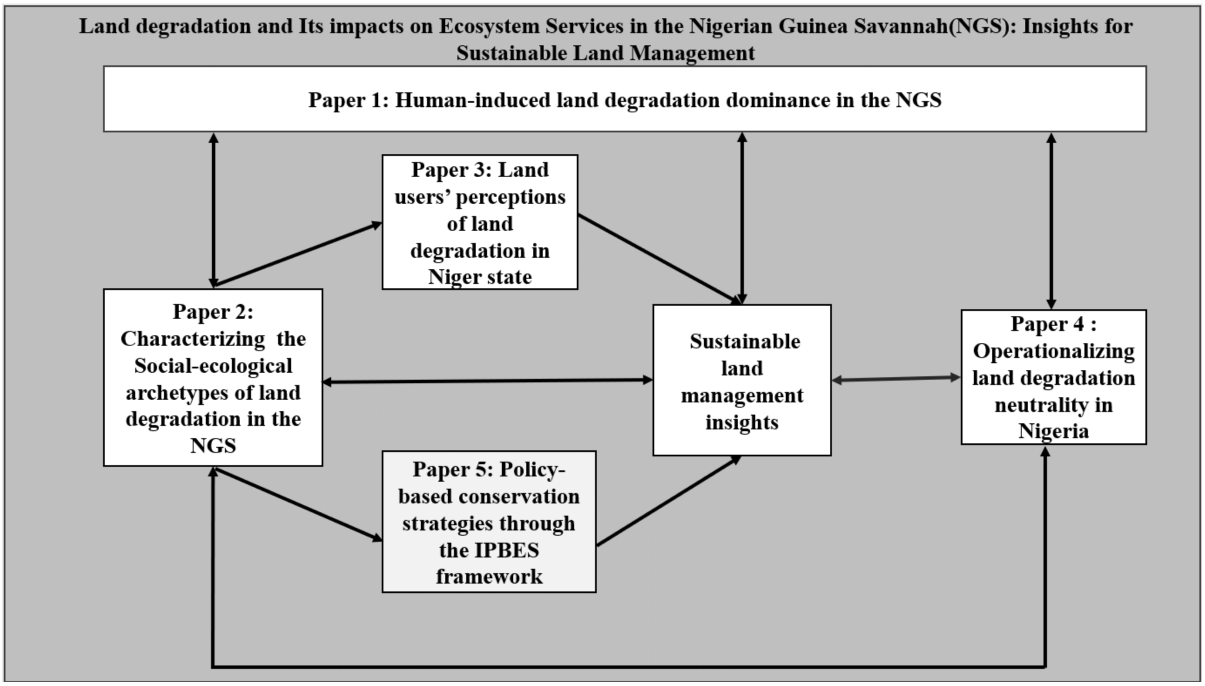

Fig.10: Thesis overview

In the area corresponding to one of the nine archetypes identified in Study 2, the archetype of rural remoteness as a driver of land degradation, a participatory assessment was conducted among land users to understand the perceptions of land degradation characteristics, drivers, and their implications for SLM and governance (Study 3). Study 3 also highlighted the key components of policies and practices that are relevant for addressing land degradation at a local scale in Niger State. Study 4 takes a wider geographical perspective to examine what implementing LDN means for the various agro-ecological zones of Nigeria. Therefore, the core of these studies (Study1-3) and their insights can be contextualized and embedded within the national governance conditions and constraints identified in Nigeria by Study 4. Finally, Study 5 was a collaborative work that applied the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework to approach biodiversity conservation in the RPG in eastern Argentina, southern Brazil, and Uruguay. This area is also a savannah-like ecosystem with predominant of land degradation activities, like the NGS. Insights won from the two regions form a basis for broader insights on land degradation and SLM in savannah ecosystems.

Chapter 4

4. 0 Key findings and synthesis

4. 1 Key findings

My study analysed land degradation in the NGS. This allowed the collection of a wide range of information and the integration of general and scientific concepts, including ideals in achieving various research objectives. In this section, I present the research outputs, which show how my doctoral work brought the research objectives to a logical discussion and conclusion.

Paper 1: Human-induced land degradation dominance in the Nigerian Guinea Savannah between 2003 and 2018

Land degradation poses a persistent challenge to ecosystems and sustainable livelihoods in the Nigerian Guinea Savannah (NGS). Whereas both human activity and climate variability have been implicated as degradation drivers, the lack of research fuels dispute over the causes and status of land degradation in the savannah. However, detailed evidence on the contributions of both rainfall and human activities can help identify appropriate measures to address land degradation. MODIS vegetation greenness and TAMSAT rainfall data were employed to (i) provide empirical insights on the pattern of savannah vegetation dynamics; (ii) control for rainfall effects in savannah degradation; and (iii) characterize the extent, severity, and geography of human-induced land degradation. The statistical techniques used highlighted the spatio-temporal dynamics of degradation in the NGS. Controlling for the effect of rainfall on vegetation greenness produces a normalized difference vegetation index (NDVI) residual that allows us to estimate the human impact on land degradation. Despite no indication of a worsening rainfall regime, interannual variation in vegetation greenness exhibits a consistently negative, declining trend. This trend in the NDVI residual strongly suggests that ongoing biomass loss in the NGS is the result of unsustainable human activity. Observed improvement is attributable to existing land management programmes, including afforestation and the planting of drought-tolerant species, initiated by states in the zone. In sum, approximately 38% of the NGS land area, including protected areas such as Kainji Lake National Park, are becoming more degraded, while 14% of the remaining area shows improvement and and 48% no real change. These results serve as a baseline information resource for tracking future land use activities, land degradation, and potential pathways for achieving more sustainable land management.

Paper 2: Social-Ecological Archetypes of Land Degradation in the Nigerian Guinea Savannah: Insights into Sustainable Land Management

The Nigerian Guinea Savannah is the most extensive ecoregion in Nigeria, a major food production area, and contains many biodiversity protection areas. However, understanding of the social–ecological features of its degraded lands and potential insights into sustainable land management and governance are limited. To fill this gap, the self-organizing map method was applied to identify the archetypes of both proximal and underlying drivers of land degradation in this region. Using 12 freely available spatial datasets of drivers of land degradation—four environmental, three socioeconomic, and five land-use management, the archetypes identified were intersected with the MODIS-derived land-degradation status of the region and the state administrative boundaries. Nine archetypes were identified. Archetypes are dominated by (1) protected areas; (2) very high-density population; (3) moderately high information and knowledge access; (4) low literacy levels and moderately high poverty levels; (5) rural remoteness; (6) remoteness from a major road; (7) very high livestock density; (8) moderate poverty level and nearly level terrain; and (9) very rugged terrain and remoteness from a major road. Four archetypes characterized by very high-density population, moderately high information and knowledge access, moderately high poverty level, and remoteness from a major town were associated with 61.3% large-area degradation; the other five archetypes, covering 38.7% of the area, were responsible for small-area degradation. Although various combinations of archetypes exist in all the states, the five states of Niger (40.5%), Oyo (29.6%), Kwara (24.4%), Nassarawa (18.6%), and Ekiti (17.6%), have the largest proportions of the archetypes. Dealing with these archetypical features and progressing towards land-degradation neutrality in the Nigerian Guinea Savannah requires policies and practices that address increasing population in combination with poverty reduction, create awareness about land degradation, and promote sustainable practices and various forms of land restoration, such as tree planting.

Paper 3: Key dimensions of land users' perceptions of land degradation and sustainable land management in Niger State, Nigeria

Declining land productivity remains a challenge for agriculture-based livelihoods and for achieving food security. Yet identifying how land users perceive land degradation and their capacity to manage land in an environmentally sustainable manner can influence the measures initiated to address it. Using a case study in Niger State, Nigeria, this study examines land users' perceptions of land degradation and land management measures in the Nigerian Guinea Savannah. We used the MODIS-derived NDVI as a proxy for degradation status and selected 30 communities based on the extent of degraded areas. We adapted the World Overview of Conservation Approaches and Technologies sustainable land management questionnaires to capture perceptions and administered 225 questionnaires to land users. To understand land degradation situations and to interpret the questionnaire surveys, we used key informant interviews to collect narrative insights and data on perspectives and motivations of land users. We analysed data through descriptive analysis, principal component analysis, and qualitative analysis. Our analysis identified four perception dimensions of land degradation characteristics, two perception dimensions of land degradation drivers, and six perception dimensions of sustainable land management. The results also confirmed that degradation in Niger State is due to widespread unsustainable human activities both within Niger state and by migrant farmers and pastoralism from adjoining Sudan Sahelian states that push people further south, leaking land degradation and conflicts into other areas. Dealing with local land degradation in Niger State critically requires improved land tenure, alternative livelihood strategies, poverty eradication and awareness, nature-based SLM practices such as tree-based initiatives, and environmentally friendly agriculture such as farmer-managed natural regeneration supported by political will and institutions.

Paper 4: Land Degradation Neutrality - Potentials for its operationalization at multiple levels in Nigeria

This paper examines the operability of the land degradation neutrality (LDN) concept in a developing country, Nigeria, highly ranked as undergoing biomass degradation. Although LDN offers an approach to monitoring land degradation through net gain in land cover, land productivity, and soil organic carbon, its operationalization poses methodological, implementation, and governance challenges. We review literature, use spatial datasets, and analyse national policies to examine the dynamics of land degradation and the prospects of LDN in Nigeria. We identify land pollution and gully erosion as indicators of LDN in the Nigerian context. We find that current institutional arrangements are largely unconducive to and incoherent for operationalizing LDN. Despite Nigeria's international commitments, current national policies relevant to LDN are vague and fragmented, based on old legislation, and have important gaps in monitoring due to inadequate data, skills, expertise, coordination, and the lack of national LDN baselines. The limited power of the national environmental agency and the lack of political will to change this situation compounds the challenges. However, two promising entry points for operationalizing LDN include incentivizing and monitoring the sustainable land management (SLM) of local resource users according to agro-ecological zones and mainstreaming SLM into initiatives in agriculture and environment sectors. These insights can inform the operationalization of LDN in other African countries.

Paper 5: Insights for policy-based conservation strategies for the Rio de la Plata grasslands through the IPBES framework

The Río de la Plata grasslands (RPG) is one of the most modified biomes in the world. Changes in land use and cover affect the RPG's rich biodiversity. In particular, the expansion of crops, overgrazing, afforestation, and the introduction of exotic species pose a major threat to the conservation of biodiversity and ecosystem services (BES). In this study, we applied the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework to approach biodiversity conservation enactments in the RPG. First, we systematically reviewed published scientific literature to identify direct and indirect drivers that affect the RPG's BES. Then, we conducted an extensive analysis of management policies affecting the BES directly in the region at a national and international level. We conclude by offering recommendations for policy and praxis under the umbrella of the IPBES framework.

4. 2 Synthesis and outlook

My study analysed land degradation in the NGS. This required the collection and analysis of a wide range of data and integration of concepts to achieve the research objectives.

This thesis confirms that land degradation is widespread in the NGS with some hotspots to its north-west, generally in the area covered by Niger State. The strongly decreasing trend in the annual rainfall-corrected NDVI (Study 1, Objective b) suggests human activity to be the dominant cause of the decline in biomass in the NGS, as no indication of declining rainfall was identified over the study period. The results (Paper 1) show that land degradation is not occurring at the same pace across the study area, as some areas experience increasing or decreasing land degradation while in some areas the biomass and NDVI remain stable. The results also show that protected areas, contrary to expectations of having better land conditions, are degraded. These differentiations in land degradation outcomes highlight that various land use processes and drivers are at play and should thus be classified and analysed to gain deeper insights into land degradation, as is done through the subsequent archetype analysis.

Nine archetypes (Paper 2) with unique characteristics were thus identified (NGSA 1-NGSA 9), Very high population density is a key feature of the archetypes associated with large areas of degradation, reflecting high pressure on land resources to meet human needs. Accordingly, four archetypes characterized by very high-density population, moderately high information and knowledge access, moderately high poverty level, and remoteness from a major town, were associated with 61.3% large-area degradation: archetypes with >10% of their total area experiencing biomass degradation. The other five archetypes, covering 38.7% of the area, were responsible for small-area degradation: archetypes with degraded areas <10% of the archetype area. Dealing with these archetypes and progressing towards LDN in the NGS require policies and practices that address increasing population in combination with poverty reduction and promote SLM practices.

Given the relevance of population density, understanding land users' perceptions of land degradation and SLM practices becomes paramount to tailoring responses to the land users. From the validated mapping of degraded areas, 30 villages were selected, and from those villages 225 land users. Results identified four key dimensions of perceptions of land degradation characteristics: (1) Vegetation-condition-dominated characteristics; (2) Soil-condition-dominated characteristics; (3) Vegetation with Sudano-Sahelian-dominated characteristics; and (4) LULC with the prevalence of drier conditions. Two key dimensions of perceptions of land degradation drivers are human-activity-dominated drivers at a smaller scale and nature-dominated drivers at a larger scale. Six key dimensions of SLM identified include (1) institutional actors' effect, (2) natural resources management, (3) environmentally friendly agricultural practices, (4) tree-based initiatives; (5) conservation initiatives, and (6) policy initiatives. The RII ranking of the SLM showed that land users rate institutional actors (70.0%), technological practices (67.6%), conservation practices (66.8%) and policy initiatives (66.5%) to be effective SLM measures to address land degradation. This highlights that institutions linked to SLM and SLM technologies are the most effective options to address land degradation in the study area. The importance of institutional measures in SLM aligns with the results on operationalizing LDN, which shows that a precondition for LDN is to reform the current land governance system by revising the Land Use Act of 1978 (LUA), which is outdated and not in tune with the current social–ecological challenges. Besides the need for reforming the LUA, Paper 4 also exposes the deficiency of national policy documents in Nigeria and their failure to align with LDN indicators. Connecting the results from the perception analysis with the policy analysis shows that appropriate institutional arrangements have the potential to reduce land degradation in the NGS.

The RPG is one of the most modified biomes in the world. Changes in land use and cover affect the RPG's rich biodiversity. In particular, the expansion of crops, overgrazing, afforestation, and the introduction of exotic species pose a major threat to the conservation of biodiversity and ecosystem services (BES). In this study, we applied the application of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework to approach biodiversity conservation in the RPG highlights the potential for linking the insights gained from research in the NGS to those in other regions such as the RPG. This thesis lays the foundation for future studies such as identifying the key socioeconomic determinants of adoption of SLM measures and testing the hypothesis that reform of institutional arrangements in SLM will reduce land degradation in the NGS.

Chapter 5

5. 0 Conclusions

The purpose of this study was to improve understanding of land degradation in the Nigerian Guinea Savannah (NGS) and to provide insights for sustainable management of its land resources. The NGS is the largest and among the most modified agro-ecological zones in Nigeria. In the NGS, the negative effects of land degradation are due to the complex interactions between coupled human and natural systems. This thesis applied qualitative and quantitative methods that enabled insights to be distilled from satellite remote sensing imagery and linked with insights derived from questionnaires, expert interviews, and focus group discussion. The results enable us to draw the following conclusions: NDVI anomaly including vegetation trend with and without adjusting for rainfall effect shows a steady decreasing trend in vegetation greenness. Thus, land degradation in the NGS is not caused by worsening rainfall regime but driven by human-induced unsustainable land-use practices. Land degradation, land improvement, and stable land status are not uniformly distributed across the NGS. The hotspots of human-induced land degradation occurred mostly around the Northwest to the North Central and Northeast of the NGS and it also affect protected areas such as the Kainji Lake National Park. The archetype analysis identified nine archetypes and provides a basis for targeted SLM measures. The perception dimensions of land degradation characteristics, drivers, and SLM identified provide another important basis for targeted SLM measures. Land users' perceptions of institutional arrangements and institutional actors as critical to effective SLM implies that adopting a bottom-up approach that involves traditional village heads as well as policy reforms will reduce land degradation and improve the effectiveness of SLM. To support this, policy reforms are necessary to support the operationalization of LDN.

Limitations of this study include the security challenges faced during the fieldwork, which affected the sample size and field work in the villages and the cultural context in which men are mainly the farmers, hence limiting respondents mainly to men. Thus, future studies need to consider these aspects in planning field work and data collection. Despite these limitations, this study provides an understanding of land degradation and associated SLM measures for addressing land degradation in the NGS, thus resolving the research gaps identified. The archetypes of land degradation and key dimensions of perceptions of land degradation and SLM provided in this study will inform the tailoring of initiatives to address land degradation more effectively in the NGS.

Chapter 6

6.0 Bibliography

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Chapter 7

7.0 Research outputs

7.1 Paper 1: Human-induced Land Degradation Dominance in the Nigerian Guinea Savannah between 2003–2018

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Human-induced land degradation dominance in the Nigerian Guinea Savannah between 2003 – 2018

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ABSTRACT

Land degradation poses a persistent challenge to ecosystems and sustainable livelihoods in the Nigerian Guinea Savannah (NGS). While both human activity and climate variability have been implicated as degradation drivers, the lack of research fuels dispute over the causes and status of land degradation in the Savannah. Detailed evidence on the contributions of both rainfall and human activities can, however, help identify appropriate measures to address land degradation. MODIS vegetation "greenness" and TAMSAT rainfall data were employed to achieve the following objectives: (i) provide empirical insights on the pattern of savannah vegetation dynamics; (ii) control for rainfall effects in Savannah degradation; and (iii) characterize the extent, severity and geography of human-induced land degradation. The selected statistical techniques proved useful for highlighting the spatio-temporal dynamics of degradation in the NGS. Controlling for the effect of rainfall on vegetation greenness produces a Normalized Difference Vegetation Index (NDVI) residual that allows to us estimate the human impact on land degradation. Despite no indication of a worsening rainfall regime, inter-annual variation in vegetation greenness exhibits a consistently negative, declining trend. This continuous, negative, declining trend in the NDVI residual strongly suggests ongoing biomass loss in the NGS is the result of unsustainable human activity. Observed improvement is attributable to existing land management programmes (afforestation and the planting of drought tolerant species) initiated by states in the zone. In sum, approximately 38% of the NGS land area, including protected areas such as Kainji Lake National Park, are becoming more degraded, while 14% and 48% of the remaining area shows either improvement or no real change, respectively. These results serve as a baseline information resource for tracking future land use activities, land degradation and potential pathways for achieving more sustainable land management.

1. Introduction

Persistent loss of biomass is a pervasive form of land degradation (UNCCD, 2013, 2016), caused by constant interactions between social and natural processes over space and time. The restoration of degraded land is intended to enhance land resources and their ability to support life on land (Cowie et al., 2018; Orr et al., 2017). For this reason, global development actors have stressed the need to prevent land degradation and restore ecosystem performance (Scholes et al., 2018). From the RIO+20 summit to the recent development of the UN Sustainable Development Goals (SDGs), emphasis on tackling land degradation has increased, as this improves the likelihood of achieving many SDGs (UNCCD, 2016). Sustainable land-based initiatives are therefore encouraged to promote the global response to land degradation (Nkonya et al., 2016). Co-benefits include improved food security, improved resilience of the productive environment, including climate risk protection and biodiversity conservation (Scholes et al., 2018).

Several studies have implicated both human activity and rainfall (climate) variability as causes of global environmental change (IPCC, 2014; UNCCD, 2016; Cowie et al., 2018). Yet a clear distinction between

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these two drivers of land degradation is rarely made (Wright, 2017; Kundu et al., 2017). Moreover, the collective impact of human-induced drivers on savannah degradation is more complex and manageable than the impact of rainfall (Zhu et al., 2016). Although several studies on land degradation exist, only a few have addressed its broader causes. Bai et al. (2008) estimated that globally, more than 20% of all cultivated areas, 30% of forests and 10% of grasslands were degraded and raised concerns about the contested causes, coverage, and severity of land degradation. Nkonya et al. (2011) identified hotspots of land degradation at global scale by clustering countries into regions and proposed using the unique and prevailing local conditions, such as climatic variations or agro-ecological differences, as guides for understanding the complicated drivers of land degradation. Wessels (2009), in a cautionary note compared and suggested methods for assessing degradation and provided an improved approach for discriminating between human and non-human-induced degradation (e.g. declining rainfall). This differentiation is necessary to ascertain the contribution of distinct causes thereby enhancing a more decisive response to land degradation (Wessels, 2009; He et al., 2015; Wingate et al., 2019).

In Sub-Saharan Africa (SSA), land is associated with natural capital and wealth (Liniger et al., 2011). Since 60% of the people depend on land for their livelihood, owning degraded land is equivalent to being poor, particularly for millions whose economies depend on the ability to manage land-based resources (Barbier and Hochard, 2018; Pingali et al., 2014). While some studies in SSA have examined land degradation (Huber et al., 2011; Ibrahim et al., 2015) they do not identify the subnational patterns of degradation. Such studies substantiate the importance of subnational and agro-ecological considerations in operationalizing and setting national Land Degradation Neutrality (LDN) targets (Ifejika Speranza et al., 2019), which are crucial elements in implementing the LDN framework (Orr et al., 2017; Kust et al., 2017). However, the coarse and generalized nature of previous studies (Fensholt et al., 2009; Fensholt and Rasmussen, 2011; Ibrahim et al., 2015), overshadow subtle subnational and localized degradation, thereby fuelling historical controversies over the true status and trend of environmental degradation in West Africa (Gautier et al., 2016).

Apart from its huge population and oil resources, Nigeria is consistently topmost on the global degradation danger list (FAO, 2010; Hansen et al., 2013). Degraded land in Nigeria surpasses the landmass of Ghana (CILSS, 2016). However, Nigeria lacks a detailed analysis of the causes of land degradation, thus hindering targeted solutions, particularly across its agro-ecological zones. A large portion of Nigeria consists of the Guinea Savannah, often categorized as a heavily-degraded dryland ecosystem (Yirdaw et al., 2017), requiring urgent restoration (Macaulay, 2014). The Nigerian Guinea Savannah (NGS) is the largest and currently most threatened agro-ecological zone (CILSS, 2016), owing to its closeness to the extensively degraded Nigerian Sudano-Sahelian region, Hence its exposure to desertification effects is compounded by pressure from the encroaching Sahara desert (Macaulay, 2014). In the NGS, land use and socioeconomic activities are strongly seasonal and rural livelihoods are tied to the primary sector, in particular to farming and other pastoral activities. These activities have actively degraded the savannah, leading to the loss of biomass and ecosystem services, and further exacerbated impoverishment (CILSS, 2016).

Currently, there is no consistent accounting of the spatio-temporal, long-term trend of biomass loss caused by human activity and climate variability in Nigeria. This weakens critical efforts for ecosystem and environmental management as no recent studies have tried to dissociate climatic variables from human-induced impacts. The historical conflict between resource users (i.e nomadic cattle herders and farmers) is linked to the encroachment of the Guinea savannah into rainforest as a result of deforestation in Nigeria (Fasona et al., 2016; Agbelade and Fagbemigun, 2015) as well as, to the desertification of the savannah (Macaulay, 2014; Naibbi et al., 2014). However, most national studies on degradation and vegetation dynamics based on agro-ecological definitions, such as by Aweda and Adeyewa (2011) and Areola and Fasona (2018) are either too coarse or outdated. Osunmadewa et al. (2018) observed the long-term phenology of vegetation in the NGS, showing human and climate effects on vegetation, but downplayed finer vegetation dynamics due to the coarseness of their datasets i.e. 1 km resolution. Fashae et al. (2017) also grouped vegetation over Nigeria without contextualizing or discriminating climate induced and human-induced causes of vegetation degradation. In all, the omission and lack of detailed assessment of biomass degradation based on human-induced activities at a refined resolution were consistently missing.

This study aims to fill these gaps by assessing recent human-induced biomass loss in the NGS at a refined scale of medium resolution between the years 2003 and 2018. The study objectives therefore are to: 1) provide empirical insights into the current vegetation status and trends, including anomalies in the pattern of savannah vegetation dynamics based on the analysis of finer medium resolution satellite data; 2) control for climate change, in particular change in rainfall, which is generally considered strongly correlated with vegetation, thereby separating rainfall changes from other factors affecting increasing degradation of the savannah; 3) characterize the extent, severity and the geography in terms of the distribution of human-induced degradation across the NGS and identify degradation hotspots. The output from this research provides a baseline for future studies in the separation, identification, and characterization of non-climate related causes of land degradation in the NGS.

2. Materials and methods

2.1. Study area

Our study area, the Nigerian Guinea Savannah (NGS), lies between 6.50°N and 9.62°N, 2.77°E and 13.20°E, and is bordered by the rainforest in the South and the Sudan Savannah in the North (Fig. 1). In Nigeria, sub-national administrative units are called states and the states in this zone are regarded as the "middle belt" of the country. The middle belt is the largest agro-ecological zone in the country, covering about 49% of the country's land mass and 25 of its 36 states. The belt is divided into two regions, the Northern and Southern Guinea Savannah, based on differences in vegetation composition (Wakawa et al., 2016; Fasona et al., 2011). In the southern region, the vegetation is characterized by a mix of trees and tall grasses, with shorter grasses and fewer trees in the Northern part. The NGS is a crucial habitat for threatened fauna, such as chimpanzee (*Pan troglodytes*), and flora, such as the African rosewood (*Pterocarpus erinaceus*). A distinct montane vegetation characterizes the central and eastern regions within the NGS (Iloeje, 2001). The belt further encompasses parts of the two major rivers, the Niger and the Benue, and their confluence.

Several national hydropower stations, such as the Kainji and Shiroro stations are located in the zone. Several protected areas such as the Foge Islands and Kainji Lake National Park, most of which are Ramsar Convention wetland sites, are also located in the zone (Ayanlade and Proske, 2016). This fertile region is a major food basket of the country, with primarily rainfed production. The zone likewise provides grazing resources for livestock, of which a large share derives from transhumance systems (i.e. seasonal nomadism). The inhabitants consist of diverse ethnic and religious groups. Several major towns and urban centres are located in the NGS, including Abuja, the capital of Nigeria. With population growth and heavy dependence on natural resources, maintaining land quality is increasingly challenging and conflicts over access to, and control of, the land often occur (Fasona et al., 2016).

2.2. Rationale and indictors for land degradation

Concerns about the assessment, monitoring and management of land degradation have risen dramatically in recent years (Orr et al., 2017; Kust et al., 2017), and have informed an agreement on the relevant

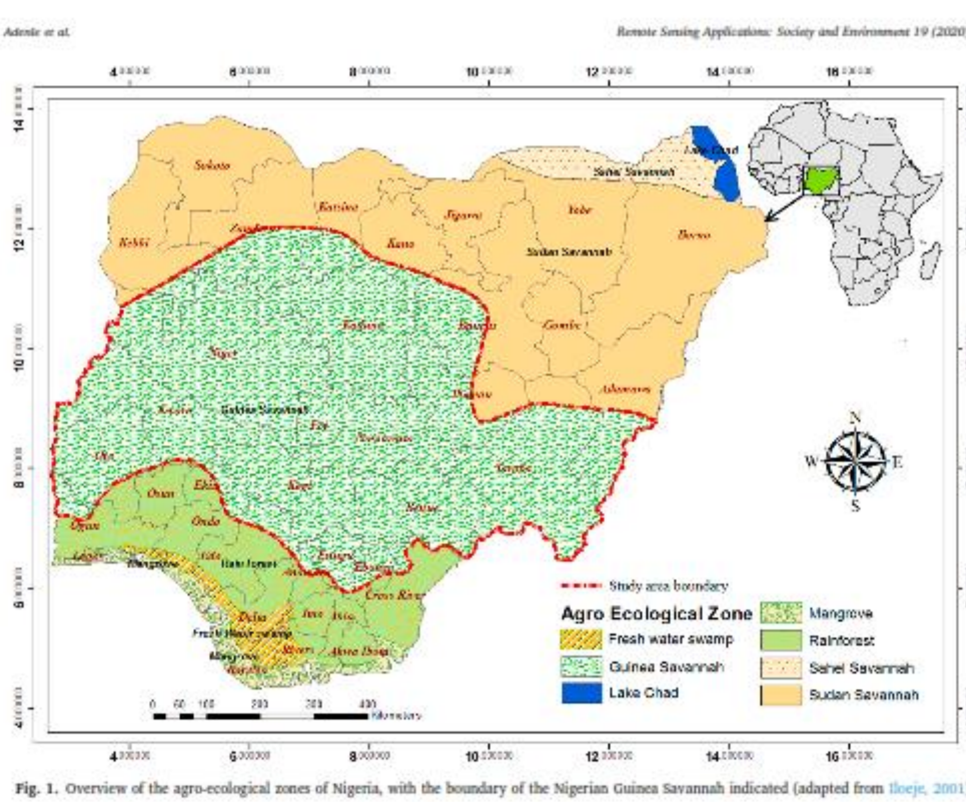

Fig. 1. Overview of the agro-ecological zones of Nigeria, with the boundary of the Nigerian Guinea Savannah indicated (adapted from Iloeje, 2001).

indictors for land degradation studies. Therefore, the performance of three indictors; 1) land cover (metric: Land Cover Change (LCC), 2) land productivity (metric: net primary productivity), and 3) carbon stocks above and below ground (metric: soil organic carbon) are prescribed as the determinant parameters for identifying degraded land and gauging neutrality (UNCCD, 2015). The Normalized Difference Vegetation Index (NDVI) is widely used as a global proxy for land productivity (Orr et al., 2017; Kust et al., 2017). Beside vegetation status and condition, NDVI is a key indicator of vegetation health condition. Therefore, adopting NDVI for discriminating human-induced from non-human-induced degradation is particularly relevant for NGS. Moreover, NDVI is more and more frequently being used to examine land degradation (Wessels et al., 2012; Kundu et al., 2017; Wingate et al., 2019).

2.3. Datasets and processing

2.3.1. NDVI data

Considering the large geographic extent and the difficulties in obtaining adequate primary data at the subnational level, we decided to assess land degradation using medium resolution (250m) satellite data. We opted for the pre-processed Moderate-resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) 10-day time series product, with a spatial resolution of 250m. MODIS' 250m spatial resolution compensates for the limitations of previous large-scale studies of the study area, such as Ibrahim et al. (2015), who used bi-weekly 8 km resolution Global Inventory Modeling and Mapping (GIMMS) NDVI (NDVI3g) datasets to assess land degradation. For our study, the Swets et al. (1999) corrected MODIS NDVI 10-day time series product was downloaded for the years 2003–2018 from the USGS Famine Early Warning System (FEWS) project (https://earlywarning.usgs.gov/fews). The dataset has proven to be a suitable proxy for detecting land degradation and vegetation greening, particularly in semi-arid to arid environments and is reportedly consistent over time (Fensholt et al., 2009; Wenxia et al., 2014). Furthermore, the 250m MODIS data resolution is able to capture human activity such as deforestation (Yengoh et al., 2015; Eckert et al., 2015) and has been extensively used in the assessment of land degradation in Africa (Zoungrana et al., 2018). In order to correct for the influence of clouds, atmosphere and solar elevation angles, the Maximum Value Composite (MVC) method for calculating the highest NDVI value was applied to the 10-day mean NDVI time series. We generated two outputs from the MVC data: (1) the monthly maximum NDVI, out of which we then calculated (2) the NDVI yearly sum (see Supplementary File, Fig. S1)

2.3.2. Rainfall data

We used TAMSAT (Tropical Applications of Meteorology using SATellite and ground-based observations) gridded rainfall data. The data has a spatial resolution of 4 km, which is suitable for assessing the spatial pattern and potential changes in rainfall, as well as its potential influence on NDVI (Maidment et al., 2017). In this study, we use the TAMSAT data to disentangle climate- and human-induced changes in NDVI. Since the TAMSAT rainfall product was specifically developed to provide meteorological data for all of Africa, we opted for the yearly sum rainfall product (Tarnavsky et al., 2014). The calibrated (i.e. over space and time) time series data of TAMSAT makes linking to the similarly calibrated MODIS NDVI product possible (Tarnavsky et al., 2014; Maidment et al., 2017). TAMSAT data can be downloaded at (http://www.met.reading.ac.uk/~tamsat/data/).

2.4. Methodology

The specific objectives of the study were addressed by means of the workflow represented in Fig. 2. The methodological steps are described in the following sections. Illustrations of the intermediate inputs and outputs can be found in the supplementary file, Figs. S2–S6.

2.4.1. Vegetation status and trends

To spatially link rainfall with the NDVI data, the TAMSAT dataset was resampled to match the 250m resolution in the NDVI dataset by applying nearest neighbour resampling. Although TAMSAT has a very coarse resolution of 4 km, which may be critical when linking to the 250m MODIS data, it is the most readily available and most reliable data for Nigeria because of its consistency with ground-based observations (Maidment et al., 2017; Tarnavsky et al., 2014). We then projected all data to the Minna/UTM zone 31N coordinate system. For each of the sixteen years, we calculated the mean of the yearly sum of the (monthly 10-day) maximum NDVI. Furthermore, to generate monthly NDVI profiles for each observed year we calculated the mean 10-day maximum NDVIs. Both outputs were generated for each pixel in our study area. NDVI is defined as a measurement of the status and presence of photosynthetically active vegetation, and ranges from −1 to +1, with negative NDVI values indicating low greenness and low presence of photosynthetically active vegetation and positive values indicating high greenness and presence of photosynthetically active vegetation. Changing NDVI over time, thus corresponds to a change in the presence of photosynthetically active vegetation and may suggest vegetation loss or gain. The standardized NDVI anomaly (Z) is defined as deviation from the long-term mean vegetation dynamics. It is particularly useful for identifying outliers of periodic NDVI events and may indicate non-periodic changes in the analyzed vegetation dynamics (Nanzad et al., 2019). To examine the magnitude of NDVI anomalies in our time series (2003–2018), two types of standardized NDVI anomalies were calculated, a monthly (Zm) and a yearly (Zy) NDVI anomaly (see Supplementary File, Tables S1 and S2). The standardized NDVI anomaly Z is calculated by subtracting observed NDVI from mean of the period, i.e. monthly and yearly, respectively, and dividing it by the monthly and yearly standard deviation of the period, respectively (Aweda and Adeyewa, 2011).

2.4.2. RESTREND

We apply the Residual Trend Analysis (RESTREND) method (Wessels et al., 2007, 2012) to control for and remove rainfall effects from the NDVI time series data. RESTREND builds on the strong positive relationship between NDVI and rainfall in arid/semi-arid regions (He et al., 2014; Ibrahim et al., 2015) and performs better than other techniques such as Rain Use Efficiency (RUE) (Kundu et al., 2017). RESTREND makes it possible to distinguish the human causes of degradation from rainfall-driven change in NDVI by using the pixel-specific differences between NDVI residuals and observed rainfall (Ibrahim et al., 2015; Wingate et al., 2019) and thus permits investigation of the trend in, and spatial assessment of, human-induced land degradation (Kundu et al., 2017; Wingate et al., 2019). Before applying RESTREND to the data, a Pearson product-moment linear correlation between MODIS and TAMSAT pixels for the entire observed timespan (2003–2018) was performed. An illustration of the resulting coefficients of spatial correlation (R) can be found in the supplementary file, Fig. S2. The linear trend of the inter-annual pixels provides further insights on the relationship between rainfall and vegetation dynamics. Consequently, the resulting outputs (Fig. 2.), from the Pearson product-moment linear correlation were used to correct the (uncorrected) yearly NDVI trend for the influence of rainfall (Ibrahim et al., 2015). The resulting rainfall corrected yearly NDVI trend can then be interpreted as follows: 1) if no trend exists, we can assume there is no human-induced degradation or

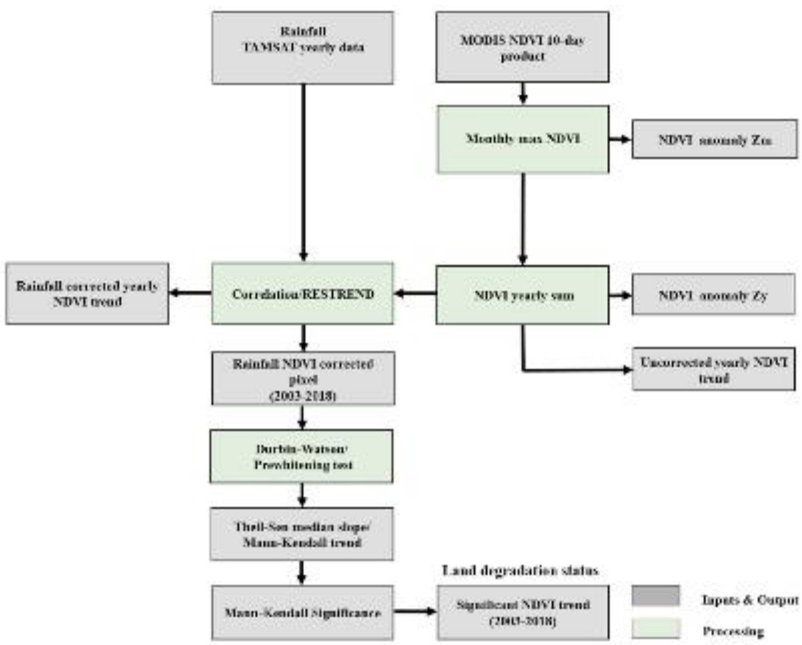

Fig. 2. Overview of the study workflow.

regeneration (i.e. improvement) happening. 2) A decreasing trend in the corrected yearly NDVI trend suggests degradation caused by human activities, while 3) an increasing trend indicates improvement in vegetation conditions due to non-climatic factors such as conservation and restoration efforts (Evans and Geerken, 2004; Wessels et al., 2007). Additionally, we verify whether there is a potential lag between rainfall and our NDVI data by applying a Durbin-Watson test and a trend preserving pre-whitening technique (Razavi and Vogel, 2018; Osunmadewa et al., 2018). For further details see the supplementary file (Fig. S3).

2.4.3. Theil-Sen slope and Mann-Kendall test

In order to derive the magnitude of the persistence of rise and fall in pixels of the yearly NDVI time series, we apply a median Theil-Sen (TS) slope estimator, a robust non-parametric statistical approach that is insensitive to small outliers and missing values (Burrell et al., 2017; Taxak et al., 2014). The TS slope is derived by calculating all pairwise combinations of rainfall corrected yearly NDVI values for the 2003–2018 time series and then deriving the median values (see supplementary file, Fig. S4). Afterwards, a Mann-Kendal (MK) trend test (Ibrahim et al., 2015) was performed to measure the direction of trend (i.e. degradation or improvement). A Kendall τ coefficient, which determines the consistent upward or downward trend, was applied. The test is based on the following equation:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1} \mathrm{sign}(x_j - x_k)$$

$$\mathrm{sign}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases}$$

x_j and x_k are the sequential data values and n is the length of the dataset. Positive values of S indicate an upward trend and the opposite a downward trend (i.e. −1 indicates a trend consistently decreasing, never increasing, while +1 indicates the opposite). A value of 0 indicates no trend or relative stability (Fensholt et al., 2009; Ibrahim et al., 2015). An illustration of the resulting monotonic trends can be found in the supplementary file, Fig. S5. Through a standardized Z scores and the corresponding probability (P) of MK, the significance of the trends of human-induced land degradation were identified at the $p < 0.05$ and $p < 0.01$ confidence intervals, respectively (Burrell et al., 2017). These results were used to derive and summarize the status of the study area and state-specific land degradation in the NGS.

3. Results

3.1. Vegetation status and rainfall effects

Fig. 3a shows the spatially aggregated yearly sum of NDVI for the study area over the complete time series (orange line). This line still contains the influence of rainfall. The NDVI trendline (dotted black line) shows a decline in vegetation greenness ranging from 0.763 to 0.734. Fig. 3b illustrates the standardized yearly anomalies in the NDVI time series. This data also contains the effect of rainfall. Nevertheless, we can still observe a clear decline in greenness (see Supplementary File, Table S2). From 2003 to 2009, a strong positive anomaly can be observed, while from 2010 onwards, with the exception of 2011 and 2012, strong negative anomalies are detected. In 2008, 2011 and 2014, no or little deviations from the trend line were observed. Fig. 3c depicts rainfall corrected yearly NDVI variations after controlling for the effect of rainfall. The NDVI also shows a declining trend in vegetation greenness and lower values in scale (i.e. ranging from 0.340 to 0.305). Aside from clearly visible fluctuations, the highest recorded corrected NDVI values were observed for 2003, while the lowest was observed in 2017. The R^2 of 82.7% suggests the observed decline in vegetation greenness is consistent, with or without correcting for the influence of rainfall. Interestingly, inter-annual variation in mean annual rainfall (Fig. 3d) indicates little variation with a slight but clear increase towards the end of the study period. The trendline increases slightly, but not significantly, suggesting very mild improvement in the NGS rainfall regime during the study period. Thus, the strongly decreasing trend in the annual, rainfall corrected NDVI (Fig. 3c) suggests human activity is the main cause of the observed decline in greenness and biomass loss in the NGS.

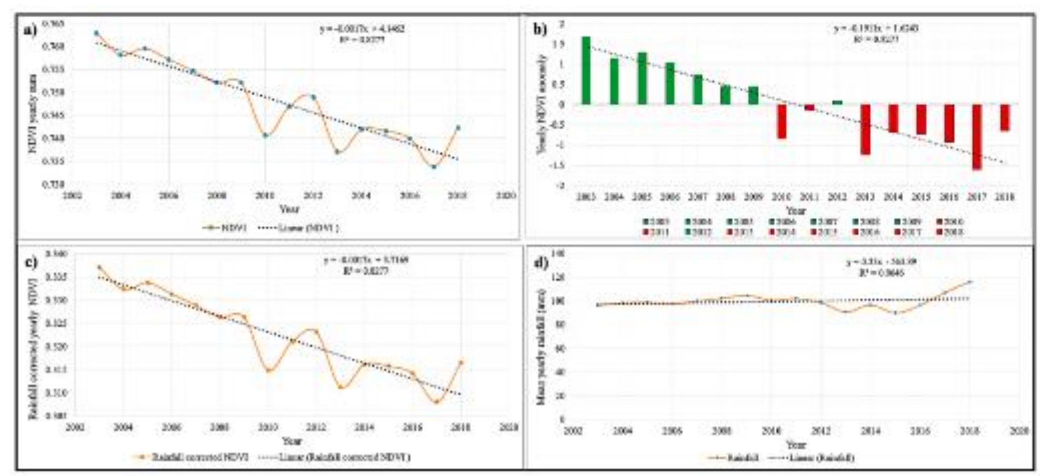

Fig. 3. (a) Spatially-aggregated yearly sums of NDVI (orange) and its linear trend (black) in the NGS for the entire time series including the influence of rainfall; (b) yearly NDVI anomaly (Zy) from 2003 to 2018; (c) spatially-aggregated, rainfall corrected yearly sums of NDVI for the entire time series; (d) inter-annual variations of the mean yearly rainfall (orange) and its linear trend (black). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.2. Mann-Kendall significance

In Fig. 4, the relative significance of the NDVI trend for the analyzed time series (2003–2018) is geographically illustrated. As thresholds for the two degradation and improvement categories, we use $P < 0.05$ and $P < 0.01$ significance levels. The illustration mirrors the pattern of the TS median slope map (see Supplementary File, Fig. S4). The additional significance categories emphasize the widespread land degradation in the NGS.

The areas ranging from the northwest to the central and northeast of the NGS, encompassing the states of Kebbi, Niger, parts of northern Kwara, FCT (mainly around Abuja, see area illustrated in Fig. 4b), and parts of the states Nasarawa, Plateau, Taraba and Adamawa have been particularly affected. Improvement can be found primarily in the north, i.e. in the states of Zamfara, Katsina, northwest Kaduna (Fig. 4c). Besides the northcentral states of Plateau and Bauchi, the southern states of Oyo, Kogi and Nassarawa also show dispersed patches of improvement. Land degradation is particularly apparent both around and within protected areas, as can be seen in and around the Zugurma sector (e.g. Fig. 4a). Table 1 provides an overview of the relative percent shares and absolute areas for each of the illustrated NDVI trend categories.

Fig. 5 presents a simplified overview of the statistics for the general NDVI trend categories (grouped by land degradation status) for all states in the NGS (for the complementary table, see Supplementary File, Table S4). Note that blue land areas lie outside the NGS and were not part of this analysis. Most of the states for which the majority of the total land cover is within the NGS experienced degradation on 16%–62% of their land. The four states with the largest shares of degraded land in the NGS are Niger (62.9%), FCT (44.7%), Nassarawa (40.1%) and Kwara (36.8%). The four states with the greatest share of improvement are Kogi (18.4%), Kaduna (17.3%), Enugu (16.8%), and Oyo (15.4%). In addition, Kogi (57.4%), Enugu (56.5%), Benue (55.2%), and Kaduna (52.2%), and Oyo (51.3%) are states with comparatively large stable areas.

Table 1
Statistical Overview of the principal NDVI trend categories in the NGS (percent shares and absolute areas).

Mann Kendal significance	Area (%)	Area (Km^2)
Degradation (significant decrease, $p < 0.01$)	0.37	1620.77
Degradation (significant decrease, $p < 0.05$)	37.59	164,661.82
Stable (no significant change)	48.25	211,357.62
Improvement (significant increase, $p < 0.05$)	13.77	60,319.06
Improvement (significant increase, $p < 0.01$)	0.02	87.61
Total	100.00	438,046.88

4. Discussion

4.1. Vegetation dynamics

Both the uncorrected, as well as the rainfall corrected, average annual NDVI time series indicate a continuous, declining NDVI trend across the entire NGS. The yearly NDVI anomaly (Zy) also illustrates a declining trend with positive anomalies in the first half of our time series (2003–2009). As of 2010, they become negative and continue to decline up to 2018. The slightly positive anomaly detected in 2012 may be the

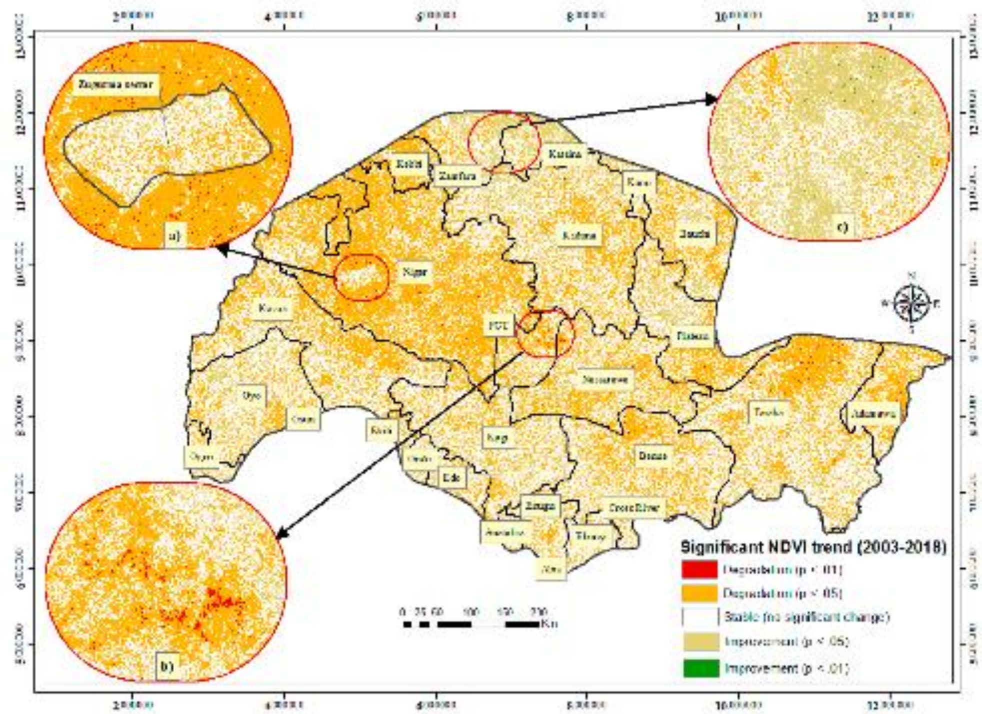

Fig. 4. Significant NDVI trend (2003–2018) indicating changes in vegetation cover induced by human activity. Zoom images of (a) a protected area, (b) a hotspot of significant ($p < 0.01$) degradation, and (c) an area of significant improvement.

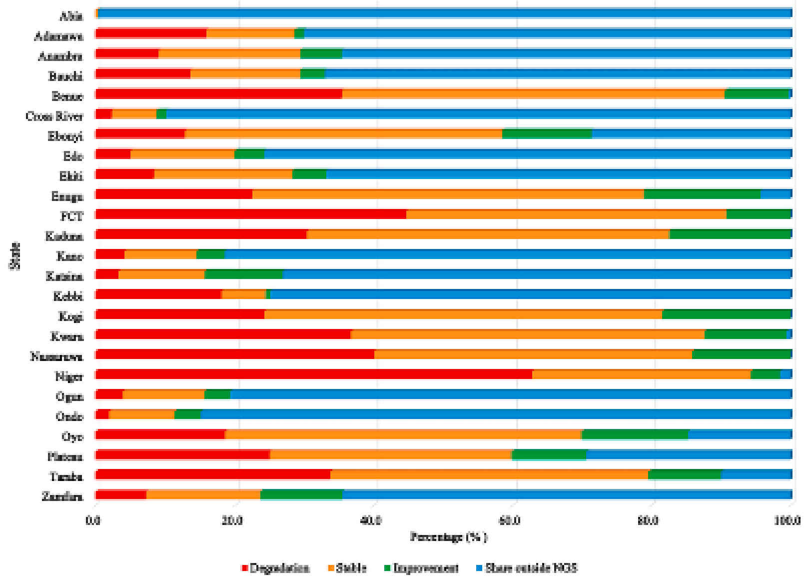

Fig. 5. Percentage shares of land status by states in the NGS. Note: The relative status of land shares outside the NGS (blue) were not analyzed. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

result of an extreme rainfall period that occurred in the same year (Nnaji et al., 2016). This might have led to increased vegetation growth in the following growing season. The extreme rainfall led to catastrophic flooding that affected most states in the NGS and other West African countries (Agada and Nirupama, 2015).

Aweda and Adeyewa (2011) performed a similar study but for a different, earlier period (1982–2000). Moreover, they used NDVI data from a different satellite sensor. Thus, it is hard to compare or link their results with ours. The year-to-year NDVI anomaly variation in their study is rather high. Nevertheless, in their study they observed a generally increasing trend in the annual NDVI anomaly for the NGS, starting with negative anomalies in 1982 and 1983, becoming positive up to 1999, and abruptly turning negative again in 2000. NDVI data for the years 2001 and 2002 are not readily available.

While the cause of the declining NDVI trends and anomalies in previous studies was attributed to the effect of droughts that occurred in West Africa in the 1980s (Epule et al., 2014; Gautier et al., 2016), the decline observed in our study can be attributed almost entirely to human activity (Osunmadewa et al., 2018). This confirms previous global forest loss assessments in which Nigeria was considered one of the countries experiencing the highest forest loss rates globally since 2000 (FAO, 2010). These findings underline the relative importance of savannah restoration, as there is obvious evidence of biomass loss (Vogt et al., 2011; Macaulay, 2014; CILSS, 2016), even after excluding the impact of change in rainfall.

4.2. Rainfall effects and offset from the degradation of Savannah

We found that the inter-annual trend in mean yearly rainfall was relatively uniform, with slightly increasing rainfall amounts in recent years (Fig. 3d). The increase towards the end of the study period supports the observations of the varying increase in rainfall amounts over parts of the NGS and Nigeria as a whole (Odjugo, 2010; Areola and Fasona, 2018), and further suggests that the long period of low rainfall in the 1970s and 1980s over West Africa is not currently affecting the NGS (Gautier et al., 2016). The results further suggest that the NGS is not under the period of declining rainfall, and that any increase in land degradation generally cannot be explained by change in rainfall (Nicholson et al., 2018). Also, the general pattern of the long-term mean monthly NDVI anomaly (Fig. S3), remains consistent – the bimodal nature of vegetation greenness and photosynthetic activity with respect to rainfall is maintained (Osunmadewa et al., 2018). Thus, the overall positive response of savannah vegetation to rainfall has not changed (Areola and Fasona, 2018; Nnaji et al., 2016).

Surprisingly, there is little difference in the variation of the correlation coefficients inside and outside national and state protected areas (see Supplementary File, Fig. S3). Vegetation loss due to extensive human activity has occurred both outside and inside protected areas (Naibbi et al., 2014; Fasona et al., 2016). As observed also in a study by Aweda and Adeyewa (2011), the range of the correlation coefficients suggests vegetation greenness in the NGS is sensitive to rainfall. Besides rainfall, which is the principal limiting factor for vegetation greenness, other variables also affect the NDVI anomaly and/or degradation, i.e. temperature (Igbawua et al., 2016) and soil moisture (Ibrahim et al., 2015). The RESTREND technique (Fig. 3c) results in a rainfall corrected NDVI which estimates the human component of land degradation. The declining trend in the rainfall corrected NDVI (Fig. 3c) suggests that large-scale land degradation in the NGS is due to unsustainable human activities and not to rainfall dynamics (Kundu et al., 2017).

4.3. Human-induced land degradation

The TS slope identifies surfaces with a persistent rise or fall in the annual, rainfall corrected NDVI (see Supplementary File, Fig. S4), thus highlighting the large differences between areas experiencing rapid loss in savannah vegetation compared to their surroundings. Negative slopes implying high vegetation loss (i.e. leading to rapid land degradation) relative to their surroundings are pervasive across the middle of the

NGS, from its north-western to its eastern border. These areas have negative trend values twice as high as neighbouring pixels and have experienced twice as much degradation as surrounding areas with positive slopes indicating a relatively stable or improving status of land quality. In the NGS, approximately 1621 km^2 i. e. 0.37% ($P < 0.01$) and 164,662 km^2 i. e. 37.59% ($P < 0.05$) experienced significant degradation, while about 88 km^2 i. e. 0.02% ($P < 0.01$) and 60,319 km^2 i. e. 13.77% ($P < 0.05$) respectively, experienced improvement in land quality. For about 211,358 km^2 (48% of the NGS), no significant change was observed (Table 1). Therefore, 38% of the total area is degraded and 14% has improved at the $P < 0.05$ significance level. The shares of severe change ($P < 0.01$) are comparatively small.

The supplementary file, Fig. S4, and the result in Fig. 4., show areas in the NGS suffering from degradation due to high human pressure on the savannah, which invariably reduces the savannahs' potential to provide ecosystem services because of the poor management of savannah vegetation (Macaulay, 2014; Zhang et al., 2016). Such human pressures usually have immediate or direct impacts that can trigger noticeable degradation in that they place huge demands on the savannah and its resources (Osborne et al., 2018). Among such pressures are agricultural expansion, urbanization, and wood fuel extraction, including deforestation and overgrazing, documented accelerators of land degradation in Nigeria (CILSS, 2016; Ighawua et al., 2016). According to our result, the pervasive degradation in the NGS is mainly caused by unsustainable agricultural activities (CILSS, 2016), fuelled by huge food and land demand from the continuously increasing population. These pressures drive the loss of biomass and ecosystem services, leading to impoverishment (Macaulay, 2014; Ighawua et al., 2016). Our results thus provide additional, direct evidence of ongoing and extensive land degradation in Niger state, Nigeria with little to no improvement in land quality in other parts of the state. This indicates the urgent need to address human-induced land degradation across the NGS, especially in states such as Niger state, which is currently experiencing degradation on more than half its territory.

Degradation caused by human activity is also particularly severe in and around protected areas (see Fig. 4a and Supplementary File, Figs. S4 and S5). This is particularly concerning because people are technically not permitted to enter protected areas. However, these protection rules are apparently inadequately enforced (Abdulaziz et al., 2015). The Zugurma sector of the Kainji Lake National Park, for example, is clearly affected by land degradation (Figs. 4a and 6a), suggesting encroachment pressures and threats to protected areas from local resource users (Ducrotoy et al., 2018; Nchor and Ogogo, 2012). Enforcing protected area status is thus required to tackle these negative human impacts. Thus, there is a need for field level studies to identify in detail which land use practices and human activities drive land degradation (Kundu et al., 2017), particularly along agro-ecological context of Nigeria (Ifejika Speranza et al., 2019).

The noticeable improvements in some of the states, mostly those bordering the Sudan Savannah, can be traced to land management programmes such as afforestation and reforestation with local species, including the adoption of drought tolerant shrub species, which have been promoted both across Nigeria (Wingate et al., 2019) and by the governments of these states. Despite the negative trend in parts of the Zurgurma Sector noted above, there are still stable areas in most protected areas. The NGS is thus very relevant for the federal government's nature conservation initiative, as the largest and oldest national parks are found in this zone ((Abdulaziz et al., 2015; Usman and Adefalu, 2010).

Although, several data sources exist that can help answer questions about national or state-level land degradation, the MODIS data from Famine Early Warning System (FEWS) has proven useful for characterizing land degradation, especially when coupled with other relevant datasets (Funk et al., 2019). The 250 × 250m spatial resolution used in our analysis makes a case for a critical assessment of land degradation using TAMSAT and MODIS data, as the coarse nature of both might raise concern especially for local level assessment. Thus, theoretically, employing finer resolution satellite data such as Landsat or Sentinel-2 data may lead to a better identification of land degradation and improvements in some areas. However, one has to keep in mind that Sentinel-2 data of Nigeria is only available from 2015 on, and frequent cloud cover, particularly during the rainy seasons, may lead to substantial data gaps in a long-term time series. In addition, we hold that assessing land degradation with the NDVI greenness trend does not adequately distinguish between different vegetation types and plant species (Dardel et al., 2014), which leaves the current analysis open to future refinements. Moreover, our study period does not adequately reflect much of historical events such as the drought of the 1970s and 1980s but rather the period after severe drought has receded (Nicholson et al., 2018). Thus, our results can be improved through ground truthing, additional land use/land cover information, or even by including novel multivariate statistical indices (see e.g. Coluzzi et al., 2019). Such refinements, however, for financial and logistical reasons, remain beyond the scope of the current study.

5. Conclusions

Our study provides evidence of ongoing land degradation in Nigerian Guinea Savannah by assessing degradation and improvement trends based on satellite imagery captured between 2003 and 2018. We have disentangled human and rainfall-induced effects on NDVI, the proxy we have employed to analyze changes in the photosynthetic activity of savannah vegetation.

We find that the annual mean NDVI and annual NDVI anomalies observed in the NGS between 2003 and 2018 show a clear declining trend. Overall, a total of 38% of the NGS land area has experienced degradation, while 14% has experienced improvement and the remaining 48% appears to be stable. In addition, we have determined that land degradation is occurring both outside and inside protected areas. Human activity appears to be the driving force threatening vegetation conditions in and around these protected areas. More generally, after correcting for the potential influence of rainfall

Fig. 6. (a) A degraded, thinned patch (front) of typical savannah vegetation (background) in Zugurma sector; (b) a mix of degraded land with few bushes and trees interspersed in Borgu, Niger state. (Source: Own field work, 2019).

variability, we find that unsustainable human activities are presumably the main force behind large-scale degradation in the NGS.

This study further reveals the need for future investigation into the local mix of unsustainable human activities and related drivers of savannah land degradation. Understanding the extent, severity, and hotspots of land degradation in the zone ultimately requires improved knowledge of the spatial mix of land degradation drivers. More importantly, these local mixes can further guide response actions for improving land quality in the NGS, particularly in the protected areas where the need to maintain the status of natural vegetation is threatened by increasing human impacts. This knowledge is particularly important for protecting natural vegetation and addressing ongoing land degradation in protected zones. Finally, our results suggest that MODIS NDVI is suitable for evaluating land degradation in a heavily-degraded dryland ecosystem.

CRediT authorship contribution statement

Ademola A. Adenle: Conceptualization, Methodology, Software, Data curation, Writing - original draft. **Sandra Eckert:** Supervision, Data curation, Writing - review & editing, Validation. **Oluwatola I. Adedeji:** Formal analysis, Software. **David Ellison:** Conceptualization, Writing - review & editing. **Chinwe Ifejika Speranza:** Conceptualization, Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rsase.2020.100360.

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7.2 Paper 2: Social-Ecological Archetypes of Land Degradation in the Nigerian Guinea Savannah: Insights for Sustainable Land Management

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Article

Social-Ecological Archetypes of Land Degradation in the Nigerian Guinea Savannah: Insights for Sustainable Land Management

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Abstract: The Nigerian Guinea Savannah is the most extensive ecoregion in Nigeria, a major food production area, and contains many biodiversity protection areas. However, there is limited understanding of the social-ecological features of its degraded lands and potential insights for sustainable land management and governance. To fill this gap, the self-organizing map method was applied to identify the archetypes of both proximal and underlying drivers of land degradation in this region. Using 12 freely available spatial datasets of drivers of land degradation—4 environmental; 3 socio-economic; and 5 land-use management practices, the identified archetypes were intersected with the Moderate-Resolution Imaging Spectroradiometer (MODIS)-derived land-degradation status of the region, and the state administrative boundaries. Nine archetypes were identified. Archetypes are dominated by: (1) protected areas; (2) very high-density population; (3) moderately high information/knowledge access; (4) low literacy levels and moderate–high poverty levels; (5) rural remoteness; (6) remoteness from a major road; (7) very high livestock density; (8) moderate poverty level and nearly level terrain; and (9) very rugged terrain and remote from a major road. Four archetypes characterized by very high-density population, moderate–high information/knowledge access, and moderate–high poverty level, as well as remoteness from a major town, were associated with 61.3% large-area degradation; and the other five archetypes, covering 38.7% of the area, were responsible for small-area degradation. While different combinations of archetypes exist in all the states, the five states of Niger (40.5%), Oyo (29.6%), Kwara (24.4%), Nassarawa (18.6%), and Ekiti (17.6%), have the largest shares of the archetypes. To deal with these archetypical features, policies and practices that address increasing population in combination with poverty reduction; and that create awareness about land degradation and promote sustainable practices and various forms of land restoration, such as tree planting, are necessary for progressing towards land-degradation neutrality in the Nigerian Guinea Savannah.

Keywords: archetypes; self-organizing maps; land degradation; drivers; savannah; Nigeria

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1. Introduction

With increasing global population, environmental change, and competing claims on land, the need to maintain land productivity and reduce land degradation has become even more critical. Various global initiatives reflecting this urgency include the United Nations Convention to Combat Desertification (UNCCD) goal of achieving a Land-Degradation Neutral (LDN) World [1]; the African Forest Landscape Restoration Initiative (AFR100) aiming to restore 100 million hectares of land in Africa by 2030 [2]; and the Great Green Wall Initiative across the Sahel [3]. Yet, land degradation (LD), i.e., the persistent reduction (negative trend) or loss of the biological productivity or ecological integrity of land or its value to humans, remains a diverse and complex issue [4,5].

The African Savannah is among the globally threatened landscapes [6], where climatic and edaphic conditions, as well as human activities, constrain vegetation regeneration [7,8].

In West Africa, the savannah ecozones are prone to LD and experience both anthropogenic and non-anthropogenic pressures [7,9]. These expose its 353 million inhabitants and their livelihoods to various impacts such as decline in ecosystem services, food insecurity, migration, and civil conflict [8]. In Nigeria, LD cases across its agroecological zones are mostly triggered by a singular factor or a combination of factors, which include: desertification, deforestation leading to biomass loss, land pollution caused by oil spillage and illegal mining, as well as extensive soil erosion [10]. Thus, agroecological zones like the Nigerian Guinean Savannah (NGS) are experiencing pressures from urbanization, agricultural expansion and an increasing population that is largely dependent on land resources for livelihoods [11,12]. The NGS, covering 49% of Nigeria, is widely degraded, its ecosystem services continue to decline, and livelihoods remain precarious [11,12]. Unsustainable land use and climate stress have been implicated in this widespread degradation [11,13–15]. While the indicators of LD drivers, their interplay, and implications at scale are generally acknowledged [14,16], there is a lack of knowledge of the constellation of factors characterizing specific degraded landscapes, such as the NGS, and their interplay [11]. The explanations of several studies in the NGS on LD drivers are often without an integrative perspective capable of exposing the interactions between potential LD drivers [16,17].

Recent studies thus stress the need for an integrative approach to enable a better understanding of the constellation and interplay of LD drivers in land systems [14,17]. One such integrative approach is archetypical clustering for identifying recurrent patterns in land conditions [18,19]. Archetypes, i.e., patterns or processes that occur repeatedly across space and time [19,20], have been found to provide a more holistic understanding of land system processes [20]. This understanding enables comparability across cases and helps identify strategic policy options to address land management across scales [18–20]. Archetype studies have been conducted on food security in the Peruvian Altiplano [21]; institutional analysis and climate change in the Peruvian Andes [22]; national analysis of ecosystem services in Germany [23]; water governance of river basins [24], and global land resources management [25]. An archetype approach thus helps to illuminate the associative patterns and influence of the complex drivers of global changes (such as LD) that have often been treated in isolation [19,20,25].

This paper thus aims to identify the characteristic patterns of social-ecological factors associated with LD in the NGS and to analyze the implications of the identified LD archetypes for land governance and sustainable land management (SLM) in the region. In the subsections, the description of the social-ecological conditions in the NGS, the study methods and hypothesis, the archetypical patterns of drivers, their thematic, and spatial characterization, including the links to different levels of LD, and the implications of the archetypes for land governance and SLM in the NGS are presented.

2. Materials and Methods

2.1. Study Area

The Nigerian Guinea Savannah (NGS) (Figures 1 and 2) is an ecological region found between 6.50°N and 9.62°N, 2.77°E and 13.18°E. Occupying central Nigeria, it is the country's most extensive ecological zone, referred to as the Middle Belt of Nigeria. The zone consists of parkland savannah, gallery forests, and derived savannah, including distinctive montane vegetation [26], with tropical dry and wet seasons. Rainfall in the wet season (April to October) is about 1240–1440 mm. The dry season lasts from November to March [27]. Average maximum annual temperature varies from 31 °C to 35 °C while the average minimum ranges from 20 °C to 23 °C [27]. The region is broadly divided into two sub-regions based on distinctive vegetation types, namely the Southern and Northern Guinea Savannahs. The Southern Guinea Savannah has taller trees, such as locust bean tree (*Parkia biglobosa*), and grasses such as Gamba grass (*Andropogon gayanus*); while the Northern Guinea Savannah is characterized by bush with some trees (e.g., *Isoberlinia* spp.) and relatively shorter grasses (e.g., *Hyparrhenia* spp.) [27]. The NGS has a high level of fauna and flora and hosts major perennial rivers such as River Niger and River Benue. Subsequent years of uncontrolled deforestation and poor land management has transformed the zone largely into a degraded landscape (Figure 2) [12].

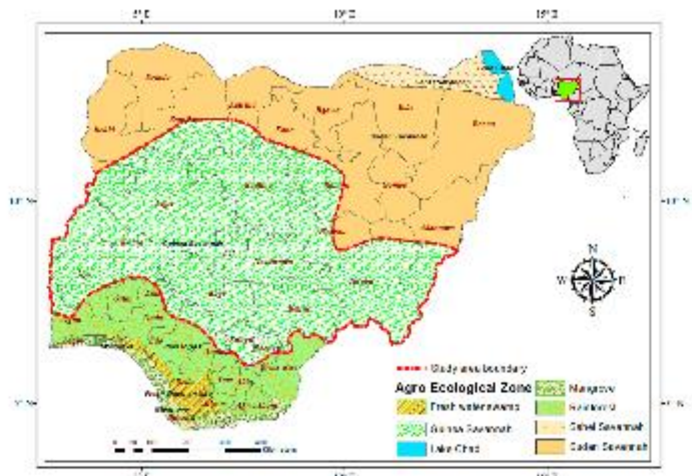

Figure 1. Map of the Nigerian Guinea Savannah including the administrative boundaries of states (Adapted from [26]).

Figure 2. (**a**) Landscape showing a degraded patch of the Nigerian savannah vegetation in Shiroro local government area, Niger state, Nigeria; (**b**) a mix of degraded land with few bushes and trees interspersed in Borgu local government area, Niger state, Nigeria. (Source: own fieldwork, 2019).

2.2. Framing Land-Degradation Drivers

In this study, LD drivers were understood as determinants, i.e., reasons, factors, or actions, shaping the rate of human activities, leading to a decision to remove or reduce vegetation cover thereby causing a decline or loss of land resources' productivity [14,28]. Factors prompting LD are broadly categorized either as proximal or underlying drivers [16,17,29]. Proximate drivers are human activities or immediate actions, including the decision to directly use or alter the land cover [14]. Underlying drivers include indirect or underpinning factors, such as socio-economic factors (e.g., poverty) and biophysical factors (e.g., topographic variables) that trigger proximate causes of LD [14]. Based on literature [17,28,29] and a report on the LDN target for Nigeria in 2018 [30], three main categories of LD drivers of the Nigerian Guinea Savannah Archetypes (NGSA) namely: environmental, socio-economic, and land-use management practices were identified. Based on the available spatial and remote sensing data, 12 drivers comprising three environmental, four socio-economic, and five land-use management practice categories were selected (Table 1a–c).

The processes through which the variables (whether as proximate or underlying drivers), drive the LD are explained in Table 1a–c.

2.3. Datasets Selection

For this study, factors were considered based on their influence on land-use decisions and LD [16,29,31] (see Table 1 for details). Climatic variables such as rainfall were not included because human-induced activities are the prevailing cause of LD, especially in the NGS [11,12]. However, human-induced drivers are better managed than climatic drivers of LD [11,32].

2.3.1. Land-Use Management Practices

Land-use management practices have been linked to degraded land in Nigeria through land clearing and conversion including intensification [13]. Other unsustainable land-use management practices include rapid agricultural expansion, uncontrolled bush burning, deforestation, excessive wood extraction, unplanned infrastructure extension, and urban development, including overgrazing [12,13,33]. For this study and based on spatial data availability, data on land-use management practices were acquired and processed, respectively. The fire-occurrence density was derived from the National Aeronautics and Space Administration (NASA) active fire hotspot data of 2018 (firms.modaps.eosdis.nasa.gov) after running a spatial point-density analysis of the active fire spots at 250 m resolution. The livestock grazing intensity data for 2005, developed by Harvest Choice in 2018 (www.ifpri.org/project/harvestchoice) was used. The generated distance to the major road in 2016 for Nigeria, at a resolution of 3 arc-second (approximately 100 m at the equator) was acquired from (www.worldpop.org/project/categories?id=14) [34]. The Euclidean distance analysis of the extracted major town polygons from Google Earth (www.google.com/earth/) was used to determine the distance to major towns at 250 m resolution. Using the International Union for Conservation of Nature (IUCN) recognized protected area polygon for Nigeria (www.protectedplanet.net/country/NGA), the density of the protected area at 250 m resolution across the NGS was generated through point-density analysis.

2.3.2. Socio-Economic Drivers

Demographic and socio-economic factors such as population density, income, poverty, and illiteracy are drivers of LD in certain contexts [16,29]. In other contexts, they may even be drivers of improved land conditions [35]. However, in the case of Nigeria, its over 200 million inhabitants and population density of 226 km^2 place a huge demand on land resources [33,36]. Thus, gridded human population density constructed for 2018 in 2020, from random forest-based dasymetric redistribution at 3 arc-second (approximately 100 m at the equator) spatial resolution, was downloaded from www.worldpop.org [34]. Male and female literacy layers of high resolution at 1 km × 1 km gridded cells developed for 2003 in 2017, based on a geostatistics approach [37], were acquired [34]. These are necessary as they are proxies for access to agricultural extension information, as previous studies show that limited information on SLM drives LD [16,38]. The poverty headcount in percentages for Nigeria at 1 km for 2013 mapped through Bayesian model-based geostatistics analysis was downloaded from www.worldpop.org [34], because poverty can foster practices that cause LD, while LD can foster a poverty trap [38]. These drivers were selected in that they are known factors that influence decisions on land and SLM LD [28,29,38].

2.3.3. Environmental Drivers

Land can be sensitive to degradation due to its environmental and physiographic characteristics, influencing human decisions to use land [31]. Such influential characteristics include soil bulk density (BD), elevation, and slope [13,39]. For this study, the already-processed NASA Shuttle Radar Topography Mission (SRTM) based slope and elevation for Nigeria by [40] at a resolution of 3 arc-second (approximately 100 m at the equator) produced for 2020 was acquired from www.worldpop.org [34]. The spatial mapping of the bulk density (BD; soil compaction) in 2018 at 250 m resolution from 0 cm to 30 cm depth were downloaded from www.soilgrids.org and then averaged to give the overview of the BD for the study area [41–43].

2.4. Methods

2.4.1. Conceptual Framework

The workflow in Figure 3 was applied to the 12 drivers (Table 1a–c), which served as inputs for identifying archetypes. The intermediate outputs from the framework, such as correlation between drivers including cluster features, can be found in supplementary material Figures S1–S5.

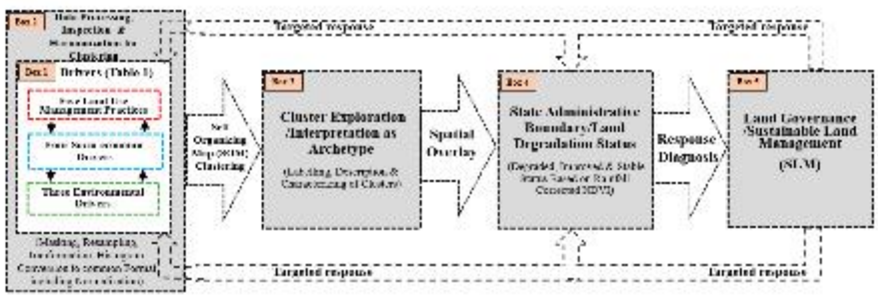

Figure 3. The conceptual framework.

2.4.2. Identifying Archetypes of Land-Degradation Drivers Using Self-Organizing Maps

To develop the Nigerian Guinea Savannah Archetypes (NGSA) of LD drivers, the 12 driver datasets were clipped to the boundary outline and resampled to a 250 m pixel size, using the nearest neighbor technique (Figure 3, Box 2), and then projected to a uniform coordinate system (i.e., Minna/UTM zone 31N). To enhance the clustering of the datasets, data were normalized (Z-score) to reformate into a common scale (Figure 3, Box 2). Correlation was calculated to identify relationships between the drivers (Figures S5 and S6) and the extent of interdependencies among the dataset that might limit the analysis. Then the Kohonen Self-Organizing Map (SOM) technique was applied to generate a single-layer map of the archetypes of LD drivers [54]. The SOM approach involves organizing data (in this case, the 12 spatial datasets) into patterns based on their inherent similarities and dissimilarities into different groups [54,55]. By testing the different combinations of clusters and using a performance analysis involving both the Davies–Bouldin index and the mean distance of the classified grid cells [23,25], nine clusters of LD drivers were identified as archetypes (see supplementary material, Figures S2–S5). The Z-score, i.e., standardized score from the SOM, was used to examine values of each driver in terms of distance from the mean and to explain the clusters. A Z-score that is equal to the mean is zero, while positive and negative Z-score, i.e., greater than or less than zero, depict distance way above or below the mean. Through an ordinal scaling, the relative standing of the Z-score from the mean was ranked. If the Z-scores = 0, this implies mean/low influence of a driver; Z-score $\leq \pm 1$ = moderate influence; $\pm 1 <$ Z-score $< \pm 2$ = high influence; and Z-score $\geq \pm 2$ = very high influence, respectively (Figure 3, Box 3). From the absolute values of the Z-scores of each cluster, the percentage dominance categories in the clusters were determined [23] (Figure 3, Box 3).

Table 1. List of driver's datasets for the development of archetypes.

(1a) Land-Use Management Practices				
Variables	**Type of Driver**	**Explanation**	**Hypothesized Effect**	**References**
Fire occurrence density derived from active fire and hotspot data	Proximate	Uncontrolled fire occurrences and bush burning destroy soil and biomass, leading to LD—while controlled fire could be a management strategy.	Frequent man-made fire activities lead to more LD. The fewer the man-made fire activities, the less the LD.	[44–46]
Livestock grazing intensity	Proximate	Overgrazing due to higher livestock intensity leads to LD, especially when the threshold limits of the support systems are exceeded, while lower livestock intensity does not lead to LD.	The higher the livestock grazing density, the higher the LD. The lower the grazing density, the less the LD.	[47,48]
Distance to major road	Proximate/Anthropogenic	Roads are a measure of infrastructural development that enhances access to markets and extension services. For instance, a good access road encourages land conversion, including the spread and the adoption of land management practices, while inadequate access discourages land conversion.	Proximity drives LD because nearer forest patches are easier to clear, while areas far away are not affected. The farther an area to a major road, the less the LD; the closer to a major road, the more the LD.	[16,29,38,49]
Distance to major towns	Proximate/Anthropogenic	Land that is close to major towns is prone to LD pushed by urban development; while land that is far from major towns is less prone to conversion and LD.	The farther an area to a major town, the less the LD; the closer to a major town, the more the LD. Areas near settlements or towns are more likely to degrade due to expanding settlements and resource extraction (e.g., wood).	[16,17,29]
Protected area status	Proximate	Human pressure that causes LD is more severe on unprotected land than on protected land.	Protected areas are less prone to degradation due to their protected status.	[50,51]
(1b) Socio-Economic Drivers				
Variables	**Type of Driver**	**Explanation**	**Hypothesized Effect**	**References**
Population density	Underlying	Population density can trigger better land management, but can also lead to LD due to overuse or poor management.	The higher the population density, the less the LD; the lower the population density, the more the degradation. Alternatively, the higher the population density, the higher the LD. The lesser the population density, the lesser the LD.	[16,17,35]
Female/Male Literacy	Underlying	High literacy indicates better access to information or knowledge for making informed decisions, while low literacy may limit people's ability to understand available information—hence they are likely to make poorer land management and investment decisions.	The higher the literacy of women/men, the better the access to knowledge on combating LD; the lower the literacy of women/men, the lesser the access to such information.	[38]

Table 1. *Cont.*

Variables	Type of Driver	Explanation	Hypothesized Effect	References
Poverty head count	Underlying	Diverging evidence. Poverty and LD are intertwined: while poverty could trigger LD, LD could exacerbate poverty. Poor land users are more likely to give up their land tenure security to other more powerful land users, for example losing their land to large-scale land investments for monocultures.	The higher the poverty, the more the prevalence of LD due to various intervening factors such as lack of capital and labor to invest in land management and insecure land tenure.	[16,29,38]
(1c) Environmental Drivers				
Variables	**Type of Driver**	**Explanation**	**Hypothesized Effect**	**References**
Slope	Proximate	Slope influences land-use decisions. Steep lands are often avoided for land-use activities such as cultivation. However, cultivation on non-terraced steep slopes and overgrazing can cause LD such as water and wind erosion.	The steeper the slope, the more susceptible to LD, but the less will be the land's attractiveness for use. The less steep the slope, the less susceptible to LD but the more the attractiveness for land-use activities.	[16,39,52]
Bulk Density (BD)	Underlying	Soils with low bulk density have favorable conditions in terms of soil pore space, texture and organic matter content that influence the choice of land for crop cultivation and biomass clearance.	Low soil bulk density encourages tillage and crop cultivation, while high soil bulk density discourages crop cultivation. The higher the bulk density, the higher the LD; The lower the bulk density, the less the LD.	[41–43]
Elevation/Topography	Proximate/Anthropogenic	Land uses such as farming, which promote degradation are often practiced on flat terrain while rough or high hilly terrains are avoided. Hence, flat terrains are more likely to be exposed to land-use pressure from crop farming.	The higher the elevation, the more susceptible is the land to LD such as erosion, but the less the land's attractiveness for use. The lower the elevation, the less susceptible is the land to LD, but the more attractive for land use because of soil attributes such as deeper soils.	[16,53]

2.4.3. Linking Archetypes of Land-Degradation Drivers to State Administrations and Land Status

In a previous study by [11], LD status was captured using rainfall-corrected vegetation greenness as a proxy (Figure 3, Box 4). By overlaying the archetypes cluster (Figure 3, Box 3) with the LD status of the area (i.e., degraded, stable, and improvement) (Figure 3, Box 4), the percentage share of each archetype per LD status was determined. This enabled the grouping of the nine archetypes as undergoing large-area or small-area degradation, respectively. Thus, archetypes with area coverage <10% of the total degraded area have a small-area degradation, while archetypes with area coverage ≥10% of the total degraded area are classified as large-area degradation clusters [56]. Through spatial overlay [23], the linking of the archetypes with the states' administrative boundaries to determine the share of each archetype per state was possible (Figure 3, Box 4). The emerging results were used to explain and discuss the implications for land governance and SLM in the NGS (Figure 3, Box 5).

3. Results

3.1. Land-Degradation Status

Using Normalized Difference Vegetation Index (NDVI) as a proxy for degradation status, Figure 4 shows the spatial distribution of LD in the NGS by [11]. About 38% (251,401 km^2) of the NGS is degraded, while 14% (91,258 km^2) and 48% (319,470 km^2) show improvement and remain stable, respectively. While improved and stable areas are mostly found in the north of the NGS and to a certain extent in the south of the NGS, large-area degradation is predominantly found in the centre of the NGS, ranging from its north-western to its eastern border.

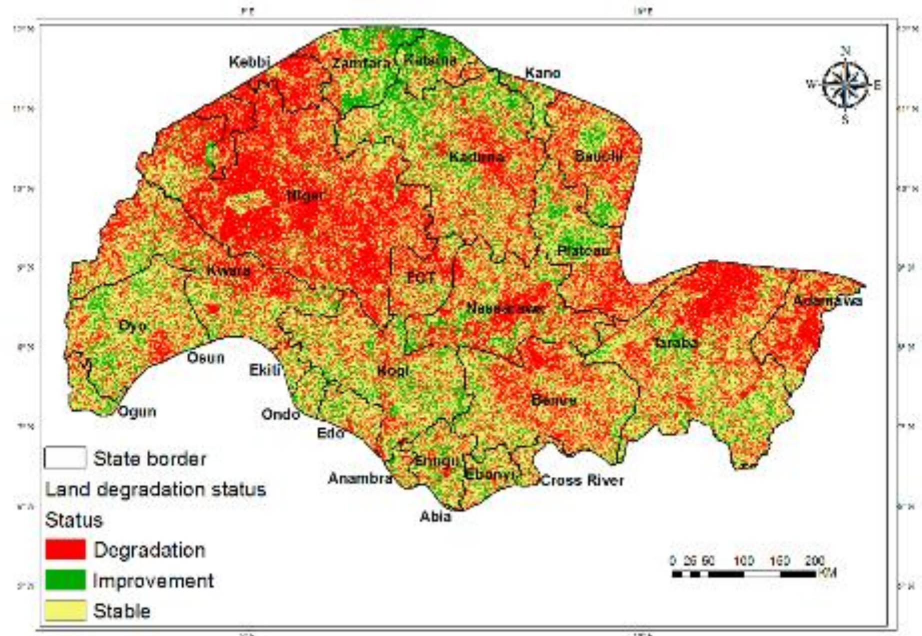

Figure 4. Land-degradation (LD) status for the Nigerian Guinea Savannah (NGS) (Source [11]) using Normalized Difference Vegetation Index (NDVI) as a proxy after correcting for rainfall.

3.2. *Land-Degradation Archetypes*

In this section, the archetypes and how they can improve the understanding of LD in the NGS are presented. Figure 5 displays each archetype according to the percentage contributions of driver categories, while Figure 6 shows the spatial distribution of the archetypes. Based on the 12 input drivers, nine archetypes of LD drivers were identified (Figure 5). Five archetypes were dominated by land-use management practices (NGSA 1, NGSA 5–8), and three dominated by socio-economic drivers (NGSA 2–4), while NGSA 9 was dominated by environmental drivers (Please refer to supplementary material, Table S1 for a description of the archetypes).

3.3. *Spatial Distribution of Archetypes*

The spatial distribution of the nine archetypes of LD drivers is shown in Figure 6. In Table 2, a brief description and share of each archetype in the NGS is provided.

From Table 2, six clusters (NGSA 2–5, NGSA 7 and NGSA 9) with individual total areas greater than 10% cover 78.5% of the total area, while the remaining three archetypes with individual total areas smaller than 10% of the area cover 21.5% of the NGS.

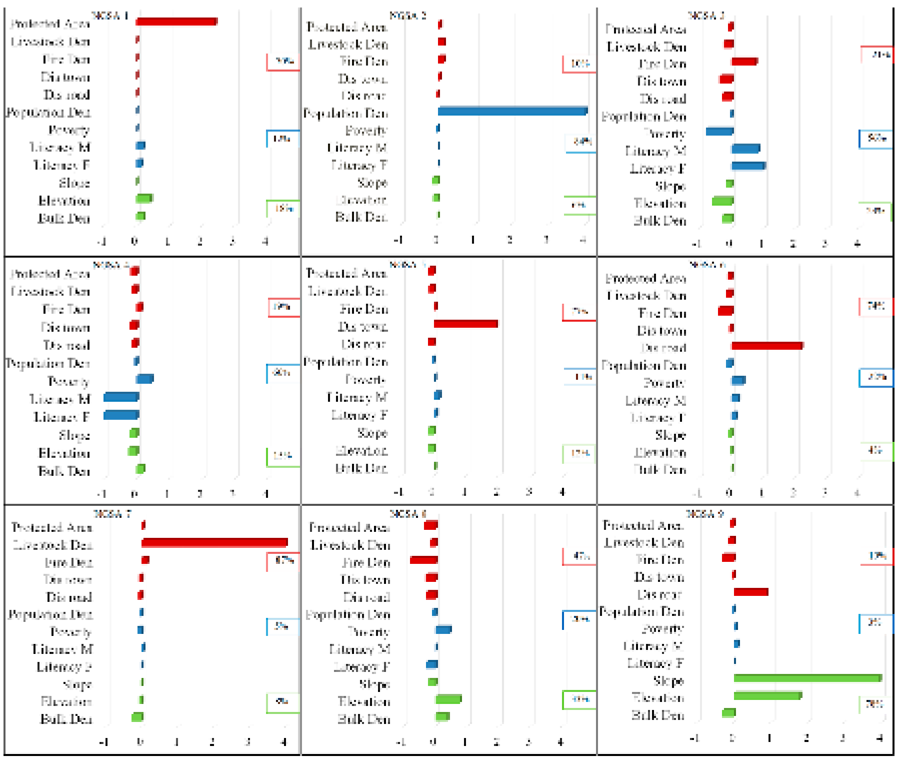

Figure 5. The Z-score normalized values of drivers characterizing the nine archetypes of LD drivers, (zero depicts the mean for the NGS; the percentage contribution of driver categories into archetype clusters is presented in the boxes: red: land-use management practice; blue: socio-economic; green: environmental drivers).

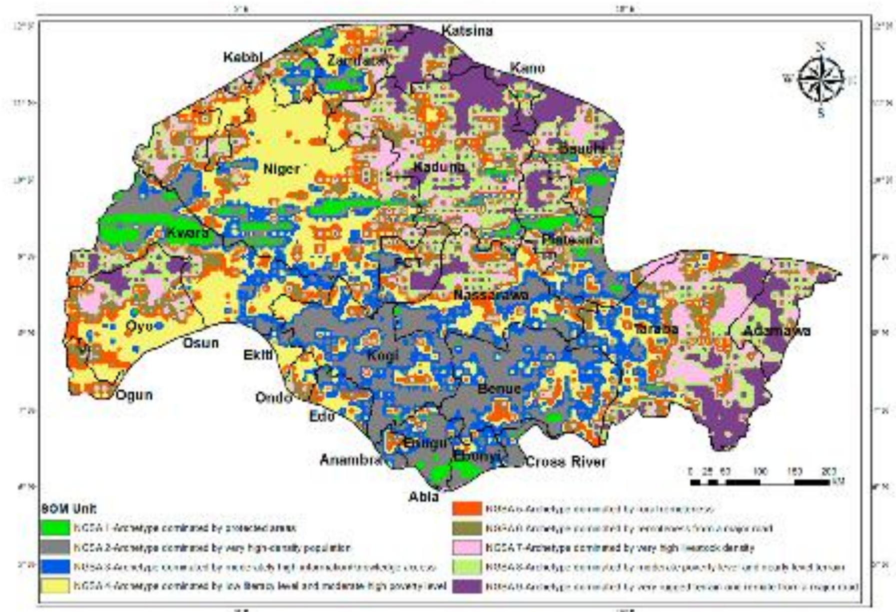

Figure 6. Spatial characterization of archetypes of LD drivers. See supplementary material, Section 6 for the full description and ranking of the archetypes in relation to administrative and land status.

Table 2. Description and share of the archetypes of LD drivers.

SOM	Brief Description	Area Share (%)	Area Share (km^2)
NGSA 1	**Archetype dominated by protected areas:** Areas with very high numbers of protected areas that are associated with the moderate–high influence of elevation, bulk density and high literacy.	3.3	14,412
NGSA 2	**Archetype dominated by very high-density population:** Areas with very high population density and with minimal influence of livestock and high fire activities.	15.3	67,169
NGSA 3	**Archetype dominated by moderately high information/knowledge access:** Mainly areas with a moderately high level of both male and female literacy, including fire-occurrence activities but with low poverty.	12.4	54,528
NGSA 4	**Archetype dominated by low literacy level and moderate–high poverty level:** Area characterized by moderate–high poverty and minimal fire activities, but with low levels of both male and female literacy.	20.1	88,036
NGSA 5	**Archetype dominated by rural remoteness:** Highly dominated by land-use management practices and remote from major towns but with a moderately low population density, protected area prevalence, and low livestock density.	10.1	44,408
NGSA 6	**Archetype dominated by remoteness from a major road:** Highly dominated by land-use management practices, which occur at a far distance away from major roads with moderately high poverty and literacy but with moderate fire and livestock activities.	8.7	38,273

Table 2. *Cont.*

SOM	Brief Description	Area Share (%)	Area Share (km²)
NGSA 7	**Archetype dominated by very high livestock density:** Areas with a very high livestock density and moderate levels of other drivers.	10.1	44,044
NGSA 8	**Archetype dominated by moderate poverty level and nearly level terrain:** Collectively driven by all drivers' categories but fairly dominated by land-use management practices, but with a moderate elevation and moderate influence of bulk density and poverty.	9.4	41,297
NGSA 9	**Archetype dominated by very rugged terrain and remote from a major road:** Areas with moderate elevation, high slope, and distant from the major road.	10.5	45,880
		100.00	438,046.88

3.4. *Categories of Archetypes According to State Administrative Boundaries and LD Status*

3.4.1. Degree of Land-Degradation Status per Archetype

Figure 6 links the archetypes with the LD status (degradation, stable, improvement; Figure 4), to highlight their proportions and potential interplay (Figure 7). Four archetypes with very high population density (NGSA 2), moderate–high information/knowledge access (NGSA 3), and moderate–high poverty level (NGSA 4), as well as NGSA 5—very remote from a major town—are associated with 61.3% of the large-area LD, while the other archetypes account for 38.7% of small-area degradation (Figure 7). Six archetypes—NGSA 2 to NGSA 5, as well as NGSA 7, with very high livestock density, and NGSA 8 with dominant land-use management practices and nearly level terrain—are responsible for 78.4% of the large-area stable status and the other archetypes for 21.6% of the small-area stable status (Figure 7). For the large-area improvement, six archetypes, NGSA 2 to NGSA 4 and NGSA 7 to NGSA 9 with rugged terrain, i.e., very high slope and moderate elevation, covered 78.7% while other archetypes account for 21.3% of small-area improvement (Figure 7). For the complementary table, see supplementary material, Table S3; and Section 6 for the full description and ranking of the archetypes in relation to LD status.

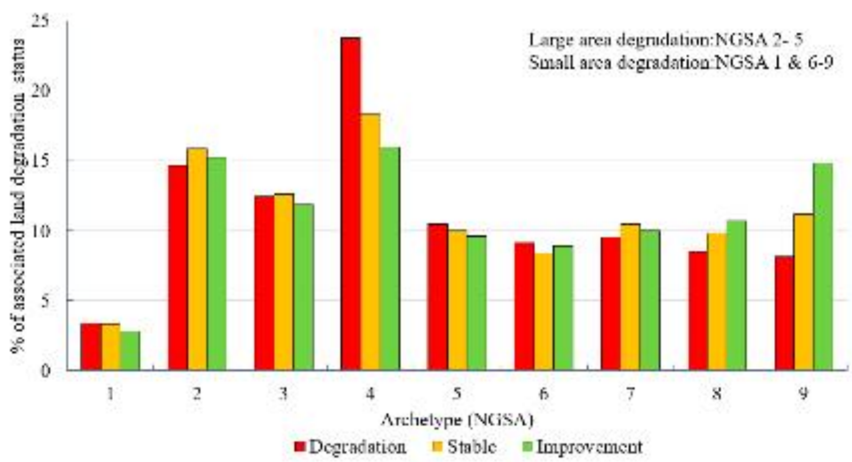

Figure 7. Archetypes in percentage of associated LD status (For full percentages, see supplementary material, Table S3).

3.4.2. Share of Land-Degradation Archetypes per State Administration Unit

State administrations manage land within their jurisdictions, hence they influence land-use decisions in Nigeria. Figure 8 shows the percentage share of the archetypes within a state's boundary (for the complementary table, see supplementary material, Table S2). Seven states, comprising Bauchi, Kaduna, Kwara, Nasarawa, Niger, Plateau, and Zamfara have all the nine archetypes. While four states, namely Benue, Kebbi, Taraba, and the Federal Capital Territory (FCT) are covered by eight of the nine archetypes. The remaining states have an uneven combination of all archetypes, with the portion of Abia state found within the NGS only embodying one archetype (i.e., NGSA 2). The five states comprising Niger (40.5%), Oyo (29.6%), Kwara (24.4%), Nassarawa (18.6%), and Ekiti (17.6%), have the largest shares of the archetype of NGSA 4, i.e., a moderate–high poverty level. The supplementary material Table S2 contains the grouping of the archetypes according to the state administrative units.

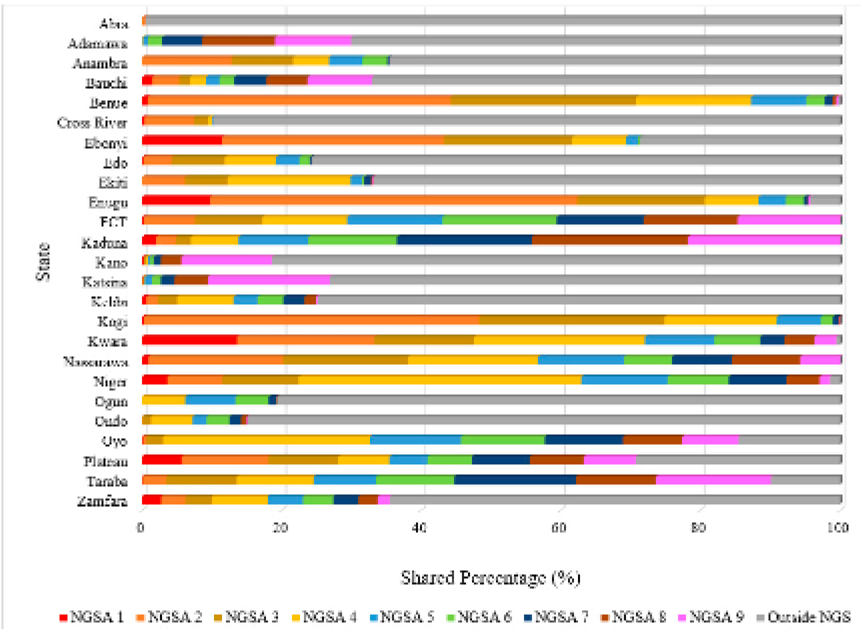

Figure 8. Share of LD archetypes by states in the NGS. Note: shares outside the NGS, that were not analyzed, are in grey. (For full percentages, see supplementary material, Table S2).

4. Discussion

4.1. Understanding the Archetypes of Large-Area Degradation

Areas identified to be under large-area degradation are archetypes with more than 10% of their areas experiencing biomass degradation (NDVI). Four major archetypes of large-area degradation were thus identified (Figures 5 and 7). Out of these, NGSA 3, with prolonged cases of fire occurrence, and NGSA 5, with rural remoteness from a major town (Figure 5), highlight land-use management practices as the drivers of large-area degradation in the NGS. NGSA 3 thus confirmed studies that have implicated fire-related activities such as charcoal making, farming, and hunting with bush burning as causes of LD [57,58]. The dominant characteristics of NGSA 5, on the other hand, contradicts the notion that land areas closer to major towns are more prone to LD than those farther away [16,17,29]. NGSA 5 rather reveals the rural areas and natural resource users in remote areas who adopt unsustainable land-use practices (of NGSA 3), such as continuous bush burning and deforestation, trigger LD [59].

Apart from archetype NGS 5 with high remoteness from a major town (Figure 5), the other three, i.e., archetypes with very high-density population (NGSA 2), moderately high information/knowledge access (NGSA 3), and moderate–high poverty level (NGSA 4), are dominated by high percentages of socio-economic drivers. Thus, socio-economic factors are major underlying causes that indirectly push other proximate drivers of large-area degradation in the NGS [29,60,61]. With the low population density of three (NGSA 3–NGSA 5) out of the four archetypes experiencing large-area degradation, high poverty, and low literacy, this factor can be inferred to be associated with large-area degradation in the NGS context [59,61,62]. This confirms studies such as [62,63], who reported that poverty intensifies a tendency to change vegetation cover, as many people deplete natural vegetation for fuel, food, and as a source of income because of fewer or no alternative livelihood options. This invariably points to the areas with high poverty and low population density, i.e., rural population, covering the northwest central and northeast of the NGS, encompassing the states of Kebbi, Niger, parts of northern Kwara, FCT (mainly around Abuja, see the area illustrated in Figure 5), and parts of Nasarawa, Plateau, Taraba, Kaduna, and Adamawa states, which have experienced extensive degradation [11]. Although, NGSA 2 with a very high-density population, hints that urban areas, with their high population density, are also associated with large-area degradation in the NGS, the degradation is not as extensive as in the low-population-density remote areas. Therefore, this result deviates from the general notion that a high-population density is the main cause of LD in Nigeria [13,33]. Hence, a high population density alone does not drive LD without certain complementary factors, such as poverty, illiteracy that restricts information or knowledge access, and poor national policies that are prevalent in Sub-Saharan African contexts [64]. Therefore, the three socio-economic sub-drivers—poverty, literacy and population density—are core interrelating drivers in large-area LD, that require attention in addressing LD in the NGS [29,62,65].

While the percentages of land-use management practices and socio-economic factors dominate as potential drivers of large-area LD, specific environmental drivers of the archetypes also underpin the large-area LD (Figure 5). The nearly level terrain condition, i.e., low-elevation–flat terrain of the four large-area archetypes, is known to encourage land cultivation in Nigeria [13]. In addition, the characteristics of low bulk density of NGSA 2, NGSA 3 and 5, and the high bulk density of NGSA 4 with moderate–high poverty level also highlight soil characteristics that encourage large-area degradation [42,43]. The low bulk density archetypes signify few areas in the southern part of the NGS with suitable soil for cultivation. The archetypes characterized by high bulk density on the other hand correspond to areas with the highest impact of agricultural management practices, such as machinery and high cropping impacts [42]. This represents 23% of the large-area degradation archetypes, and in turn reflects the widespread LD due to the high agricultural engagement by the rural dwellers in the zone [63].

4.2. Understanding the Archetypes of Small-Area Degradation

Five archetypes of small-area degradation were identified, that is, archetypes where degraded areas are less than 10% of the archetype area. LD and their drivers thus differ locally and are context-specific [5,60], and an archetype approach can help identify the socio-ecological contexts [66]. From the five small-area archetypes, three archetypes identified with very high presence of protected areas (NGSA 1), that are very remote from a major road (NGSA 6), have a very high livestock density (NGSA 7), and have high percentages of land-use practices (Figure 5). While the NGSA 1 reflects its conservation and restricted use status, the additional association of NGSA 1 with high and rugged elevations like NGSA 9, further explains its small extent of degradation. However, with its low proximity to major roads and major towns, degradation in protected areas as captured in NGSA 1 call for an investigation into the specific activities driving degradation in protected areas, such as encroachment by human activities [11,63], despite government regulations, particularly around communities that host protected areas [67,68].

In archetypes NGSA 6 and NGSA 9, the small-area degradation is highly driven by non-proximity to a major road, without much influence of other sub-drivers (Figure 5). Nearness to major roads is a measure of infrastructural development that influences accessibility and the spread of land-use management practices, including information [69]. Thus, NGSA 6 represents remote areas with restricted access, which can hamper the propagation of sustainable land-management initiatives [29,38,49]. As in NGSA 1 and NGSA 6, the very high livestock density configuration of NGSA 7 (Figure 5) is also associated with small-area degradation (Figure 7). The Guinea savannah in particular is currently under pressure from high grazing activities because the Sahel and Sudan savannahs have been extensively degraded by overgrazing [15,70], leading to competition for grazing resources and conflicts in the region [71]. Overgrazing has been associated with the disappearance of the typical savannah vegetation and the emergence of the Sudan–Sahelian Savannah in the NGS [15,72]. Thus, from the combination of drivers above, there is a critical need for an improved management of grazing resources, protected areas, and the governance of land resources in the NGS [11,36,68]. While all small-area archetypes are mostly dominated by the land-use management drivers, NGSAs 6 and 8 are the only small-area archetypes that are distinctly driven by the socio-economic drivers characterized by areas with low population density, i.e rural population with corresponding moderate information/knowledge access. Unlike other factors, poverty (high or low) is not a distinctive feature of these archetypes (Figure 5), hence this study cannot confirm the notion that 'the higher the poverty, the more the degradation' held by many studies of small-area degradation [38], as noted Table 1. Considering that poverty is widespread in the NGS, there is a need for integrating other social-demographic and social-relational data for a better understanding of the interactions between poverty and LD.

4.3. Archetypes and Policy Insights

As multiple factors are associated with LD, policy interventions aimed at achieving SLM need to be inter-sectoral. However, many policies in Nigeria, such as the Nigerian National Agricultural Policy, focus on single sectors and often do not have LD reduction as a primary objective [10]. Key policy topics related to these findings are sustainable use and management of natural resources, poverty reduction, environmental awareness and education, strategy to reduce dependence on land and natural resources for livelihoods, and inclusion of LD in land-use planning.

With the extensive LD in the NGS, policies for the sustainable management of natural resources including water, soil, and biodiversity, as well as their coherence, are essential [73]. While several response programmes such as the Nigeria National Policy on Environment are promulgated to address activities that cause LD [74], they remain reactive without an effective scaling up to tackle the drivers of LD. For example, the proposed national policy on the rediscovery of grazing routes and reserves remains unprepared to address LD because the advocates focus on the profit and the pressing need to tackle the farmers and herders clashes in Nigeria [67,71], without a recourse to the fact that spatial developments in Nigeria have overtaken several historical grazing spaces [67]. The polarized nature of Nigeria between sectional and ethnic divides further raised several counter notions with socio-political undertones to such policy moves by the government [75]. This subsequently affected the acceptance of related policies such as the 10-year National Livestock Transformation Plan (NLTP), ranching plan, and open grazing [67]. While it is obvious that degradation induces competition and tension among natural resources users, policy decisions on land-based issues require a special focus on LD and land restoration.

Although results did not explicitly show that only low/high poverty is associated with large-/small-area degradation, poverty contributes to the different archetypes identified. Nigeria has about 83 million (40%) of its population living below $1.90 per day, comprising 52% rural dwellers whose livelihoods are predominantly tied to agricultural activities [76,77]. About 30 million more Nigerians are expected to be added to the national population living in extreme poverty by 2030 [77]. Many of the poor depend on livelihood activities such as charcoal making and hunting with bush burning that promote LD [57,58]. Archetype NGS 4, which covers the largest proportion of the NGS (20%) and has moderate–high poverty and a low level of both male and female literacy, is characterized by large-area degradation. Two broad groups of the country's poverty alleviation programmes (PAPs) have been identified in Nigeria [78]: (a) the Core Poverty Alleviation Programmes (CPAPs) such as Better Life Programme for Rural Dwellers (BLP) and Family Economic Advancement Programme (FEAP), and (b) the Non-Core Poverty Alleviation Programmes (NCPAPs), which include the National Agricultural Land Development Authorities (NALDA). Such policies had no long-lasting effects [78,79] and did not focus on the intersections between poverty and LD. Other policies such as the Agricultural Development Projects (ADPs) and Vision 20-2020 are in a dying state [78,79], with most interventions aimed at increasing farmer revenue and reducing poverty, and mainly focus on improving input supply without giving attention to improving land management.

Nigeria has about 56.9% adult illiteracy [80], with variations across states and regions including urban and rural areas (i.e., urban 74.6% and rural 48.7%). NGSA 3 shows the linkage of low male and female literacy with large-area degradation. Most farmers and herders in Nigeria did not finish primary education and are less likely to access and understand the little knowledge and information disseminated through extension services or lack the resources to access this information themselves [79,81,82]. While the use of mobile phones is promoted to improve access to information, little or no information is provided on sustainable land-use and management. According to [83], technology is necessary to scale up the adoption of initiatives amongst resource-poor users. With the widespread poverty, weak industrial presence to absorb the increasing population, and the reliance on the primary sector, the quest to exploit environmental resources supersedes interest for environmental protection and management [84]. Hence, pathways to improving land management need to be sought both outside agriculture (e.g., creating employment opportunities outside agriculture) as well as within agriculture through improving farmers/herders' access to sustainable land management practices as well as motivating their adoption [85].

With the growing LD, effective policy on land-use planning is critical for degradation response in Nigeria as the current land-use policies and practices do not adequately consider sustainable land management [10,86]. The historic lapses in the National Land Use Act (LUA) of 1978 persist, whose focus only recognizes land ownership and promotes land access without a sustainable land-use plan or governance to cater for the pressure from the growing population. Calls to review the LUA to give room for a more sustainable policy for land-use planning and governance in Nigeria [10,13], remain unheeded. A challenging question is thus: what opportunities can be identified for promoting SLM [10]?

4.4. Archetypes and Sustainable Land Management (SLM)

Based on literature and the study results, sustainable fuelwood management/energy efficiency, reforestation and afforestation, sustainable pastoralism, and structural land management measures are potential interventions to address LD.

In Nigeria, over 70% of the population rely on wood fuel for cooking, which is an underlying driver of deforestation and associated LD [63]. In recognition of the reliance on fuel wood, sustainable fuelwood management (SFM) is being promoted under the United Nations Development Programme (UNDP)/Global Environment Facility (GEF) project on management of fuel wood in mitigating the effects of climate change such as in Kaduna State, Nigeria [87,88]. While such initiatives have made some progress in establishing woodlots, producing energy-efficient cooking stoves, and establishing local forest management committees, low community buy-in, land tenure, and governance remain key constraints [88]. A review of such initiatives can provide insights on how to improve states' SLM outcomes and out-scale them to other states in the NGS. Thus, SFM has some potential for promoting landscape stewardship in the region [87,89].

Tree-based programmes also hold potential to reduce LD and remain the principal focus of restoration programs [90]. Reforestation, afforestation, and agroforestry have been found advantageous and successful around the world and in Nigeria, particularly in LD response [91]. In Nigeria, successive governments at all levels have worked collaboratively to encourage and implement various afforestation projects [92]. For instance, among the frontline states of the Great Green Wall Afforestation Programme, tree planning campaigns with eucalyptus species and shelter belts for sand dune and degradation fixation are commonly practiced [74,92]. Therefore, land users in Nigeria can be incentivised to participate in tree-based initiatives, which have recorded successes elsewhere, such as in Kenya [64], to reawaken interest in combating LD. Such initiatives can focus on Niger, Nassarawa, Kwara, and Kogi, including Kaduna and Oyo states, due to the prevalence of large-area LD archetypes. Agroforestry, a multifunctional practice of cropping with trees and shrubs on arable land, is also a potential SLM practice that can improve land productivity, is a low-cost and adaptable tree-based initiative [91,92], that contributes to food security and land resource conservation [91].

With the evidence of high livestock grazing activities in archetype NGSA 7 (Figure 5), traditionally, pastoralism is predominantly practiced in northern Nigeria, with southward movement following the rain and in search of pasture and water during the dry season. Overgrazing causes LD, and indiscriminate overgrazing has caused negative stereotyping and fuelled tensions between pastoralists and non-pastoralist-actors, causing loss of lives and properties as well as communal crisis [67,71]. In some cases, overgrazing by livestock and excessive open grazing lead to the failure of afforestation programmes, including severe violation of protected areas across West Africa [67,93]. While pastoralism under a proper management system is ecologically, economically, and socially viable [94,95], climate change and poor land management in the face of growing national population and pressures from neighbouring herding countries make traditional pastoralism unsustainable in Nigeria [71,93,94]. Studies thus call for controlling open grazing to check indiscriminate overgrazing and secure livestock production in Nigeria [75,96].

In view of several environmental consequences of the archetype driven by terrain characteristics, avoiding degradation-prone rugged terrain is key to maintaining the remaining biomass of the zone. Investing in SLM structures such as land levelling, terracing, and contour farming are critical to tackling LD [97,98], particularly on agricultural landscapes like the NGS, where engagement in farming remains necessary for livelihood sustenance [12,13], and biodiversity and natural conditions are threatened largely by agricultural expansion [13]. Terracing and high-altitude afforestation for erosion control, for example, have been recognized to reduce loss of soil and LD on sloped terrain [99]. Similarly, contour farming and staggered contour trenching, which involves planting of crops across a slope based on elevation contour lines are also effective for managing degradation on rugged–steep terrain [99].

5. Conclusions

This study identified nine archetypes of LD drivers in the NGS, which are mostly dominated by social-economic, land-use management practices, and a slight influence from environment drivers. Specifically, four archetypes characterized by a very high-density population, moderately high information/knowledge access, and moderate–high poverty level, as well as remoteness from a major town, account for 61.3%, 78.4%, and 78.7% of total degraded, stable, and improvement areas, respectively. LD is mostly evident in states bordering the northwest to the central and northeast of the NGS, such as Niger state, which have predominantly large rural farming communities. Besides revealing the LD drivers, the archetypes characteristics provide a basis for determining and prioritizing relevant SLM policies and practices such as poverty reduction, creating environmental awareness and promoting sustainable pastoralism as well as robust land-use planning to strengthen land governance in Nigeria. Despite the limitations of spatial data on the driving factors, the outputs from this study provide a useful guide on how archetypes can serve as a tool for progressing Nigeria's LDN through SLM. Like most unsupervised classification techniques, field validation of the archetypes results is necessary because of the adopted self-organizing mapping techniques. However, this could not be conducted because mobility limitations and scarcity of spatially explicit data limited the number of variables that could be used for this study. As more spatially explicit data on Nigeria and Africa become available, they need to be integrated in future studies of archetypes as well as validating them with field observations.

Supplementary Materials: The following are available online at https://www.mdpi.com/2072-4292/13/1/32/s1, Figure S1: Correlation matrix between the selected drivers of land degradation archetypes, Figure S2: Training process for determining the nine cluster separations that are suitable for the land-degradation archetypes, Figure S3: The plot showing the aggregated profile of each neuron as synthesized by the selected drivers of land degradation, Figure S4: Quality of the nine clusters in the codebook, Figure S5: Neighbor distances between the neurons for the clusters, Table S1: Calculated Z-score normalized values of drivers characterizing the nine (9) distinctive archetypes of land degradation, Table S2: Archetypes and percentage share per state administration unit, Table S3: Archetypes and share of land status.

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Conflicts of Interest: The authors declare no conflict of interest.

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7.3 Paper 3: Key dimensions of land users’ perceptions of land degradation and sustainable land management in Niger State, Nigeria

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Key dimensions of land users' perceptions of land degradation and sustainable land management in Niger State, Nigeria

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Abstract

Declining land productivity remains a challenge for agriculture-based livelihoods and for achieving food security. Yet identifying how land users perceive land degradation and their capacity to manage land in an environmentally sustainable manner, can influence the measures initiated to address it. Using a case study of Niger State, Nigeria, this study examines land users' perceptions of land degradation and land management measures to address it in the Nigerian Guinea Savannah. We used the Moderate-resolution Imaging Spectroradiometer derived Normalized Difference Vegetation Index as a proxy for degradation status, selecting 30 communities based on the extent of degraded areas. We adapted the World Overview of Conservation Approaches and Technologies, Sustainable Land Management questionnaires to capture perceptions and administered 225 questionnaires to land users. Through key informant interviews, we collected narrative insights and data on perspectives and motivations of land users to understand land degradation situations and to interpret the questionnaire surveys. We analysed data through descriptive and Principal Component Analysis and qualitative analysis. Our analysis identified four perceptions dimensions of land degradation characteristics, two perceptions dimensions of land degradation drivers, and six perceptions dimensions of sustainable land management. The results also confirmed that degradation in Niger State is both due to widespread unsustainable human activities within Niger state and those by migrant farmers and pastoralism from adjoining Sudan Sahelian states that push people further south, a leakage of ongoing LD and conflicts in other areas. To deal with local land degradation in Niger State, improved land tenure, alternative livelihood strategies, poverty eradication and awareness, nature-based SLM practices such as tree-based initiatives, environmentally friendly agriculture such as Farmer Managed Natural Regeneration supported by the necessary political will and institutions are critical.

Keywords: Land users, Perceptions, Land degradation, Sustainable Land Management, Savannah, Nigeria

1.0 Introduction

Land degradation (LD), that is, the long-term loss of biomass or decline in land productivity (Le et al., 2016; UNCCD, 2015) occurs in several world regions, with differentiated impacts on ecosystems and human well-being (Olsson, et al., 2019). In Sub-Saharan Africa (SSA), where many rural population depend largely on agriculture and natural resource use, LD contributes to worsening their livelihood vulnerability (Webb et al., 2017). About 28% of the 924.7 million Africans occupy or own degraded land (Le et al., 2016). LD in the SSA involves the progressive loss of vegetation, the conversion of vegetated land to bare lands or desert-like landscapes, including an increase in sand dunes, which results in the silting, drying, and shrinking of water bodies, such as the Lake Chad in the West African Sahel (FGN Federal Government of Nigeria, 2012; Gadzama, 2017). In West Africa, Nigeria experiences one of the highest rates of LD with biomass decline amounting to about 400,000 ha per year and agricultural productivity losses (FAO, 2010). Demand for agricultural land displaces forests or leads to agricultural productivity losses (Arowolo and Deng, 2018), which drives degradation in remote areas (Adenle and Ifejika Speranza, 2020). The management of the country's agroecological zones such as the semi-arid savannah ecosystem and their resources are constrained by land-use change, unsustainable agricultural practices, and poor land governance (CILSS, 2016; Ifejika Speranza et al., 2019).

In addition to socioeconomic constraints, a poor understanding of land users' experiences, inappropriate governance and low attention to sustainable land management (SLM) limits the effectiveness of measures to reduce LD (Adenle and Ifejika Speranza, 2020; Ifejika Speranza et al., 2019). Thus, considering the perceptions of LD by land users and other actors is crucial for implementing effective measures (Jendoubi et al., 2020; Mirzabaev, 2016). This is important given that the local context, local responses to multi-level drivers, and associated land-use decisions influence global land change (Lambin et al., 2006; Malek et al., 2019). Although various SLM measures exist (Liniger et al., 2019), their misalignment with land users' experiences hinders their extensive adoption and performance (Mirzabaev, 2016; Pulido and Bocco, 2014). Also, the low priority given to SLM practices and implementation slows the successful tackling of LD through SLM (Nkonya et al., 2016). Though studies have attributed regreening success to approaches that incorporate land users' perspectives and apply appropriate governance arrangements (Mortimore, 2016), there is still a strong need for a people-centred approach that integrates land users' and other relevant actors' perspectives and experiences of LD into SLM measures for more effective outcomes (Jendoubi et al., 2020; Mirzabaev, 2016). Understanding perceptions of LD by multiple actors is thus essential for identifying pathways to SLM and effective governance (Aíza et al., 2021; Herrmann et al., 2020).

This paper examines how local land users in Niger State in the Nigerian Guinea Savannah (NGS) perceive LD and how they rate SLM solutions. With LD affecting 16%–62% of the land, Niger State is a representative of LD-affected areas in the NGS (Adenle et al., 2020). Our study aligns with the global interest of integrating people, local knowledge and community experiences in understanding land concerns (Kugler et al., 2019; Mashi and Shuaibu, 2018), and tackling global challenges such as climate change (Badmos et al., 2018), biodiversity management as well as LD

(Díaz et al., 2015; Scholes et al., 2018). This is particularly relevant in rural contexts in Nigeria, where degradation threatens and adversely impact people with natural resources dependent livelihoods (Adenle et al., 2020; Ifejika Speranza et al., 2019). Despite the worsening degradation and the urgent need for better governance of land and natural resources (Ifejika Speranza et al., 2019; Macaulay, 2014), the identification of LD mitigation measures based on local experiences has received little attention in Nigeria (Adenle and Ifejika Speranza, 2020). Therefore, understanding perceptions of LD by multiple actors is essential for identifying pathways to SLM and effective governance (Aíza et al., 2021; Herrmann et al., 2020). We however focus on how rural land users in Niger state, a region affected by LD in the NGS, perceive LD, their drivers, and related SLM and governance measures. We addressed the following research questions: (i) What is the spatial extent and status of LD in Niger State? (ii) How do land users characterise and identify indicators of LD in Niger State? (iii) What drivers of LD do they identify in the study area? (iv) How do the land users perceive SLM practices and strategies for minimizing LD? Lastly, (v) what insights can be drawn for SLM and governance in the study area?

2.0 Materials and Methods

2.1 Study Area

Niger state is located in west-central Nigeria (the middle-belt). It is the largest of the country's 36 states covering one-tenth of the country's landmass (Fig. 1). Niger state is in the Nigeria Guinea Savannah (NGS) agro-ecological zone, with a mean annual rainfall of 782-1250 mm and a mean annual temperature of about 27ºC (Iloeje, 2001). Trees such as the African locust bean *(Parkia biglobosa)* and Shea butter (*Vitellaria paradoxa*) are widespread in the state.

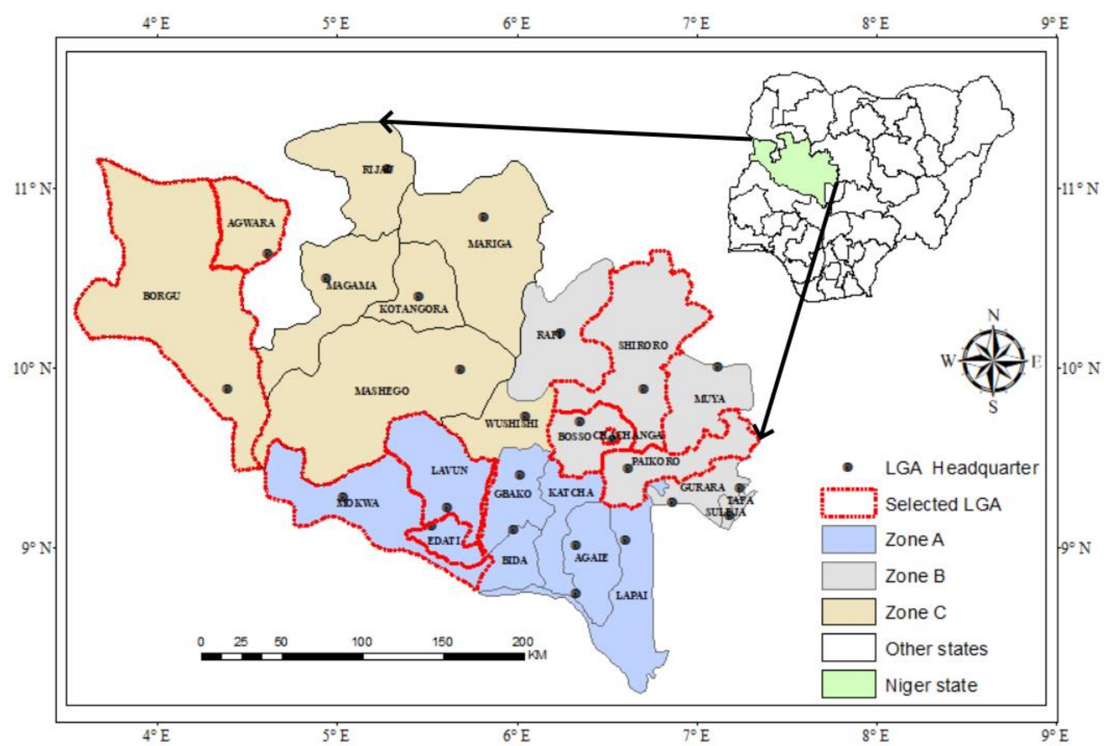

Fig. 1: Map of Niger State, showing the three Geopolitical zones (A, B, C) and the LGAs

The River Niger and the River Kaduna flow through the state. Niger state also includes protected areas such as the Foge Islands and the Kainji Lake National Park, and tourist sites such as the Gurara Waterfalls. Administratively, the state comprises 25 Local Government Areas (LGAs) and 3 "Geopolitical Zones" (a category used by the Nigerian government to select political representatives), namely zone A-B-C, with their headquarters in Bida, Kuta and Kontagora, respectively (Alhaji et al., 2018). These three geopolitical zones also correspond to three agro-geographical zones of Niger state with varying climatic conditions and farming methods (Alhaji et al., 2018). The state had an estimated population of about 5,550,000 in 2016 -National Bureau of Statistics (NBC, 2017), mostly rural dwellers, who engage in farming crops such as yam (Iloeje, 2001). They also keep livestock such as cattle, goats, and sheep for meat production. The population belongs to diverse ethnic groups including the Nupes' who are in the majority, the Gwaris', the Kambaris' and the Bisasan as well as the nomadic Fulani pastoralists.

2.2 Theoretical framework

We understand human-induced LD as an outcome of social-ecological interactions (Batunacun et al., 2019; Nkonya et al., 2016). We adapt Schakelton et al's., (2019) conceptual framework of the factors influencing peoples' perceptions to the case of LD (Fig. 2). The authors identified six broad factors influencing LD perceptions which correspond with the boxes and circles in Fig. 2. These factors are:

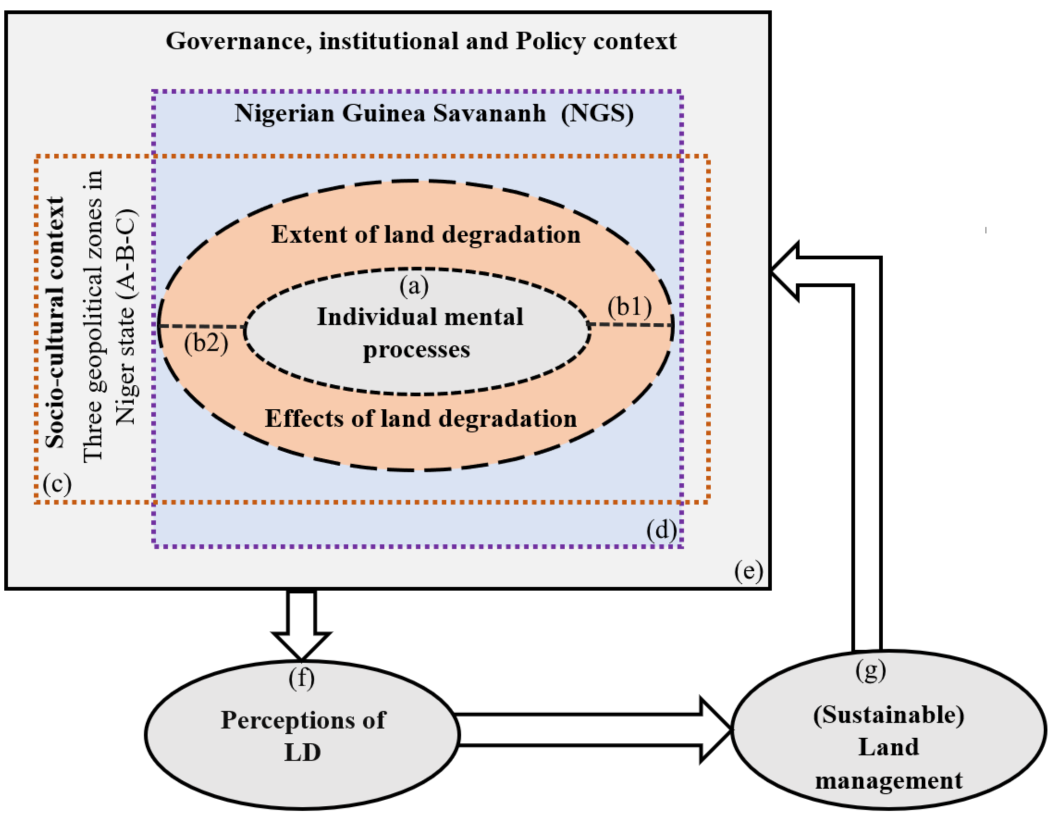

Fig. 2: Conceptual approach for linking land users perceptual experience for LD (Adapted from (Shackleton et al., 2019)

a) Individual (e.g., land users') mental processes: As perception is a mental construct that changes over time and space, Shackleton et al., (2019: 7) identify demographic factors, experience, "*knowledge systems, sense of place, social relationships and group membership, and value systems*" as fundamental factors influencing perceptions at the individual level **(Fig 2.f).** In this study, we chose socio-economic attributes such as age and education.

b1) Extent of LD in Niger state: The ecosystem of study is the savannah in Niger State and its characteristics include the degree of LD. Degradation can occur in various severity and spatial extent such as in small patches (small-area degradation) or over larger areas-large-area degradation (Adenle and Ifejika Speranza, 2020). Thus, perceptions of degradation might differ depending on the type of LD, its history or duration.

b2) Effects of LD: With effects, we refer to changes (positive or negative) to the social-ecological system (SES) or its parts due to LD (Shackleton et al., 2019). The social and economic effects of LD have been widely described (Nkonya et al., 2016; von Braun et al., 2013). Ecologically, LD is negatively perceived as it reduces productivity, but perceptions might differ depending on the type and severity of degradation as well as the degree of livelihood dependence on land and the ecosystem services (Crossland et al., 2018; Pulido and Bocco, 2014; Tesfahunegn, 2019).

c) Socio-cultural context: The socio-cultural context refers to the three geopolitical zones, namely zone A-B-C. Shackleton et al., (2019: 11) describe socio-cultural context as the ways people interact with one another in "*a social realm of rules, traditions, practices and ideas*". The authors differentiate between structural socio-cultural factors such as "*social institutions and rules*" including land tenure systems, land ownership and land management history, "*level of socio-economic development*" such as wealth levels or social value systems including those shaped by media discourses. Further, social structures such as gender, class, ethnicity or race and their intersections, influence how land users respond to LD and how LD affects them (Shackleton et al., 2019). Non-structural socio-cultural factors include social memory, which can change over time.

d) Landscape context – the NGS: The landscape context is the NGS agro-ecological zone. With this dimension, a focus is on the larger context, that is, the NGS, which covers about 49% of the country's landmass and 25 of its 36 states. In this context, ecosystem type, land use and cover, availability of land for conversion to agriculture, management history are key factors identified to influence perceptions of LD.

e) Governance, institutional and policy context: This includes "*historical processes, institutional frameworks, international agreements, legislation, regulation and enforcement, policy and governance strategy*" (Shackleton et al., 2019: 7). Policy and governance affect people's perceptions by shaping values and social relationships, and attitudes and behaviours (Shackleton et al., 2019) through land management **(Fig. 2 g)** that over time feedback to the social-ecological system of focus.

Other definitions used in this study relating to SLM **(Fig 2. g)**: Institutional actors refer to persons, stakeholders, or policymakers, who are respected, including those involved in formulating and making decisions on SLM (von Braun et al., 2013). Technological practices are field based/physical SLM approaches that reduce LD using measures such as agronomic, vegetative, structural, and management measures to enhance land productivity (Liniger et al., 2011; WOCAT, 2018). Conservation practices aim to conserve land resources such as soil, water, and vegetation, to ensure the maintenance or improvement of a healthy and functioning landscape (Liniger et al., 2011; WOCAT, 2018). Policy initiatives refer to activities guided by specific visions of a government or organization (e.g., legislation, regulations, and plans), and principles to achieve set goals (Ifejika Speranza et al., 2019).

2.3 Methods

2.3.1 Assessing land degradation

To capture land conditions in Niger state and the landscape context for the greater NGS, we used a LD map derived from the Moderate-Resolution Imaging Spectroradiometer Normalized Difference Vegetation Index (MODIS NDVI) between 2003 to 2018 as a proxy (Adenle et al., 2020) (Fig. 3, Box 1). The map was developed by calculating the mean of the yearly sum of the (monthly 10-day) maximum NDVI and by applying Residual Trend Analysis (RESTREND) to adjust for the effects of rainfall on the biomass condition over the NGS. The result captures land with declining (degrading), stable, and increasing (improving) biomass conditions in Niger State (Adenle et al., 2020), which guided in identifying the LD status and communities affected by LD in the 3 geopolitical zones (Fig. 3, Box 1). In the zones, 8 accessible LGA's with no security threats (Fig.1) were purposely selected. From the selected LGAs, 30 LD affected villages linked to the identified archetypes of rural remoteness (Adenle and Ifejika Speranza, 2020) were selected.

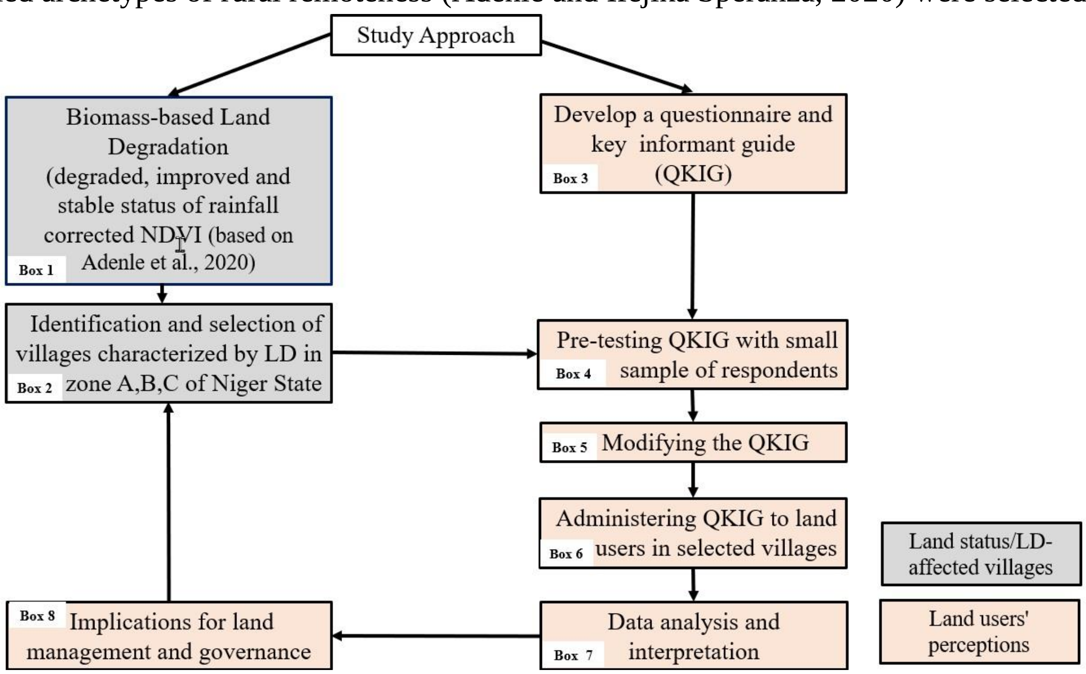

Fig. 3: Flowchart of the research process

They include in zone A, eleven villages in Mokwa, Lavun and Edati LGA, in zone B, ten villages in Boss, Shiroro and Paikoro LGA, and in zone C, nine villages in Agwara and Borgu LGAs (Fig.3, Box 2), (Supplementary Table (ST) 1-3). The difference in the number of selected villages was due to access and insecurity reasons. The eligibility criteria for selecting respondents for questionnaire administration in each village includes household heads with age ≥20 years or people who have engaged in land use-based activities in the NGS for (≥10 years) and live in the village. We assumed that respondents fulfilling these characteristics will be able to provide relevant information on LD. Before data collection, village meetings were conducted to inform the villagers about the study and to obtain approval from the relevant authorities and willing respondents.

2.3.2 Questionnaire

We developed a semi-structured questionnaire based on the qualitative results from three Focus Group Discussions (FGD), the LDN workshop report from Nigeria and the WOCAT (FGN, 2018; Liniger et al., 2011; Mganga et al., 2015) (Fig. 3, Box 3-5). We then presented respondents a list of LD characteristics and LD drivers and asked them to rate them on a 1-5 Likert scale (1 =Strongly disagree, 2 =Disagree, 3 =Neutral, 4 =Agree, 5 =Strongly agree). The questionnaire contained sections on the LGA, village, house and socio-economic characteristics of the respondents and their experiences (characteristics /drivers) of LD. The respondents also provided information on SLM by ranking four categories - institutional actors, technological- and conservation practices, and potential policy initiatives relevant for SLM.

2.3.3 Data collection

Fieldwork was conducted from February to May 2019, with 225 questionnaires distributed across the three geopolitical zones (Fig. 3, Box 6). The respondents were mostly farmers (Fig. 3, Box 2), who cultivate crops such as yam and sorghum. They were mostly male respondents due to the socio-cultural and religious context, which encourages men to engage in farming activities while women assist or engage in post-harvest processing. Most interviews took place on a one-one basis and lasted between 50 minutes to 1 hour 30 minutes. Based on respondent availability, key informant interviews (10-15 experts) for the three geopolitical zones were used to obtain additional information for interpreting the questionnaire data (Fig. 3 Box 7) and the land management implications of LD (Fig. 3 Box 8). The questionnaires were administered in local languages (Hausa, Nupe, and Gbagi) and translated back to English with the help of trained field assistants. Narratives were collected through the recording of key informant interviews and three focus group discussions (FGD). The data was anonymized to protect respondents' privacy.

2.3.4 Statistical analysis

Using the Statistical Package for Social Sciences (SPSS), we performed descriptive and inferential analysis of respondents' perceptions of LD characteristics/drivers/SLM. We examined the preliminary examination of (no) multicollinearity (correlation matrix) between variables at a correlation coefficient > 0.8 (Matter et al., 2021) showing that most of the variables were not highly correlated. We tested the suitability of the variable set for Principal Component Analysis (PCA), through the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test based on previous studies, with a KMO value >0.5 and a significance level <0.05 considered appropriate (Matter et al., 2021). Using PCA, we reduced the dimensionality of the initial large set of LD characteristics/drivers/SLM. Based on the total variance explained by the breaks from the scree plot (Supplementary File 1), and the insights from parallel analysis, the transformed and the extracted LD characteristics/drivers/SLM with strong influence were reported as components (Jolliffe and Cadima, 2016; Patil et al., 2017). The components are derived aggregates of the original variables that are representative of the loading from the original large dataset (Tabachnick and Fidell, 2014). Through the components loading and rotation (i.e., Varimax/Promax Rotation), we interpreted the components based on contributions from LD characteristics/drivers/SLM. We considered Eigenvalue contribution >0.75, 0.75–0.5, and 0.5–0.3 as 'strong', 'moderate', and 'weak' perception influence respectively (Liu et al., 2003). Interpreted components were identified for the Perceptions of LD Characteristics (PLDC), Perceptions of LD Drivers (PLDD) and Perceptions of Sustainable Land Management (PSLM) practices. To capture the Sustainable Land Management (PSLM) practices. To capture the respondents' priority for SLM measures, we analysed the SLM practices with the Relative Importance Index (RII). RII has been applied to capture perceptions and to rank measures that can guide the formulation of policies (Azman et al., 2019; Somiah et al., 2015). The RII (Eq. 1) involves calculating the mean for the SLM options based on the weights on the Likert scale assigned by the respondents.

$$\mathrm{RII} = \frac{\sum \mathrm{W}}{\mathrm{A}*\mathrm{N}} \text{ (Eq. 1)}$$

Where RII = Relative Importance Index; W= weight given to each SLM by respondents (ranging from 0 to 4); A = highest weight (i.e., 4 based on a 5-point Likert scale in this case); and N = total number of respondents. The higher the RII, the more important/effective the land users consider the SLM practice. Thus, SLM with the highest weight is ranked RII = 1, while the next lower weight has RII = 2, and so on. The narrative data collected through informant interview/FGD were analysed through content analysis.

3.0 Results

3.1 Land conditions

Based on the MODIS derived NDVI as a proxy for ongoing degradation status, Fig. 4 and Table 1 shows the extent of LD in Niger State (Adenle et al., 2020).

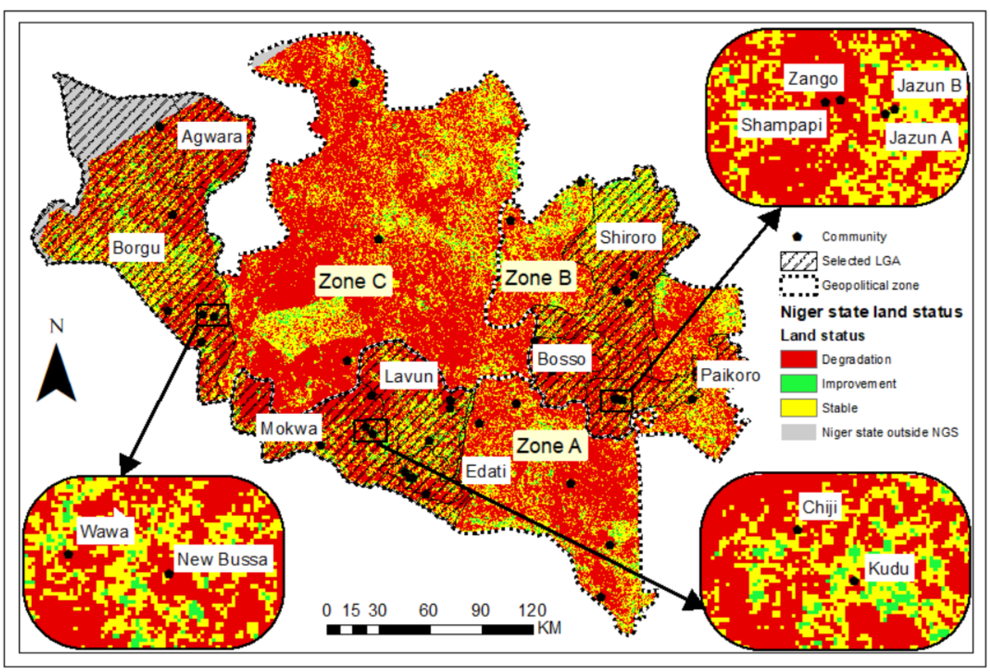

Fig 4: Selected villages and Land-degradation status in Niger State based on MODIS NDVI (Adapted from (Adenle et al., 2020) (Note: the grey area in the Northwest lies outside the NGS and was not part of this analysis)

Table 1 Extent of land degradation status in Niger state (in % and km²)

Land status	Total Area (km^2)	Total area (%)	Zone A (km^2)	Area (%)	Zone B (km^2)	Area (%)	Zone C (km^2)	Area (%)
Degradation	48045.4	62.9	12273.2	65.5	10199.7	57.8	25964.1	66.8
Stable	24060.9	31.5	5651.3	30.2	6736.8	38.2	11449.8	29.5
Improvement	3131.7	4.1	807.6	4.3	721.4	4.1	1434.2	3.7
Area within NGS	75238.1	98.5	18732.1	100.0	17657.9	100.0	38848.1	100.0
Area outside NGS	1124.9	1.5	0	0	0	0	1124.9	1.5
Total area	76363.00	100.00						

Table 1 shows the LD status according to the three geopolitical zones in Niger state over the 16 years (Adenle et al., 2020). Degradation is extensive across the three zones and occurs in two-thirds of the area. Zone C has the largest extent of LD, next to zone A and zone B. Zone B accounted for the largest stable area covering 38.2%. Improvement is visible in less than 5% of the area in each zone.

3.2 Respondents' socioeconomic characteristics

Table 2 shows the socioeconomic characteristics of the 225 respondents.

Table 2: Socio-economic and other characteristics of respondents in Niger state (n= 225)

Parameters	Frequency (N)	Percentage (%)	Parameters	Frequency (N)	Percentage (%)
Gender			**Source of livelihood**		
Male	218	96.4	Farming	160	71.1
Female	7	3.1	Household activity	5	2.2
Age			Wage labour	5	2.2
20 to 29	22	9.8	Small business	4	1.8
30 to 39	54	24	Salaried employee	36	16
40 to 49	62	27.6	Studying	1	0.4
50 to 59	49	21.7	Remittances	1	0.4
60 and above	38	16.9	Others	10	4.4
Marital status			**Average income per month (USD)**		
Single	10	4.4	1 to 24	3	1.3
Married	144	64	24 to 48	7	3.1
Divorced/Widowed	59	26.2	48 to 72	22	9.8
Education level			72 to 96	155	68.9
Quranic/Vocational	43	19.1	None	38	16.9
Primary	29	12.9	**High access to land for farming**		
Secondary	34	15.1	Yes	212	94.2
Tertiary	69	30.7	No	13	5.8
None	39	17.3	**Land ownership**		
Years of residence			Do not know	42	18.8
10yrs - < 20yrs	9	4	Inherited	140	62.3
20yrs - < 30yrs	29	12.9	Bought/Ownership	27	12.2

30yrs and above	175	77.8	Rented/Leased	5	2.2
Household size			Others	10	4.5
1 to 4	56	24.9	**Awareness of LD**		
5 to 8	110	48.9	Yes degraded	191	75.1
9 to 12	52	23.1	No not degraded	30	11.5
13 and above	7	3.1	Do not know	34	13.4

(Source own field survey 2019)

3.3 Perceptions of land degradation characteristics

Fig. 5 shows that more than 70% of the land users agreed to the presented LD characteristics as occurring in their communities. The major indicators of LD in Niger State (over 80% agreement), include soil erosion, desertification, the decline in native species, change in vegetation structure with loss of palatable species, the experience of drier conditions with loss of soil fertility and increasing encroachment into protected areas (Fig. 6). The breakdown of the response on LD characteristics is presented in ST:4. The PCA identified four components of perceptions of LD characteristics (PLDC) (Table 3) with a cumulative loading of 62.8% (ST 6c)

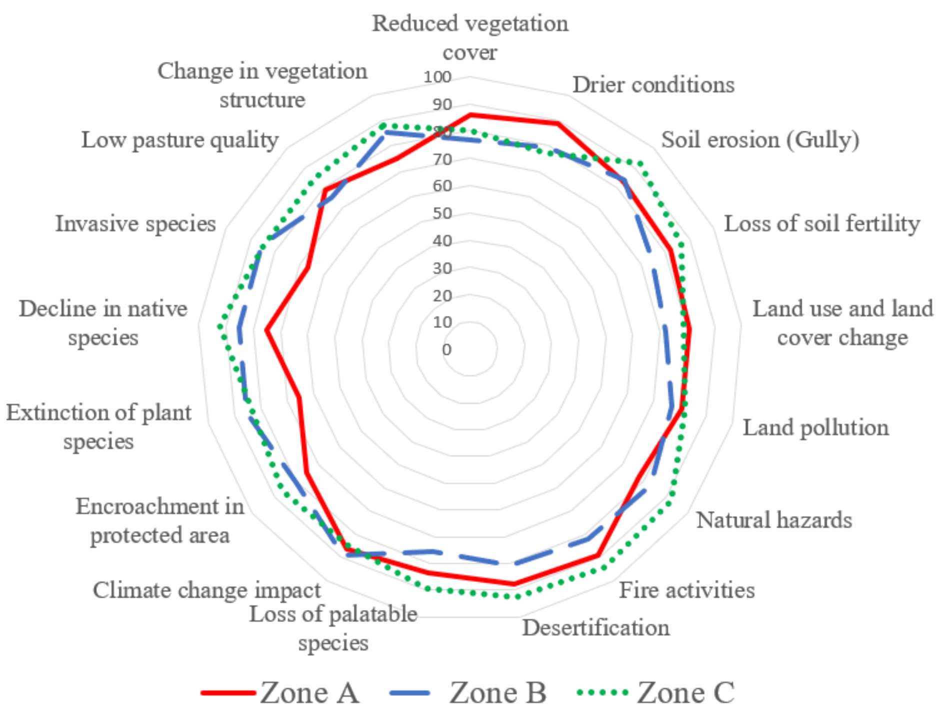

Fig. 5: Land users' perception of LD characteristics (Source: own field survey data 2019)

Table 3: Perception components of LD characteristics (PLDC)

Components	Brief description of PLDC
PLDC 1: Vegetation condition dominated characteristics	Perception is dominated by changes in vegetation structure, low pasture quality, presence of invasive species, and extinction of plant communities (SL), but moderate declining native vegetation, encroachment into protected areas, fire and desertification (ML).
PLDC 2: Soil condition dominated characteristics	Perception loading is dominated by moderate soil erosion (Gully), loss of soil fertility, land pollution, fire and desertification.

PLDC 3: Vegetation with Sudano-Sahelian characteristics	Perception is dominated by strongly reduced vegetation cover typically found in the Sudan-Sahel (SL), drier conditions, natural hazards, fire and desertification (WL).
PLDC 4: LULC with the prevalence of drier conditions	Perception dominated by Land Use Land Cover Change (LULCC) (ML), drier conditions (SL), reduced vegetation, gully erosion and encroachment into protected areas (WL)

Legend: Strong loading; SL, Moderate Loading; ML, Weak Loading; WL.

key informant interviews from LGAs in the zones confirm these characteristics of PLDC and descriptive analysis According to informant 1 from Wabi village, Lavun LGA, zone A, *"here is a great concern about our environment because some of the characteristics of the Sahel and Sudan region, which we hear or see on television are now noticeable in our areas like sandiness, barren soil and loss of vegetation (Fig.6). There are many species of wood and plant that have been lost due to logging promoted by international trade with the Chinese who entice people with money to get those woods. Our environment is now changing with a lot of degradation and pollution with more absence of natural vegetation; we do not feel comfortable like we used to feel".*

In Bako village Bosso LGA, zone B Informant 2 said *"before we only had just two houses and families living here but looking around, we have more people and more houses. It was even very difficult to get to the Lapia market or main Niger to Abuja express road because we were surrounded by thick dense natural forest, which is no more available like in my father's time. From the old Lapia Market, there was no road but thick forest. We had to pass through another route to another village to go to Abuja. Also, our soils are eroded, and our lands are not doing well for our crops like before. We now need plenty of expensive fertilizers or else no food from the farm for our family.*

The was also corroborated by the observation by another key informant in Borgu LGA in zone C: *"In the entire Niger state, there is nowhere you will get a land that is uncultivated except Borgu LGA but now those lands are almost gone due to soil erosion and vegetation loss. For instance, abnormal dryness and desertification already in Niger state after the Borgu sector of the national park immediately after the second bridge to Luman village, just observe the other side of the national park, just compare the landscape you will find out more as you are moving up to Lumna Baare, Swanshi, Gala till Agawara. In the entire Agawara and Magama area, they are semi-desert, you will not find natural vegetation and they cannot produce much again because the LGA is degraded. Also, there is Kali Hill that serves as boundary and protection to the Kanji Lake National Park but now farming has encroached into the hill, affecting the habitat of the animals in the park and causing animals to migrate".*

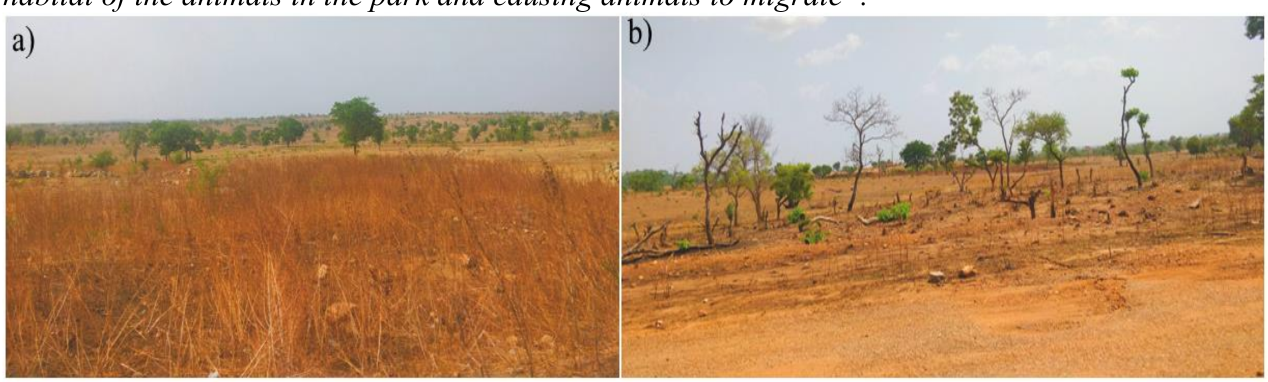

Fig. 6: Degraded savannah in Niger state (a) cleared land in Lavun LGA (b) logged and burnt woodland patch in Agwara LGA (Source: Own fieldwork, 2019)

3.4 Perception of land degradation drivers

Over 65% of respondents mostly identified factors such as God, sin and failure to pray, secret sales of communal land for selfish gains, migrants' activities from surrounding degraded states such as

Kebbi and Zamfara, deforestation/logging, over-cultivation, overgrazing, and crime due to armed banditry and kidnapping in all three zones. In zone A, dry spell/drought and mining were most mentioned. More than 60% of respondents mentioned urbanization across the three zones. Mining, overpopulation due to higher birth rates leading to large family size and "western ways of doing things", which introduces sophisticated equipment like tractors compared to traditional farming approaches considered more environmentally friendly was also key in zone C (ST:5) From the PCA, two major components of PLDD were identified for Niger state (Table 4) with a cumulative loading of 51.3% (ST:7c).

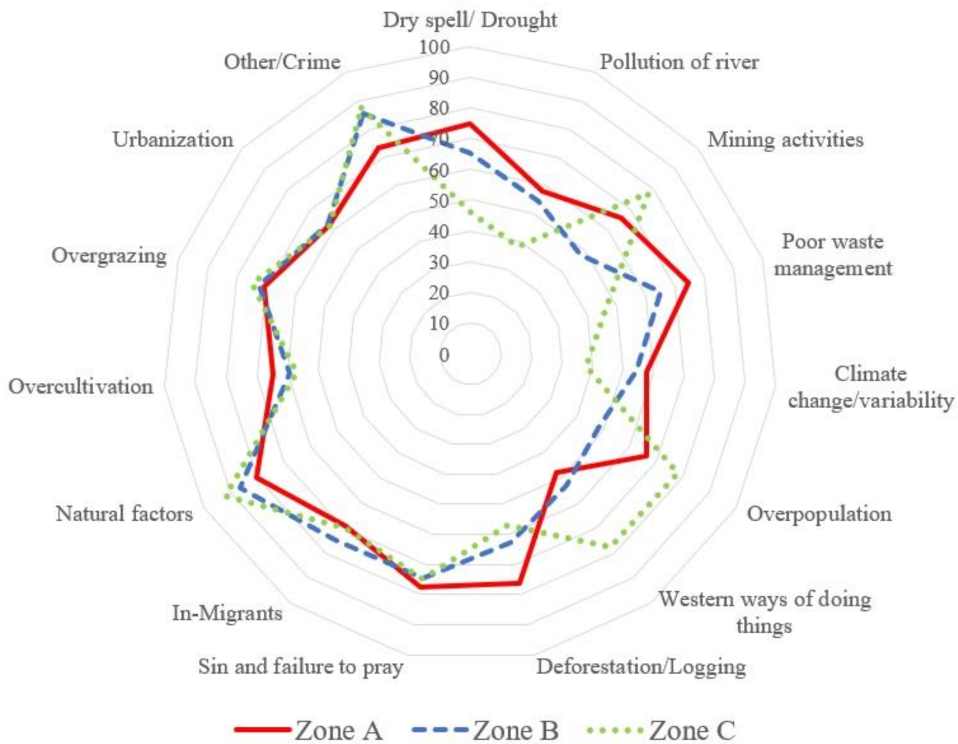

Fig. 7: Land users' perceptions of drivers of LD. Note: Natural factor refers to elements that people presume to cause change to the environment such as nature or God. Also, the respondents further identified crime as a driver of LD although it was not presented on the list of drivers.

Table 4: Perception components of LD drivers (PLDD)

Components	Brief description PLDD
PLDD 1: Human activities dominated drivers at a smaller scale	Perception dominated by strong agreement with over-cultivation, overgrazing, migrants' activities (SL) and moderate deforestation/logging, overpopulation, urbanization, sin and failure to pray, and crime including western ways of doing things – i.e. technologies (ML)
PLDD 2: Larger-scale drivers (nature-driven)	Perception dominated by high loadings from climate change and variability (SL), moderate dry spell/ drought, pollution of rivers, mining activities, poor waste management (ML)

Legend: Strong loading; SL, Moderate Loading; ML, Weak Loading; WL

Information from key informant interviews supports the two major PLDD (ST:7c) loading and perceptions of LD drivers by the respondents. A land user in Shiroro LGA, zone B reports, *"after my house, there is a stream and thick forest that cannot be accessed by strangers, the kidnapper attacked* *us once from there because the forest is an access route to kidnapers' hideout. They were pursuing one Fulani man with a large cattle-herd, so they followed the stream and mentioned my name. They came in to take control of my house while pursuing a Fulani man but then they were not kidnapping but now they have started kidnapping. The persistence of kidnapping activities makes us cut down the thick vegetation around our villages. Aside from the use of savannah trees for timber, firewood and charcoal, bandit activities and kidnappers visit the village at night to kidnap people into the forest. So, we decided to cut down trees and forests around our village to prevent kidnapping and to see them when they are coming. Last night, bandits from Alawa Forest still came to kidnap people from the village".*

Another key informant in Borgu, zone C reports: *"Because of the proximity of Niger state to Kebbi state, which is in the Sudan Savannah with fewer trees, people from Kebbi state do most of their logging and charcoal making in Niger state. Their farmers also migrate into Niger state. I can say 60% of the farmers in Niger state are from Kebbi, Zamfara and Sokoto state. Go to Mashegu Zurgurma, Ibi, virtually all the farmers are from Sokoto, Kebbi and Zamfara, and they do not care for economic trees that our people cherish".* His opinion was also corroborated by another key informant in Borgu, zone C who said *"there are two major causes of LD in Niger state. The Influx of foreign farmers that is in-migrating farmers mostly from Kebbi, Zamfara, Sokoto and foreign farmers from Togo and Benin Republic including our neighbouring degraded local governments such as Magama and Rijau. Second is the activity of wood loggers who cause biomass degradation usually from the southern parts and middle-belt of the country like Plateau, Nasarawa, Ebonyi, from the southwest like Ekiti and Osun. Initially, our people do not know about mobile sawmills, they only know about the traditional approach of looking for a mature tree, cutting it down and taking it to the sawmill. With the coming of mobile sawmill and sophisticated equipment, the majority of our people now practice "sawmill on the go".* Others include overgrazing by Fulani herders and fuelwood activities like charcoal making, firewood collection and mining activities.

3.5 Perception of SLM

Table 5: Ranking of the SLM categories

Category of SLM	RII (%)	Rank order
Institutional actors	70.0	1
Technological practices	67.6	2
Conservation practices	66.8	3
Policy initiatives	66.5	4

Table 6: Perception components of SLM (PLDS)

Components	Brief description
PLDS 1: Institutional actors' effect	High perception influence from all institutional actors i.e have similar strength (SL)
PLDS 2: Natural resources management	High influence from natural resource management: diversion/drainage, surface water management, groundwater management and wetland protection, disaster risk reduction (SL) and water harvesting and irrigation management (ML).
PLDS 3: Environmentally friendly agricultural practices	High perception influence of agricultural practices: improved ground/vegetation cover, integrated crop-livestock management, pastoralism/grazing land management, and minimal soil disturbance (SL). Moderate loading (ML): rotational system, integrated soil fertility, improved plant varieties/animal breeds and water harvesting.

PLDS 4: Tree-based initiatives	Strong contribution from natural and semi-natural forest management, forest plantation management agroforestry (SL) and loadings from windbreak, area closure and crop rotation (ML)
PLDS 5: Conservation initiatives	High perception influence from conservation practices. i.e., SL from all the conservation practices (SL)
PLDS 6: Policy initiatives	High perception influence from policy initiatives. i.e., SL from all listed policies.

Legend: Strong loading; SL, Moderate Loading; ML, Weak Loading; WL

3.5.1 Perceptions of the importance of institutional actors for implementing SLM

From Fig. 8a, all the institutional actors were considered relevant, aligning to the single perception-component loading from all the institutional actors in the PCA (i.e PLDS 1). The four highest ranked (i.e responses >70%) include local institutional actors such as traditional rulers, Community Based Organisations (CBO), local government agencies, and religious institutions. However, respondents also perceived the Federal Government's (70.4%) efforts as more important than the state government in addressing LD. A key informant confirmed the ranking preference, reporting that "*..the death of the Wawa traditional village head in Borgu, zone C in 2009, caused more areas to be degraded especially during the chieftaincy tussle because of the absent traditional head who authorize and make allocation decision over land"*. Another key informant in zone C, highlights the need for community and local actions and institutions: "*Not God but human activities like selfish farming and selling of community land including having more of the local young men who because of civilization do not want to assist their fathers on farmland but want to sell native land to foreigners, sand miners for quick money. We are more helpless because the act of selling the land for sand mining is encouraged by the local government and community heads that give receipt to the landowners who sell the land and sand to these sand miners. Here, the government does not interfere in the giving of land but traditional rulers and village chiefs like the Seriki Dagi, Seriki Maranba, and Seriki Noma who belong to the local palace, mostly give land to migrant farmers for money without considering the environmental implications like degradation".*

3.5.2 Perceptions of effectiveness of technological practices in tackling land degradation

Technological practices in tackling LD received the second highest RII value of 67.6% (Table 5). Based on Fig. 8b, most respondents highly ranked vegetative measures, which include natural and semi-natural forest management, agroforestry, forest plantation management, and windbreaks, as well as area closure as the five most effective technological practices to combat LD while the remaining technologies ranked below 70%. The three PCA components identified include PLDS 2-natural resources management; PLDS 3-environmentally friendly agricultural practices and PLDS 4-tree-based initiatives (Table 6). Respondents in zone C rated all technological practices higher than respondents in the other two zones (i.e with choices ranging from >35 %). However, other practices such as energy efficiency technology, beekeeping, aquaculture, poultry, home garden and disaster risk reduction were highly rated across the three zones.

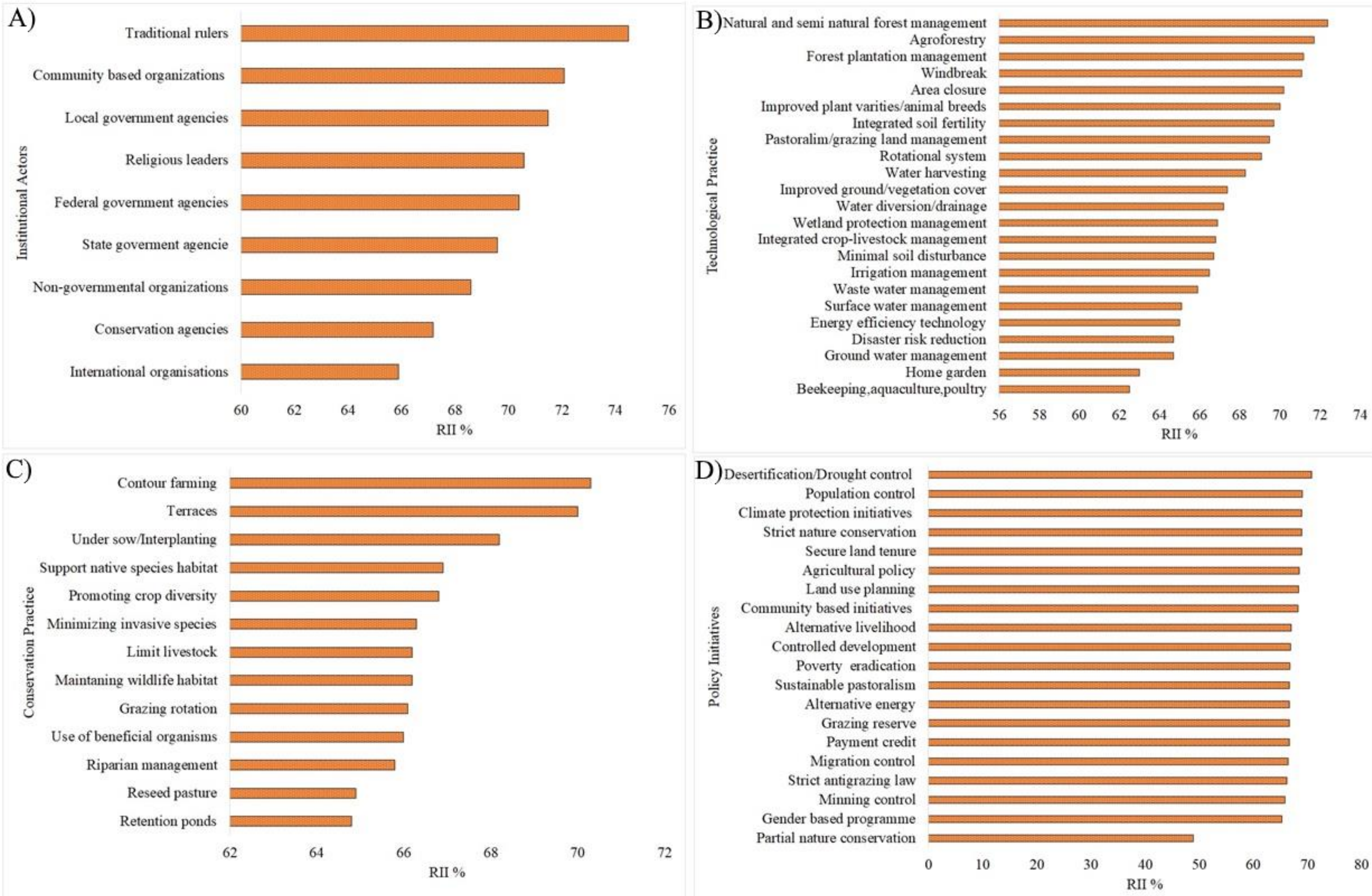

Fig. 8: RII (a) Institutional actors;(b) Technological practices; (c) Conservation practices; (d)Policy initiatives (ST:12 -15)

3.5.3 Perceptions of effectiveness of conservation practices in tackling land degradation

With an RII of 66.8% conservation practices is ranked third (Table 5). In Fig. 8c, most of the respondents identified agronomic measures (contour farming) and structural measures (terraces) as effective for tacking LD i.e., response >70% and above, while the combination of other measures such as promoting crop diversity and native species habitats ranked <70%. However, the component PLDS 5 shows that all the conservation practices were considered relevant (Table 6). A key informant in Borgu, zone C captured the insights of the various SLM technological and conservation practices: "*Most farmers are not well informed that different trees and vegetation cover have importance beyond firewood and charcoal. Crops have different nutrient absorption rates like Maize and Guinea corn and if they continue farming on a particular land for say five years that area will need some agricultural practice to bring the soil nutrient back. But a traditional Kamari farmer does not think of replenishing the soil nutrient through improved means when they till for years, they move to another place to farm. That is why you see migrant farmers moving from neighbouring state in search for fertile land without engaging in practices to replenish soil fertility but continuous cultivation till the land fertility is lost*". In another instance, he said that "*it is a taboo to cut economic trees like shea butter and locust bean found on their farmlands but for the migrant farmers with a different farming approach they have no selection for trees through the indiscriminate cutting of trees*".

3.5.4 Perceptions of effectiveness of policy initiatives in tackling LD

With an average RII of 66.5%, policy initiatives/themes occupy the fourth position among the SLM categories (Table 5). According to the RII (Fig. 8d), the top five ranked factors for the land users include desertification and drought control, population control, and climate change response including strict conservation, and land tenure, while the least-ranked five factors are migration control, strict anti-grazing, mining control, gender-based policies, and controlled/partial conservation. From the PCA, the matching component PLDS 6 shows that all the policy practices are relevant in the study context (Table 6).

4.0 Discussion

4.1 Land users' perceived characteristics of land degradation

4.1.1 Perceived vegetation-related characteristics of land degradation (PLDC1 & PLDC 3): Vegetation related indicators such as desertification, change in vegetation structure and decline in native species, as well as reduced vegetation (PLDC 1), were ranked high as LD indicators in the study area. These characteristics align with UNCCD's consideration of biomass quality and productivity as characteristic of LD conditions. However, other most mentioned indicators such as soil erosion, desertification with drier conditions experienced along with loss of soil fertility are the effects of the absence or shortage of vegetation cover reflecting LD as a process (Macaulay, 2014). Further, LD drivers such as deforestation, the emergence of Sudano-Sahelian vegetation (i.e (PLDC 3) desertification/drought) further worsen the declining biomass conditions.

4.1.2 Perceived soil-related characteristics of land degradation (PLDC 2): Soil erosion and loss of soil fertility (Fig. 5) indicators of LD are connected to the absence of vegetation cover. However, the dominance of farming activities as the sole livelihood engagement of most rural inhabitants in Niger State makes this indicator pronounced (Macaulay, 2014; Sule et al., 2020). Extensive biomass loss due to unsustainable human activities (PLDD 1), expose the soils to the wind and rain, which increases the risk of soil degradation (Le et al., 2016) such as soil erosion as mentioned by most respondent across the zones. It thus follows that addressing vegetation-related LD is likely to reduce soil-related degradation in Niger state.

4.1.3 Perceived Land Use and Land Cover Change (LULCC) as land degradation (PLDC 4): Perceptions of vegetation loss, desertification, the decline in native species, change in vegetation structure with loss of palatable species and drier conditions as well as increasing encroachment into protected areas are captured under LULCC in the study area. Studies have also linked these characteristics of land cover change to land use activities across the zones (Arowolo and Deng, 2018; CILSS, 2016). These local perceptions of LD highlight the need for people-centred initiatives for addressing LD (Mortimore, 2016; Pulido and Bocco, 2014).

4.2 Land users' perceived drivers of land degradation

4.2.1 Land use and management practices: Drivers such as over-cultivation, overgrazing, farming activities, mining and deforestation/logging, were highly scored over 70% as the observable drivers of change in biomass condition (Macaulay, 2014; Olorunfemi et al., 2020). These same drivers trigger LD through promoting land clearing for agricultural expansion, and excessive wood extraction (Arowolo and Deng, 2018; Fagbemigun, 2015). They represent the driver that load strongly into the PLDD 1. However, the slight difference observed shows that perceptions were relatively similar but depend on the prevalence of the drivers in the zone. For instance, that overgrazing is ranked higher than cultivation can be linked to the prevalence of encroaching grazing activities into protected areas in zone C. Mining in zone C corresponds to sand mining activities. Deforestation and logging prevail in zone A. Thus, the emergence of Sudano-Sahelian (i.e dry spell/drought) conditions (PLDD 2) in a Guinea savannah region (Macaulay, 2014) was corroborated by the key informant interview in zone C

4.2.2 Urbanization as a driver of land degradation: The identification of urbanization (Fig. 7) as a driver (PLDD 1) of LD depicts the degree to which zones has diversified away from farming and exploitation of natural resources. Urban centres provide other job opportunities and means of livelihood away from farming but require land conversion for housing (Gautam and Andersen, 2016; Owusu, 2009). Zone B for instance has the highest urbanization but the least degradation in terms of NDVI decline due to cities pre-existing the 15 years of analysis, such as Suleja, which shares a boundary with the Federal Capital Territory (FCT), Abuja. The State capital Minna as well as moderate commercial and industrialized urban centres providing alternative livelihoods are also located in this zone. This is unlike zone C and A, which are dominated by remote farming communities with a high proportion of their population relying on natural resources. Urbanization increases agriculture in adjacent rural farming areas due to the demand for food, triggers land-use change and LD in Nigeria (FGN, 2018; Olorunfemi et al., 2020), but the rate of urbanization in Niger State is not fast enough to drive LD through increased agricultural activities (Arowolo and Deng, 2018; Macaulay, 2014). However, at the LGA level, Bosso, in which the State capital is located, has the greatest LD (75%) through urbanisation.

4.2.3 Agrarian activities-driven land degradation: Niger is the largest state in Nigeria in terms of landmass and is one of the least developed with low urbanization. In such areas, most degradation is caused by the dominance of the agrarian economy and poor land management practices such as burning, deforestation and logging and agricultural expansion into savannah areas (Arowolo and Deng, 2018; Macaulay, 2014). With the national restrictions on food importation and incentives to encourage domestic food production by successive governments, the promotion of rural food supply further drives land users to cultivate more land in an exploitative manner and hence more LD (Arowolo and Deng, 2018).

4.2.4 Perceptions of technological innovations as drivers of land degradation: Technological innovations linked to (PLDD 1) "western ways of doing things" such as, tractors and the "sawmill on the go" (mobile sawmills) together with inadequate laws and regulations make it easy to cut down trees, resulting in biomass loss. While technological innovations in this context is a driver of LD, technology has been identified in other studies as contributing to the sustainable use of land resources (UNCTAD, 2021, 2018). This negative perception of technology as a driver of LD may be related to the faster pace of resource extraction compared to manual approaches, as in some cases, technology increases degradation (Ali, 2004; Assunção and Bragança, 2015). Thus, the negative perceptions of innovative technology, without accompanying sensitization measures, can hinder the adoption of environmental smart technologies (Crossland et al., 2018).

4.2.5 Migrant farmers and links to land degradation: Migration under PLDD 1 driver, is on the one hand an adaptive measure for the migrants that can result in degradation in destinations areas. (In)migration involves inter-state immigration i.e., the movement of farmers and herders from LD threatened areas like the drought-prone Sahel into the Guinea savannah (Macaulay, 2014). Land-use pressure, degradation and (armed) conflicts in northern States displaces land users and cause them to migrate further south, where available land for agriculture pulls migrant farmers and herders hence contributing to land conversions and LD (Macaulay, 2014). Without socio-cultural embeddedness, immigrant farmers and herder can be perceived to disrespect local values associated with economic trees (e.g., shea butter) which in some cases might trigger conflict (Ofuoku and Isiefe, 2010)

4.2.6 Crime and responses to crime as drivers of land degradation: Local crimes such as armed banditry, kidnapping and terrorism have led to clearing thick native vegetation that serves as hideouts for criminals in rural areas (Kuo and Sullivan, 2001). Crime and insecurity have led to reduced control over land use, the loss of power of traditional authorities and communities, the erosion of institutions and rules to protect economic trees (Ofuoku and Isiefe, 2010). Thus, respondents believe that cutting down such dense vegetation around communities will reduce criminal and terrorism activities thereby causing LD (van Schaik and Dinnissen, 2014). According to the global peace index, Nigeria ranked 17th among fewer peaceful countries and third, as a country most affected by terrorism. As LD is an outcome of violent conflict and nature (IUCN, International Union for Conservation of Nature, 2021; van Schaik and Dinnissen, 2014), understanding the indirect causal links between people's behaviour, ethics, social cohesion and curbing communal, armed conflict and crime management is essential for tackling LD.

4.2.7 Religious interpretations: High responses on "sin and failure to pray" including natural factors "due to God" reflects religious interpretations of global environmental change (Boillat and Berkes, 2013; Jenkins et al., 2018). This interpretation might make some religious people rely on their belief that God will provide solutions to their socio-ecological problems while disregarding the causal links between their actions/inactions and the ensuing conditions (Jenkins et al., 2018), affecting the adoption of SLM. However, religious interpretations of global environmental change can also be beneficial in promoting local institutions and sustainable attitudes (Boillat and Berkes, 2013).

4.3 Land users' perceptions and implication for SLM and land governance

4.3.1 Perceptions by land users of institutional actors in SLM: While traditional rulers play a key role in land use practices (Gadzama, 2017), our results show that some traditional rulers, as land trustees for the people, also sell or give out native land to immigrants without giving conditions for their sustainable use. This confirms the erosion of local authorities in terms of corruption and lack of accountability. In this context, though rural land users are important agents in rural landscape modification, they lack decision-making power in land ownership and allocation. Land tenure and governance in Nigeria remain a challenge due to the lack of land reforms (Ifejika Speranza et al., 2019; Mabogunje, 2010). Many SLM initiatives fail due to institutional gaps and challenges (Gnacadja and Wiese, 2016; Ojehomon et al., 2006). Expanding local leadership to involve heads of CBOs like the association of farmers (*Seriki Noma),* local hunters (*Seriki Maranba),* and forest (*Seriki Dagi)* who work with traditional rulers in regulating land user practices (Gadzama, 2017) can be a way to reduce LD and promote accountability to preserve land resources. Studies analysing why SLM adoption succeeded (Kiage, 2013) or failed in certain regions highlight the absence of strong traditional participation, poor dissemination approaches and weak stakeholder involvement (Liniger et al., 2019). While top-down approaches usually face adoption challenges and misalignment between the local communities and interest groups (Pulido and Bocco, 2014), bottom-up approaches face barriers in spreading initiatives beyond the local. Hence the need to better link initiatives by government and international organizations (Gadzama, 2017), with the local scale, and to promote a bottom-up approach to locally mainstreaming SLM (Ifejika Speranza et al., 2019). This should also inform other international and country-led efforts such as the African Forest Landscape Restoration Initiative (AFR100) which targets restoring 100 million hectares of land in Africa by the year 2030 because re-greening will require bottom-up approaches and grassroots initiatives (Thor West et al., 2020).

4.3.2 Perceptions of SLM technology and conservation practices: The ranking shows that there is no single solution to solving LD but the selection of appropriate SLM based on land users' preference is key. The mentioned tree-based options (PLDS 4) have also been echoed in several international landscape initiatives such as the AFR100, and the Great Green Wall (GGW) initiative where countries like Nigeria and its northern States (Sudano-Sahelian region) such as Kebbi and Zamfara States have committed to planting more trees to reduce desertification and LD (Gadzama, 2017). As a response to LD, Nigeria has also committed to attaining LDN by growing more trees and preserving protected areas (FGN, 2018). However, growing trees without the strong involvement of local land users and institutions usually yield little and can even be harmful (Binam et al., 2015; Mortimore, 2016). Tree-based initiatives will perform better if the land users, relevant stakeholders and institutions (PLDS 1) are integrated through local stewardship (Liniger et al., 2019). Tree-based programmes (PLDS 4) such as afforestation are recognized but have not succeeded in Nigeria mainly because there are no alternative sources of energy to firewood. Uncontrolled land access, open grazing and pastoral mobility and water scarcity to irrigate the planted trees also hinder afforestation and reforestation programmes (Ofuoku and Isiefe, 2010). Farmer Managed Natural Regeneration (FMNR), found to reduce livelihood risk due to LD in other West African countries (Binam et al., 2015), can offer promising alternatives to tree planting (Ojuok and Ndayizigiye, 2020).

4.3.3 Policy initiatives related to SLM: Along with the interest of incorporating local knowledge, and a bottom-up approach in managing LD, almost all identified policy initiatives were reported by the land users as highly relevant in addressing LD (PLDS 6). Since land tenure is highly unregulated due to the lack of reforms, the current land tenure system promotes LD (Mabogunje, 2010). Protected areas also lack effective management and remain prone to encroachment in Nigeria (Fagbemigun, 2015). Thus, the five topmost policy initiatives identified (Fig. 8d) by the land users such as desertification and drought control, "population control" and climate change adaptation and mitigation, strict conservation and improved land tenure align with those identified in other studies addressing land-related problems in Nigeria (Adenle and Ifejika Speranza, 2020; Ifejika Speranza et al., 2019). Therefore, a policy shift in the direction of the identified land users' preference is needed to address LD (Crossland et al., 2018; Mortimore, 2016).

5.0 Conclusion

Using a combination of remote sensing and analysis of questionnaire survey of land users, this study exposes the status of LD in the three geopolitical zones of Niger State. It substantiates the land user's perceptual experience with remote sensing data about LD. The results from principal component analysis yielded four perception components for LD characteristics (PLDC 1: Vegetation condition dominated characteristics; PLDC 2: Soil condition dominated characteristics; PLDC 3: Vegetation with Sudano-Sahelian characteristics; PLDC 4: LULC with the prevalence of drier conditions), two perception components for LD drivers (PLDD 1: Human activities dominated drivers at a smaller scale; PLDD 2: Larger-scale drivers (nature-driven)) and six perception components for SLM practices (PLDS 1: Institutional actors' effect; PLDS 2: Natural resources management; PLDS 3: Environmentally friendly agricultural practices; PLDS 4: Tree-based initiatives; PLDS 5: Conservation initiatives; PLDS 6: Policy initiatives). Land users' perceptions also highlight how the activities of migrant farmers from neighbouring states drive LD in Niger state. The study also shows that conflicts in these areas, as well as a local crime due to terrorism and banditry drive LD. Some of the land users' views give new insights on how to curb degradation which include promoting alternative livelihood strategies, poverty eradication and awareness about nature-based SLM practices such as tree-based initiatives, environmentally friendly agriculture supported by the necessary political will and institutions. This study can further be improved by deepening research to identify other determinants of perceptions of LD, to understand their interrelations and to identify the different aspects to be tackled in addressing LD and promoting SLM.

Credit author statement

Ademola A.Adenle: Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation. **Sébastien Boillat:** Supervision, Writing- Reviewing and Editing**. Chinwe Ifejika Speranza**: Conceptualisation of the research project, Supervision, Validation, Writing - Review & Editing.

Conflict of interest

The authors declare no conflict of interest.

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7.4 Paper 4: Land Degradation Neutrality - Potentials for its operationalisation at multilevels in Nigeria

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Land Degradation Neutrality - Potentials for its operationalisation at multi-levels in Nigeria

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ABSTRACT

This paper examines the operability of the Land Degradation Neutrality (LDN) concept in a developing country context illustrated with the case of Nigeria, a country highly ranked as undergoing biomass degradation. While LDN offers an approach to monitor land degradation, through net-gain in land cover, land productivity and soil organic carbon, its operationalisation poses methodological, implementation and governance challenges. Based on a review of literature, available spatial datasets and the analysis of national policies, we examine the dynamics of land degradation and the prospects of LDN in Nigeria. We identify land pollution and gully erosion as further relevant indicators for LDN in the Nigerian context. We found that current institutional arrangements are largely unconducive and incoherent for operationalising LDN. Despite Nigeria's international commitments, current national policies with relevance to LDN are vague and fragmented, based on several old laws, and have important gaps for monitoring due to inadequate data, skills and expertise, inadequate coordination, and the lack of national LDN baselines. The limited power of the national environmental agency and the lack of political will to change this situation compound the challenges. However, two promising entry points for operationalising LDN include incentivising and monitoring Sustainable Land Management practices (SLM) of local resource users according to agro-ecological zones, and mainstreaming SLM into initiatives in its agriculture and environment sectors. These insights can inform the operationalisation of LDN in other African countries.

1. Introduction

Land Degradation Neutrality (LDN) is a framework promoted by the United Nations Convention to Combat Desertification (UNCCD) to achieve a land degradation-neutral world by 2030. LDN refers to "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (Orr et al., 2017: 8). The LDN framework includes three indicators: a) land cover, b) land productivity and c) carbon stocks, with Land Cover Change (LCC), the Normalised Difference Vegetation Index (NDVI) as a proxy for Net Primary Productivity (NPP), and Soil Organic Carbon (SOC) as main parameters (UNCCD, 2015).

LDN is particularly relevant for developing regions such as sub-Saharan Africa where economic development depends largely on the use of local land resources. Forest loss in Africa remains high (Keenan et al., 2015; Köhl et al., 2015). Nigeria contributes to the total forest loss in the region with about 410 K ha y-1 (Keenan et al., 2015); it has lost 55.7% of its native forest between 2000 and 2005 (FAO, 2005) and ranked fourth globally as undergoing biomass degradation from 2000 to 2010 (FAO, 2010). Therefore, the context of LD in Nigeria is particularly relevant to examine how and to what extent LDN can be operationalised in developing countries in general and in Africa in particular. We argue that to be effective, LDN operationalisation must be situated within existing institutional arrangements (governance structures, policies, laws and regulations), the agro-ecological conditions and land management practices in the different parts of the country.

Orr et al. (2017) proposed five steps to assess and monitor progress towards achieving LDN (Table 1) The LDN framework nevertheless raises questions about the entry points to identify for its implementation and its potential limitations. To become operational, the application of the driving principles such as like-for-like counterbalancing, response hierarchy and "one out, all out" principle (Table 1) need to be tied to specific national conditions. The objective of this paper is thus to identify specific entry points and limitations to the LDN framework in Nigeria. To do this, we analyse literature on the dynamics associated with Land-Based Natural Capital (LBNC) in the country and provide an overview of the governance and institutional arrangements related to land and LD as well as the extent to which they engage with LDN.

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Table 1
Steps to achieving LDN and some key principles underlying LDN as proposed by Orr et al. (2017).

Steps to achieving LDN	Recommended principles for an LDN-process
1 Setting the vision and objective for LDN	The goal is to maintain LBNC, thereby protect human rights and enhance human well-being, and respect national sovereignty.
2 Setting the frame of reference or baseline	LDN target should be same as the baseline (e.g. if Nigeria decides to maintain the 2018 state of its LBNC, this becomes the baseline - a minimum that should not be underachieved); In rare situations negative-baselines (losses) can also be set.
3 Establishing a counterbalancing mechanism for neutrality	Like-for-Like-Counterbalancing (LfLC) - counterbalance anticipated losses in LBNC with gains in the same land type (could be in different locations); manage counterbalancing at the same scale as land use planning; LfLC should not occur between different land types except where there is a net gain in LBNC.
4 Defining elements necessary to achieve LDN	The elements include an enabling environment and preliminary assessments; integrated land use planning for tracking LDN; interventions to achieve LDN; learning and adaptive management; governance. Apply a response hierarchy of avoid > reduce > reverse LD;
5 Monitoring LDN	Use the three global land-based indicators and associated metrics: land cover (proxy: land cover change), land productivity (proxy: Net Primary Productivity; NPP) and carbon stocks (proxy: SOC), as the minimum set of indicators/metrics, as adopted by the UNCCD for reporting and understanding LD status. Monitoring and reporting primarily based on data generated by the country (national or subnational); Integration of results of the 3 global indicators based on a "one out, all out" principle whereby if one indicator shows significant negative change then LBNC is at a loss, hence LDN is not achieved.

2. Materials and methods

2.1. Study area

Maintaining LBNC implies tailoring LDN measures to the relevant Agro-Ecological Zones (AEZ), defined as units of land with similar climate, soil, vegetation and landform that reflect the potentials and limitations for land use (FAO, 1996). Nigeria has six AEZs (Fig. 1): (i) Salt-water swamp (coastal and mangrove forest) (ii) Fresh-water swamp forest, (iii) High/Rain forest; (iv) Guinea savannah (including montane savannah) (v) Sudan savannah, and (vi) Sahel savannah (Iloeje, 2001).

In the coastal zone, oil exploitation in the Niger-delta has degraded natural mangroves, fresh water swamp vegetation and farmlands (Kadafa, 2012). Invasive species such as *Nypa fruticans* have become widespread (Ayanlade and Drake, 2016). Oil pollution and spillage, caused partly by vandalisation (Onwuteaka, 2016) as well as gas flaring

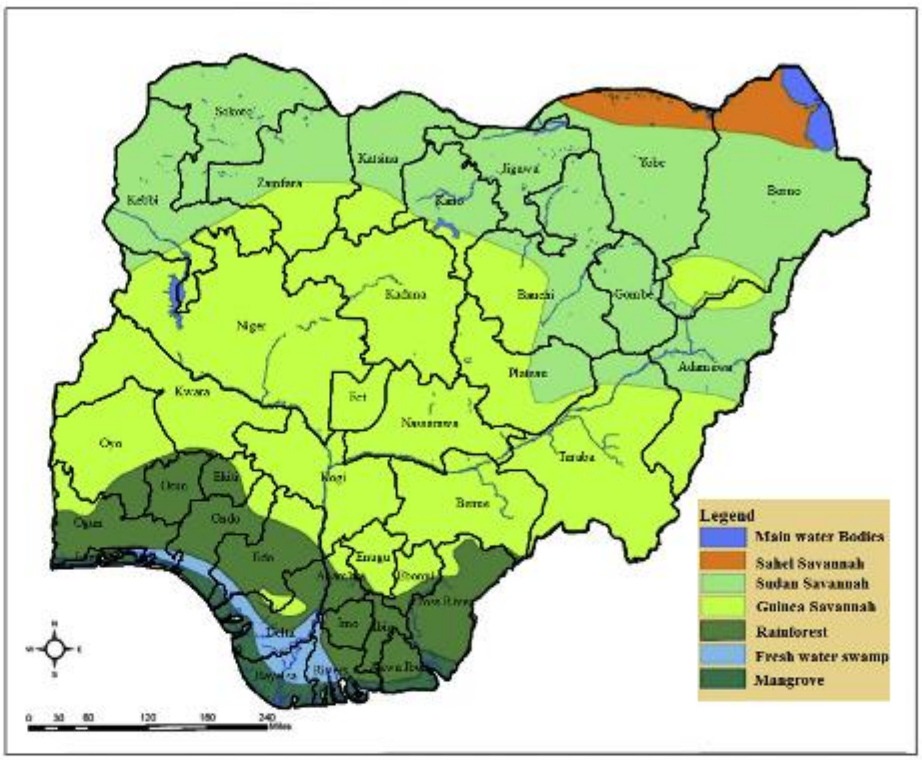

Fig. 1. Agro-ecological zones in Nigeria and their overlap with administrative divisions (Adapted from Iloeje, 2001).

(Tawari and Abowei, 2012) have polluted the air, damaged vegetation, aquatic resources and contaminated soils (Federal Ministry of Environment; FME, 2006), affecting both ecosystems and livelihoods. The rainforests of Southern Nigeria are characterised by a high human population density and are subject to intensive hardwood logging and urbanization. This makes Nigeria a global deforestation hotspot with 3.5% annual forest loss in 2010 (FAO, 2010).

The Guinea Savannah is characterized by a mix of trees (e.g. locust bean tree: *Parkia biglobosa*) and grass that have resulted from fire and long-term human-nature interactions. This region is a major food basket for Nigeria and experiences substantial cropland expansion at the expense of dry forests. In Eastern Nigeria, severe gully erosion threatens infrastructure and livelihoods (Igwe, 2012). While the vegetation of the Sudan Savannah is largely drought-resistant (e.g. Acacia, Baobab), soil cover is sparse and the felling of trees for fuelwood remains a threat to vegetation in the region (FRN, 2003). In the Sahel zone, desertification, moving sand dunes and the silting of water bodies, particularly the Lake Chad are main issues (Tiffen and Mortimore, 2002). Furthermore, the current insecurity in this region drives internal displacement and constrains environmental management.

2.2. Adapting the LDN conceptual framework for analysis

We contextualised the LDN framework (Fig. 2, box 1) to the Nigerian social-ecological characteristics by first reviewing the state of Nigeria's LBNC, the current land management and governance (Fig. 2, box 2). This contextualisation served as a lens to conduct the literature review. Through literature review and policy analysis, we then analysed the prospects (entry points and limitations; Fig. 2, box 3) for operationalising LDN in Nigeria.

2.3. Methods for assessing LDN prospects in Nigeria

We reviewed available spatial datasets and literature related with the three main parameters of the LDN framework (LCC, NDVI and SOC), plus Land Pollution (LP) and Gully Erosion (GE) for the country's AEZ.

For LCC, we reclassified data on LULCC from the Comité Inter-États de Lutte contre la Sécheresse dans le Sahel (CILSS) for West Africa between 1975 and 2013 (Supplementary Table; ST 1). As we could not access spatial datasets on NDVI, SOC, LP and GE, we reviewed literature on these indicators. For NDVI, we used Fashae et al.'s (2017) threshold study, which groups vegetation density and distribution over Nigeria as non-vegetated, sparsely vegetated and densely/thickly vegetated (NDVI values between -1-0; 0-0.4, 0.5–1) respectively. For SOC we used Akpa et al. (2016) and we relied on estimated amounts of oil spills for LP (ST 2). For GE, we refer to Fagbohun et al. (2016) and Igwe (2012).

To assess the extent to which LD and LDN are addressed in current land governance, we performed policy analysis focusing on the level of engagement of policies with LD and LDN, as well as the current institutional arrangements (Ifejika Speranza et al., 2018a,b). A policy refers to a government's vision and course of action, which can include legislations, regulations and plans, guided by principles, to achieve specific goals. In Nigeria, policy documents may contain a general plan of action but such plans are detailed out in proposed bills, which can be approved by parliament to be signed into law as an Act by the country's president. Thus, policy documents, bills and acts provide insights on the intentions and actions of various government bodies. We analysed 21 documents comprising the national constitution, four sectoral policies, six acts, two action plans, three reports, one bill and two national communications including two official meeting reports of the National Council on Environment. These documents are national (federal)

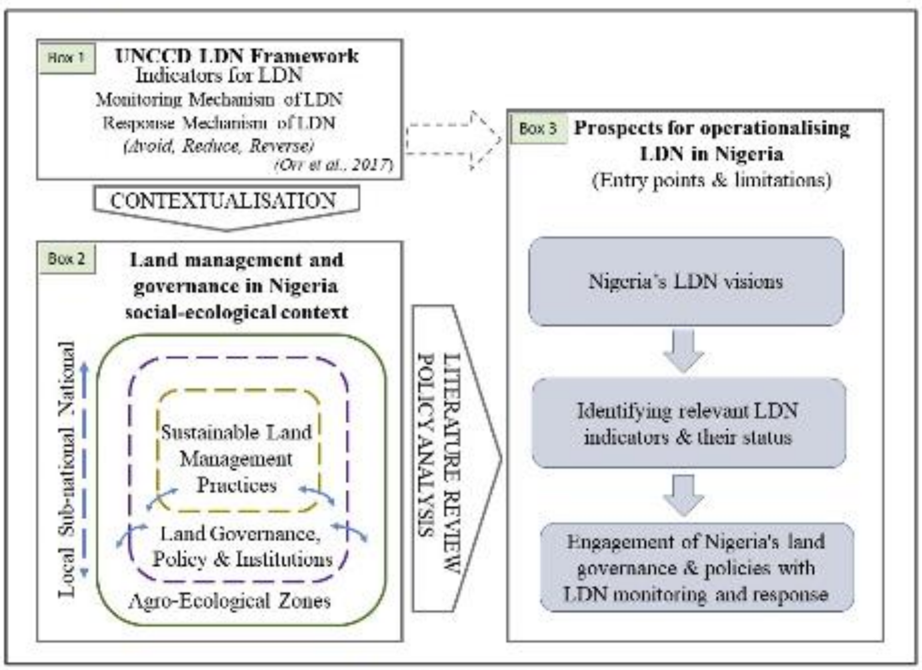

Fig. 2. Conceptual approach for operationalizing LDN at Country Level.

documents, which serve as the basis for other subnational policies and legislations. Using MaxQDA® Qualitative Data Analysis (QDA) software, we scored the documents according to the extent the LDN indicators (LCC using LULCC data, NDVI, SOC, LP and GE) as well as the LDN response strategies (Avoid, Reduce and Reverse) were captured. The scores range from 0 to 3, namely, 0: not mentioned; 1: mentioned; 2: proposed action; 3: actions taken. If there is one legal document with several "proposed actions" or "actions taken" per indicator, the document is scored on the highest action (that is, a document with proposed action plus action taken is scored 3 and not 2 if it proposes and initiates action on an indicator). Scoring and ranking allowed identifying policy focus and gaps in relation to LDN. Thus, the higher the total score, the higher the prospects of operationalising LDN under current institutional arrangements.

3. Results and discussion

3.1. Indicators of LDN for Nigeria

In general, all three UNCCD-LDN indicators (LULCC, NDVI, SOC) are relevant for all AEZ but have different characteristics in terms of nature of vegetation affected, while land pollution by crude oil and gully erosion are prevalent in the more humid areas (Table 2).

3.1.1. Land use and land cover change (LULCC)

Our reclassification based on the CILSS data shows that the area for agriculture (orange cells, ST 1) has consistently increased by over 20% at the expense of the natural vegetation (forests, woodlands and grassland) since 1975, which other more detailed studies confirmed (Arowolo and Deng, 2017). This corresponds to the largest agricultural expansion in West Africa (CILSS, 2016). Built-up areas experienced a mild increase. Other studies confirm that urbanisation is increasing at the expense of croplands and forests as exemplified for Bauchi city in the savannah and Umuahia in the forest zone (Kafi et al., 2014; Ochege, 2014). Arowolo and Deng (2017) found that most of the conversion of land to agricultural use occurred in the northern part of the Guinea Savannah zone and in the Sudan and Sahel savannah (Arowolo and Deng, 2017), confirming a susceptibility to LD in northern Nigeria compared to the South (Macaulay, 2014). These observed zonal differences in LD stress the need for differentiated baselines in relation with agro-ecological zones, instead of a uniform baseline at national scale.

3.1.2. Vegetation - net primary productivity

NDVI studies show a trend of substitution of high-productivity vegetation with lower-productive vegetation (Macaulay, 2014; Fashae et al., 2017). This includes the conversion of rainforest to savannah in the South (Agbelade and Fagbemigun, 2015), the increase of Sudan Savannah vegetation in the Guinea Savannah zone and a southward extension of Sudano-Sahelian grassland (Abbas, 2009). The CILSS (2016) data shows that from 1975 to 2013 savannah experienced a larger decline compared to forests, though about 45% of the forests was lost in southern Nigeria. The emergence of derived vegetation and the disappearance of dense primary forest are the most notable effects of these dynamics. Since the LDN framework is flexible for national application but does not allow for the loss(es) or gain(s) from any vegetation type to be compensated by another (Cowie et al., 2018), the national vegetation baseline should reflect the productivity of the country's different vegetation types and AEZs. Hence, to capture AEZ-specific LD, at least six national vegetation baselines for Nigeria would be needed to meet the like-for-like counterbalancing requirements.

3.1.3. Soil organic carbon

Soil types can vary within short distances and in relation with LULC, vegetation conditions, climate and soil types (Anikwe, 2010; Akpa et al., 2016). This heterogeneity challenges the characterization of SOC over large areas. Existing studies concentrate on the potential for SOC according to land cover classes and AEZ (Obalum et al., 2012; Akpa et al., 2016). For example, SOC concentration in the top 15 cm depth was highest for forests, cropland, shrubland, savannah and grassland but below 30 cm depth it is higher in shrubland and savannah (Akpa et al., 2016). At a depth of 1 m, the derived savannah, a product of degrading rainforest, has the highest percentage of total SOC compared with the humid forest and Guinea, Sudan and Sahel savannah (Akpa et al., 2016). In relation with AEZs, SOC decreases from the humid forest to the semi-arid Sahel zone at a spatial depreciation between 47.3 and 117.6 Mg C ha − 1 southwest to northeast (Akpa et al., 2016). Akpa et al. (2016: 209) identifies the derived savannah, the transition zone between rainforest and savannahs as having the highest potential for soil carbon sequestration (19.0 to 30.8 Mg C ha − 1). This variability shows that a uniform national SOC baseline is not justifiable; hence, this range can serve for baselines in the respective zones. While SOC has the potential to improve agricultural productivity, it depends on land management practices (Deekor et al., 2012), yet environmentally friendly practices that increase soil fertility without polluting streams and rivers have received little attention in most projects and programmes of government (Ifejika Speranza et al., 2018a,b). Hence, with respect to achieving the Sustainable Development Goals, the impacts on soil conditions need to be integrated into initiatives aiming to improve agricultural productivity and food security (Keesstra et al., 2016).

Table 2
LD indicator across the AEZs with references (Source: Authors' compilation 2018).

AEZ	Major LD Types	LDN Indicators	Studies
Mangrove forest	Deforestation, oil spillage, erosion	LULCC, SOC, NDVI, LP, GE	Idowu, 2012; Ehiorobo and Ogirigbo, 2013; Akpa et al., 2016; Ayanlade and Drake, 2016
Fresh-water swamp	Deforestation, oil spillage, illegal mining, erosion	LULCC, SOC, NDVI, LP, GE	Morakinyo and Tooze, 2007; Ashekoya, 2009; Allison et al., 2018
Rain forest	Deforestation, erosion, illegal mining	LULCC,SOC, NDVI, LP, GE	Salami et al., 2003; Igwe, 2012; Ochege, 2014
Guinea savannah	Deforestation, illegal mining	LULCC, SOC, NDVI	Salako, 2006; Aigbedion and Iyayi, 2007; Adeyeri et al., 2017
Sudan savannah,	Desertification, deforestation	LULCC, SOC, NDVI	Pate and Dauda, 2013; Fabeku and Okogbue, 2014; Macaulay, 2014
Sahel savannah	Desertification, Deforestation	LULCC, SOC, NDVI	UNEP, 2013; Macaulay, 2014; Besinachi, 2015

3.1.4. Land pollution

Land pollution is particularly relevant to the coastal region of Nigeria, with oil spillage in the Niger Delta affecting mangrove and fresh water swamp forests (Allison et al., 2018). Although the severity is widely contested (ST 2), the role of oil spills in degrading croplands and ecosystems, and destroying dependent livelihoods in the Niger Delta cannot be overlooked (Chima and Vure, 2014). Entry points for LDN in LP will be to establish a more transparent monitoring of oil spill events and to set a minimum tolerable number of spills as a first step to their reduction. As the Nigeria oil sector has its special laws and regulations, the involvement of top-level government actors and politicians as well as the private sector and civil society actors and in particular, the local communities is necessary. Such a goal can also be a motivation to calm the social tensions characterising this region.

3.1.5. Gully Erosion

Gullies have developed in various regions of Nigeria, leading to loss of farmlands, houses and infrastructure (Ehiorobo and Ogirigbo, 2013). Geographically, they concentrate in south-eastern Nigeria (derived savannah and forest zone) with over 600 acute gully sites recorded, the most prominent being the Nanka/Agulu gullies in Anambra state (Igwe, 2012). Control initiatives have been partially successful but gully erosion remains a threat. Defining GE as an indicator of LDN means setting a gully baseline against which to establish the neutrality of GE-development. Neutrality will mean preventing the growth of gullies at various locations. Since erosion types leading to soil loss are facilitated by different geo-environmental characteristics such as rainfall-runoff erosivity, soil erodibility, and slope length factor, slope steepness including cover management factor (McCool et al., 1995), their geographic variations across Nigeria need to be captured in setting an LDN baseline (Fagbohun et al., 2016).

3.2. Land governance in Nigeria and prospects for operationalising LDN

The Land Use Act (LUA), which nationalizes land in Nigeria, was enacted during the military government in 1978, and embedded into the 1979 and 1999 constitutions. Through the LUA, the Federal Ministry of Lands, Housing, and Urban Development (FMLHUD), acts as the primary land management body at the federal level, but is mainly concerned with urban development and housing. The LUA confers each Governor of the 36 States (Fig. 1) a custodian right (in trust for the people) over land in the state territory, without considering the majority of people that already had customary possession rights to their land (Mabogunje, 2010). Similarly, control over land in the rural area was vested in the 774 local governments. Yet the customary lineage-based land tenure prevalent in the South or the general "pre-LUA" norms associated with land informally persists until date. Despite its shortcomings, the LUA has not been reformed during the forty years following its declaration (Mabogunje, 2010). Thus, periodic tensions over land ownership and access rights between federal and state governments, state and communities, tenants and landowners as well as gender inequality characterise land governance in Nigeria (Adeniyi, 2013).

Prospects for operationalising LDN within the governance context must therefore take into account overlapping claims and a situation of legal pluralism. The federal government and states including governors as custodians of state land as well as local governments and communities have to actively engage and support any issues related to land reform and management in Nigeria. Addressing LDN thus calls for a multi-level governance and participatory approach that gives enough room to local specificities.

Besides multi-level issues, cross-sectoral approaches are required to address LDN. At federal level, the main public organizations responsible for measures to control desertification and LD are the Federal Ministry of Environment (FME) and the Federal Ministry of Agriculture and Rural Development (FMARD). These ministries often take the lead while other government organs attempt to align with their strategies. Nigeria also engages in other continental initiatives such as the Bonn challenge and the pan-African strategy (the African Forest Landscape Restoration Initiative; AFR100) with the objective to reverse 4 million hectares of degraded and deforested land, thereby addressing climate change, biodiversity and ecosystem restoration and livelihood security. However, implementing these initiatives is hindered by the frequent change of focus due to policy shifts, insufficient funding or dependence on international donors, and lack of inter-sectoral coordination.

Furthermore, programmes such as the River Basin Development Authorities, National Fadama Development Project, afforestation projects, and agricultural development programmes, are organised mostly top-down, leaving local actors little room for influence. Such initiatives could be improved by building on what land management users are already doing instead of privileging prescriptive approaches (Ifejika Speranza et al., 2018a,b). A few recent initiatives such as the Great Green Wall Initiative (GGWI) adopt a more integrative and participatory approach to connect local actors to higher-level actors and to build on already existing local land management practices (FGN, 2012).

Finally, most measures to address LD focus on the Sudano-Sahelian belt of Nigeria. An example is the reforestation initiated in the frame of the GGWI at the northern fringes of the Sudan Savannah. However, as LDN applies to all AEZ in Nigeria, there is a need to extend initiatives addressing LD to the forestry and agriculture sectors in the other AEZ.

3.3. Consideration of the LDN indicators in Nigeria's land governance

To identify the prospects for operationalising LDN, we analysed the extent to which policies engaged with LDN indicators. The policies and plans analysed (Table 3) frame land issues in general terms without specific focus on the LDN indicators and on the need for their management. Many rather focus on establishing federal control over strategic land areas. Excerpts from policy documents (ST 3) exemplify how Nigeria deals with land governance at the national level.

Table 3
The extent current policies and plans address the governance of land and environmental problems including indicators of LDN.
(Source Authors 2018)

Policy documents	Code	LULCC	Vegetation Change NDVI	SOC	Land Pollution	Gully Erosion	Total
NATIONAL CONSTITUTION							
Nigeria Constitution (amended) 1999	NC 1999	3	0	1	0	0	4
POLICIES							
National Policy on Environment 1999	NPE 1999	2	2	2	2	2	10
National Agricultural Policy 1999	NAP 1999	2	2	2	1	2	9
National Energy Policy 2003	NEP 2003	2	2	0	2	1	7
National Policy on Women 2006	NPW 2006	1	1	1	1	1	5
ACTS							
Land Use Act 1978	LUA 1978	3	0	0	0	0	3
Environmental Impact Assessment Act 1992	EIA ACT 1992	3	2	0	2	0	7
Environmental Guidelines and Standards for the Petroleum Industry in Nigeria Act 2002	EGASPIN 2002	1	1	3	3	0	8
National Oil Spill Detection and Response Agency Act 2006	NOSDRA 2006	1	1	1	2	2	7
Nigerian Minerals and Mining Act 2007	NMMA ACT 2007	3	2	0	2	0	7
National Environmental Standards Regulation Agency Act 2007	NESREA_A 2007	1	1	1	2	1	6
BILLS							
Grazing Reserve Law (1965); (GRL) BILL 2016	GRL_B 2016	3	0	0	0	0	3
VISION / ACTION PLANS / STRATEGIES							
The Green Agenda of the VISION 2010 Report	NV20: 2020 2010	1	1	1	1	2	6
Great Green Wall For the Sahara And Sahel Initiative National Strategic Action Plan	GREEN 2012	1	2	1	1	2	7
National Biodiversity Strategy and Action Plan 2006	NBSAP 2006	2	1	1	2	2	8
National Action Programme to Combat Desertification	NAPCD	1	2	1	0	0	4
National Economic Empowerment and Development Strategy 2005	NEEDS 2005	1	1	0	0	1	3
NATIONAL COMMUNICATIONS							
Nigeria First National Communication on Climate Change 2003	NFNC 2003	2	2	2	2	2	10
Nigeria Second National Communication of Climate Change 2014	NSNC 2014	2	2	2	2	2	10
MEETING REPORTS							
The 10th Meeting of the National Council on Environment 2016	MNCE 10_2016	0	2	0	1	1	4
The 11th Meeting of the National Council on Environment 2017	MNCE 11_2017	0	1	1	1	1	4
TOTAL SCORE PER LDN INDICATOR		35	28	20	27	22	

Legend: 0: not mentioned; 1: mentioned; 2: proposed action; 3: actions taken. The higher the total score, the higher the conduciveness of the institutional arrangement for LDN; Lowest/highest total score: 0/15.

Table 3 shows that land use-related degradation (including vegetation/deforestation) receives more policy attention followed by land pollution-related issues. Gully erosion and SOC receive less policy attention, although measures to address deforestation or desertification can generally contribute to increasing SOC and reducing GE. In the following, we discuss the policy focus on each indicator in detail.

LULCC: Five documents such as the LUA initiated actions on LULCC, 6 proposed actions, 8 acknowledged while 2 disregard LULCC. The examined policies mainly express the right of the federal and state governments to acquire tenure over land in national interest to support oil exploration, mining, urbanisation and livestock grazing. The focus is less on concern about LD. Environmental issues are exclusively expressed in policies and plans of the FME and FMARD. In the National Policy on Environment (NPE 1999), sustainable land use is framed based on land capability inventory and classification.

Vegetation - NPP: Concerning vegetation conditions, 10 documents proposed actions, 8 acknowledged vegetation while 3 ignored it (Table 3). Several Acts such as the LUA 1978, GRL-B, and EIA ACT 1992 highlight government ownership, decision priority and control over land for economic use. Although the National Constitution (NC) of 1999, LUA 1978, GRL_B 2016 focus on land governance, they make no direct reference to vegetation condition. The GRL-B prescribes the establishment and administration of grazing reserves across the country to sustain transhumance.

Soil Organic Carbon: The NC 1999 makes provisions for land conservation, which include soil, and various policies on the environment such as NPE 1999; NAP 1999; NFNC 2003 propose actions. For example, the NPE 1999 calls for a dedicated strategic management of land and soil through the assessment of land use practices and the causes and extent of soil degradation. Only the EGASPIN 2002 provides guidelines and actions to be taken by oil industries in relation to land. Four policies proposed actions on soil; 9 acknowledge soils while 7 disregard it (Table 3).

Land Pollution: The NC 1999 establishes agencies to manage pollution in Nigeria. NFNC 2003 and NSNC 2014 strongly proposed actions on LP, and the NEP is sensitive to pollution caused by energy use, and proposed strategies to mitigate it. Section 19 subsection (3) of the NMMA ACT 2007 established a committee to discuss pollution and degradation of any land being mined and to advise the Minister. In the oil sector, NOSDRA under the National Oil Spill Contingency Plan (NOSCP) plans to halt LP while NESREA_A 2007 addresses LP in non-oil related sectors. EGASPIN 2002 is the only document with action on LD while 9 documents proposed actions, 6 acknowledged LP and 5 ignored it (Table 3).

Gully Erosion: Many policies related to land ignore action against gully erosion. Eight policies including NEP 2003 and NESREA_A 2007, proposed indirect actions such as the enforcement of management practices and guidelines for soil and water conservation in erosion areas. While 6 only generally acknowledge erosion without providing guidance on how to monitor and address it, 7 documents including the LUA disregard GE (Table 3).

In summary, Table 3 implies that many policies need to be revised to capture LD in Nigeria. It also shows that environmental concerns are poorly integrated into broader policy objectives.

3.4. Consideration of LDN monitoring and response objectives in Nigeria's land governance

Table 4 presents the analysis of the policy documents in relation with LDN monitoring and the objectives of avoiding, reducing and reversing LD.

Monitoring objectives: The NPE, NFNC 2003 and NSNC scored high

Table 4
The extent to which the examined policies engage with the LDN monitoring and response strategies.
(Source: Authors 2018)

Policy Literature	Environmental/LD Monitoring Mechanism	Avoid	Reduce	Reverse	Response Total
NATIONAL CONSTITUTION					
NC 1999	0	0	0	0	0
POLICIES					
NPE 1999	2	2	2	2	6
NAP 1999	1	2	2	2	6
NEP 2003	1	2	2	2	6
NPW 2006	2	1	1	1	3
ACTS					
LUA 1978	0	0	0	0	0
EIA ACT 1992	2	2	1	1	4
EGASPIN 2002	2	2	2	2	6
NOSDRA 2006	2	2	2	2	6
NMMA ACT 2007	1	2	2	2	6
NESREA_A 2007	2	2	2	2	6
BILLS					
GRL_B2016	3	0	0	0	3
VISION / ACTION PLANS / STRATEGIES					
NV20: 2020 2010	1	1	1	1	3
GREEN 2012	0	3	3	3	9
NBSAP 2006	2	2	2	2	6
NAPCD	2	2	2	2	6
NEEDS 2005	1	1	1	1	3
NATIONAL COMMUNICATIONS NFNC 2003	2	2	2	2	6
NSNC 2014	2	2	2	2	6
MEETING REPORTS					
MNCE 10_2016	2	2	2	2	6
MNCE 11_2017	2	2	2	2	6

Legend: 0: not mentioned; 1: mentioned; 2: proposed action; 3: actions taken.

(Table 4), on monitoring mechanisms for environment or LD. For LD / environmental monitoring mechanism, 12 documents proposed actions, while 5 and 4 documents respectively were sensitive and non-sensitive to a monitoring mechanism. The NESREA Act allows for collaboration with National Agencies such as the National Space Research and Development Agency (NASRDA) and Nigerian Meteorological Agency to confirm the status of ecological indicators across the country. Thus on paper, Nigeria has various mechanisms that can serve for monitoring LDN. However, empirical insights indicate inadequate resources for effective monitoring (Ladan, 2012).

Response objectives: Most policy documents (14 documents) acknowledge the need to *avoid* LD while 3 documents each proposed actions to avoid LD, such as the inclusion of gender based approaches. Key policies such as the NPE emphasise government commitment to reduce or avoid further environmental degradation and pollution. The EIA ACT 1992 stipulates projects to avoid impacts on the environment, and the NMMA ACT 2007 specifies avoiding degradation in minerals exploration and exploitation including penalty for illegal mining, and prohibition of exploration outside mining lease areas. The GREEN 2012 is the only document that details actions to avoid LD such as the development and implementation of an integrated approach to SLM and sustainable agriculture. While policies and plans equally engage with a LD reduction strategy, a difference is the NAP 1999, which proposes to promote water conservation by harvesting run-off water and reducing desertification by tree planting (Table 4).

The strategy to *reverse* LD is similar to those on avoidance and reduction but statements differ. For instance, the NMMA ACT 2007 stipulates the need to liaise with relevant agencies of government with respect to the social and environmental issues involved in mining operations, mine closure and reclamation of land. Further, section 61 subsection (1d) of the Act states that the licence holder must maintain and restore the land to a safe state from any disturbance resulting from exploration and related activities. GREEN 2012 scores highest in avoiding, reducing and reversing LD and is the only document that details actions to reverse LD through implementing the GGWSSI. In relation with the GGW project, Nigeria has established the National Agency for Great **Green** Wall (NAGGW), under the FME. Its activities range from afforestation, mobilising communities and fostering local livelihoods as well as land resources management. While the NAGGW adopts a participatory and community driven approach, it is still too early to assess the effectiveness and the social-ecological impacts of these initiatives. In sum, many policies and plans provide entry points for the LDN response strategy (Table 4) but more effort and commitment are required to implement the proposed actions.

3.5. Potential coordination options and limitations

Our analysis highlights possible entry points and limitations for planning/implementing LDN in Nigeria. First, various policies have some relations with LDN indicators and strategies, however with a rather vague framing and no clear actions plans. Second, options for integrating LDN into national policies are highly fragmented across sectors. A key actor to overcome this fragmentation and mainstream LDN into national policies could be the National Environmental Standards Regulatory and Enforcement Agency (NESREA) of the FME. Established in 2007, the agency is responsible for enforcing all environmental policies, guidelines, laws, standards and regulations at the national level. NESREA is responsible for developing environmental monitoring networks and compiling environmental data from other sectors. It also ensures compliance with international agreements regarding global and regional environmental issues. Finally, it has the mandate to liaise with local and international stakeholders, create public awareness and promote SLM among farmers and land users.

Nevertheless, NESREA's competences explicitly exclude the oil and gas sector, with the agency expected to "*enforce through compliance monitoring, the environmental regulations and standards on noise, air, land, seas, oceans and other water bodies other than in the oil and gas sector*" (NESREA_A 2007, p. 5). This undermines NESREA's handling of LD due to LP, which is pervasive in the oil producing areas of the country. The tensions raised by LP in Nigeria's oil producing regions and its impacts on health, land and water resources justify its place as an LDN indicator (Allison et al., 2018). Due to this exception, the "Petroleum Act", sensitive to the growing adverse environmental impacts from oil related pollution, proposes the EGASPIN to "*establish Guidelines and Standards for the Environmental Quality Control of the Petroleum Industry [in Nigeria; EGASPIN] taking into account existing local conditions and planned monitoring programmes*" (Paragraph 4(a, b, c), part 1, 'Introduction', EGASPIN 2002). The guideline along with the provision of the National Oil Spill Detection and Response Agency (NOSDRA) Act, under the NOSCP foresees a joint effort to monitor all degradation in Nigeria, under the FME, and in conjunction with other ministries and agencies.

Besides its exclusion from the oil and gas sector, NESREA also faces other constraints, such as a lack of relevant skills and expertise in monitoring and inadequate funding, and the challenge of implementation into the country's federal structure. The agency has established five zonal headquarters in the six geo-political zones and plans to establish offices in all 36 states (13 established) of Nigeria (Ladan, 2012). However, how the mandate of NESREA and that of state agencies in land planning (in which the states have the control), and in issues related to development and environment are to be coordinated remains open.

4. Conclusions

LDN is a novel concept with a composite frame to counter LD and provides the basis for countries to assess their readiness and position to achieve neutrality. However, it cannot function without relevant institutional arrangements at national to local levels. We explored the possibility of operationalising LDN in Nigeria considering existing institutional arrangements. Deforestation, land pollution by oil spillage, gully erosion and desertification reflect the challenge of LD in Nigeria.

We found that current institutional arrangements, despite international commitments, are largely unconducive for operationalising LDN. Our overview of LD and LDN in Nigerian national policies highlights their very general framing and their high fragmentation among different policy sectors. Even though various policy documents and mechanisms capture and provide inputs for LDN, more coordination efforts and stronger political will are required to achieve LDN in Nigeria. The meetings of the council of ministers poses an entry point in coordination and could create awareness among other non-environment ministries about the importance of LDN.

Explicit management of LD is exclusively delegated to the FME, although the FMARD is a key actor in the conversion of land to agriculture. Shortcomings are also visible in the National Agriculture policy (NAP) which has focused mainly on desertification and drought, while excluding other types of degradation such as land pollution, thus not capturing issues due to oil spills.

While the LDN should apply in tracking all types of LD, the special treatment of institutional arrangements in the oil sector means that more dedicated efforts are needed for the affected oil-producing zones. As NOSDRA and NESREA are under the FME, an entry point would be to intensify and support collaboration between the two agencies in addition with cooperation with actors at the state and local levels.

Another key challenge is the definition of national LDN baselines that reflect the agro-ecological variability in the country. These baselines must be transparent, flexible, acceptable and compliant with international standards and are yet to be established. Tying LD indicators to AEZs should provide the basis for compensation of losses with gains within the same zone.

Taking a decision on the reference time for baselines is also a challenge. For instance, 2018 or an earlier date can be set as the reference year on which all LDN indicators will be measured. Monitoring of neutrality can then be applied to the different AEZs and their various management practices. Thus, each AEZ will require a distinct monitoring system coordinated by the FME/NESREA.

Furthermore, elements for achieving neutrality in terms of policies and practices including multi-level governance need to be coordinated differently along the various land types to ensure that gains prevail over losses. For example, the degraded areas in the Sahel region or the rainforest and mangrove region affected by large-scale gullies, land pollution or severe logging should receive specific response strategy when compared with states with other LD types. We suggest to address the various LDN indicators at the sub-national levels through a synthesis of the archetypes of local studies on LD. In addition, the various environmental agencies monitoring LD need to improve coordination to harmonise the baseline for each land type.

Moreover, there is a need for a reform of the LUA 1978, which is almost 40 years old, to reflect current developments in land governance and SLM. While acknowledging that policy reform can be a very slow process, LDN mechanisms are likely not to gain ground in Nigeria without such reforms. In particular, there is a need to reconcile the overlapping customary land tenure and the control the state governments have over land tenure. The FME with other key government organs, need to initiate a deliberative process that highlights the benefit of such reconciliation to governors, traditional authorities and local communities even if it reduces their power over land. As this reform may not be achieved in the short-term, there are limitations currently to using land use planning as a way to integrate LDN into local practices. Two promising entry points for operationalising LDN are first, to identify those farmers and land users already practising SLM and incentivising them to continue and to monitor their progress, and second, to mainstream SLM into various relevant development initiatives. Such an approach enables linking bottom-up strategies with top-down plans and is hence likely to take hold in the everyday practices of land use.

The insights from the method of literature review is also constrained by available literature. To generate further knowledge on operationalising LDN, there is a need for studies on state-level policies, the role of non-state actors and on piloting a methodology to operationalise LDN. Such an empirical study can provide further insights on other entry points and necessary adaptations to specific social-ecological contexts.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2018.12.018.

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7.5 Paper 5: Insights for policy-based conservation strategies for the Rio de la Plata Grasslands through the IPBES framework

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Insights for policy-based conservation strategies for the Rio de la Plata Grasslands through the IPBES framework

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Abstract: The Rio de la Plata Grasslands (RPG) are one of the most modified biomes in the world. Changes in land use and cover affect the RPG's rich biodiversity. In particular, the expansion of crops, overgrazing, afforestation, and the introduction of exotic species pose a major threat to the conservation of biodiversity and ecosystem services (BES). In this study, we applied the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework as a new lens to approach biodiversity conservation enactments in the RPG. First, we systematically reviewed published scientific literature to identify direct and indirect drivers that affect the RPG's BES. Further, we conducted an extensive analysis of management policies affecting the BES directly in the region, at a national and international level. We conclude by offering recommendations for policy and praxis under the umbrella of the IPBES framework.
Keywords: *Land Use Change; Biodiversity; Ecosystem Services; Drivers, Nature's Contributions to People.*

Insights para estratégias de conservação baseadas em políticas para as pradarias do Rio da Prata através da estrutura do IPBES

Resumo: As pradarias do Rio da Prata são um dos biomas mais modificados no mundo. Alterações nos usos do solo afetam a rica biodiversidade deste ecossistema. A expansão da agricultura, sobrepastoreio, arborização e a introdução de espécies exóticas, principalmente, representam uma grande ameaça para a conservação da biodiversidade e dos serviços ecossistêmicos (BES). Neste estudo, aplicamos a estrutura conceptual da Plataforma Intergovernamental sobre Biodiversidade e Serviços Ecossistêmicos (IPBES) como uma nova forma de abordar as políticas de conservação da biodiversidade neste bioma. Primeiro, revisamos sistematicamente artigos científicos publicados de forma a identificar fatores diretos e indiretos que afetam os BES nas pradarias do Rio da Prata. Adicionalmente, realizamos uma extensa análise das políticas de gestão que afetam diretamente os BES na região, quer a nível nacional, quer internacional. Concluímos com propostas e recomendações de políticas e práticas sob a égide do quadro do IPBES.
Palavras-chave: *Alterações de Uso do Solo; Biodiversidade; Serviços Ecossistêmicos; Contribuições da Natureza para as Pessoas.*

Introduction

Obtaining natural resources for fulfilling human needs has been made at the expense of environmental degradation (Foley et al. 2005, MEA 2005, Zhang et al. 2019a). Based on the current trends in land use and land cover (LULC) changes worldwide, humans can obtain goods and services to improve their quality of life only by diminishing the capacity of global ecosystems to sustain the provision of such benefits (Foley et al. 2005, MEA 2005). Hence, contemporary societies face the challenge of developing regional land-use strategies that recognize short and long-term needs while reducing the negative environmental impacts and maintaining social and economic benefits (Foley et al. 2005, MEA 2005).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is an international body that works to strengthen the science-policy interface for biodiversity and ecosystem services. IPBES aims to assess the state of biodiversity and ecosystem services (BES) incorporating different disciplines and types of knowledge (Díaz et al. 2015). Nature's contribution to people (NCP) is a concept promoted by IPBES that refers to all the positive and negative contributions of nature to the quality of life of people, which can be recognized and valued in a range of existing worldviews. This approach underlines the central and pervasive role that culture plays in defining all links between people and nature (Díaz et al. 2018). According to Pascual et al. (2017), a multiple value perspective should be encouraged in decision making, focusing on three types of values: intrinsic, relational, and instrumental. In order to achieve sustainable development, it is important to consider long-term human well-being, the drivers, and the consequences of land-use changes (Crossman et al. 2013, Nagendra et al. 2013, Ellis et al. 2019). Therefore, the link between drivers, valuations, and NCPs might serve as holistic guidance for policy formulation.

Grasslands are one of the most modified biomes of the world (Hannah et al. 1995, Paruelo et al. 2007, Baldi & Paruelo 2008), which cover over 50 million km^2, accounting for 37% of the earth's terrestrial surface (O'Mara 2012). Native grasslands have been replaced or degraded by intensively managed agricultural lands (Hannah et al. 1995, Vega et al. 2009, O'Mara 2012, Gang et al. 2014), representing 70% of the agricultural areas worldwide (Schlesinger & Andrews 2000, Ramesh et al. 2019). Thus, grasslands play a unique role in food security by providing agricultural products (O'Mara 2012).

In the Neotropics, the Río de la Plata Grasslands (RPG) are the most extensive grassland ecosystem, covering an extent of 750,000 km^2 (Soriano et al. 1991, Carbutt et al. 2011). The RPGs are shared by eastern Argentina, southern Brazil, and Uruguay, encompassing two main sub-regions, Pampas and Campos (Soriano et al. 1991) (Figure 1). The mean annual temperature of the region is 10 to 20°C, and the mean annual rainfall is between 400 and 1,600 mm (Soriano et al. 1991).

After the European colonization, the native grasslands of the RPG have become one of the most essential regions of grain and beef production in the world (Bilenca & Miñarro 2004, Paruelo et al. 2005, Baldi et al. 2006). Until the 20th century, cattle ranching was the most common and important land use, but then, cropping became the most important one (Vervoorst 1967, Soriano et al. 1991, Viglizzo et al. 2001, Baldi et al. 2006). For example, between 2000 and 2010, the cultivation of genetically modified soybean generated an intensification and expansion of monocultures of this crop in the region (Aizen et al. 2009, Redo et al. 2012, Modernel et al. 2016). Although there was a predominance of soybean, other crops also increased, such as sunflower, maize, rice, wheat, pine, and eucalyptus (Baldi & Paruelo 2008, Cubbage et al. 2012). In the last decade, the cropping systems became less diverse raising concerns about the sustainability and environmental risks associated with crop production in a region which is relevant for the world grain and oil market (FAO 2014). As such, the RPG have represented one of the most rapidly expanding agricultural frontiers not only in Latin America but in the world (Baeza & Paruelo 2020). Currently, most of the area is represented by sown pastures, annual crops, overgrazed areas, and tree plantations, and only a small portion of semi-natural native grasslands remain (Modernel et al. 2016, Paruelo et al. 2005).

All aforementioned LULC changes have affected the ecosystem functioning, the provision of ecosystem services (ES), and the state of biodiversity in RPG (Paruelo et al. 2005, Modernel et al. 2016). This region represents a biodiversity-rich area encompassing more than 550 different species of grass, 450-500 birds, with some endemic species, and a hundred species of terrestrial mammals (Bilenca & Miñarro 2004; Di Giacomo & Parera 2008, Azpiroz et al. 2012, Andrade et al. 2018). However, these species are being threatened by LULC changes in the area (Di Giacomo & Krapovickas 2005, Codesido et al. 2013, Dotta et al. 2015). Based on these and the fact that the RPG are the least protected sub-region in South America (Henwood 2004, Michelson 2009, Baeza & Paruelo 2020), it highlights the importance of protecting this area in order to conserve and maintain its BES (Baldi & Paruelo 2008, Modernel et al. 2016, Oyarzabal et al. 2019).

Most of the land is private in the region, belonging to families and corporations, often international (Modernel et al. 2016). LULC transformation is also driven, in turn, by global economic issues (the increase in the prices of commodities) and the availability of new technologies (no-tillage cropping, genetically modified organisms, afforestation know-how, etc.) (Satorre 2005, Trigo 2005, Céspedes-Payret et al. 2009). Therefore, land-use policies play a fundamental role in determining LULC dynamics (Lambin et al. 2003, van Meijl et al. 2006, Brannstrom et al. 2008). These policies can promote or restrain particular crops or types of land management using taxes and regulations (Redo et al. 2012). Internal policies established within a given country are the primary underlying drivers of LULC changes (Geist & Lambin 2002). Furthermore, political boundaries and biophysical heterogeneity of RPG also influence these trends (Vega et al. 2009).

New strategies should be considered to allow the coexistence of agricultural activities with grassland biodiversity conservation in the RPG. In this study, we applied the IPBES framework (Díaz et al. 2015) as a new lens to approach biodiversity conservation enactments in the RPG. Specifically, we sought to 1) identify the main drivers (direct and indirect) that are affecting the BES in the RPG and link them with the different values and categories defined by IPBES, 2) identify national and international policies related to RPG that affect the drivers underlying the BES, 3) build a conceptual framework for the RPG using the IPBES framework, based on the drivers, values, and policies identified in the previous objectives; 4) and finally, propose policies that could help the co-management of grasslands in this region and halt the rapid loss of BES.

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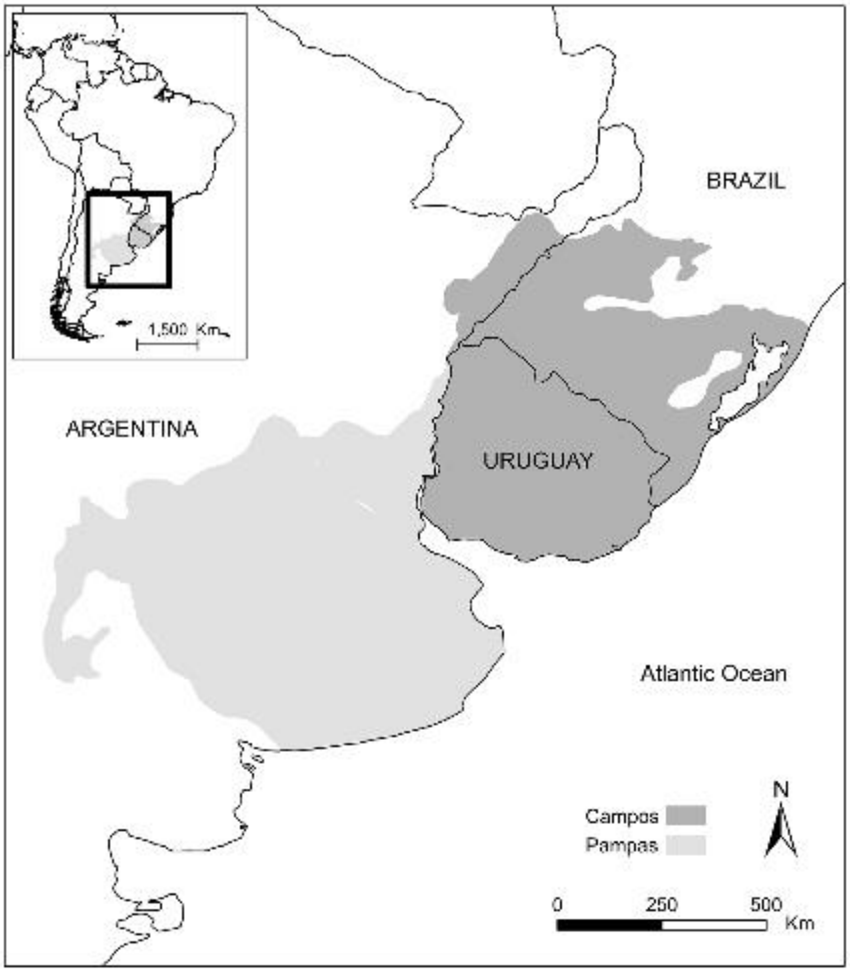

Figure 1. Location of the Rio de la Plata Grasslands (RPG) and sub-regions, Pampas and Campos, in Southeastern South America (sensu Soriano et al. 1991).

Material and Methods

We engaged in a qualitative systematic review approach (Finfgeld-Connett & Johnson 2013) to centralize and consolidate pre-existing knowledge on LULC changes and BES in the RPG.

1. Scientific literature review: Linking BES with IPBES in the RPG

A literature search was conducted in two steps. First, we performed a Boolean search in Web of Science platform (July 22nd, 2019), using the following string of keywords: ("Rio de la Plata grasslands" OR "Pampas grasslands" OR "Campos Grasslands") AND ("land use" OR "agriculture" OR "afforestation" OR "pasture" OR "grazing") AND ("ecosystem services" OR "biodiversity"). To add several papers that did not appear in the first search but were relevant for this study, we performed an ad hoc search using various resources, e.g., other database searches, such as Google Scholar, checked cited literature, etc. Following this procedure, we included different reviews and other articles relevant to the study area. From the selected papers, we chose the ones that were published between 2015 and 2019, because most of the papers before this period were included in the other reviews (e.g. Bilenca & Miñarro 2004; Modernel et al. 2016). From each one of the selected papers, we extracted the main ES mentioned in the study and the drivers of the loss of the BES (direct and/or indirect). We then organized the information following the 18 categories of the NCP and placed them into the types of contribution (regulating, material, and non-material) (Diaz et al. 2018).

2. Review of current policy-based conservation in the RPG

Current policies for RPG management were reviewed by conducting a systematic search of policies, regulations, and legislation available on official websites for each one of the countries. For our analysis, we identified and selected policies that are exclusively related to issues of BES conservation in RPG. We took into account historical national and regional legislation. Relevant information was extracted, in order to contrast to what extent these policies are addressing the drivers depicted in the scientific literature. We listed applicable laws or initiatives that promoted the LULC changes in RPG and represented the conservation situation within each country. Finally, we described the conservation efforts at an international and national level.

3. An approach to IPBES conceptual framework

Based on the key findings of these searches, we developed a conceptual model for the RPG using the IPBES framework (Díaz et al. 2018).

Results

1. Scientific papers review: Linking BES with IPBES in RPG

Based on our literature search, we found that most studies in the region focused on regulating contributions, highlighting material ones, while a few studies considered non-material contributions (Table 1).

Several papers focused on the ecological functions of RPG's biodiversity and the effect that agricultural activities have on them, highlighting and emphasizing nature's intrinsic value. In particular, these studies identify the importance of the RPG as habitat for pollinators (Sabatino et al. 2016, Marrero et al. 2017), and areas of high plant and animal diversity (Modernel et al. 2016). All the studies agree that biodiversity loss is associated with the transformation, homogenization, and perturbation of the habitat. Modernel et al. (2016) described other drivers of biodiversity loss, such as the invasion of exotic species, expansion of crops and implanted pastures, urbanization, and overgrazing. Illegal hunting and zoonotic diseases introduced by exotic species also threaten native species (Bilenca & Miñarro 2004).

Instrumental values were identified in several publications studying the benefits people can obtain from grasslands and associated biodiversity (Table 1). Goijman et al. (2015) stated that the agricultural intensification is detrimental to birds and their ecological functions, potentially causing a decrease in ES provided by them. For instance, insectivore birds play a role as pest controllers, a valuable ES in agricultural landscapes. Native grasslands provide regulation of water quality and availability, climate regulation, water provision, nutrient cycling, and erosion control (Modernel et al. 2016, Eguren et al. 2018, Villarino et al. 2019). All these benefits are affected by LULC changes, crop type and management, and climate change. Most of these papers reiterate the adverse consequences of climate change and LULC changes in the provision of agricultural products, which highlights the importance of sound and sustainable practices for the economy in the RPG.

Finally, we found that studies on both relational values and non-material contributions are scarce for the RPG (Table 1). Auer et al. (2017) identified agricultural activities that provided cultural benefits based on traditional activities in particular geographical areas. Furthermore, different aspects of the natural landscape sustained cultural values, giving local people a sense of place and cultural heritage. The authors also stated that although this study is from a small local area, the trends in agriculturalization processes follow a general pattern in the region, and based on socio-ecological similarities along the Pampas, this effect could be found in the entire sub-region (Auer et al. 2017).

Although we made a classification, it is recognized that the NCPs are perceived by people in different ways and each contribution can fit more than one category (Pascual et al. 2017, Díaz et al. 2018).

2. Review of current policy-based conservation in the RPG

2.1. National laws and initiatives that promote the degradation of grasslands

In Argentina, during the first half of the 20th century, there were cattle ranching and agriculture development under extensive or semi-intensive conditions, which consolidated the crop rotation model with annual pasture and forage (Viglizzo & Jobbágy 2010). By the 1970s and 1980s, increases in production were correlated to the expansion of cultivated areas over native grasslands and other types of environments (Carreño & Viglizzo 2007). In fact, between 1960 and 1990, the rate of grain production was six times higher than that of cattle ranching (Sturzenegger 2006). By the 1990s, intensive use of agricultural inputs and technology was prevalently escalating the LULC changes in the region (Viglizzo et al. 2001), while biotechnological innovations allowed an increase in yield per hectare. Technological advances were simultaneous to economic policy reforms that favoured Argentina's agriculture, such as export tax elimination; the reductions in tariff and non-tariff protection on fertilizers, agrochemicals, machinery and irrigation equipment; the deregulation of private economic activities, mainly commercial and financial, which allowed the reductions of agricultural financial marketing costs (Sturzenegger 2006). In 2002, the government announced the application of withholdings to exports primary products, and both agricultural and industrial manufactures (Colomé 2008). The tax retentions were by 2015, 23% for wheat, 20% for corn, and 35% for soy. In 2016, a new government adopted different measures such as the elimination of withholdings to exports wheat, corn, and meat and a 5% decrease for soybean retention (MA 2015).

From the mid-1990s, timber production has experienced significant growth driven by legislation that promoted forest plantations. In 1999, a law of Investments in Forestry in Planted Forests (N° 25,080) was promulgated and later expanded in 2019 (Law N° 27,487). The aim was to increase the stock from 1.3 to 2 million ha of cultivated forests by 2030, which contributed both to sustainable development goals and the climate change commitments assumed with the Paris Agreement (MAGyP 2018). This law established a regime that promotes investments made in new forestry ventures and the expansion of existing forests. It also favors the initiation of forest industry enterprises and the development of existing ones, as long as the timber supply is increased through the introduction of new forests. The benefits granted are tax stability for at least 30 years, tax benefits, and non-reimbursable economic support which will consist of an amount per hectare, variable by zone, species, and forestry activity. These ventures must comply with the zoning of forestry basins that must respect the territorial planning of native forests established by national law of minimum budgets for

Table 1. Summary of Nature´s Contribution to People (NCP) studied in the Rio de La Plata Grasslands (RPG) based on the scientific paper review. The NCP is organized based on the generalizing perspective of the IPBES framework, and 18 reported categories are distinguished (Díaz et al. 2018): *1. Habitat creation and maintenance; 2. Pollination and dispersal of seeds and other propagules; 3. Regulation of air quality; 4. Regulation of climate; 5. Regulation of ocean acidification; 6. Regulation of freshwater quantity, location, and timing; 7. Regulation of freshwater and coastal water quality; 8. Formation, protection, and decontamination of soils and sediments; 9. Regulation of hazards and extreme events; 10. Regulation of detrimental organisms and biological processes; 11. Energy; 12. Food and feed; 13. Materials, companionship, and labor; 14. Medicinal, biochemical and genetic resources; 15. Learning and inspiration; 16. Physical and psychological experiences; 17. Supporting identities and 18. Maintenance of options.* The NCP categories are divided into three broad groups depending on the type of contribution they provide to people into Material, Non-material, and Regulating (Díaz et al. 2018). The studied region of each paper is specified: Argentina (ARG), Uruguay (URU), Brazil (BR); the entire region (All).

Type of contribution	NCP Categories	ES	Specification	Drivers of the loss of the BES	Reference
Regulating	2, 14 and 18	Biodiversity and ecosystem functioning	Pollination	LULC change, agriculture intensification	Sabatino et al. 2016 (ARG), Marrero et al. 2017 (ARG)
Regulating	14 and 18		Species richness and diversity	Expansion of eucalyptus plantations, land-use type, loss of natural and semi-natural habitats and farming intensification	Phifer et al. 2016 (ARG), Hodara & Poggio 2016 (ARG), Winck et al. 2017 (BR)
Regulating	1, 14 and 18	Biodiversity and ecosystem functioning	Plant diversity	Low forage, high stocking rates, invasion of exotic species, expansion of crops and implanted pastures, overgrazing	Modernel et al. 2016 (All)
Regulating	14 and 18	Biodiversity and ecosystem functioning	Animal diversity (endemic species, migratory species)	Landscape perturbation and homogeneity, agricultural expansion (high proportions of cereal crops and forest), habitat loss and fragmentation, hunting pressure and zoonotic diseases introduced by exotic	Modernel et al. 2016 (All), Pedrana et al. 2015, 2018 (ARG), Bilenca & Miñarro 2004 (ARG)
Regulating	10	Biological control of insects and weeds by grassland species	ES provided by bird species	Agricultural intensification and monoculture, hunting pressure	Goijman et al. 2015 (ARG), Gorosábel et al. 2019 (ARG)
Regulating	10			Expansion of eucalyptus plantations	Phifer et al. 2016 (ARG)
Regulating	2	Seed dispersal by bird species		Expansion of eucalyptus plantations	Phifer et al. 2016 (ARG)
Regulating	6 and 7	Water quality and availability	Groundwater contamination control	LULC change, type and management of the crop	Rositano et al. 2018 (ARG), Modernel et al. 2016 (All), Eguren et al. 2018 (URU)
Regulating	6		Regional hydrology	LULC change (from native grasslands to crop)	Modernel et al. 2016 (All), Garcia et al. 2019 (ARG)
Regulating	6		Groundwater levels	Afforestation, agricultural expansion	Cerri et al.2015 (All), Modernel et al. 2016 (All)
Regulating	6 and 9	Flooding mitigation (water regulation)	Flood regulation	Agricultural expansion	Cerri et al 2015 (All), Barral et al. 2019 (ARG), Garcia et al. 2019 (ARG)
Regulating	4	Climate regulation and/ or mitigation	Soil organic carbon stock	LULC change (from native grasslands to crops)	Modernel et al.2016 (All), Villarino et al. 2019 (ARG)
Regulating	4		N2O emission control	Type and management of the crop	Rositano et al. 2018 (ARG)
Regulating	4		Carbon footprint	Beef production	Modernel et al. 2016 (All)

Continue...

Continuation...

Regulating	8	Soil conservation	Soil C and N balance	Type and management of the crop	Rositano et al. 2018 (ARG), Ferraro & Gagliostro 2017 (ARG), Lara et al. 2018 (ARG), Villarino et al. 2019 (ARG)
Regulating	8		Aboveground net primary productivity	Precipitation and water balance, climate change, energy and biomass flows.	Durante et al. 2016 (ARG), Modernel et al. 2016 (All), Baeza et al. 2018 (All)
Regulating	8		Carbon and nitrogen cycling	Agricultural intensification	Bedano & Dominguez 2016 (ARG), D'Acunto et al. 2018 (ARG)
Regulating	8		Soil erosion	Land use transformation (grassland to crops)	Cerri et al. 2015 (All), Modernel et al 2016 (All), Villarino et al. 2019 (ARG)
Material	12	Food and feed provision	Low input, cattle grazing beef production	LULC change Indirect: Soil productivity, transportation cost, economic gains	Piquer-Rodriguez et al. 2018 (ARG), Modernel et al. 2018 (All)
Non-material	15, 16 and 17	Cultural identity		Industrial agriculture and economic values	Modernel et al. 2016 (All), Auer et al. 2017 (ARG)

environmental protection of native forests (Law N° 26,331). This zoning aims to conserve native forests, but not other native ecosystems.

In Brazil, several policies that favor the expansion of different types of land-use activities have existed for decades. Within these activities are agriculture, mainly corn, soy and wheat crops, afforestation, and cattle ranching. Additionally, policies have been directed to manage productivity in beef cattle in pastures, through the establishment of minimum stocking rates (number of a particular type of animal per unit area). As a result of these policies, in 1970, there were 14,078 million hectares of natural pastures, but by 1996, only 10,524 million hectares remained. An example of cattle management was the project S3CR11 (1969/1970), which involved a forage improvement phase of the native grasslands of Rio Grande do Sul (Pillar et al. 2009).

Recently, the National Strengthening Program for Family Farming (PRONAF in Portuguese) was enforced. Although this program contributed socially and economically, it has negative environmental impacts. Grisa & Schneider (2015) state that in the municipality of Rio Grande do Sul, this program was predominantly oriented towards productive developments based on the use of chemical inputs. It also promotes a specialization in grain production and other agricultural commodities, which has led to the development of environmentally detrimental agricultural production models.

Finally, in Uruguay, internal policies regarding afforestation had a significant impact on the quantity and distribution of LULC changes (Cubbage et al. 2012). In 1987, Forestry Law (N° 15,939), was approved as a commitment to supporting and growing the forestry sector. Its objective was to replace marginal and unprofitable farming and ranching on poor soils with afforestation and pulpwood production to supply mainly European markets (Snoeck et al. 2008). This law identified priority regions for afforestation and provided financial incentives such as subsidies, tax reliefs, and exemptions and targeted loans to investors (Cubbage et al. 2012). These incentives encouraged large-scale plantations and forest products manufacturing facilities (Mendell et al. 2007, Redo et al. 2012). Consequently, the tree plantations area in Uruguay increased rapidly, reaching the highest afforestation rate in Latin America between 1988 and 1998 (Mendell et al. 2007, Cubbage et al. 2012). However, in the early to mid-2000s, all incentives were revoked leading to a 24% decline in plantation areas between 2001–2009 (Redo et al. 2012). More recently forest companies are trying to promote joint ventures with cattle ranchers who own land by leasing their plantations to local farmers, forming silvopastoral systems (Cubbage et al. 2012).

Before the beginning of the century, soybean was not considered an essential crop within other agricultural staples in Uruguay. However, between 2000 and 2009, a soybean production boom exceeded the most dominant crop in the country, wheat, occurring at the expense of the country's herbaceous cover (Redo et al. 2012). Global demand and prices have played an essential role in driving soy expansion post-2002 (Oyhantçabal & Narbondo 2011). However, price alone cannot account for the sudden expansion, considering that the price was already relatively high in the mid-1990s. For this, it is essential to take into consideration external policies. The soybean export taxes in Argentina had a direct impact on the quantity and distribution of LULC changes in Uruguay (Redo et al. 2012). Between 2002-2013, the soybean area increased from 10,000 ha to 1.2 million ha (Souto 2012). On one hand, this increase was mainly due to the lower land prices and the lack of export taxes in Uruguay; and on the other, high land prices and high agricultural taxes in Argentina introduced in the early 2000s (Redo et al. 2012).

2.2. *Conservation efforts in RPG at the international level*

At an international level, there are two important initiatives focused on the RPG: (1) The Southern Cone Grassland Alliance (Alianza del Pastizal in Spanish) created in 2006 with the support of BirdLife International and in collaboration with NGOs (non-governmental organizations) from Argentina, Uruguay, Paraguay, and Brazil. This alliance seeks to protect the habitat of migratory birds and grassland diversity in general by working with different stakeholders (cattle ranchers, environmental NGOs, provincial and national governments, and researchers). In 2010, the Southern Cone Grassland Alliance developed a certification label for meat producers who protected 50% of their grasslands. In 2012, meat produced under this label became available to consumers (Alianza del Pastizal 2019). (2) The 'Official Incentives Project for the Conservation of Natural Grasslands of the Southern Cone of South America' that seeks to protect the BES in the region (Alianza Pastizal 2019). This project began in 2012, and its main goal was to promote an incentive system (payment for ES scheme) for cattle ranchers who carry out conservation management of natural grasslands on their lands (Parera et al. 2012). For this purpose, a technical tool (Grassland Conservation Index) was built to evaluate and quantify the rancher's contribution to grassland conservation, thereby enabling estimation of the amount of their economic compensation. However, objectives were only partially achieved, and in no case, the payments were done (Weyland et al. 2019). One possible reason for this result was that the scheme coincided with the end of the government's mandate and the change in the authorities (Weyland et al. 2019).

2.3. *Conservation efforts in RPG at a national level*

In each country, different policies or private initiatives have been attempted in order to protect biodiversity and the environment of the RPG (Table 2). To date, conservation initiatives in Argentina are mostly driven by NGOs in collaboration with researchers with the goal of boosting sustainable management practices as well as identifying areas for potential conservation (Table 2). Contrary, in recent decades, Brazil has made significant progress to link biodiversity conservation and economic development, which has played an essential role in international discussions related to conservation. The triggering within the Brazilian society of a specific concern regarding the Campos Sulinos appears to be related to two public discussions: the legal prohibition of burning as a practice of management of the fields in the Rio Grande do Sul (established under the State Constitution of 1989) and the debate surrounding the future of the Pampa biome alongside the announcement of extensive plantations of exotic trees for pulp production (Pillar et al. 2009). Finally, in Uruguay, conservation strategies promoted institutional strengthening, participatory research, and good management practices, by the government in an inter-institutional frame and international organizations (Table 2). All of them focus only on this environment, recognizing natural fields as one of the most important assets of the country in terms of biodiversity.

Based on these initiatives, different levels of conservation were reached in each country. Regarding the scientific community consideration, a natural region is adequately protected when at least 10-15 % of the area is protected by law (Burkart 1999, Bertonatti & Corcuera 2000) but this condition is not met in any country. Argentina protects 1.05% of the Pampas eco-region (Moreno et al. 2008, Burkart 2006, Sistema de Estadistica Ambiental 2019), while Brazil protects 2.23% with the integration of federal level protected areas (Bilenca & Miñarro 2004). In Uruguay, the National System of Protected Areas (SNAP) constitutes approximately 0.98% of the national territory but with a high representation of specific species and ecosystems for conservation (Ávila et al. 2018, MVOTMA 2019). However, its low connectivity and surrounding landscapes (intensified production systems) are hostile to biodiversity and accentuating their biological isolation.

3. *An approach to applying the IPBES conceptual framework to the RPG*

It is important to note, that as the RPG extend into Argentina, Brazil and Uruguay, the associated values are affected not only by the spatial scale under analysis (local, regional, national or international), but also by micro and macro cultural, social, and political dynamics and complexities.

The conceptual framework we have developed for the RPG (Figure 2) has LULC changes as the main focal point and as the principal direct driver for the grassland BES. Based on our literature and policy review, there is a clear tendency to focus on the material contributions, which are traceable to the meat production history of the area (Viglizzo et al. 2001), as well as a distinct trend to increase crop production and afforestation with various incentives. The identification, valuation, and study of non-material values are scarce (such as learning and inspiration, physical and psychological experiences, and supporting cultural identities). Finally, the regulating contributions are becoming more relevant in the literature, especially in the face of climate change, but there is still a long way to go regarding policy application and implementation. However, in this framework, we emphasize the importance of all three of these interrelated components.

On one hand, LULC changes as the primary direct driver of change in the RPG includes three main elements: cattle grazing, crop production, and afforestation. The framework also articulates the values (NCP categories of IPBES framework) provided by these land uses, as a result of recognizing its social-economic importance. A relevant note regarding LULC changes is that the values provided, and the negative impacts on grasslands can profoundly differ according to the management applied. Traditional uses such as low-density cattle grazing or family farming will be more compatible with conservation concerns related to grasslands; intensive agriculture and afforestation, in turn, would be more detrimental to grassland's BES. Therefore, we assume that the transformations of this landscape are mostly to high-intensity LULC changes with inherent ecological consequences.

On the other hand, we organized the indirect drivers of LULC changes into two groups. The first one integrates technology, climate change, and international commodity prices. Technology, through technological advances, allows increasing productivity per unit area leading to less area needed. Climate change has the capacity to alter (un)suitable land uses and international commodity prices as market forces for higher or lower pressures from specific uses. Therefore, all these are affecting the weight that agricultural activities put on the remaining grasslands. The second group reflects the importance of highlighting the influence of politics and inherent political instability in the LULC changes, but also its integration in the remaining indirect drivers. Lastly, direct and indirect drivers' dynamics are viewed as a two-way relationship.

Table 2. National policies and conservation initiatives in the Rio de la Plata Grasslands (RPG). NA: not applicable, or information not available.

Country	Initiatives	Level	% Area protected or to be protected	Public/private promotion	Conservation goals	Year	Law	Outcomes	Other remarks and challenges	References
Argentina	National System of Protected Areas (PAs), and other preservation areas	National	1.05% of total grasslands within the national territory	Public	To conserve pristine grassland areas representative of the region for its biodiversity and scenic values	1980	Law N° 22,351; other policies	493 PAs of different biomes at different levels (national, provincial)	To increase representation of at-risk ecosystems within the protected network. To increase budget for protected area management	Burkart 2006, Moreno et al. 2008, Sistema de Estadística Ambiental 2019, SAyDS 2020
	Sustainable livestock grazing	National	NA	Private: Fundación Aves Argentinas and Fundación Vida Silvestre Argentina	To generate knowledge on good management of natural grasslands to improvement production and economic gains, without compromising grasslands sustainability	2012	NA	Several workshops and technical documents aiming at grassland management	To reach a greater number of local producers and stakeholders; replacement of input technology with process technology; to reach a sustainable development public-policy management	Aves Argentinas 2019
	Inventory of Important Birds Areas (IBAs)	National (based on regional initiative)	10.4% of the total RPG	Private: Fundación Aves Argentinas and BirdLife International	To identify and protect a network of critical sites based on the presence of globally threatened species, restricted distributions and/or confined to a singular biome, and/or congregating species	2000	NA	33 IBAs in Argentina; updated population data; monitoring and action plans were improved. Partnerships (Committee for the Conservation of Pampas Biodiversity, BIOPAMPA)	Some IBAs and Valuable Grassland Areas (VGAs) are overlapped	Bilenca & Miñarro 2004, Di Giacomo & Krapovickas 2005, Di Giacomo et al. 2007
	Valuable Grassland Areas (VGAs)	National (based on regional initiative)	3.5% of the Argentinean RPG	Private: Fundación Vida Silvestre Argentina (FVSA)	To define and identify well preserved natural grasslands, based on biodiversity, endemism, indicator species, land tenure and law, and cultural relevance	2002	NA	36 VGAs were identified in Argentinean Pampas and Campos	61% of VGAs overlapped total o partially with existing PAs; 47% on private lands, and most within areas with little agriculture aptitude. VGAs should be considered as "priority areas for protection by law" in future declarations (i.e. National Strategy on Biodiversity 2016-2020)	Bilenca & Miñarro 2004, Miñarro & Bilenca 2008, MAyDS 2017a
	Conservation strategy of Fundación Vida Silvestre Argentina (FVSA)	National (applied within regional approach)	NA	Private: FVSA	Creation of new PAs (public and private) and supporting existing ones; to promote policies and incentives for sustainable practices; conservation of flagship species; training, education and outreach for grassland conservation; partnership with entities experienced in grassland conservation.	2004	NA	Creation of public areas ("Campos del Tuyú") and private areas ("Refugio de Vida Silvestre Bahía Samborombón"), where the goals were undertaken.	NA	Miñarro & Bilenca 2008

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Brazil	National System of Conservation Unit (SNUC, in Portuguese)	Federal, state and municipal	3.24% of Pampas Biome in Brazil(0.7% within Full protection and 2.5% within sustainable use areas) in private and public lands	Public: Brazilian government	Regulation of PAs (federal, state and municipal areas)	2000	Law Nº 9,985	Land classification in two groups according to use and management strategy: fully protected and those that allow sustainable use.	To protect 17% of the area representative of the biome until 2020, under Convention on Biological Diversity (CONABIO 06/2013)	MMA 2019
	National Biodiversity Policy	National	Promote the conservation of 10% of the Pampa Biome (i.e. Campos)	Public: Brazilian government	Biodiversity conservation by promoting sustainable practices involving government and NGOs pertaining to resource use and valuations, considering economic, environmental, social and cultural values.	2002	Law Nº 4,339	Biodiversity valuation determined by its ecological, genetic, social, economic, scientific, educational, cultural, recreational and aesthetic contribution.	To link benefits of conservation to people wellbeing	MMA 2006
	Environmental Zoning plan for silviculture	State level (Rio Grande do Sul, Campos)	NA	Public: State Council	To conserve biodiversity (especially natural grasslands) and prevent expansion of agricultural frontier, particularly of large-scale industrial afforestation	2004	Resolution Nº 84/2004	Establishment of maximum plantation size buffering distances. Established of 3.5 million hectares as afforestation prone.	Disagreements between silviculture companies, activist groups and governmental institutions led to a reformulation with less restrictions	Gautreau & Vélez 2011
	Legal Reserve law	National	Variable between biomes (20% in the case of the Campos)	Public: Brazilian government	To ensure the sustainable use of natural resources, assisting the conservation and rehabilitation of ecological processes that maintain biodiversity.	2012	Law Nº 12,727	Instrument applied on private land including Permanent Preservation Areas (protecting water resources, soil and biodiversity) and Legal Reserves (required on all private rural land, to preserve portions of native areas). Allowed alternative albeit compatible with conservation goals.	Effective implementation.	Silva & Ranieri 2014
Uruguay	National System of PAs (SNAP)	National	0.98% of the total territory are PAs along adjacency zones	Public: Uruguayan Congress	To harmonize planning and area management criteria; adoption of landscape level approach	2000	Law Nº 17,234	16 PAs identified. Strategic plans that articulate socio-economic and conservation aspects were generated; technical documents were produced for responsible land use and management.	To continue generating opportunities compatible with conservation (recreation, tourism, education, research and production) and increase native grasslands representation within PAs.	Ávila et al. 2018, Moraes Sabio & Ribeiro Gómez 2018, MVOTMA 2019
	Inventory of Important Birds Areas (IBAs)	National (based on regional initiative)	18% total IBAs area of the total territorial extension	Private: Aves Uruguay, Birdlife International	To identify and protect a network of critical sites for bird species based on the presence of globally threatened species, the existence of species with restricted distribution and the presence of species confined to a specific biome and/or species that form big bird congregations	2008	NA	22 IBAS proposed. Updated population data; monitoring and action plans were improved.	NA	Aldabe et al. 2009

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	Livestock Bureau in Natural Fields	National	NA	Public: Ministerio de Ganadería, Agricultura y Pesca (MGAP)	Cattle ranching management practices compatible with conservation and efficient use from an integral perspective; to identify and promote benefits obtained from native grasslands, and valuation regarding production and BES, especially resilience capacity to face climate change.	2012 to present	NA	Training workshops and meetings among ranchers to promote sustainable management and integrate research institutions with government sectors; GIS mapping of natural grasslands; institutional strengthening for conservation action; education and outreach; participatory research integrating farmer's knowledge.	NA	Pereira-Machín & Morales 2012, Jaurena et al 2013, IICA 2017
	Climate Change Adaptation Development Project (DAAC)	National	NA	Public: MGAP	To support rural producers for the sustainable use of natural resources, while generating greater adaptation and resilience to climate change.	2012-2021	NA	Application of sustainable land management practices; project financing; strengthening capacities of farmer organizations; support for the Land Use and Management policy (National Agricultural Information System)	NA	Pereira-Machín & Morales 2012, Banco Mundial 2017
	National Plan for Adaptation to Variability and Climate Change for the Agricultural Sector	National	NA	Public and International: National System of Response to Climate Change and Variability (SRNCC); MGAP, Food and Agriculture Organization of the United Nations (FAO)	To guide public policies with a long-term vision (2025-2050) around the productive, environmental, social and institutional dimensions	2019	NA	Participative process involving different stakeholders	NA	OPYPA 2019
	Climate-smart Livestock Production and Land Restoration project (GCP/URU/034/GFF)	National	4 Ecoregions with direct and indirect intervention	Public and International: Global Environment Facility, MGAP, MVOTMA; FAO	To mitigate climate change and restore degraded land through the promotion of climate-smart practices in cattle ranching	2019	NA	More efficient use of resources and lessen environmental impacts; reduction of greenhouse gas emissions; carbon sequestration in soil; positive impacts on biodiversity and other ecosystem services.	NA	OPYPA 2019

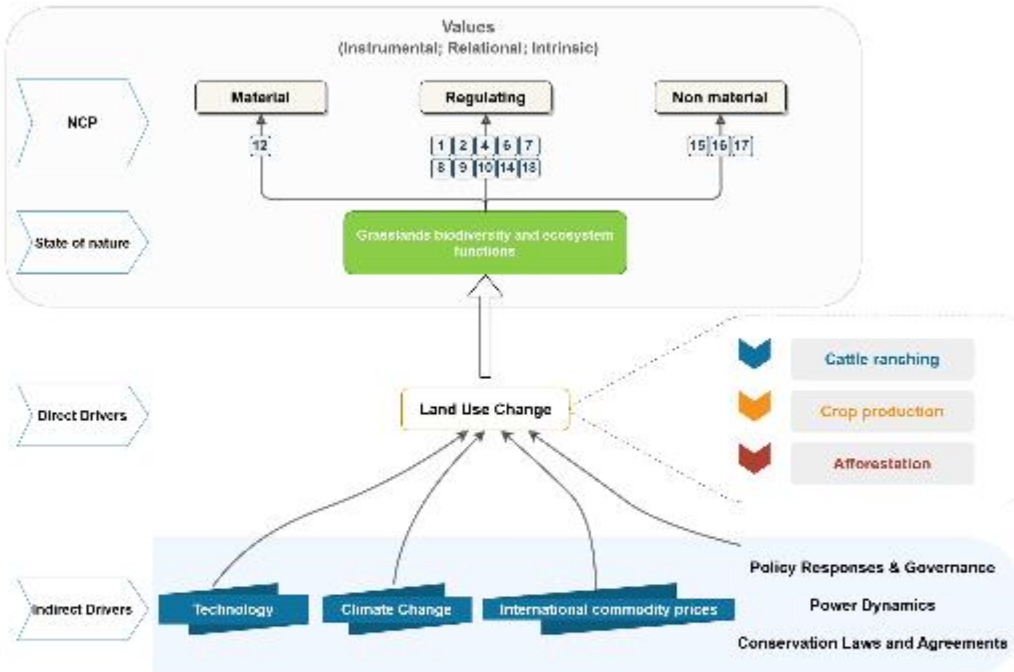

Figure 2. Conceptual framework for policy-based conservation of the Rio de la Plata Grasslands (RPG) following the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and Nature's Contribution to People (NCP) notion.

Discussion

The main goal of this study was to contribute to policy-based strategies for biodiversity conservation and ecosystem services provision for South America's Rio de la Plata Grasslands, within a novel conceptual approach. From our review, we evidenced that the unsustainable practices that have resulted in negative consequences for BES over the RPG are currently still ongoing. We found that the different regions within the RPG share similar drivers of change (e.g. land-use change due to overgrazing, crop expansion, and afforestation, climate change, and invasive species) and are experiencing comparable negative consequences regarding the conservation of BES. Most studies highlighted regulating and material NCPs, while we found scarce information on non-material NCP. Similar results were evidenced by Mastrangelo et al. (2015), showing a tendency to focus on the biophysical processes and patterns of the ES rather than on assessing its cultural component and benefits to people. Thus, the LULC changes have occurred at the expense of the loss and degradation of natural environments, the system's sustainability, and cultural values (Mastrangelo et al. 2015, Modernel et al. 2016, Auer et al. 2017). Consequently, it is essential to develop a regional assessment of the RPG adapted to the cultural, social, political, and economic issues of the region. In addition, a transdisciplinary approach could help strengthen the interface between science and policy-makers while enhancing the participation of different stakeholders.

Current policy approaches for BES conservation differ between regions and countries. Based on our conservation-policy review, we found the pervasive and systemic grassland ecosystem degradation concerning. Although all countries recognize the importance of this biome and consequently express an interest in its conservation, the implementation and execution of plans and actions have been sparse. Lack of action is reflected in the limited inclusion of protection mechanisms in regional and local land planning strategies, as well as in the very low levels of protected-area coverage of native grassland within the RPG.

Policies for the conservation of BES in the study area are uncommon and incipient, particularly in Argentina and Uruguay (Azpiroz & Rilla Manta 2007, Modernel et al. 2016), while Brazil appears on the lead as far as current existing laws for grassland's BES conservation. To date, most conservation initiatives in Argentina are non-normative and territorial planning that includes grasslands is lacking. The Argentinian legislation considers only native forests as a priority for conservation when it regulates the promotion of productive developments. We propose that different types of biomes should be included, in order to reduce the potential threats to other vulnerable ecosystems. These could help increase the recognition of the grasslands' ecological value and its conservation, from regional to national scales (Bond & Parr 2010, Overbeck et al. 2007). Thus, there is an urgent need to implement initiatives that establish a minimum proportion of grasslands to be protected, with special emphasis on at-risk areas, along with strategic territorial planning initiatives. These could ensure that productive activities do not represent a threat to vulnerable ecosystems, especially where the most natural tracts of grasslands still remain. In Uruguay, a series of governmental initiatives were proposed in the last decades, which aimed at sustainable management of cattle ranching in natural fields and conservation of its BES (Bartesaghi et al. 2015, Ávila et al. 2018). Although there are concrete actions in the conservation of grasslands, it is necessary to create national legislation to regulate and enforce conservation policies. Contrary to these sustainable proposals, a recent law aims at intensifying agricultural production (Irrigation Law, N° 19,553, 2017), which could negatively affect the grassland conservation.

In Argentina and Uruguay, conservation policies are more oriented towards the protection of a few threatened grassland species and their habitats (Di Giacomo et al. 2007, Soutullo et al. 2013, MAyDS 2017b). On the other hand, Brazilian policies for grassland conservation present a more optimistic perspective for the future. Expectations are on the enforcement of the Environmental Rural Registry code, which has the potential to constitute a reserve of preserved native grasslands. The possibility of linking the Permanent Preservation Areas and Legal Reserves should safeguard a minimum of 20% of the private grassland areas, and those within the governmental protected areas. However, grasslands in southern Brazil are considered a "neglected biome" (Overbeck et al. 2007), since it is not given adequate consideration and protection in comparison to other Brazilian biomes, and where policies focusing on farming intensification pose a significant threat to the BES sustainability of the grassland ecosystem.

We agree with Hoekstra et al. (2005) that conservation efforts should be addressed at large scales, as national and regional perspectives are the scales at which conservation policies will be more effective in halting habitat and biodiversity loss across the RPG (e.g. Di Minin et al. 2017). As previously mentioned, the management of the region has been mainly driven by national policies centered on rural economic development. Nevertheless, there are international initiatives that are applied to RPG conservation, mostly driven by NGOs actors. These initiatives are encouraging, but require institutional support enabled by national political approaches to reach a broad, transnational, and effective conservation outcome. There are several examples of successful multinational conservation efforts that transcend geographical boundaries and work together in pursuit of conservation, such as Natura 2000 network in the European Union through the EU's Birds (79/409/EEC), Habitats Directives (92/43/EEC) and the UN Convention on Biological Diversity. Regarding grassland management and conservation in the RPG, it is possible to address some similarities in comparison with European conservation approaches. Identified threats to European grasslands (Silvia et al. 2008) are in line with the ones found in our case study (EEA 2012). Concerning protected areas, different EU Member States define different approaches toward conservation. In effect, 25% of the 27 EU terrestrial lands are protected under either Natura 2000 (where human activities must be harmonious with the conservation of sites of natural importance), national designations, or a combination of both. Grasslands ecosystem share was 9.2% of the total area of protected sites in Europe, while for the total of areas included in Natura 2000, 11% were classified as grasslands (EEA 2012). Some of the policy proposals for these areas include the promotion of high nature value farmland or payments to farmers for the environmental services provided (Silvia et al. 2008).

Following the IPBES framework and the NCP concept, we sought to link scientific knowledge on biodiversity and ecosystem function, the values for society, and the policies that could promote conservation in the RPG. We concluded that the different regions in the RPG have in common not only the drivers but also the underlined negative consequences regarding the conservation of BES. Therefore, the conceptual framework built in this study is generalizable to the full extent of the RPG. This framework could be used as a tool to communicate the relevance and the benefits to society of preserving native grassland's BES in this region. Also, it could help to focus attention on the consequences of not applying sustainable management, which can result in the direct loss of the long-term productive capacity and resilience of this ecosystem (Foley et al. 2005, MEA 2005). Furthermore, this model would also aid in detecting the lack of information and policies in some areas, and serve as a base model to integrate new information. Lastly, the framework could be useful as a primary input in qualitative or quantitative modelling of relevant socio-economic scenarios and conservation outcomes (for instance, the Shared Socioeconomic Pathways; O'Neill et al. 2014), identification of policy options for future management (e.g. Anton et al. 2010, Paracchini et al. 2011), and to construct spatial models for synergies or trade-offs between different ecosystem functions and its conflicts (e.g. Zhang et al. 2019b).

1. Conservation policy proposal

Taking into consideration the "emerg[ent] biome crisis" (Hoekstra et al. 2005) that temperate grasslands face, and based on the threats identified in this study, we highlight a combination of policy mechanisms for conservation of the RPG. Based on the proposed framework, the following initiatives could enhance and/or maintain the existing biodiversity as well as increase connectivity throughout the RPG. In addition, we associate the different values and NCPs that these policies could enhance. However, we acknowledge that these efforts are not an end but a starting point to reach long-term conservation goals.

First and foremost, an expansion of the natural protected areas in the RPG is crucial. Dinerstein et al. (2019) state that there is a small window of opportunity of 10 years to halt climate change below 1.5°C and to prevent 'points of no return' in terms of habitat loss and species extinction. Following this idea, we concur that a higher percentage of the RPG should be under some form of protection. Protection here is understood as defined by the International Union for Conservation of Nature (Dudley 2008). In order to protect all subregions in the RPG, each country could use a combination of the following: (1) establish multiple protected areas through legal mechanisms in zones identified as hotspots for BES, including the creation of buffer zones and natural corridors within agricultural landscapes (e.g. Nin et al. 2016, Schröter et al. 2017) to increase interconnectedness throughout the RPG; (2) Create incentives (in the form of tax breaks or payments for ES) for landowners who allocate part of their properties to grassland conservation (Alianza del Pastizal 2019). (3) Argentina and Uruguay could adapt and implement similar measures to that of Brazil (Environmental Rural Registry) to protect 20% of each private property.

We are aware that effective grassland biodiversity conservation outcomes cannot be achieved through protected areas alone (Harlio et al. 2019). Thus, it is important to take into consideration the connectivity of these conservation areas to minimize landscape fragmentation and its detrimental effect on biodiversity (Batáry et al. 2011). The connectivity of these natural areas is essential to dispersal success, persistence, and genetic diversity of species in fragmented landscapes (Schooley & Branch 2011). Some of the agri-environment schemes implemented by the European Union's Common Agricultural Policy did not have a positive effect on biodiversity and it was associated with the lack of regional and landscape conservation planning in farmlands (Batáry et al. 2011; Harlio et al. 2019). Looking at the trends of the RPG, there is an increase in cropland areas, so the maintenance of rural roadside could play an important role. Roadsides can host a diverse and representative flora and fauna of the region, supporting their importance as refuges and reservoirs of biodiversity (Saez et al. 2014; Arenas et al. 2017). Herrera et al. (2017) suggested a novel and simple index to assess the conservation status of roadsides that could serve as an initiative to implement in other areas and to take these landscape elements into consideration in decision-making.

Second, the regulation of LULC changes throughout the RPG is fundamental to the long-term conservation of this biome. Existing economic regional bodies such as MERCOSUR (Common Market of South America) could be used to establish biome-wide conservation goals, legislation, and control mechanisms that align with each country's economic growth models (Soutullo & Gudynas 2006). Such actions could include, but are not limited to, the establishment of national zoning and land use regulation schemes based on socio-economic information and BES hotspots identification (Nin et al. 2016; Di Minin et al. 2017). This process could be expanded to the entire RPG region, and even to larger spatial scales within a multi-biome land-use prioritization approach (i.e. the entire Del Plata Basin; Viglizzo & Frank 2006). These guidelines could help reach an agreement between countries about land-use policies focusing on particular areas that are crucial for the RPG's biodiversity and ecosystem services provision. This will require control mechanisms that can verify such activities are following and meeting national and regional agreements. Coordinated actions between the involved countries, along with well-defined management objectives and regulations, could represent a key strategy for developing an effective regional network of conservation strategies inside and outside of protected areas (Bicknell et al. 2017; Moraes Salvio & Ribeiro Gòmez 2018).

Lastly, the inclusion of socio-cultural values into all management policies and plans is necessary. The identification and comprehension of the different nature values and worldviews are essential steps to link the NCP and their influence on human well-being. This approach is applicable to initiatives at the science-policy interface in order to obtain sustainable management of the environment (Pascual et al. 2017). Policies that consider stakeholder's welfare based on local and scientific knowledge and allow compatibility between different land uses could support long-term sustainable use of grassland ecosystems (see examples on Pillar et al. 2009). Effective conservation measures must be implemented with the full support of local communities (Modernel et al. 2016). Furthermore, Dujin et al. (2008) identified three major types of values related to protected areas: economic, social and environmental, which presents benefits that can be enjoyed at multiple levels: local, regional, cross-border, international or global benefits, including the public and private sectors (Kettunen et al. 2009).

Protected areas are the cornerstone of conservation, but taking into consideration the economic relevance of the region to each country, biodiversity conservation cannot rely only on those areas. Sustainable conservation also requires policies for managing the entire region, including areas dedicated to agricultural activities, within a regional perspective, and taking into consideration people's outlooks and values (Margules & Pressey 2000, Tscharntke et al. 2005, Harlio et al. 2019). Following IPBES' aim to promote the conservation and sustainable use of biodiversity, long-term human well-being, and sustainable development, our study addresses the main drivers of change in the RPG. Our conceptual framework can provide an approach to integrate international policies and increase the conservation level of this biome, connecting it with the different grassland values. We are aware of the complexity of these efforts and the implementation of international policies highlighted in this study. However, national and local governments should realize the importance of conserving the RPG and the consequences of not addressing the drivers affecting it.

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Conflicts of Interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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Chapter 8

8.0 Appendix

8.1 Curriculum Vitae

Andrew Ademola Adenle

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Sustainable Land Management
Geographic Information Systems & Remote Sensing
Sustainable Natural Resources Use, Management and Governance,
Landscape Ecology

SKILLS

Environmental studies: Land Degradation Assessment, Vegetation Monitoring, Remote Sensing Landscape Ecology, Climate Variability & Climate Change Adaptation, Climate Risk Management and Policy, Ecosystem services in changing Climate, Agriculture, Land Systems Dynamics and Science, Ecosystems.

Social studies: Stakeholder Workshops, Surveys and Questionnaires, Land Management & Land Use Planning, Transdisciplinary and Sustainability Research.

Software proficiency: GIS (QGIS; ArcGIS and extensions), Remote Sensing (Erdas Imagine, Idrisi Andes TerrSet and ENVI IDL suite) Google Earth, Global Mapper, Map Source, Sufer, ENVI IDL, Google Earth Engine (GEE), Geostatistics (R, Excel-Stats, SPSS)

Project management: Writing of project proposal (EU, Rufford Foundation, TETFUND) IDEA WILD Small equipment Grant), Scientific project designs, Management and Coordination

Social skills: Multicultural & Multidisciplinary work and interactions with land users, Policymakers, experts teaching and training.

EMPLOYMENT HISTORY

Oct.2017-Present **Research Assistant/ Doctoral Scientist**
Institute of Geography, University of Bern, Switzerland

- Co-supervise undergraduate research students, contribute to the units teaching and research as required.
- Contributing to proposals, which includes drafting grant proposals, and planning for potential calls from grant organizations to support future research.

Jan 2015-Oct 2017 **Assistant Lecturer, Department of Geography,**
Federal University of Technology, Minna, Niger State, Nigeria

- Anchored the teaching of undergraduate students in courses/ topics, which includes: Advance Digital Image Process (DIP), Geographic Information System (GIS), Radar Remote Sensing, Research Design and Methodology including fieldwork activities.
- Undertake personal research projects and actively contribute to the University's research profile.

Jan 2015-Oct 2017 **Research Assistant, West African Science Service Centre on Climate Change and Adapted Land Use, Minna (WASCAL), (Secondment)**

- Participated in conjunction with other young West African scientists in a rural community-based project on climate change, its impacts on water resources, agriculture and the rural economy.
- Assisting WASCAL students in preparing and summarizing research results for discussions, meetings, poster presentations, and publications.

- Managing Library functions including organization, ordering, and scheduling books/equipment used, including supporting WASCAL's Director with research projects, logistics and administrative tasks.

EDUCATION

2017- Date	**Ph.D. in Geography & Sustainable Development (In View)** University of Bern, Switzerland
2014	**M.Tech, Climate Change and Adapted Land Use,** Federal University of Technology, Minna, Niger State, Nigeria
2012	**M.Sc, Geographical Information System,** University of Ibadan, Oyo State, Nigeria
2009	**B.Sc. Water Resources Management and Agrometeorology,** Federal University of Agriculture, Abeokuta, Ogun, Nigeria

CERTIFICATIONS AND TRAINING

Low Carbon Development Planning and Modelling(World Bank Institutes)-Carbon Monitoring in the CDM Afforestation and Reforestation Projects (World Bank Institutes)- Junior Scientist Certification on Greening the Future: Sustainable Agriculture and Forestry in African and Asian Drylands (Right Livelihood Junior, (RLC/ZEF)-Scientific Writing(International Graduate School (IGS) North-South-Certificate of Specialization in Sustainable Development (International Graduate School (IGS) North-South), German Language A1 (University of Bern, Switzerland)

GRANTS, AWARDS, HONOURS (NATIONAL & INTERNATIONAL) RECOGNITIONS

- **Leading House for Africa(2021), Research Partnership Grant I**, by the Swiss Tropical and Public Health Institute **(Swiss TPH).** Grant value: $15000
- **Doctoral Scholarship Position** (2017), UniBE International 2021, University of Bern, Switzerland
- **Overall Best Student** of the West African Science Centre of Climate Change and Adapted Land Use (WASCAL) CC & ALU (Class 2012)
- **Young Fellow of The World Academy of Sciences** for Developing World **TWAS/BioVision** Alexandria. NXT 2014
- **Finalist** of the Alexander von Humboldt (AVH) Foundation (2014) on Climate Protection and Climate-Related Resource Conservation, Germany.
- **Funding & Scholarship** by German Federal Ministry of Education and Research **(BMBF)** through the West Africa Science Centre of Climate change and Adapted Land Use **(WASCAL)**
- **IDEA WILD Small equipment Grant** for Drone **DJI Mavic Air Quadcopter with Remote Controller**. **Grant value $1500**
- **Rufford Foundation Small Grant** *"Land Degradation and Its Impacts on Ecosystem Services in the Nigerian Guinea Savannah: Insights for Sustainable Land Management. (part Project in Niger State Nigeria)"* Grant (27153-1). **Grant value €5,512.91**

PERSONAL INFORMATION

- Gender: Male
- Date of Birth: 25.01.1983
- Marital Status: Single
- Resident Permit: B

LANGUAGE SKILLS

English: Advanced
German: Basic
French: Basic
Yoruba: Advanced

CONTACT

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Research profile: http://www.researcherid.com/rid/R-4687-2018
https://scholar.google.com/citations?user=N-Guck4AAAAJ&hl=en&oi=sra

8.2 Declaration of consent