Landscape Restoration through Agroforestry: Options for Reconciling Livelihoods with Conservation in the Sahel of Mali

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A thesis submitted to the School UTG WASCAL, School of Agriculture and Environmental Sciences, in partial fulfilment of requirements for the award.

DOCTOR OF PHILOSOPHY (PHD) Degree (Climate Change and Education)

Of The UNIVERSITY OF THE GAMBIA, THE GAMBIA

MAY 2023

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DEGREE: PhD. Climate Change and Education

YEAR: 2023

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Acknowledgment (s)

I gratefully acknowledge the WASCAL (West African Science Service Centre on Climate Change and Adapted Land Use) sponsored funded by The Federal Ministry of Education and Research (BMBF) Germany, for the scholarship support to the first author for my Ph.D in Climate Change and Education which led to the writing of this thesis of this study executed at the University of The Gambia (UTG). I also appreciate the support from World Agroforestry Centre in Partnership with ENABEL for the facilitation of the field research, and finally the University of Freiburg for supervision and technical support in manuscript development and publication. I acknowledge the support of the Open Access Publication Fund of the University of Freiburg for publishing my first article through the technical and financial facilitation of Melanie FEURER, Benno POKORNY, and Jurgen BAHAUS. Melanie highly contributed to the improvement of my research work and social networking.

Great thank is to Benno POKORNY, his wife Anja, and his sons Yuri, and Paulo for the joy and love they gave to me and for allowing me to stay in their flat situated in the beautiful forest landscape view in Vauban) throughout my visit in Freiburg/ Germany. Moreover, I deeply thank Patrice SAVADOGO for his mentorship support throughout my scientific career in Climate Change and Education and networking facilities. Sidzabda Djibril DAYAMBA, my main supervisor, is greatly thanked, who is always available on time to sort out technical and financial issues facing my research and my social life. Special acknowledgments are addressed to Fabrice RENAUD who always paid painstaking observed the thesis with attention to the thesis especially scope of respecting adherence to scientific rules and regulations and creating a harmonised environment for collaboration.

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List of key Acronyms

CICES: Common International Classification of Ecosystem Services

CSV: Comma-Separated Values

EMT+: Enhanced Thematic Mapper

ES: Ecosystem Services

FMNR: Farmer Managed Natural Regeneration

GIS: Geographical Information Systems

GPS: Global Positioning System

GHGs: Green House Gases

IER: Rural Economic Institute

ICRAF: International Centre for Research on Agroforestry

ILUS: Integrated Land Use System

ILMS: Integrated Land Management Strategies (ILMS)

IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

LOA: Loi Orientation Agricole

LULC: Land Use and Land Cover

LULCC: Land Use and Land Cover Changes

MB: Mega Bite

NGO: Non-Governmental Organisation

OLI: Operational Land Imager

RAM: Random Access Memory

SSA: Sub-Sahara Africa

SES: Social-Ecological System

SPSS: Statistical Package for the Social Sciences

TM: Thematic Mapper

UNCCD: United Nations Convention to Combat Desertification

USGS: United States Geological Survey

WASCAL: West African Science Service Centre on Climate and Adapted Land Use

ABSTRACT:

Land provides the basis for human livelihoods through primary production, food and freshwater supply, and multiple other ecosystem services (ES). The last three decades have recorded frequent drought events as well as rapid population growth, which has often resulted in adverse Land Use Cover Changes (LULCC) in the Sahel of Sub-Sahara Africa, particularly in Mali. With regards to the above challenges, the study evaluated the dynamic of LULCC and its driving factor. using mixed method of remote sensing, GIS supported by FGD with local people. Moreover, people's contextual livelihoods need species prioritization, experimentation, and perception on the potential ecosystem services from restoration interventions was conducting through workshops, direct field observation and FGD. As results, it was found that the study area faced a rapid decrease in wooded savannah ecosystem and was converted into shrub savannah, farmland, and settlement. Bivariate correlation shows that within the time frame (1990 to 2020), the increase in farmland significantly correlates with population growth (p-value = 0.04), whereas the decrease in wooded savannah correlates with the increase in settlements (p-value = 0.005) and the increase in grassland (p-value = 0.03). Moreover, a conversion of shrub savannah into grassland has also been recorded (p-value = 0.05). These changes were directly or indirectly related to the pressure of rapid population growth, high cotton price which encouraged cropland expansion and recurrent drought. Firewood extraction, and charcoal production were also recorded but exacerbated by the poverty. For addressing LULCC, people's preferred and are motivated when all fruits, fodder tree and grasses species are promoted under business-based platform, specific varieties of fruits species under Agri silviculture systems and fodder trees, shrubs, and grass under silvopastoral systems. This incentive is attributed, not only to the species socio-ecological value but also to their suitability to the soil type, climate, agroforestry system and proper management practices. Moreover, people preferred fodder specific grass, shrubs, and tree species under silvopastoral systems at an appreciation score of ≥ 80% while fruits trees species are mainly appreciated under Agri silvicultural systems ≥ 60% and business-based platform recorded ≥ 70% a score for all the species. In term of germination, it was found that fodder grass species geminate faster when planted under half-moon management practice under sandy soil than open tilled land (3 to 7 days in soil specific in dry spell condition). Grasses and leguminous fodder recorded high survival rate when planted under clay soil followed by clay and sandy mixed soil (70 to 90 %) while low survival was noticed under sandy and lateritic soil. All the Fodder trees and shrubs recorded significant survival rate (≥ 80 %) under Business based platform system and Agri silvicultural system while fruits trees recorded (≥ 69 %). Restored lands under above conditions provide significant ecosystems from both men and women perception but more services are perceived by men than women and much attention has not been paid on water supply facilities when restoring degraded land with agroforestry systems. With regards to these finding, land restoration intervention needs to considered gender balance centered approach for sustainable ES profits sharing. To address these issues, this study recommended the promotion of Integrated Land Use system (ILUS) strategies that consider current and future livelihood needs and preserve the environment for the benefits of future generations. The adopting of ILUS should considered people's livelihoods need based species or varieties preferences, soil nature, management practices under a specific climatic condition. National ILIUS policies strategies need to be developed and applied considering contextual land use dynamics, driving factors, adapted agroforestry systems under proper management practices with introduction of suitable livelihoods specific species to be introduced.

Key Words: *Land Use Cover Changes, Driving Factors, Species Conservation, Ecosystems Services and Livelihoods*

CHAPTER ONE

INTRODUCTION

1.1. Background to the Study

Land has been naturally made in such way that a state of equilibrium exists among its components (flora, fauna, water, rock etc…). Thereafter, human species being has been introduced into the natural system. Since the survival of humans depends on land-based resource exploitation, anthropogenic activities engender and caused natural resources disruption (Díaz et al., 2019) . Globalisation of the world's economy and population growth have large environmental consequences and increased pressure on land resources. This scenario is negatively affecting livelihoods sustainability mainly in the developing world (Buchhorn et al., 2020). Since decades, human ecosystem needs exceeded the natural supply which caused disturbance in the ecological functions universally, but the rate and indicators of the changes differs contextually across continents (González-García et al., 2020).

With regards to the African continent, natural resources potential is among the highest in terms of richness, density, and diversity. At the same time, it is a continent considered among those in which natural resources are the most exposed and fragile (Raven *et al*., 2020). The rationale reason behind its exposition climate change and its fragility of natural resources, African land faces rapid changes. This has been attributed mainly linked to its socio-economical and demographical driving factors (Kouassi et al., 2021).

Land degradation results is the decrease in land productivity for use. Land degradation can be caused by soil erosion, wind erosion or water erosion; soil salinization; waterlogging; chemical deterioration; and any combination of these elements (Bado et al., 2016). On the contrary, it is known as a long-term decrease in the productivity and efficiency of an ecosystem, which can be determined by examining long-term remotely collected time-series data (Bai et al., 2008). Land degradation may be described as a decline in the quality of land due to human-induced factors, including climate change, that causes a decrease or elimination of its biological productivity, ecological integrity, and any benefits it may have for humans (Olsson et al., 2019). Land use corresponds to the socio-economic description functional dimension of areas. This includes areas used for residential, industrial, or commercial purposes, for farming or forestry, recreational or conservation purposes. Links with land cover are possible: it is, under certain circumstances, viable reasonable to infer land use from land cover and conversely. Land cover data document how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types (Elagouz et al., 2020). Water types include wetlands or open water. Land use, on the other hand, describes how people use the landscape, i.e., for development, conservation, or mixed uses. Natural degradation of land is called desertification which is drives (caused) by natural phenomenon while land degradation is mostly related to human-induced activities (Masson-Delmotte et al., 2019).

In sub-Saharan Africa, different types of land cover can be managed or used quite differently. For instance, changes in vegetation cover characteristics and soil erosion are important indicators of desertification as they both result from all desertification processes (Symeonakis & Drake, 2010).

The demand for food, fibre, fodder and build up etc…attributed to land cover-based resources increases due to the socio-economical activities for the purpose of satisfaction (Kouassi et al., 2021). Natural resources degradation / depletion has long been an observed fact event/phenomenon because of the diverse uses made of it for livelihoods sustenance. Land, with its lakes, rivers, and seas, is the foundation of human prosperity through its capacity for efficient productivity, its supply of sustenance, freshwater, and a variety of other ES (Couzin, 2019). Neither our individual nor societal identities, nor the world's economy would exist without the multiple resources, services, and livelihood systems provided by land ecosystems and biodiversity. Moreover, looking at the climatic and biophysical conditions, land acts both as a source and a sink for Greenhouse Gases (GHGs) and is integral in maintaining the energy balance, water balance, and aerosols between the land surface and atmosphere (Masson-Delmotte et al., 2019) .

Despite the provided ES provided by the land, human-induced activities combined with natural factors contribute to ecosystem disruption. Flora and fauna production and productivity are shrinking over time but differently from continental to regional and local scales to climatic condition (Hoffmann et al., 2019).

Sub-Saharan Africa, especially its Sahel region, has been classified among the most vulnerable areas in terms of LULCC, trees, shrubs, and grass species non-suitability in the face of ongoing climatic conditions and socio-economic activities (Fenta et al., 2020). This scenario is threatening the livelihoods of people, especially small -scale farmers and pastoralists whose livelihoods depend on rainfed agriculture and natural pasture grassing grazing. These sectors have been threatened at an alarming rate which call for actions.

With regards to the contextual livelihood's insecurity in the Sahel, efforts have been deployed through restoration project interventions in implementing climate friendly agroforestry technologies with local trees and shrubs species under various management practices as livelihoods improvement options. However, these projects are far from achieving expected goals (Goffner et al., 2019). One of the reasons attributed of the failure of most these restoration interventions are attributed to the non-suitability of promoted trees, shrubs, and grass contextually. This phenomenon calls for suitable actions. This study examines how to put more light on LULC dynamics, attributed driving factors and the potential of other existing agroforestry systems, management practices, and tree, shrubs and grass species used for conservation on the study area and which specific local specific suitable options are needed by farmers and pastoralists for livelihoods improvement in Wacoro/Mali.

1.2. Statement of Research Problem

For centuries, land degradation has been one of the major global development issues which need to be addressed for a better future life. UNCCD, (2015b reported that every year, 24 billion tons of fertile soil are degraded all over the world. Land degradation is extensive, covering approximately 23.0% of the globe's terrestrial area, increasing at an annual rate of 5-10 million ha, and affecting about 1.5 billion people globally (Stavi & Lal, 2015).

Although the entire world is affected, Africa is classified among the most affected continent due to its land's high vulnerability to the factors causing or driving land degradation. It has been found by Bai et al., (2008) that 24.0% of the global degraded land mainly lies in Africa south of the equator.

Moreover (Mbow, 2019) projected that, by 2080, an increase risk of 5.0 to 8.0% of arid and semi-arid lands in Africa is projected under a range of climate scenarios and LULCC have been observed throughout the continent but the change rate and driving factors are location-specific (Assede et al., 2023).This is a threat to the future livelihoods under business-as-usual scenario. As the population is growing over the period, land stability is not maintained, because the pressure on arable land is also increasing due to high food demand with consumer preferences. It has been well established that, the last decade has witnessed a rise in consumer-driven demand for sustainable land use and land management, as well as commitments to restore degraded land that is unprecedented in human history due to the negative impacts it is making on food systems (IPBES, 2018). As is projected that the human population will increase to nearly 9.8 billion people (+/-1) by 2050 and reach 11.2 billion by 2100 this may cause unpredictable consequences on land-based resources Couzin, 2019.

It has been also reported by the World Bank (2012) that, in Mali, the major causes of land degradation stem from a) climatic conditions, which include an arid environment and low and irregular rainfall patterns; b) climatic processes such as wind and water erosion; and c) human activities, which consequently, are negatively affecting agriculture, forest, wildlife productivity and production. If these phenomena continue as it is, severe impacts are expected on humans being through food shortage which may lead to a cascading scenario. The deterioration of agricultural and grazing lands is a serious risk to humanity's future in the Sahel region, in general and Mali due to deeply people’s livelihoods dependency (Fenta et al., 2020).

The Land degradation of these lands would not only decrease food production but would also alter the provision of other ES essential or vital for human's well-being, including climate regulation, and habitats for biodiversity (Oldeman,1998; Lee; Stavi & Lal, 2015). Indeed, the Sub-Saharan Africa is likely to face a complex dynamic of human security issues (food insecurity, natural resource-related conflict and political instability related to livelihood support and other unpredictable unfavorable conditions), especially in the Sahel zones where migration, food shortage and geological conflict mostly related to natural resources are taking place with unproductive environmental conditions. In this scenario, the pressure on the available arable land for meeting livelihood demand is likely to increase at greater extend. Land degradation is becoming a threat to human well-being in the Sahel region of Mali due to our people's reliability on it. The dire consequences of land degradation demand immediate and comprehensive action to stop it (Stavi & Lal, 2015).

To minimize expected risks, technologies were developed by researchers in addressing land degradation issues, especially agroforestry technologies which are considered among the effective land restoration options, especially in the face of climate change through the stabilization of soils. The advantages of agroforestry systems for providing livelihood needs and ES in the face of changing climatic conditions are acknowledged, however, due to the large range of agroforestry landscapes and extended life-cycles of trees and production systems, it can be difficult to determine the best combinations of tree species, staple crops, vegetables, animals etc. and how to manage them together in a particular environment (Jamnadass et al., 2013). Moreover, a diverse number of trees, shrubs and grass species has been promoted at the larger scale but still the success of most those species in contextual land use restoration is not significantly recognized.

Thereby, there is strong need for research in determining LULCC tendency, prioritizing successful trees, shrubs and grass by agroforestry systems and generated ES for livelihoods improvement. but however, only limited capitalization has been conducted using gendered lens.

Identifying and proposing successful options, though it might guide future scaling up, requires that the reasons / drivers of success / failure be identified. Despite, agroforestry potential through ES provision, support, regulation, and cultural values, its adoption should couple with the deployment of efforts into contextual LULC and driving factors, species suitability and potential ES to be generated by a particular agroforestry system. Moreover, gender consideration in the agroforestry ecosystems resources sharing is less documented. Thereby, contextual studies need to be conducted on agroforestry socio-ecological systems to harmonize messages to be delivered to communities.

1.3. Research Questions

1. How was Land Use Cover pattern from 1990, 2000, 2010 to 2020 and what were the driving factors causing disturbance?

2. What drives people's preference / choice of agroforestry species and management practices to reconcile ecological and social functions in the Sahel of Mali?

3. What potential does agroforestry systems possess in providing ES for livelihoods resilience in a gender respect?

1.4. Objectives of the Study

1. evaluate the changes and driving factors of land use/cover (LULC) pattern over the period 1990-2020.

2. identify people's preferences and motivation when adopting agroforestry systems under management practices and species for reconciling ecological and social functions.

3. Assess dry-landscape restoration potentials to provide ecosystem services under Agri silvicultural and clavipectoral systems scenarios using a gender disaggregation approach.

1.5. Research Hypothesis

Hypothesis 1:

Ho: LULCC is not driving by population growth

H1: Population growth drives LULCC

Hypothesis 2:

Ho: Wooded savannah decreases is not attributed to the increases in settlement, shrubs, and grass savannah cover

H1: The increases in settlement grass savannah cover are attributed to the decreases in wooded savannah.

1.6. Scope of the Study

This study has examined the potential of existing agroforestry systems, management practices, and tree species conservation on the ground and which local specific suitable options are needed by farmers and pastoralists for livelihoods improvement through generated ES with gender implication in Wacoro Mali. The study used a mixed-methods approach, including literature review and case studies. The literature review will cover scholarly articles, reports, and other relevant documents related to the adoption of agroforestry technologies.

The case studies involved interviews with farmers, extension workers, and other stakeholders involved in agroforestry. Relevant stockholders (local people's, extension workers, researchers, and NGOs) knowledgeable in socio ecological context observation on LULCC, driving factors and agroforestry interventions potentials using participatory approaches.

1.7. Significance of the Study/Justification for the Study

Land degradation is a serious threat to local people's livelihoods in Mali. Erratic climatic conditions combined with the desertification and land use changes are forcing elements inducing human pressure on land-based resources. At the same time, human population is growing exponentially. To address these challenges; agroforestry technologies have been promoted since decades, but the people's livelihoods are still being threatened. Questions needs to be put on the discussion table in order find out factors driving LULCC, species non suitability under management practices and agroforestry potential to supports people's livelihoods. Is the context not properly analysed? Are the technologies wrongly identified with regards to people's needs? Are the promoted species not appropriate under management practices and soil type? Are technologies not providing expected outcome in terms of ES? Therefore, scientists have key roles to play. This study is in line with the desire to (contribute answers to some of the above questions. The study seeks to analyse context specific LULCC, attributed driving factors, promoted species under management practices in agroforestry systems and how generated ES from the systems contribute to the livelihoods improvement of local people.

By evaluating the impacts of LULCC and agroforestry interventions, a study can help to identify the most effective and sustainable interventions for promoting sustainable land use and improving the well-being of local communities in Mali.

It can also provide insights into the barriers and opportunities for implementing these interventions at scale, and the potential for scaling up successful interventions to other regions in Mali and beyond. Overall, an impacts study of LULCC and agroforestry interventions in Mali can contribute to the development of evidence-based policies and programs that promote sustainable land use and improve the lives of people in Mali.

1.8. Definition of Key Terms

Agroforestry: Sustainable management of land, which increases their productivity by properly combining agricultural crops with forest crops simultaneously or sequentially over time through the application of management practices which are compatible with the local climate, topography, and slope.

Annual cropland: Land cultivated with crops with a growing cycle of up to one year, which must be newly sown or planted for further production after harvesting.

Assisted Natural Regeneration: The process of rehabilitating denuded forest lands by taking advantage of trees already growing in the area. This usually involves the following activities: locating and releasing indigenous trees, maintenance, and augmentation planting and protection.

Bare area: Land not covered by (semi-) natural or artificial cover. This includes among others, sand dunes, river wash, lahar-laden areas and rocky or stony areas.

Biodiversity: Variability among the living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

Built-up area: Composed of areas of intensive use with much of the land covered by structures. It includes cities, towns, villages, strip developments along highways, transportation, power, and communication, facilities, and areas occupied by mills, shopping centers, etc.

Catalyst: A substance, usually present in small amounts relative to the reactants, that modifies the rate of chemical reaction without being consumed in the process.

Charcoal: A product obtained from the destructive distillation or thermal degradation of wood.

Climate change: A condition attributed directly or indirect to human activity that alters the composition of global atmosphere, and which is, in addition to natural climate variability, observed over comparable time periods.

Conservation: Protection of plant and animal habitat including the management of renewable natural resource with the objective of sustaining its productivity in perpetuity while providing for human use compatible with sustainability of the resources.

Cultivated land: Land not classified as forest or other wooded land used by man for agriculture or pastures.

Deforestation: The conversion of forest to another land use or the long-term reduction of the tree canopy cover below the minimum 10% threshold.

Degradation: A decline in the productivity of an area of land or in its ability to support natural ecosystems or types of agriculture.

Desertification: The progressive destruction of a vegetative cover that will lead in formation of dry land condition.

Ecosystem: A dynamic complex of plants, animal and micro-organism communities and their non-living environment interacting as a functional unit.

Ecosystem capacity: In general terms, the concept of ecosystem capacity refers to the ability of a given ecosystem asset to generate a set of ecosystem services in a sustainable way into the future.

Ecosystem condition: Overall quality of an ecosystem asset, in terms of its characteristics such as extent, conguration, landscape forms, and climate and associated seasonal patterns.

Ecosystem degradation: The decline in an ecosystem asset over an accounting period due to economic and other human activity. It is generally reflected in declines in ecosystem condition or declines in expected ecosystem service flows.

Ecosystem resilience: The capacity of natural system to recover from disturbance.

Ecosystem services: The multitude of material and nonmaterial provisions and benefits from healthy ecosystems necessary for human sustenance, well-being, and survival including support processes, provisioning and environment regulating services, and cultural resource preservation services.

Ecosystem sustainability: The capacity of an ecosystem to maintain its composition, function, and structure over time, thus maintaining the productivity of the land and diversity of plants and animals.

Endangered species: Species or subspecies that is not critically endangered but whose survival in the wild is unlikely if the casual factors continue operating. Species with small populations that could be threatened if the environment worsens.

Equity: Equal opportunity to resource utilization and sharing of benefits derived there from.

Fast growing species: A tree species that grows relatively faster than common forest trees and whose rotation age is 4 to 20 years with a mean annual increment of at 10 cubic meter per hectare under favorable site conditions.

Fauna: All species of animals found in each area.

Firewood: Wood intended for use as fuel.

Flora: All species of plants found in each area, including ferns, lycopods and mosses.

Fodders: Coarse grasses such as maize and sorghum, shrubs, trees, harvested with the seed and leaves green or live, cured and used as feed for livestock or game animals and ruminants.

Grassland: Areas predominantly vegetated with local grasses.

land classification: A system for determining land of the public domain into forest land, mineral land, national parks, and agricultural land.

Land cover: Refers to the observed physical and biological cover of the Earth's surface and includes natural vegetation, abiotic (non-living) surfaces and inland water bodies such as rivers, lakes, and reservoirs.

Land suitability: The applicability of a given type of land for a specific kind of land use.

Land use: The manner of utilizing the land, including its allocation, development, and management.

Land use classification: The process of delineating or allocating lands according to protection, production, settlements, and infrastructure.

Land use conversion: The process of changing the current use of a piece of land into other uses.

land unit: An area of land defined in terms of land qualities and characteristics that may be demarcated on a map. A hierarchy of land units might consist of land provinces, land systems, landforms, and terrain units.

NB: These definitions were adopted from Philippine **Foreign Assisted and Special Project Service glossary.**

CHAPTER TWO

LITERATURE REVIEW

2.1. Conceptual Review

Land use and Land Cover Change (LULCC) refers to the changes in land use and land cover that occur over time, because of human activities and natural processes. In Mali, LULCC has been driven by several factors, including population growth, agricultural expansion, urbanization, and climate change. These factors have led to deforestation, soil degradation, loss of biodiversity, and other environmental problems, which have negatively impacted the livelihoods of many Malians.

To address these issues, various restoration interventions have been proposed and implemented in Mali, including reforestation, agroforestry, soil conservation, and sustainable land management practices. These interventions aim to restore degraded lands, improve ecosystem services, and promote sustainable development.

A conceptual framework for understanding LULCC and restoration interventions in Mali can be developed using a socio-ecological systems (SES) approach. This approach recognizes that social and ecological systems are interdependent and that changes in one system can have impacts on the other. The framework can be organized into three interrelated components:

1. LULCC and Drivers factors: This component includes the various factors that are driving LULCC in Mali, such as population growth, agricultural expansion, urbanization, and climate change. Understanding these drivers is important for identifying the underlying causes of environmental problems and developing effective restoration interventions.

2. Species compatibility with agroecological principles: Agroecology emphasizes the importance of ecological sustainability, social justice, and food sovereignty. Therefore, species prioritization should consider the compatibility of the species with agroecological principles, such as their ability to support sustainable farming practices, enhance food security and resilience, and empower local communities. Moringa (Moringa oleifera): This tree is highly nutritious, providing a range of vitamins, minerals, and antioxidants. It is also drought-tolerant and can be grown in a variety of soils.

3. Agroforestry Systems Ecosystem Services potentials: This component includes the potential of the various interventions that are being proposed and implemented to restore degraded lands and improve ecosystem services in Mali, such as reforestation, agroforestry, soil conservation, and sustainable land management practices. Understanding these interventions is important for identifying the most effective approaches for restoring degraded lands and promoting sustainable development. Moringa leaves and seeds are used in traditional medicine and have a range of health benefits. Indigenous fruit trees: Mali has a rich diversity of indigenous fruit trees, such as baobab (Adansonia digitata), shea (Vitellaria paradoxa), and tamarind (Tamarindus indica). These trees provide important ecosystem services, such as soil conservation and carbon sequestration, and their fruits are highly nutritious and have cultural and economic significance.

Overall, a conceptual framework for understanding LULCC and restoration interventions in Mali should be based on a SES approach that recognizes the interdependence of social and ecological systems, and that integrates the various components of LULCC, restoration interventions, and ecosystem potentials assessment. Such a framework can help to guide research and practice in the field of environmental restoration in Mali, and in other similar contexts.

2.2. Empirical Review

Globally, land uses have been facing multiple changes during the last three decades. Their causes and driving factors are mainly related to human-induced activities but also to natural factors (Liu et al., 2021). In dry lands, increasing farming activities, bush fires, and climate change and variability contribute LULCC. Physical factors influencing the environment in dry areas particularly refer to desertification and droughts, while human-induced effects are related to farming activities, overgrazing, agricultural intensification, and deforestation (Kangalawe, 2009).

It is well established that the last decade has witnessed a rise in consumer-driven demand for sustainable land use and land management as well as commitments to re-storing degraded land that is unprecedented in human history due to the negative impacts of land degradation on the food system (IPBES, 2018). The degradation of agricultural lands is one of the major threats to the future of humankind because of decreased food production and provision of other services including regional and global climate regulation and habitats for biodiversity (Michalk et al., 2019).

In SSA, changes have been observed in the distribution and dynamics of distinct types of terrestrial ecosystems (Stavi & Lal, 2015). Grasslands, shrublands, savannahs, woodlands are severely threatened terrestrial ecosystems whose productivity has been diminishing throughout recent years (Ofori et al., 2021). Furthermore, Africa's population size is projected to double by 2036 and to represent about 20.0% of the world's population by 2050 (Asongu et al., 2020), a trend that can drive the continuous loss of vegetation cover in the Sahel, provided that no major change in land use policies and management practices is taking place. This regional trend in degradation is also supported by country level data. For instance, a study conducted in the Tougou Watershed in Burkina Faso concluded that the conversion of natural vegetation into cultivated areas led to a significant increase in the runoff potential (Yonaba et al., 2021a). Therefore, the productivity of livelihood related activities will decline if appropriate decisions and measures are not taken to contain and reverse these trends.

In Mali, it has been reported that the major causes of LULCC stem from (a) climatic conditions, which include an arid environment and low and irregular rainfall patterns; (b) climatic processes such as wind and water erosion; and (c) human induced land use changes (World Bank, 2012). Land-related issues are threatening the livelihoods of rural and peri urban communities to an extent that causes the migration of young people (to migrate) abroad or to gold mining sites in Western Mali in search of alternative income opportunities (Coulibaly & Li, 2020). Moreover, because of complex challenges around livelihood insecurity and increasing food prices, community conflicts, jihadism and terrorism are spreading throughout Mali, especially in the Sahel Agroecological Zone (ECB, 2012). For instance, as productive land is becoming increasingly scarce, relations between groups of farmers and pastoralists have shifted from a complementary one to one of increasing tension and conflict because of competition for land-based resources. Moreover, unproper land management strategies and lack of livelihood sources contributed to the intensification of the tension among people. At the same time, some regional studies have indicated signs of recovery or regreening in the area (Neimark et al., 2018). They found that even though the West African Sahel was once synonymous with land degradation and desertification, it is now often celebrated as a region of environmental rehabilitation and recovery (West et al., 2020). This contradictory information in the literature makes it a prerequisite to have context-specific information across Sahelian countries for the purpose of proposing contextual sustainable land management options for resilient local livelihoods and a healthy environment. This study addresses the case of Wacoro Municipality in Mali and aims to identify trends in LULCC in the past thirty years and the key drivers behind these changes.

Sahel Mali is a region naturally fragile due to the extreme socio-ecological conditions (Koloma, 2022). (Since) For some decades, the region has been facing drought, high energies demand and incentives increases in cotton price attributed to population growth which drive LULCC throughout the time Sanogo et al., (2022). That change is negatively affecting livelihoods of people through low food and fodder production and productivity contextually (Hiernaux et al., 2022). As an alternative, people, especially small-scale farmers, and pastoralists are among the most vulnerable groups due to the rapid land use cover changes LULCC. From wooded savannah to farmland, species suitability became an issue, not only due to human induced exploitation but also soil and climatic conditions. Pastureland and farmland face rapid decreases in local tree, shrubs and grass species which are environmentally, socially, and economically valuables for human livelihoods (Ouédraogo et al., 2022). Regarding this phenomenon, development projects have promoted various livelihoods-based supports trees, shrubs, and grass species for propagation as an alternative but unproper consideration of local people preferences and motivational factors remain problematic (Massaoudou et al., 2022). Moreover, species long production and productivity cycle are at the centre of people's demotivation. Thereby, research centres and institutes have conducted research in improving the production and productivity of these species in a shortest time (4 years maximum. As a result, valuables local trees, shrubs and grass species have been improved by research centre which needs to be promoted for livelihoods security. But species suitability has been problematic contextually due to the socio-ecological disturbances (Ky-Dembele et al., 2022). To ensure sustainable adoption of these species, farmers need to prioritize based on their preferences considering their socio-ecological values through a participatory experimentation. To contribute to the filling of this gap, this research has investigated the contextual preferences of local people on livelihoods-based tree, shrubs and grass species under agroforestry systems supported by management practices.

Ecosystem degradation is a major global problem that over proportionally affects developing countries and the African Continent in particular (Wang & Dong, 2019). Reports demonstrate that approximately 46.0% of Africa's overall land is enduring land degradation, affecting around 485 million people (65.0%) with an annual cost of US$9.3 billion (Chasek, 2022). About 75.0%. Up to this point, you have used the former of the region's population depends on subsistence agriculture, primarily rain-fed agriculture in SSA (Tully et al., 2015). There is little use of sustainable land management practices in this region, leading to soil degradation (Baumgartner & Cherlet, 2015).

This scenario is exacerbated in the Sahel Agro-ecological Zone due to its complex, highly exposed location and its vulnerability to socio-economic and environmental stresses with low adaptive capacities. Nutrition and income in the Sahel are mainly based on rain-fed agriculture, livestock, and tree-based products.

According to United Nations estimates "about 80% of agricultural land in the Sahel is no longer able to provide proper ES while temperatures are rising 1.5 times faster than the global average agency (Fahad et al., 2020). “As a result, droughts and floods are becoming longer and more frequent, undermining food production.” Intergovernmental Panel on Climate Change [IPCC] (2019) found that terrestrial ecosystems and biodiversity are at risk from prolonged climate extremes. Heavy rainfall following a long dry spell can seal the soil surface, cause runoff, and erode bare soil (Bado et al., 2016). In addition, external hazards such as flooding, drought, water erosion, and wind erosion cause disturbances in the socio-ecological system. It is well known that water runoff tends to increase with land degradation. Factors of production are threatened as access to natural resources rapidly decreases due to the decline of ES (Blake et al., 2018).

To address the projected risks of LULCC, researchers and practitioners have developed technologies for improving livelihoods in the Sahel, particularly agroforestry technologies (Flintan et al., 2022). Agroforestry, in addition to agricultural diversification, typically contribute to resilience building in the face of climate change and food security and improved livelihoods (Streck, 2019). Promoted technologies include farmer managed natural regeneration (FMNR), tree planting, food bank, windbreak, rainwater harvesting, stone rows, zai technic, crescent.

Agroforestry systems have been acknowledged for their potential to help mitigate the effects of climate change, however, considering the great variety of agroforestry landscapes, and the lengthy lifespans of trees and production systems, it can be challenging to determine what the optimal combinations are between trees, crops, livestock, and other elements in particular environments, as well as how they should be managed (Lancelloti, 2019.).

Although agroforestry is known to be beneficial to farmers and the environment, its implementation rate falls far short of its intended goals (Mbow et al., 2008) .To address livelihood fragility, NGOs and research centers in the Sahel have taken some initiatives to identify and propose successful options (Mechiche-Alami et al., 2022). Agroforestry has the potential to provide many ES, but for successful adoption, there needs to be an effort to raise awareness, let farmers select their own technologies, and supply necessary inputs during the initial phase. To achieve this, it is important for policymakers, researchers, and extension providers to work together and ensure that they are all conveying the same message to farming communities. The Year 2021 World Environment Day, held annually on June 5, marks the official launch of the UN Decade for Ecosystem Restoration, a Ten-Year initiative to halt and reverse the decline of the natural world. Because ecosystem restoration is a global concern, every country has set goals, but in most cases lacks national figures to meet its international commitments (Umoh & Lugga, 2019) . This is because reference data have not always been produced against which to measure progress in restoration actions by governments and other development actors. This study is an attempt to provide perception-based data to accelerate investment in land restoration and raise awareness of its potential to improve livelihoods in the Sahel. The study examined the extent to which restored cropland and pasture provide ES to support livelihoods from the perspective of local people.

Using the lens of ES (Costanza et al., 2017) can be useful to systematically analyze and compare a variety of benefits provided by different land uses. Restoration approaches such as farmer managed natural regeneration or agroforestry in the Sahel region are believed to be able to sustainably enhance ES provided by these lands.

The positive relationship between restoration and ES is well known and a better understanding and communication of this interconnection can support the scaling up of restoration activities across different landscapes (Alexander et al., 2016). In the context of SSA, a meta-analysis revealed predominantly positive impacts of agroforestry on ES provision and a reduction in trade-offs between multiple ES and crop productivity (Kuyah et al., 2019).

Yet, the services provided highly depend on the perception of the respective stakeholder. Naturally, important ES such as biodiversity or carbon sequestration may not have the same relevance or may be understood differently from the perspective of local land users (Feurer et al., 2019) . It therefore aimed to investigate ES attributions from restored farmlands and pasturelands in Sahelian Mali from the perspective of local land users, including men and women.

2.2.1. Land use cover changes and driving factors.

Examining the changing in landscape is essential for addressing wide-scale issues like food safety, climate change, and biodiversity reductions. The combination of such phenomenon is drive by mainly human induced activities for livelihoods supports (Assede et al., 2023).

As human population grows exponentially, the demand for food, water and energy need increases while supply is limited. Thereby, disequilibrium is created in the ecosystem supply and demand chain.

This leads to supply of insufficient livelihoods supporting natural resources, adverse collapse of the environment, and obliterated/or threatened and caused insufficient livelihoods supply for people and adversely collapse the environment. As environmental conditions vary from global to local level, the rate and the nature of disturbances differ due to the varieties of socio- ecological conditions. SSA in general and its Sahel region, is considered as naturally fragile to the ecological disturbance due to its high exposure and sensitivity and low adaptive capacities in the face of climatic hazards. Major part of the population depends on land-based resources for their livelihoods.

The arable part of the Sahel is also limited due to the low flora and fauna density and diversity, low rainfall pattern and difficult access of ground water and increasing desert coverage. The mixture of these phenomenon underpins the economic growth of the region and creates an environment of tension among communities due to insufficient livelihoods sources.

Sahelian Savannah is naturally rich and dense in flora and fauna to support the livelihoods of the communities but since some in the last few decades, its potential is diminishing over the period due to the changes in land use cover dynamics generally (Yonaba et al., 2021b) . This change is characterized by low productive woody vegetation due to the erratic climatic conditions and human induced pressure for livelihoods needs and low arable land potential (Yonaba et al., 2021c). Heavy grazing prevents or delays vegetation regrowth, wind erosion removes topsoil, while swirled sand can damage crops or cropland. Symeonakis & Drake, (2010) also find that overgrazing leads to trampling and compaction of the soil, which reduces the infiltration rate and thus increases runoff, which contributes significantly to topsoil erosion. This event is expected to threaten the future food system if adequate measures are not taken, especially in arid areas such as Mali.

Some 50 million people in the Sahel region of Africa depend on cattle ranching for survival. This is exacerbated by rapid population growth, which is forcing farmers to expand their cropland to pasture, the main cause of conflict between pastoralists and farmers in most countries in the Sahel (Sanogo et al., 2022a).

Stott (2007) has projected that by 2020, yields of rain-fed croplands could diminish by as much as 50.0% in some countries. Agricultural production, including food access, is expected to be severely negatively affected in many African countries, especially in Mali. This would further affect food security and exacerbate malnutrition. Degradation of ecosystems becomes a threat to human well-being whose livelihoods depend on them. These adverse processes require urgent and comprehensive action to halt land degradation (Stavi & Lal, 2015).

Land restoration should consider a participatory approach, especially in the Sahelian agroecology (Flintan et al., 2022). Considering this statement, socio-economic and environmental parameters must be considered when implementing a participatory approach for it to be effective. In Mali, land tenure issues are primarily political and social in nature but ecological also. Recent study conducted by Savadogo *et al.*, (2017b) found reports that there is always an overlap of land rights (traditional and modern), that the political decision on the use of a particular land is usually unpredictable, and that the socio-cultural norms that shape the division of labor between genders and different social classes need to be considered. The study concluded that answering the question of how land can be restored requires an integrative approach.

The agroecological zone of the Sahel in Mali is currently considered one of the most degraded ecosystems due to low soil potential and poor agricultural practices such as overgrazing, clearing and burning of crop residues, short fallow periods, soil acidification, and water and wind erosion. In addition, the vegetation cover is threatened by massive clearing of woody plants, mainly for fuel and timber, which has also led to large-scale degradation (Hermans & McLeman, 2021). All of these contribute to the destruction of water reservoirs. This threatens the livelihoods of local people, especially smallholder farmers and pastoralists.

At the same time, it is a region in which a strong potential exists for resilience through synergy actions based on the existing potential (Mbow et al., 2021). Research has a role to play for proposing technologies and management practices around natural resources for sustainable livelihoods through Integrated Land Use Systems (ILUS). Therefore, analysing contextual LULC dynamics and attributed driving factors could contribute to the knowledge creation for oriented participatory decision synergies for action. Regarding this gap, this study seeks to investigate contextual LULCC and attributed driving factors over three decades in Wacoro Municipality of the Sahel Agro-ecological Zone of Mali.

2.2. 2. Agroforestry and management practices interventions with species in addressing land use cover changes

Regarding the livelihoods challenges related to land use changes LULCC and its associated driving factors, various interventions have been implemented One of the biggest is the Great Green Wall which gives hope to the Sahel communities, but evaluation results revealed that it is far from achieving the expected goals (Goffner et al., 2019).

Moreover, international organisations such as Center for International Forestry Research (CIFOR) International Center for Research in Agroforestry (ICRAF) in partnership with governmental Rural Economic Institute (IER) and others non-governmental organisations and institutes have developed some package of agroforestry technologies (drought tolerance fodder and food banks) and management practices addressing LULCC issues in the Sahel, particularly in Mali. Drought resistant crop improved packages of local trees, shrubs and grass species which are ecologically and economically valuable (Abberton et al., 2021). The potential of Agroforestry (potential) has been (having been) proved in soil fertility management, climate regulation and biodiversity conservation (Diallo et al., 2019). Thereafter, its significant contribution to the livelihoods improvement is proved according to Agroforestry for Degraded Landscapes, 2020). It is widely promoted as a sustainable land use management practice in the different landscapes, in the Sahel, especially in Mali.

Anecdotal agroforestry practices have been adopted worldwide since time immemorial as these have been evolved based on traditional knowledge of the natural resources (Abberton et al., 2021). Agroforestry interventions have become an increasingly popular approach to promote sustainable agriculture and improve rural livelihoods in Mali. However, the success of agroforestry interventions largely depends on the suitability of tree species to the local ecological and social contexts.

In this empirical review, we aim to analyze the issues of species suitability under agroforestry interventions in Mali.

However, despite the importance of tree species selection, several issues exist in ensuring the suitability of tree species for agroforestry interventions in Mali. One of the major issues is the lack of knowledge and information on the ecological and social factors that influence the suitability of tree species. For example, the availability of water and nutrients, soil type, and local social norms and practices can significantly influence the selection of suitable tree species. However, many farmers and extension workers lack the knowledge and information needed to make informed decisions on species selection.

Another issue is the lack of access to high-quality planting material, including seeds and seedlings of suitable tree species. In many cases, farmers rely on local markets or seed exchange networks, which may not always provide access to the appropriate planting material. Additionally, the quality of the planting material may be poor, leading to low survival rates and reduced growth of the trees.

There are innumerable examples of traditional agroforestry systems involving combined production of livestock, trees, forages, and agricultural crops on the same unit of land across the Sahel. To facilitate the adoption of these species, demonstrations have been conducted with farmers and one of the most common reasons for the failure was attributed to the local people contextual preferences issue. the issues of species suitability under agroforestry interventions in Mali are complex and require a multi-sectoral approach. To address these issues, there is a need for increased investment in research and development of suitable tree species, as well as increased access to high-quality planting material.

Additionally, there is a need to promote awareness and knowledge of the ecological and social factors that influence species suitability, through training and extension programs targeted at farmers and extension workers. Such efforts will be crucial in promoting the success of agroforestry interventions in Mali. This is a gap in knowledge to the be sorted out using a participatory approach through contextual species prioritisations and practical demonstrations for adoption. This needs to be documented and promoted by context. Although the Sahel ecology has more similarities across Sahelian context, but still, social, and economic parameters vary which define their contexts. Even within a country, the context may differ from one locality to the other.

To promote improved technologies under management practices with local trees, shrubs and grass species, people's preferences in satisfying contextual livelihoods still needs to be a subject for a roundtable discussion on which every stakeholder needs to contribute for sustainable solutions. Science has a role to play. To contribute to the knowledge creation around for filling this gap, this study is seeking to investigate livelihoods preferences of local people regarding the promoted species and how they operate these species practically on the field in various socio-ecological context.

2.2.3. Ecosystem services under agroforestry systems and management practices

Healthy ecosystem is the source of food, fiber, fodder, energies, and clean water environment. Earth is composed of two types of ecosystems (terrestrial and aquatic). Both systems are related and forms a complementary hotspot for securing human species survival. This is done through the supply of ES to satisfy people's needs. For some decades now, the natural ecosystem supply has been diminishing while the demand is on the increase.

The Sahel ecosystem is naturally fragile and is getting more degraded due to the land use changes attributed to the socio-ecological disturbances.

Thereby, agroforestry-oriented restoration interventions have been promoted mainly in the dryland and (to) address the socio- ecological issues (Elagib & Al-Saidi, 2020a). It is scientifically known that biodiverse agroforestry is needed in land use systems to maximize the ecological benefits (Santos et al., 2019) . It improves soil quality which is important in boosting soil-based ES for people whose livelihoods depend on it through for the supply of food, fiber, energies etc(Udawatta et al., 2017).

One of the primary issues related to ecosystem potential is the degradation of soil quality. Agroforestry systems involve the planting of trees alongside crops, which can lead to soil compaction, nutrient depletion, and erosion. In addition, the removal of biomass from agroforestry systems for fuel and other uses can lead to a loss of soil organic matter, further exacerbating soil degradation. This can have negative impacts on ecosystem potential, reducing the productivity of crops and the growth of trees, and limiting the potential for agroforestry systems to contribute to climate change mitigation and adaptation.

Another issue related to ecosystem potential is the loss of biodiversity. Agroforestry systems can provide important habitat for a range of species, including birds, insects, and mammals. However, the selection of inappropriate tree species or the use of monoculture systems can lead to a loss of biodiversity, reducing the ecosystem potential of agroforestry systems. In addition, the use of pesticides and other agrochemicals can have negative impacts on non-target species, further reducing biodiversity.

Climate change is another issue that can impact ecosystem potential under agroforestry systems in Mali. Changes in temperature and precipitation patterns can impact the growth of crops and trees, leading to reduced productivity and ecosystem potential.

In addition, extreme weather events such as floods and droughts can have significant negative impacts on agroforestry systems, reducing their potential to provide important ecosystem services such as carbon sequestration and soil conservation.

In the dryland areas, agroforestry systems supported by management practices and improved species have been highly promoted but their potential to support livelihoods of farmers and pastoralists but has not been well documented. Therefore, this gap is calling for actions in which science has a role to play.

Regarding that need, this research is seeking to assess the potential ES generated from contextual livelihoods-based agroforestry systems in gender consideration in the Sahel Mali (Wacoro) which is one of the hotspots of rapid LULCC.

2.3. Theoretical Review

Socio-ecological theory provides a useful framework for understanding the complex relationships between social and ecological systems and the factors that influence land restoration interventions in Mali. The theory posits that social and ecological systems are interconnected and influence each other through feedback loops and interactions. In the context of land restoration interventions in Mali, socio-ecological theory can help to identify the social and ecological factors that influence the success of these interventions, and the feedback loops and interactions between these factors.

Social factors: Social factors that influence land restoration interventions in Mali include land tenure systems, access to resources, cultural and institutional norms, and governance structures. For example, unclear land tenure systems and limited access to resources can create barriers to implementing successful land restoration interventions.

On the other hand, cultural and institutional norms that promote sustainable land use and governance structures that facilitate community participation can support the success of these interventions.

Ecological factors: Ecological factors that influence land restoration interventions in Mali include soil health, water availability, biodiversity, and climate variability. For example, degraded soils and limited water availability can create challenges for implementing successful land restoration interventions. However, interventions that improve soil health, promote water conservation, and restore biodiversity can enhance the success of these interventions.

Feedback loops and interactions: Socio-ecological theory emphasizes the importance of feedback loops and interactions between social and ecological systems in shaping the outcomes of land restoration interventions in Mali.

For example, successful interventions that improve soil health and restore biodiversity can enhance the livelihoods of local communities and promote social well-being. In turn, social well-being can facilitate the adoption of sustainable land use practices, which can enhance the success of future land restoration interventions.

In Mali, land restoration interventions that are guided by socio-ecological theory can be more effective in promoting sustainable land use and improving the well-being of local communities. By considering the social and ecological factors that influence the success of these interventions and the feedback loops and interactions between these factors, interventions can be designed to promote sustainable land use, enhance ecosystem services, and improve the livelihoods and well-being of local communities.

Overall, a socio-ecological theoretical review of land restoration interventions in Mali can provide insights into the most effective and sustainable approaches for promoting land restoration and enhancing the resilience of social-ecological systems in Mali.

2.4 Existing Gap in Literature

In the Sahel, significant number of studies have been conducted in analysing LULCC and its driving factors but investing the suitability of contextual interventions suitability in addressing those changes for livelihoods improvement is limited. Sahelian ecological context is quite similar but socially and economically different. Thereby, studies investigating socio-ecological phenomenon in the Sahel should consider contextual LULCC and attributed factors as starting point of livelihoods support interventions.

These supports (technologies and management practices and species) are promoted but farmers' and pastoralists' livelihoods-based species preferences are still problematic due to socio-ecological context. Moreover, most of the promoted land use management interventions have limited consideration about gender balance in ecosystem profit sharing while current decade is calling for incentives. There is a critical gap in ES assessing to account ecological and social benefits of species under agroforestry systems supported by management practices. Regarding that gap, this study investigated the contextual LULCC and attributed drivers to the changes and how promoted agroforestry systems supported by management practices and improved species are ensuring the provision, regulation, and cultural ES potential to satisfy people's livelihoods improvement in Wacoro/Mali.

Despite the growing interest in land use and land cover change (LULCC) and agroforestry interventions in Mali, there are still some research gaps that need to be addressed to fully understand their effectiveness. Some of the research gaps in LULCC and agroforestry interventions in Mali include:

Limited understanding of the ecological impacts of LULCC and agroforestry interventions: While some studies have evaluated the environmental impacts of LULCC and agroforestry interventions, there is still limited understanding of the ecological impacts of these interventions. For example, more research is needed to understand the impacts of LULCC and agroforestry interventions on soil health, biodiversity, and carbon sequestration in Mali.

Lack of information on the social and economic impacts of LULCC and agroforestry interventions: While there is some information available on the social and economic impacts of LULCC and agroforestry interventions in Mali, there is still a lack of comprehensive studies that evaluate these impacts. More research is needed to understand the impacts of these interventions on local communities, including their livelihoods, food security, and access to natural resources.

Limited understanding of the effectiveness of different agroforestry systems: While agroforestry systems have been promoted as a sustainable land use option in Mali, there is still limited understanding of the effectiveness of different agroforestry systems. For example, more research is needed to understand the effectiveness of different agroforestry systems in promoting soil health, biodiversity, and carbon sequestration in Mali.

Limited research on the scalability of LULCC and agroforestry interventions: While some successful LULCC and agroforestry interventions have been implemented in Mali, there is still limited research on their scalability.

More research is needed to understand the barriers and opportunities for scaling up successful interventions to other regions in Mali and beyond.

This serves as premise for decision making in restoring degraded land though agroforestry for reconciling livelihoods of vulnerable communities. The following questions were addressed in this study: Is the context not properly analysed? Are the technologies wrong regarding people's needs? Are the promoted species not appropriate under the management practices and soil type? Are technologies not providing expected outcome in terms of ES?

Overall, addressing these research gaps can help to improve our understanding of the effectiveness of LULCC and agroforestry interventions in Mali and guide the development of evidence-based policies and programs that promote sustainable land use and improve the well-being of local communities.

2.5 Theoretical Framework

The current study is framed around LULCC system, human system and ES generated from various systems and their interactions. Due to the limitation and the complexity of studying each system separately, the concept of Social-Ecological Systems (SES) has been adopted. SES concept was developed by scholars from interdisciplinary areas in the early to mid-1990s. A Social-Ecological Systems is defined as a cohesive and an integrated system characterised by "strong connections and feedbacks within and between social and ecological components that determine its overall dynamics"(Biggs et al., 2021).

SES are among complex adaptive systems characterised by six organizing principles: (1) they are constituted relationally; (2) they have adaptive capacities; (3) their behavior comes about as a result of dynamic processes; (4) they are radically open, they do not have clear boundaries; (5) they are determined contextually (context dependent); and (6) novel qualities emerge through complex causality (Preiser et al., 2018). Research on land degradation responses within a farming community emphasize on the above principles as they relate to the concept of the system resilience. Land use changes has triggered adjustments and transformations within the SES (vegetative areas) due to shifts in normal conditions. Consequently, a new equilibrium is needed for a sustainable development of the system. Therefore, building resilience is needed. The resilience of a SES is defined as (Folke, 2006):

(1) "A system's ability to withstand disturbance while maintaining its condition or zone of attraction.

(2) The system's capacity for self-organization (as opposed to lack of organization or organization imposed by outside forces).

(3) The system's capacity to develop and expand its capacity for learning and adaptation.

Resilience thinking or framework tackles the dynamics and development of complex SES. It has three central and interrelated aspects namely resilience, adaptability, and transformability. Resilience and adaptability are both concerned with the capacity of a system to withstand changes while remaining within critical thresholds. Transformability is the emergence of an improved system as a response to internal or external changes (Folke, 2010). The resilience method places a strong emphasis on "non-linear dynamics, thresholds, ambiguity, and surprise, how times of slow change interact with times of fast change, and how such dynamics interact across temporal and spatial scales" (Folke, 2006).

Agroforestry system is a SES that puts land use system, species under the system, crops or animal, farmers, and other stakeholders into interplay. This study focuses on four components of the system namely land use system, trees, shrubs and grasses species and farmers. The strong connections between these elements explain how much the dynamics in the system are affected with changes in the land use/cover, soil, and climate. These changes are related to the dynamics, the systems conversion, and species vulnerability into various land use cover systems. Consequently, continued use of improved trees, shrubs, and grass species in the production calls out for adjustments at various levels. Farmers need to rethink the species selection, prioritization and management practices in agroforestry system and soil specific for livelihoods improvement. Thus, the profit the farmer's and pastoralists revenue is also jeopardized in generating income.

Understanding the complexity around a Socio-Ecological System (SES) calls for investigation component participatory step by step approach. This study seeks to determine the dynamics of LULC, its driving factors and how agroforestry system could contribute to the reinforcement ES for smallholder farmers' and pastoralists' livelihoods improvement.

Thereby, the first step consisted of analysing land use cover changes LULCC over 30 years over the study area and related driving factors of the changes from people's perception. Secondly, adapted trees, grass and shrubs species that could be incorporated into that land use systems (agri silvicultural, business-based platform and silvopastoral systems) for the purpose of generating socio-ecological benefits for people, were investigated. Thirdly, a gender specific assessment has been conducted on the ES under Agri silvicultural and silvopastoral systems. Theoretical inspiration came from the following framework developed by (Biggs et al., 2021).

CHAPTER THREE

METHODOLOGY

3.1 Research Design

To investigate the dynamic of LULCC, remote sensing technology shave been applied to collect spatial data (satellite images) and been analysed through Geographic Information System (GIS) The generated output (Map) and LULCC statistic information were presented to the various Focus Groups of local people or interpretation. This step was followed by participatory trees, shrubs and grass species varieties prioritisation and bloc experimentation on an open field. Thereafter, potential ecosystem services under successful agroforestry systems were assessed in genders lens.

Table 3. 1 Research processes

KEY ACTIVITIES	APROACH USED
LULCC EVALUATION	REMOTE SENSING AND GIS
LULCC DRIVING FACTORS ASSESEMENT	FOCUS GROUPS DISCUSSIONS
SPECIES PRIORITISATION	STACKHOLDERS PARTICIPATORY WORKSHOP
PRIORITITSED SPECIES EXPERIMENTATION	BLOC DESIGN AND DIRECT OBSERVATION
ECOSYSTEM SERVICES	FOCUS GROUPS DISCUSSIONS

Source: Author's illustration 2023

A mixed-methods approach, suggested as a key approach for the research, was chosen to assess LULCC quantitatively through remote sensing and the drivers behind these changes qualitatively through social valuation in FGDs. The different steps followed in this study for data collection and analysis are presented in the figure 3.1.

Table 3. 2 Definitions of Land Use and Land Cover Classes

Land Cover Class	**Definition**
Wooded savannah	Wooded savannah is a mix of woody and grass layers where the canopy of the woody component is not closed.
Shrub savannah	Shrub savannah is a mix of shrubs and grass layers.
Farmland	Farmland corresponds to cultivated land that can also show presence of woody components.
Water bodies	Water bodies represent standing water surfaces during most of the year.
Grassland	Grasslands are characterized as lands dominated by grasses and herbaceous annuals rather than trees or large shrubs.
Settlement	Settlements consist of residential areas, roads and other concrete infrastructure including areas for sheltering people, animals, or machinery.
Bare soil	Bare soil is barren land that has sand, rocks, and thin soil. It includes dry salt flats, sand dunes, deserts, beaches, gravel pits, quarries, exposed rock, strip mines, etc.
Rocky	Rocky areas are covered mainly by blocks of rock.

Source: Author' illustration 2023

Two series of workshops have been conducted with relevant stockholders (farmers, pastoralists, researchers, community leaders and extension workers) to prioritize preferred grass, shrubs and trees species based on people's livelihoods needs. Later, selected species were experiment on the field under Agri silvicultural, silvopastoral and business-based platform to assess their suitability through first appearance discovery, and survival rate taking into consideration soil and climatic conditions. The following figures shows the experimental designed.

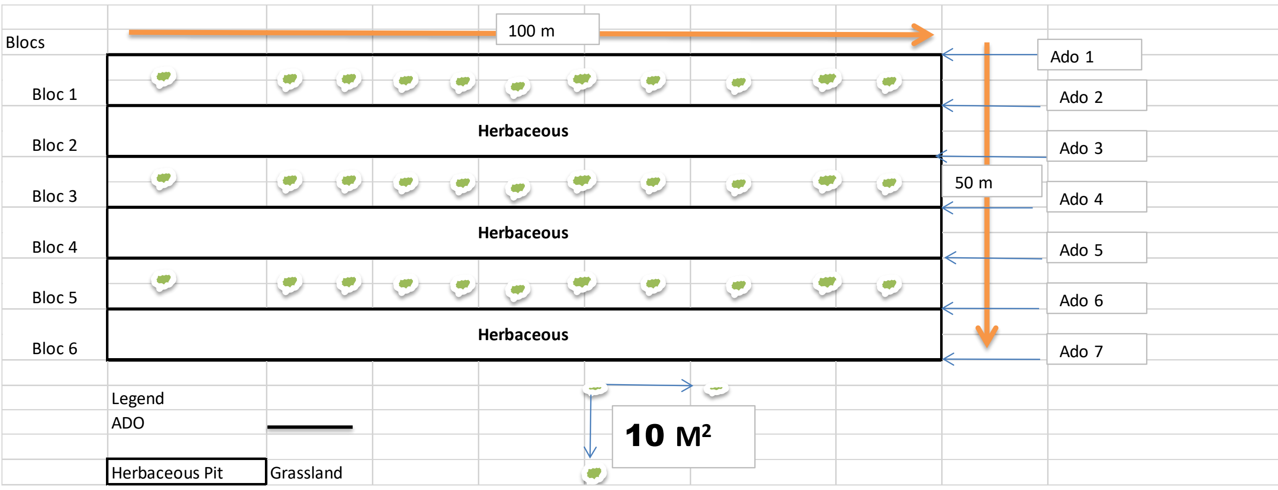

Plate 3.1 Preferred species experimental design

Plate 3.2 Technical workflow of the experiments

Source: Author' Illustration 2023

ES have been categorized into three key pillars of CICES V4.3 (Roy Haines-Young & Potschin, 2018) . Moreover, it is further broken into six segments as described on the chart. Each item of ES was collected from both restored and unrestored pasture and farmland with agroforestry technologies and management practices.

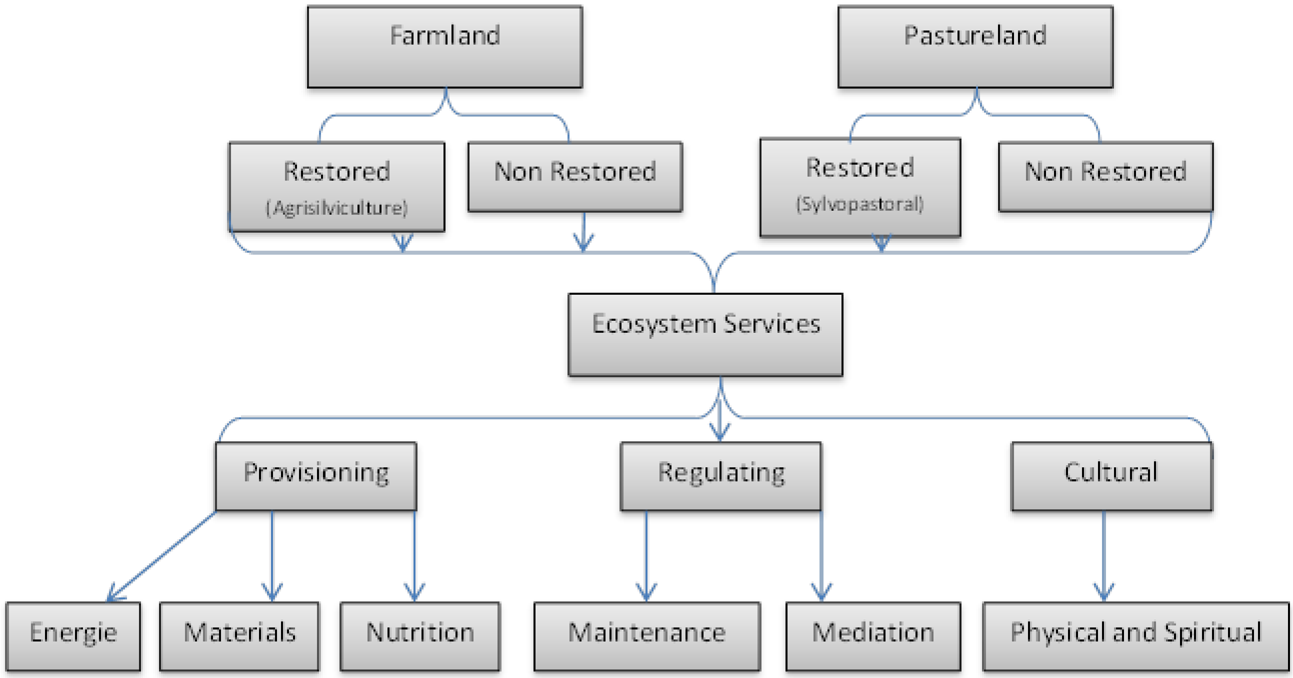

Plate 3. 3 Ecosystem services assessment workflow

Source: Author' illustration 2023

3.2 Study Area

Wacoro is in the Sahel agroecological zone of Mali in West Africa (Plate 3.4) at a latitude of 12°36′6″ north and a longitude of 6°41′34″ west. It is home to primarily Bambara and Malinké farmers and previously formed part of the pre-colonial Bambara Empire. Because of its rural character nature, Animism persisted in this area well into the 20th century. There are also populations of Muslim Maraka, Fula, and Bozo fishing communities. The Wacoro Municipality falls largely south of the dryer Sahel land, in the wetter Sudan, and is home to the headwaters of the Bani River.

The major socio-economic activities are crop farming and livestock keeping. The main cultivated crop in the area is cotton, followed by maize and groundnut. In terms of livestock, small ruminants (goat and sheep) predominate, although there are also big ruminants such as cows and donkeys. The particularity of the study area is that it has common socio-economic and environmental characteristics compared to most municipalities within Mali's Sahel region which attract a large share of development interventions. Trees, shrubs, grass, and animal species are representative for other areas within the Sahel region. In Wacoro, the dry season lasts from March to June, the rainy season spans from June to September, and the cold season lies between October and February with a drying Saharan wind called the harmattan. Over the course of the year 2021, the temperature varied from 17 °C to 39 °C and was rarely below 14 °C or above 41 °C with an annual average rainfall of 492.9 mm (Dioila Met Service, 2022).

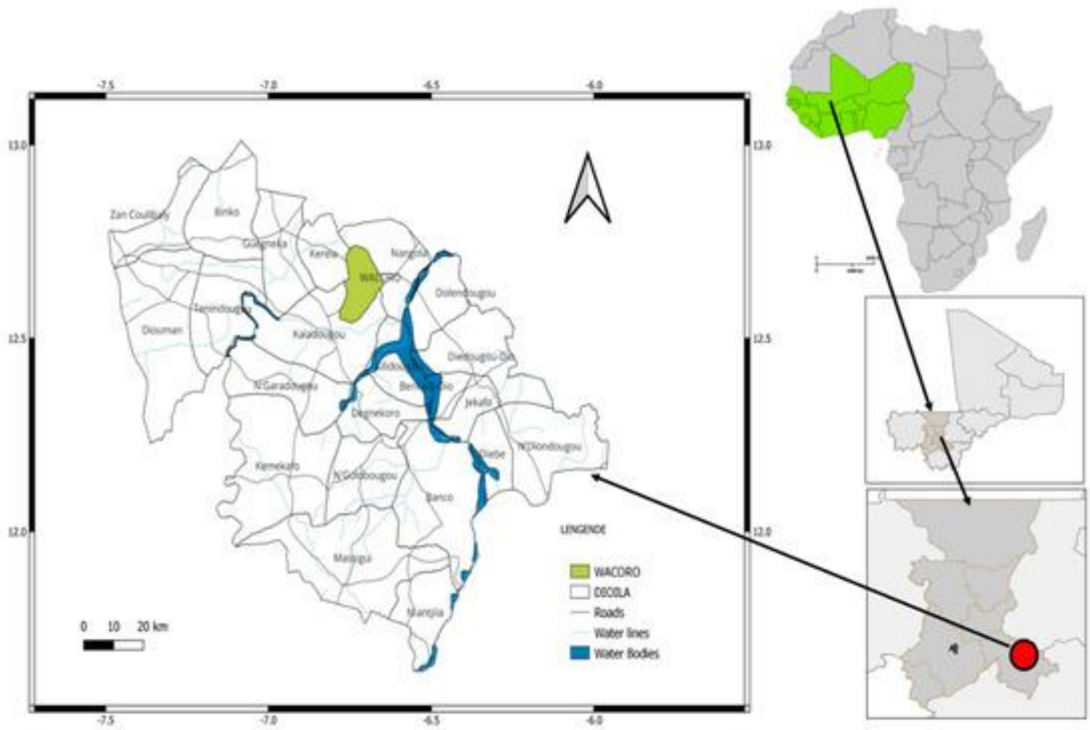

Plate 3.4 Study Area

Source: Author' illustration 2023

The land use in the study area is not diverse. For this research, the land use in Wacoro has been classified into the following seven classes: Wooded savannah, Shrub Savannah, settlement, water bodies, grassy steppe, bare soil and rocky areas. The farmers in **Wacoro** usually practice subsistence farming. Maize is the predominant crop grown on dryland followed by millets and sorghum and barley intercropped with groundnut and beans. The most dominant cash crop is the cotton at larger scale. The areas have also a larger pastureland which favours pastoralism especially small ruminants (goats and sheep) and cattle (cows).

3.3 Population of the Study

The study population was mainly agroforestry project intervention beneficiaries. The list of 520 direct and indirect beneficiaries was collected from the affiliated NGO's and was considered as the targeted population in this study. The main targeted respondents were smallholder farmers and pastoralists who are experienced in their living areas biophysical changes and who were promoters of agroforestry systems for their livelihoods improvement. Moreover, community leaders, extension workers and researchers were also involved at certain level of the studies due to the objective based nature of the research. The reason behind the choice of the target was attributed to the contextualisation of the approach by linking LULCC, driving factors, people's motivational factors and ecosystem services potential of the interventions on the field.

3.4 Sampling Technique and Sample Size

Wacoro Municipality is composed of 37 villages. To apply context-based study, objective based village selection was conducted. Firstly, the driving factors of LULCC were assessed in the entire villages. Due to the limited resources constraint and security issues, a total of 200 respondents were purposively sampled based on: their biophysical knowledge of the area, their age, social position in gender respect and their wiliness to provide useful information. The sampling unit were local people all social classes included.

Secondly, to prioritize species varieties suitability under agroforestry system through participatory workshops, another group of 200 samples of respondents divided into two group of 100 were purposefully selected from the list of a group of stakeholders 4 villages where agroforestry interventions are taking place. The sample unit was small holders' farmers, pastoralists, extensions workers, researchers, and community leaders of agroforestry intervention projects.

Thirdly, 112 (56 women and 56 men) respondents were purposively sampled from four villages where significant number of project beneficiaries have demonstrated successful agroforestry systems and management practices. The sample unit was men and women small-holder's farmers and pastoralist experienced in perceiving the potential ecosystem from agroforestry interventions under agric silvicultural and silvopastoral systems. The criteria considered for their selection are cited in the table 3.3.

Table 3.3 Sampling criteria

Participants by livelihood sources		Experiences	FDGs Groups	Age
Smallholder farmer's	People holding <=5ha of cultivated	>=10 years of experiences in the farming activities	Men	>=40
Pastoralists	People holding >=30 small or and big ruminants	>=10 years of experiences in pastoralism	Women	

Source: Author's illustration 2023

3.5 Types and Sources of Data Collection

3.5.1. LULCC and driving factors.

Landsat images for the study site for the years 1990, 2000, 2010, and 2020 were downloaded from the USGS (United States Geological Survey) website (https://earthexplorer.usgs.gov/) accessed 10 March 2021. Landsat 4 and 7, which were used in this research, are the most accurately calibrated Earth-observing satellites and the latest in a long history of land remote sensing spacecraft, spanning 40 years of multispectral imaging of the Earth's surface. The annual time series of land cover maps (collection 3) were obtained at 30 m resolution through the classification of Landsat images (Mas et al., 2019). The remote sensing literature presents several supervised methods to tackle the multispectral data classification problem (Xu et al., 2020).

The statistical method employed for the earlier studies of land cover classification is the maximum likelihood classifier (Lawrence & Wrlght, 2001). More recently, various studies have applied artificial intelligence techniques as substitutes to remote sensing image classification applications (Shi et al., 2020).

In addition, the diverse ensemble classification method has been proposed to significantly improve classification accuracy (Muñoz-Marí et al., 2007). Scientists and practitioners have made great efforts in developing efficient classification approaches and techniques for improving classification accuracy (Kraemer, 2015). Among them is supervised classification. The quality of a supervised classification depends on the quality of the training sites (Bai et al., 2019). All supervised classifications usually have a sequence of operations that must be followed: (1) definition of training sites, (2) extraction of signatures, (3) image classification. The training sites are carried out with digitized features. Usually, two or three training sites are selected but more can be selected to gain better results (Song & Shi, 2018). This study applied supervised classification, which has been used in previous studies and shown to yield valid results (Perumal & Bhaskaran, 2010). This study used supervised classification for the purpose of computing accurate results with high precision. Supervised classification is a commonly used technique in GIS because it allows for accurate and efficient classification of remote sensing imagery or other spatial data. Supervised classification involves using a set of training samples, or ground truth data, to teach a computer algorithm to classify new data based on the same criteria.

The advantages of supervised classification include:

1. Accuracy: Supervised classification can produce accurate results, as it is based on ground truth data and can consider the complex relationships between spectral characteristics and land cover types.
2. Efficiency: Supervised classification can be more efficient than other methods, such as unsupervised classification, as it allows the user to classify large amounts of data quickly and accurately.

3. Flexibility: Supervised classification can be customized to fit specific project needs, including selecting specific training samples, classifying multiple land cover types, and incorporating ancillary data.
4. Reproducibility: Supervised classification results can be reproduced easily, as the same training samples can be used to classify new data or to update previous classifications.
5. It is a process of pattern recognition in Remote Sensing which consists of carrying out the correspondence between the elements of an image scene, generally materialized by their radiometric values, and classes known or not by a user (Piramanayagam et al., 2018). The correspondence is carried out by discriminant functions in the form of a decision rule such as the maximum likelihood of probabilities, or geometric distances. The chosen classification algorithm is the "Maximum likelihood." Indeed, this algorithm has the advantage of being a probabilistic method. It allows the classification of unknown pixels by calculating for each class the probability that the pixel falls in the class with the highest probability (Sisodia et al., 2014). If probability does not reach the expected threshold, the pixel is classified as unknown.

Geospatial tools and approaches are one of the cutting-edge technologies that are guiding the future of urban development and land use planning. By employing its data gathering, processing, and map presentation techniques in solving a wide range of challenges that affect the environment, health, safety, transportation, and land use demarcation, among many other concerns, remote sensing offers a proactive means of resolving problems. For the management and monitoring of land systems, satellite imagery has been heavily utilized in land use planning and management.

This approach offers a step-by-step process for using Remote Sensing and GIS techniques to perform supervised classification on Landsat 8 imagery, adding to the existing land use assessment and management tools in the geospatial sector. Despite the development of numerous categorization algorithms remote sensing was measured using maximum algorithm and accuracy was assessed throughout through the computation of Kappa coefficient (see the section 3.8 Objective 1) while workshop and FGDs related variables were measured through ranking method.

After maps been produced, several FGDs were held with with local people to assess the potential driving factors for the changes observed over time (1990–2000–2010 to 2020). LULCC data (maps and graphs) were presented in the form of posters to the participants during the FGDs. The LULCC observed on the posters over time were clearly explained to the FGD participants to set the basis for discussing the potential drivers of change.

A total of 37 villagers was purposively selected exhaustively for FGDs considering gender (male and female), socio-economic groups and the requirement of being old enough to have experienced LULCC over the period considered (1990 to 2020). All participants were selected by local leaders based on the following criteria:

- Age (50 and above).
- Knowledge of the long-term biophysical and socio-institutional context of the study sites.
- Experience in local decision-making approaches.
- Experience in working with extension workers.

Each FGD consisted of 5–7 people and had a duration of two to three hours (Schielein & Börner, 2018). Driving factors for LULCC were discussed by participants, who then agreed on a score in order of importance (Munthali et al., 2019).

The interval score was from 0 to 5 for each direct or indirect driving factor. The following scores were used: 0 = no effect, 1 = low effect, 2 = medium effect, 3 = relevant effect, 4 = very relevant effect, and 5 = highly relevant effect. Each Focus Group (FG) was expected to provide a common score. In case of disagreement among the participants in the scoring of a given driving factor, all members in the FG were asked to provide a score (Bayala et al., 2018). Then, the modal value (score that was most frequent) was retained. The scores for different criteria for each driving factor were then summed up and the results announced to the participants. Ethical guidelines for research with people were followed and all participants were kept anonymous.

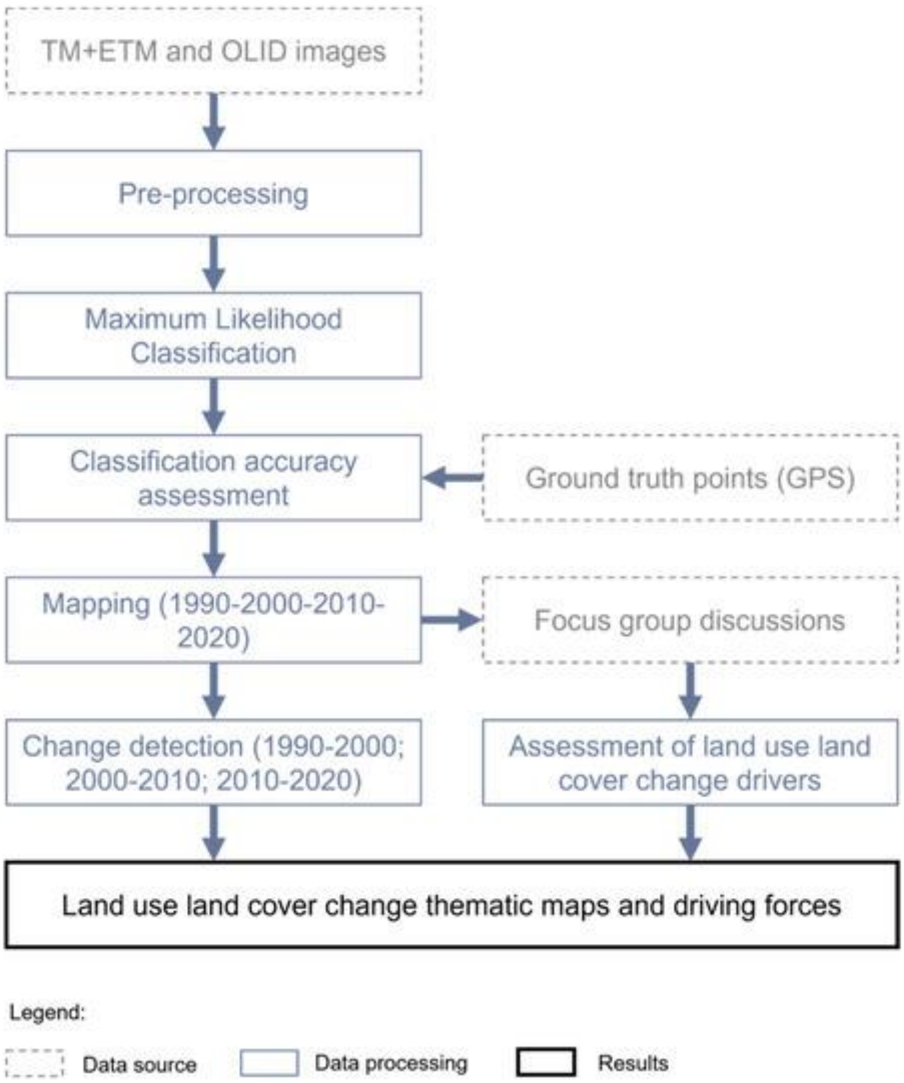

Figure 3.1 Schematic View of the Working Step Applied in this Study.

Soucre: Author's illustration 2023

Ground truthing was conducted in October 2021 to validate all land use and land cover-LULC classes. GPS coordinates were also taken at each selected plot per class (Komatsu, et al., 2020).

3.5.2. Species Prioritization and Experimental design

Step 1: Species prioritization based on the farmers preferences for livelihoods.

This step consisted of prioritising suitable fruit trees, fodder grass, fodder trees and shrubs species under agroforestry systems for reconciling ecological and social functions. In this session, the inventoried suitable agroforestry systems and management for tree species must be prioritized by assessing each identified practice against seven criteria.Two workshop sessions were held in Wacoro. Each workshop regrouped a total of 100 participants. A total of 200 participants was purposefully selected for the two workshops.

Each workshop purposefully gathered adult participants over 30 years plus 30% of communities' participants of women who have a good knowledge of the biophysical and socio-institutional contexts of the sites. Moreover, all the key social groups/ethnic groups in the community including crop and livestock farmers; representatives from the community formed 50% of the workshop participants and there were 2 representatives (with a background in agronomy, livestock, and agroforestry) from research institutes, development agencies (NGOs), private sector, and Government agencies.

The workshop team consisted of a team leader, a facilitator, and 2 rapporteurs. The roles of each Workshop team were to define the effective conduct of the meeting. Moreover, the detail on all the participants were recorded for tracking purposes.

Criteria used for the technology's prioritization exercise included:

- ability to sustainably improve agricultural productivity.
- the market value of the different products generated by the technology.
- viability as an adaptation strategy.
- potential for reducing GHG emissions (mitigation).
- potential for up-scaling.

- economic viability (cost and benefit) /income generation and
- impact on ES.

Participants were first asked to score each identified technology under management practice and species for each criterion on a scale of 0 (none/not at all) to 10 (Excellent/highly suitable). In case of disagreement among the participants in the scoring of each variable, all socio-professional groups in the workshop were asked to provide a score. Then the modal value (a most frequent score) was retained. The scores for different criteria for each technology under management practices, and species were then summed up and the results announced to the participants. The scope was critical to prevent any FG participant from dominating in giving scores for the technologies. Technologies/social practices with higher score was considered as promising and used for the next assessment regarding the identification of the suitable options in designing agroforestry solutions which the scaling up of the technologies/social practices focused on.

Step 2: Experimentation of species suitability under dry spell scenario

To test species (grass, shrubs, and trees) suitability under various agroforestry systems and management practices, some experiments were set with the prioritized species. These experiments were set under silvopastoral, agrisilvisultural and business-based platform systems for the purpose of analysing technical suitability of the species under socio-ecological conditions of the area. Four categories of soil (sandy, clayey, clay-sandy, and lateritic) were identified and where the experiment was set with all the species. Various scientifically improved trees, shrubs varieties were planted on an open field respecting standard planting rows and path per species under agrisilvisultural and business-based platform while grass species were sowed using direct seed sowing method under silvopastoral.

To identify resistance species under various agroforestry systems and management practices as livelihood support option, the number of germination days of grass species and their survival was evaluated. After sowing the seed, a daily direct observation was conducted to assess the first emergence days of the grass seeds under various soil type.

For the fruit and fodder tree and shrubs species, seedling was planted on various sites (farmland, pastoral land, and a multi-functional platform) and survival rate was monitored. Each agroforestry system was considered as one plot and within each plot 30 subplots were set. Each subplot was composed of 100 sample of seedling tree, shrub, or grass seed. After experiment been set, an unexpected 45 days of dry spell scenario occurred. Thereby, analyse timeframe was set within that dry speel period. Survival rate was assessed after 45 days of dry spell. Rule of three was applied to calculate the germination and survival rates of each subplot throughout the entire period of the experiment.

A myriad of approaches exists to assess ES both quantitatively and qualitatively. The matrix approach, which is increasingly common in ES studies, was used for its advantage of providing assessments rapidly and in an appropriate format that can serve decision-makers directly (Campagne et al., 2018). Leaning on the ES supply matrix developed by Burkhard et al., (2012), a matrix that included all relevant provisioning, regulating and cultural services provided by restored and non-restored farmland and by restored and non-restored pastureland, was prepared. A total of 26 context-relevant services from the Common International Classification of Ecosystem Services (CICES V4.3) according to Czúcz et al., (2018), was used. Within the matrix, participants in FGDs had to rate the services provided from the respective land use from 0 to 5.

Additional qualitative data from discussions around the scoring helped to better understand the perceptions and reasons why certain land user groups valued certain services.

For contextualization purpose and gender consideration, FGDs included two categories of participants (men and women) and smallholders and pastoralists (Smithson, 2000). The reasons for choosing these groups depend on the nature of their segmentation in the socio-economic context. In this study, the target groups were defined as follows: Smallholders are people who own less than or equal to five hectares of cultivated land and whose livelihood depends mainly on agriculture, while pastoralists are people whose livelihood depends mainly on livestock. In terms of selection criteria, each category of target had more or equal to 10 years of experience in their sector and was knowledgeable about land restoration activities.

Data were collected using the simplified ecosystem service classification tool according to the Common International Classification of Ecosystem Services (CICES V4.3) in the form of a matrix (Haines-Young & Potschin, 2012). In four villages, a total of 16 FGDs was conducted in the study area, which included separate male and female groups for each livelihood in each village. Each FGD group consisted of 7 participants, resulting in a total of 112 participants (56 women and 56 men) in 4 villages that benefited from pasture and cropland restoration activities from project interventions. Each FGD lasted between 120 and 180 minutes. The long timing of the FGD was due to the respondent's interest to the topic and willingness to understand scientific process of generating remote sensing and GIS data on their environment before answering questions. The average age of participants was 52 years.

3.6. Definition and measurement of Variables

- **Agri silviculture system:** Farmland composed of crop, fruits trees, fodder trees and shrubs and grass species for the purpose of restoration or conservation and livelihoods improvement.
- **Silvospastoral system:** Pastureland composed of crop, fruits trees, fodder trees and shrubs and grass species for the purpose of restoration or conservation and livelihoods improvement.
- **Business based platform:** Multiple functional platforms composed of crop, fruits trees, fodder trees and shrubs and grass species for the purpose of restoration or conservation and livelihoods improvement.
- **Gola, ICRAF 8 and 3A:** Are the approved varieties of Ziziphus mauritiana by the World Agroforestry Center for dryland restoration and livelihood improvement trees.
- **Cenchrus biflorus, Brachiaria, Miscanthus sinensis:** Are drought resistance grass varieties for the dryland restoration and livelihood improvement.
- **Mucuna:** Is a variety of leguminous plant for dryland restoration and livelihood improvement crop.
- **Nonokene and A200**: Varieties of Adansonia digitata for dryland restoration and livelihood improvement tree.
- **T. Sucre, Niger309 and Gros-fruit**: Are the varieties of Tamarindus Indica for dryland restoration and livelihoods improvement trees.
- **Gliricidia sepium, Jatropha curcase, Accacia Senegal, Piliostigma, Pterocarpus Lucens**: Are the fodder species for dryland restoration and livelihoods improvement trees and shrubs.
- Unrestored farmland is any farm with a vegetation cover of less than 30 fruit trees/ha with low nutritional and economic value to support the livelihood of the household.

- Restored farmland is a farm where farmers have implemented a mechanism to support the regeneration of native fruit trees on the farm, enhancing the planting of trees in conjunction with the cultivation of drought-resistant crops to improve their livelihoods in the face of climate change. Each restored cropland has more or equal to 30 trees that are nutritionally and economically valuable.
- No restored pastureland is shrubland and grassland with less than 10 % of fodder tree, shrubs, and grass coverage to meet livestock feed needs.
- Restored pastureland is shrubland and grassland that has been supported by the promotion of native fodder trees, shrubs, and grass species or by planting in conjunction with minimum tillage and crescent management as soil and water conservation techniques with a minimum coverage of 30 %.

These definitions were illustrated based on the agro ecological realities and available information and mechanism on the grounds.

Source of the definitions: Author' illustration 2023

3.7 Validity and Reliability of Research Instruments

The study used Remote Sensing, GIS, Focus Groups guides as instrument. The validity and reliability of these instrument is described as followed:

Quality control procedures and validation techniques are essential in ensuring the accuracy and reliability of GIS data and analysis results. Here are the used techniques in GIS:

Quality control of input data: This involves verifying the accuracy and completeness of the input data, including data sources, data format, data, and attribute information. This involved checking for errors such as missing data, inconsistencies, and incorrect formatting.

Data cleaning and pre-processing: This involved correcting errors and inconsistencies in the data and standardizing data formats, coordinate systems, and units of measurement.

Accuracy assessment: This involved comparing the output data or analysis results with known or ground-truth data to measure the accuracy and precision of the GIS results.

Validation of spatial analysis algorithms: This involves testing the validity and accuracy of spatial analysis algorithms used in the GIS software. This may involve comparing the results of different algorithms, using alternative methods, or testing the algorithms on known datasets.

Cross-validation: This involved dividing the input data into subsets and testing the analysis on one subset while using the other subset for validation. This can help to verify the accuracy and reliability of the analysis and ensure that the results are consistent across different subsets of the data.

Interpolation techniques: This involved verifying the accuracy of the interpolation techniques used in GIS, such as kriging. This was done by comparing the results of different interpolation methods or using known data for validation.

Metadata validation: This involved checking the completeness and accuracy of data associated with GIS data, including data source, data quality, accuracy, and resolution (30X30).

These quality control procedures and validation techniques were critical in ensuring the accuracy and reliability of GIS data and analysis results and have been applied consistently throughout the GIS workflow.

The reliability of the FDGs and workshop outputs were checked up using Cronbach's alpha. It was used as a coefficient that measures how well a focus groups and workshop participants are internally consistent to assess the reliability of the scales, indicating how closely related a set of items are to each other. However, a high alpha value used does not guarantee that the scale is unidimensional. To test for dimensionality, exploratory factor analysis was be used. Cronbach's was not used as a statistical test, but rather a coefficient of reliability.

The formula for Cronbach's alpha can be expressed as a function of the number of items in a test and their average inter-correlation. Here is the formula for conceptual purposes:

Equation 3.1

$$ \alpha = \frac {N \bar{c}} {\bar{v} + (N-1) \bar{c}} $$

Here N is equal to the number of items, $\bar{c}$ is the average inter-item covariance among the items and $\bar{v}$ equals the average variance.

One can see from this formula that if you increase the number of items, you increase Cronbach's alpha. Additionally, if the average inter-item correlation is low, alpha will be low. As the average inter-item correlation increases, Cronbach's alpha increases as well (holding the number of items constant). The generated coefficient from this study is .89. In most of social science research situations, reliability coefficient of .70 or higher is considered "acceptable".

3.8 Method of Data Analysis

To validate the results obtained from classification, the error matrix or confusion matrix was generated in ENVI 5.5.2 to identify the proportion of well-classified pixels. Thus, errors of omission and commission were calculated. For a land use study, the results can be considered valid if the Kappa coefficient is equal to or higher than 50% (Yonaba et al., 2021a). A method based on the evaluation of control points was tried. This method consisted of field verification, from the minute of interpretation, of the points previously identified before the field mission for each land use class and determination of the percentages of these verified points corresponding to those defined beforehand (Oseph et al., 2003). The ground truthing in this study was carried out as follows:

Stratified sampling was adopted so that the control points to be verified in the field were defined in proportion to the size of the stratum; 30 control points were determined for each of the classes. A total of 210 points were defined for the entire study area (seven land cover classes). At the level of each stratum, the control points were as dispersed as possible over the entire study area.

A confusion matrix was constructed to report the results; the matrix revealed not only the general errors made at the level of each class during the interpretation but also the errors due to confusion between land cover classes.

Errors of omission and confusion were calculated for each land cover class; the values obtained reflected the details of the interpretation of each class. Considering a class such as woodland savannah, it was referred to as an error of omission whenever this woodland class had been omitted from the map. It was a confusion error when the wooded savannah area had been classified as another class. Coordinates of each land cover class were collected from the field and incorporated into the maps for validating classified areas.

The Kappa coefficient was used to assess the precision of the classification adopted as described above (Vieira et al., 2010). Its formula is:

Equation 3.2

$K = P0 - Pc/1 - Pc$

P0 is equal to the actual percentage obtained from the classification of land use elements; it is equal to the quotient of the sum of the figures on the diagonal of the matrix with the total number of observations.

Pc is the estimate of the probability of obtaining a correct classification.

to calculate Pc, the computation of Pc proceeded as follows: The marginal products of the column and row values were calculated at the level of each cell of the matrix; then, the sum of the values of the diagonal was divided by the total of the products of each cell of the matrix. For correct classification, the value of Pc is generally less than P0,

Pp is the percentage obtained when the classification is perfect, i.e., 100%.

All maps were drawn with ArcGIS software version 10.8.

The mean value for each factor was calculated using SPSS 24 and the comparative frequency of each factor was drawn using bare 2D The score of each indicator was presented as the mean score given by all six groups, which determined the level of the effect on LULCC. The higher the score, the more likely it was classified as a main driving factor.

Population data for our study years 1990, 2000, 2010 and 2020 were derived from the 2009 National Institute of Statistic (INSTAT) census, 2009) obtained from the Malian National Institute of Statistics. These data do not consider people who passed away or migrated out of the village during these periods. The following equation, according to Dansoko (2015), was used to compute the population of the years of unavailable data:

Equation 3.3

$$Pn = Po * (1 + r) ^\wedge n$$

Pn is the population projection for year x,

Po is the population at the reference year.

r is the growth rate, and

n is the number of years

Due to limited data availability related to internal population mobility, out-migration could not be included in the final estimation of the population.

Pearson correlation analysis was computed between population data and land use/ land cover classes in the last 31 years (1990 to 2020). One assumption of the Pearson statistic is that the relationship to be tested is a linear one. In this case, the outcome is easy to derive.

Equation 3.4 $$r = \frac{C(xy) - C(x)C(y)}{\sqrt{CxxCyy}} = \frac{A}{|A|} = \pm 1$$

In other words, if y and x are exactly linearly related, $r = \pm 1$, depending on whether the slope is positive or negative (correlation or anti-correlation). More likely, with real data of any kind, there will be a spread in the values of x and y, in which case the correlation will be less than maximal, i.e., $[r] < 1$ (Sedgwick, 2012).

Additionally, correlation was computed among LULCC classes to detect possible specific conversions.

The data from FGD were coded into SPSS and were extracted from the server in Comma-Separated Values (CSV) format. Descriptive analysis (mean score) was used, and the data reported in the form of tables and graphs. As legend the closer the score is to 10, the more a specie or varieties is preferred by people. The collected data one ecosystem services were categorized in SPSS 24 to calculate the mean of each "driver" factor, using descriptive analysis. Then, the mean scores each factor was plotted using 2D and is presented as the mean of the sixteen groups. The legend of the score is defined as follows:

0=no impact,

1=low impact,

2=moderate impact,

3=relevant impact,

4=very relevant impact, and

5=very relevant impact.

Perceptions were analysed using the following segment:

- ES of restored and unrestored farmland by gender (men and women).
- ES of restored and non-restored pastureland (men and women).

As a result of the above analysis, the following questions were answered:

To what extent is restored and non-restored rangeland able to provide ES from the perspective of smallholder men and women farmers?

To what extent is restored and unrestored rangeland able to provide ES according to men and women pastoralists?

CHAPTER FOUR

RESULTPRESENTATION, ANALYSIS AND DISCUSSIONS

4.1 Socio-Demographic Characteristics of the Respondents

The results of the descriptive analysis of the socio-economic characteristics of the respondents shows that the sample was made up of both sexes 82 % and 18 % of women with an average age of 52 years. This shows that respondents were old enough to provide relevant and complete information on within the timeframe considered in the study. In term of education, majority of the respondents 52 % are alphabetised and 16 % did coranic school.

This reflected their ability to read and understand scripted/written information. However, most of producers had not been to school. This category of respondents was more important at the level of Wacoro Municipality (14.0%). Households had on average, two sources of income. The two main sources of income are small scale farming (96.0%) as primary income source and livestock keeping as secondary source of income (54.0%). The average annual household income is 540,000 CFA in Wacoro municipality. In term of structuration, 88 % is members of cooperatives or associations. The average farmland hold by an individual is 5 hectares. A total of 88 % of landowners get their land through heritage.

Table 4.1 Socio demographic Characteristics of the Respondents

Variables	Wacoro town (n=200)
Households caracteristics	
Average Age	52
Gender of the respondent (% homme)	82
Average Households members (number)	16
Education level (%)	
Alphabetisised (%)	52
Coranic school (%)	16
Inferior or equal Grade 6 (%)	14
Inferior or equal Grade 9 (%)	6
Superior or equal grade 10 (%)	6
Association/coopratives	
Members of rural association (%)	88
Revenu	
Number of livelihoods sources (%)	2
Average household yearly income (FCFA)	540 000
Primary source of livelihoods	
Farming (%)	96
Livestock keeping (%)	4
Trade (%)	0
Other (%)	0
Secondary source of livelihoods	
Farming (%)	6
Livestock keeping (%)	54
Trade (%)	20
Others (%)	20
Agricultural land	
Average farmland surface ha	5

Land ownership	
Herritage (%)	84
Aid (%)	14
Rent (%)	2
Others (%)	0

Source: Author's Illustration 2023

4.2 Data Presentation on Research Issues (Objective by Objective)

Objective 1

4.2.1. Land Use and Land Cover Changes between 1990 and 2020 in Wacoro Municipality.

Remarkable changes were observed in LULC in Wacoro Municipality over the past thirty-one years. These are presented in Figure 4.1.

From these results, all LULC classes had recorded spatial and temporal changes. However, the degree of change varies from class to class. Wooded savannah recorded the most significant decrease while settlement, shrub savannah, grassy steppe, and farmland coverage increased consistently. The most important LULCC, the decrease in wooded savannah and increase in shrub savannah, took place between 1990 and 2010. The findings indicate that between 2010 and 2020, mostly shrub savannah was converted to farmlands. Over the entire study period (1990–2020), two-stage change was observed for the wooded savannah as follows, the first was conversion to shrub savannah and then converted to farmlands, which was the second stage.

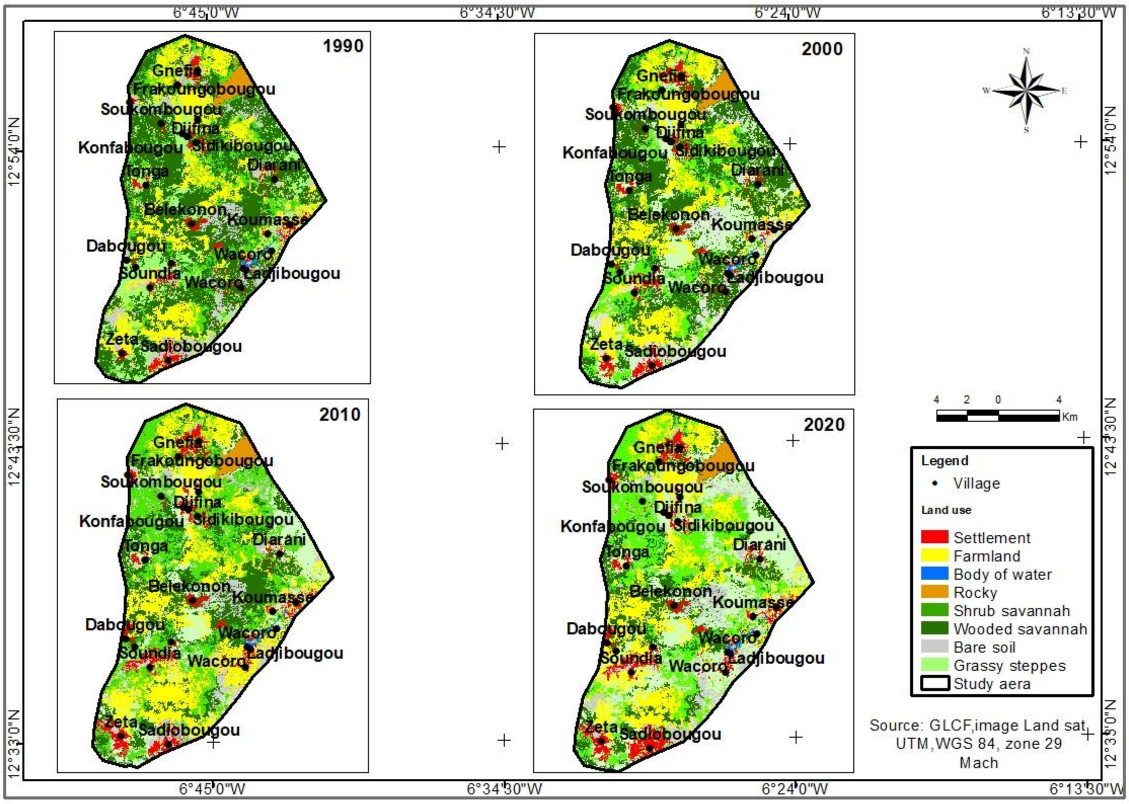

Plate 4.1 Land Cover Change Maps between 1990 and 2020 in Wacoro Municipality, Mali

Source: Author' illustration 2023

The following graphs describe the quantitative results of LULCC over the entire considered timeframe in the study. It shows the changes per category of land use cover classes within 10 years frame over 31 years period (1990-2000; 2000-2010; 2010-2020).

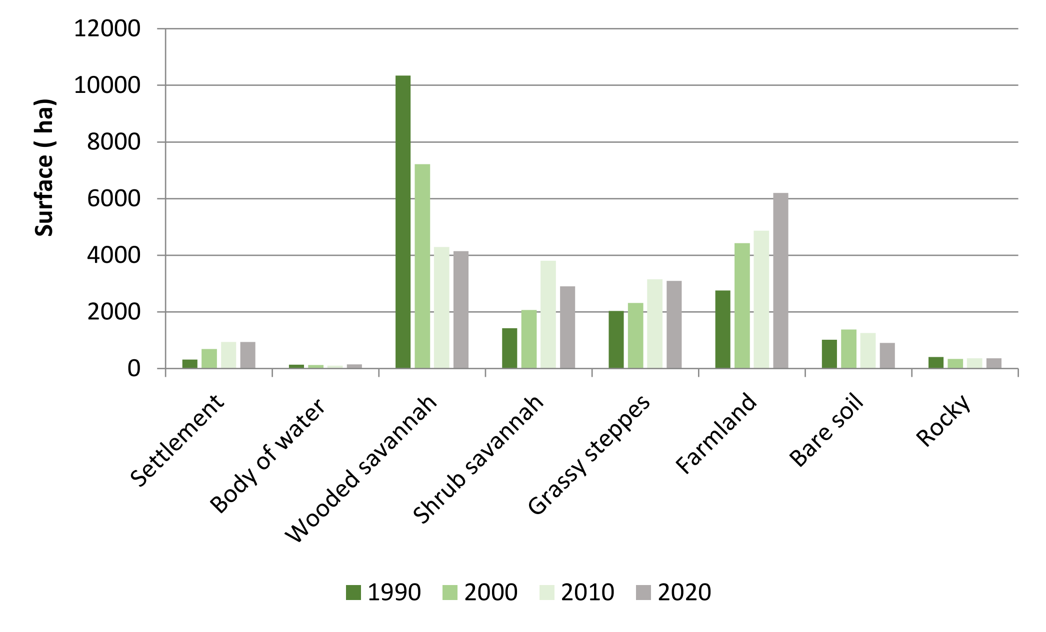

Plate 4.1 LULCC from1990 to 2020 in Wacoro Municipality

Source: Author' illustration 2023

The primary application of the classification was to establish maps and statistics of land use. Moreover, an accuracy assessment was conducted using the confusion matrix to compare the classification results of 2020 with ground truth data collected on the field. As shown in Table 4.2, the Kappa coefficient on each image analysed was above 50% (Vieira et al., 2010).

Table 4.1 Analysed Images Accuracy

Images	Global Precision	Coefficient Kappa
TM 1990	88.7%	0.87
ETM+ (2000 and 2010)	87.4%	0.85
OLI 2020	93.5%	0.93

Source: Author' illustration 2023

Bivariate correlation shows that within the time frame (1990 to 2020), the increase in farmland significantly correlates with population growth (p-value = 0.04), whereas the decrease in wooded savannah correlates with the increase in settlements (p-value = 0.005) and the increase in grassland (p-value = 0.03). Moreover, a conversion of shrub savannah into grassland has also been recorded (p-value = 0.05). Degraded wooded savannah has been mainly converted into settlement and grassland savannah.

Table 4.2 Correlation Matrix between Different Land Covers and Population Growth from 1990 to 2020 Using Pearson Correlation

Person's Correlations										
		Pop	Settlement	Water Bodies	Wooded savannah	Shrub savannah	Grassy steppes	Farmland	Bare soil	Rocky
Pop	Pearson's r									
	p-value									
Settlement	Pearson's r	0,865								
	p-value	0,135								
Body of water	Pearson's r	0,091	-0,402							
	p-value	0,909	0,598							
Wooded savannah	Pearson's r	-0,893	-,995**	0,365						
	p-value	0,107	0,005	0,635						
Shrub savannah	Pearson's r	0,692	0,896	-0,619	-0,912					
	p-value	0,308	0,104	0,381	0,088					
Grassy steppes	Pearson's r	0,888	0,94	-0,333	-,968*	0,944				
	p-value	0,112	0,06	0,667	0,032	0,056				
Farmland	Pearson's r	,960*	0,927	-0,042	-0,927	0,695	0,857			
	p-value	0,04	0,073	0,958	0,073	0,305	0,143			
Bare soil	Pearson's r	-0,405	0,092	-0,808	-0,011	0,138	-0,135	-0,167		
	p-value	0,595	0,908	0,192	0,989	0,862	0,865	0,833		
Rocky	Pearson's r	-0,417	-0,7	0,438	0,626	-0,437	-0,416	-0,655	0,578	
	p-value	0,583	0,3	0,562	0,374	0,563	0,584	0,345	0,422	
* p < .05	** p < .01	*** p < .001								

Source: Author’s illustration 2023

4.2.2. Local People's Perception of the Main driving Factors of LULCC

According to the local communities, the main driving factors of decreasing wooded savannah were increase in cotton price inducing agricultural expansion as well as drought, population growth and settlement expansion. Cotton price increase, agricultural expansion and settlements have been scored particularly high by respondents for the period 2010 to 2020. This somewhat contrasted with the findings from Remote Sensing, which indicated that farmland expansion during these years mainly came from the conversion of shrub savannah, not wooded savannah. Moreover, firewood and charcoal exploitation have also contributed significantly to the loss of wooded savannah. All of these were exacerbated by recurrent poverty and low environmental law enforcement in rural areas during the past 31 years. Most driving factors, such as firewood and charcoal exploitation, timber extraction, bushfires, wind erosion and poverty, recorded their peak from 2000 to 2010 during which severe droughts affected the communities. These are the years where much of the wooded savannah decreased, while shrub savannah increased (Figure 4.1), indicating a loss of woody biomass and degradation.

To cope with droughts that threatened livelihoods, people put pressure on natural resources as alternative income sources to combat poverty, thus contributing extensively to degradation and deforestation. The period between 2010 and 2020 is considered as a recovering period from drought due to the favorable weather conditions and rural development restoration project interventions supporting natural resources management. Although challenges remained serious, these conditions and the increase in cotton price contributed to agricultural land expansion.

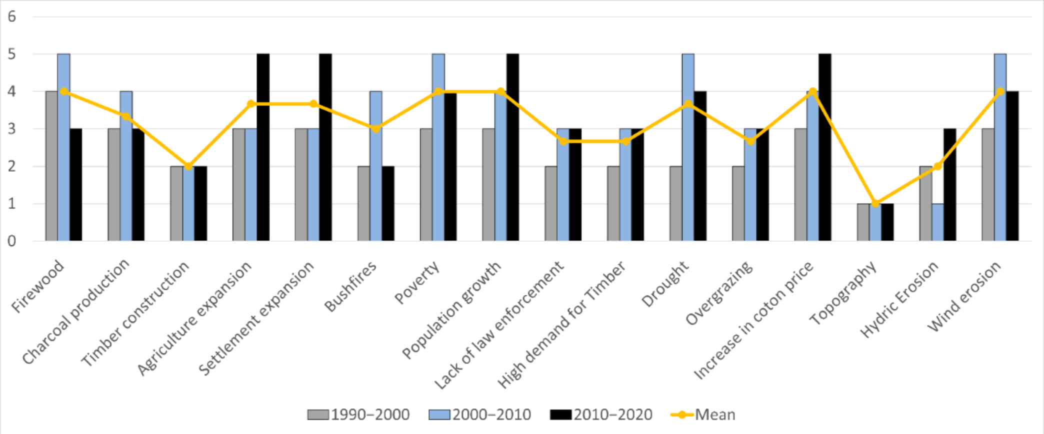

Figure 4.2 Driving Factors of Wooded Savannah Area Decrease in Wacoro Municipality between 1990 and 2020.

Source: Author's Illustration 2023

The observed increase in farmland was attributed (with high relevance) mainly to the rapid population growth, increase in cotton price, low soil fertility, access to agricultural inputs for cotton farming. Moreover, remittances, family labor force availability and low law enforcement contributed but with medium relevance. The results also shows that although agricultural land expansion was related to the above driving factors, their effects differ from one period to another. Most of the driving factors recorded their peak between 2010 and 2020, for which a strong decrease in shrub savannah but not in wooded savannah, was found. This phenomenon was mainly due to the high demand for agricultural products for livelihood support (income and subsistence food) caused by population growth. In addition, the cotton price had its peak from 2010 to 2020 compared to the period 1990 to 2010. This finding supports the hypothesis of socio-economic activities' contribution to the LULCC.

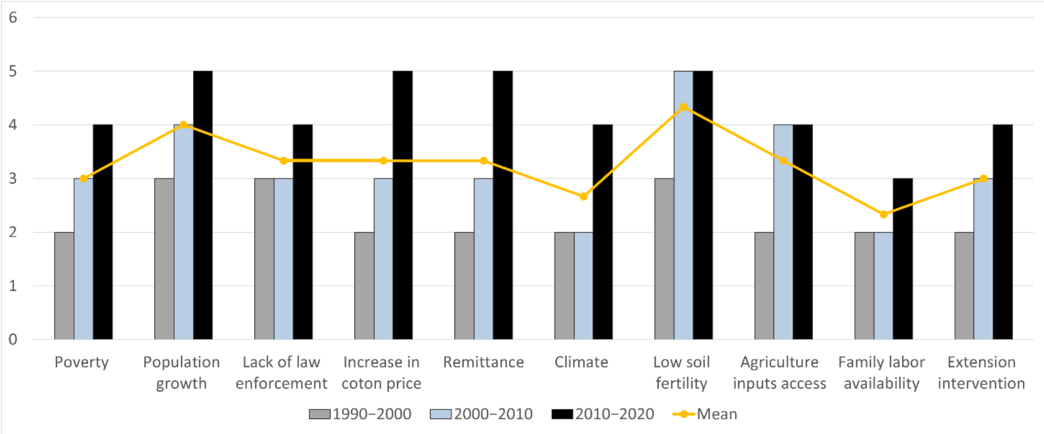

Figure 4.3 Driving factors of Farmland area Increase in Wacoro Municipality between 1990 and 2020.

Figure 4.3

Source: Author's Illustration 2023

Increases in settlement area, found mainly between 1990 and 2010 were mainly attributed to population growth, easy access to construction materials (tree-based products), remittances from internal and external migrants, and income from cotton production. Labor force availability and construction knowhow were also contributing factors but with low relevant effects. While local people's technical capacities, labor availability and good topographical conditions have also contributed, all these factors were directly or indirectly related to the rapid population growth that the area has seen during the last three decades. In addition, external supports from migrants in form of remittances, income from cotton and access to construction materials contributed to increased settlements. These drivers recorded their peaks between 2010 to 2020, which coincided with the period when cotton prices increased. More remittances were received therefore, more pressure was put on the shrub savannah as well as on grasslands, and even agricultural land was often converted into settlements. This is shown in Figure 4.4.

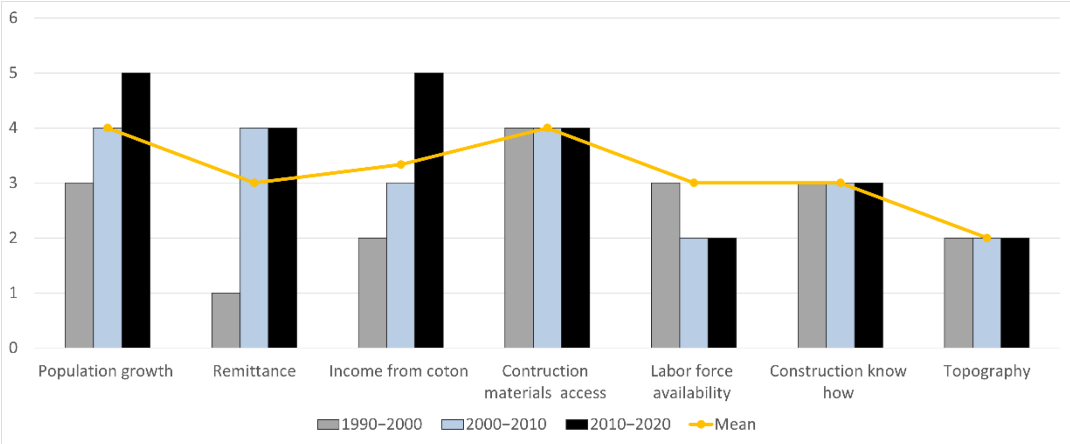

Figure 4.4 Driving Factors of Settlement Area Increase in Wacoro Municipality between 1990 and 2020.

Source: Author's Illustration 2023

The increase in grass and shrub land area over the last 31 years has been attributed, mainly to the decrease in wooded savannah. It was found that grassland cover was negatively correlated with wooded savannah cover. This means that part of the already degraded wooded savannah became grass and shrub savannah with time. This finding confirmed local communities' perception of grassland and shrub savannah cover increase due to the severe destruction of the wooded savannah for livelihood needs from 2000 to 2010, when damage caused by negatively impacted on livelihood. Moreover, annual rainfall distribution affected grassland and shrubland and their covers and, consequently, fuel availability over the study period.

To cope with this, transhumance was used as a local strategy to counteract the drought stress affecting agro-pastoralists between 2000 and 2010. The approach consisted of migrating most of the livestock (both big and small ruminants) to humid areas for a long period of time before the drought negatively affected the landscape. In the meantime, between 2007 and 2010, although climatic conditions were not as expected, livestock pressure reduced the areas covered by grassland and shrub savannah.

According to local communities, from 2010 onwards, all livestock was brought back without any further measure. From 2010 onwards, the pressure on the regreened grassland and shrubland increased again.

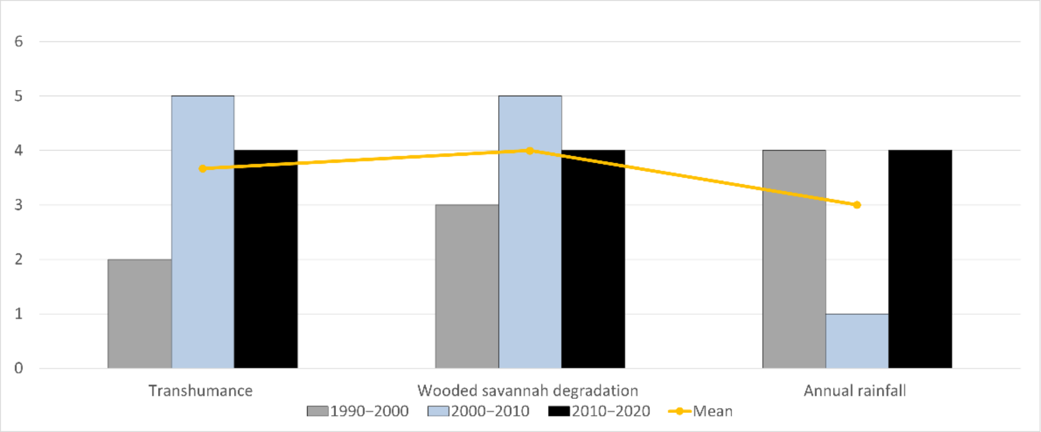

Figure 4.5 Driving Factors for Slight Increases in Shrub and Grass Savannah area from 1990 to 2020.

Source: Author's Illustration 2023

Objective 2

4.2.3. Respondent's perception on species preferences and suitability

From the result, fodder grass, shrubs and trees and fruits trees were all suitable under Agri silviculture system except *Miscanthus sinensis, cenchrus biflorus and Pterocarpus lucens* while fruits fodder trees, shrubs and grass were suitable under silvopastoral system. All the species proved suitable under the business-based platform system. About the fruits trees varieties, they were not suitable under silvo-pastoral system.

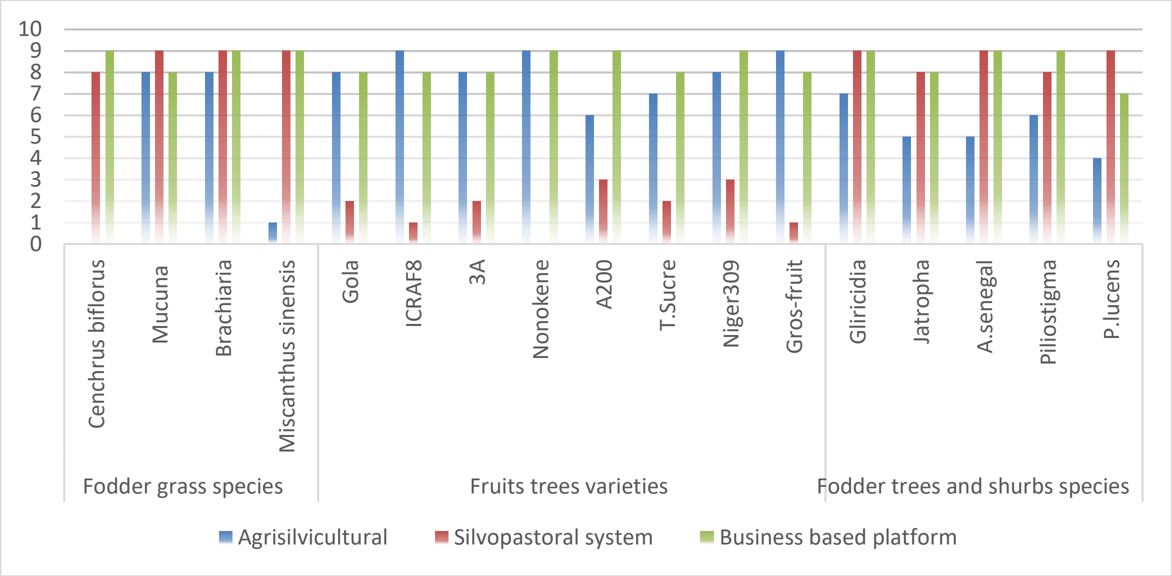

Figure 4.6 Adapted Species Prioritization Diagram under Various Agroforestry Systems.

Legend: 0 (non-prioritized) to 10 (very highly prioritized)

Source: Author's Illustration 2023

The result shows that, all the species recorded fast germination day (3 to 5 days) on sandy under half-moon management practices, clayed, clayed-sandy, and lateritic soils, respectively. It was also found that species germinated quickly in half-moon management practices than tilled field. The highest germinations day was recorded by Cenchrus biflorus on lateritic tilled soil. Andropogon was the species with the lowest germination days (3 days) on both tilled and half-moon in the four types of the soil. Cenchrus biflorus expressed a particularity as it germinated quickly on clayed soil than sandy soil with a difference of 1 day.

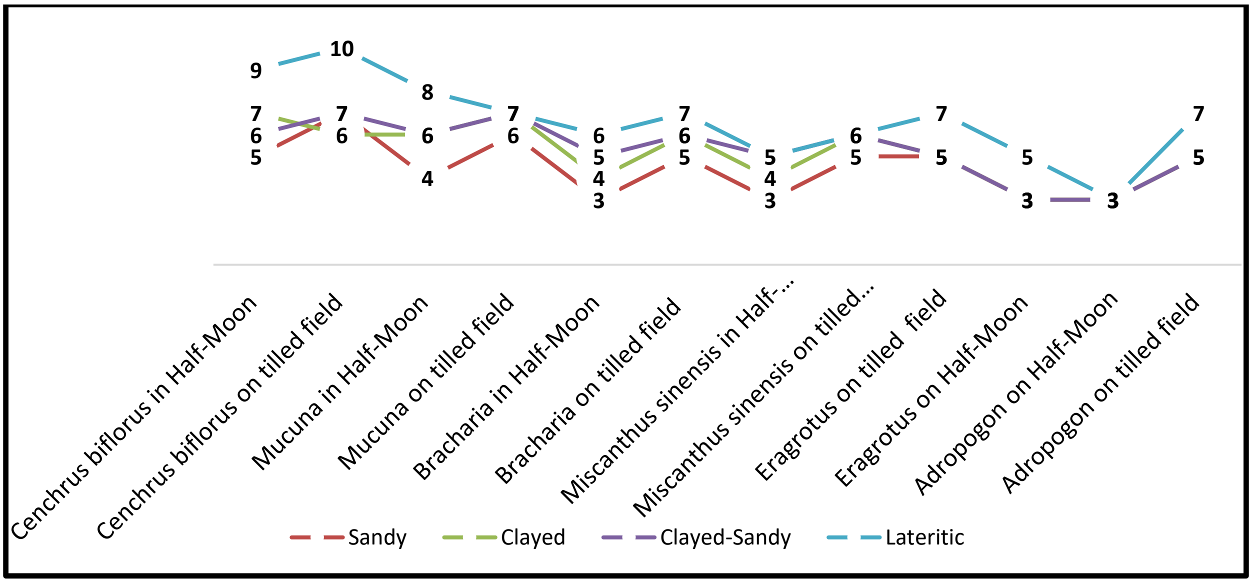

Figure 4.7 Number of Species First Appearance throughout 45 days of Dry Spelt

Legend: the number describe the number of days seed took to germinate.

Source: Author's Illustration 2023

These findings show that, all the species recorded highest survival rate in half-moon than tilled field. However, the lowest survival rates were recorded on the lateritic soil followed by sandy and clayed-sandy soil. The highest survival rates were computed from clayed soil from all the species with the exception being Andropogon in half-moon. It survived more on the sandy soil than clayed in half-moon. The more clayey the soil type, the more the survival rate increases exponentially excepted Andropogon which was more suited to sandy soil.

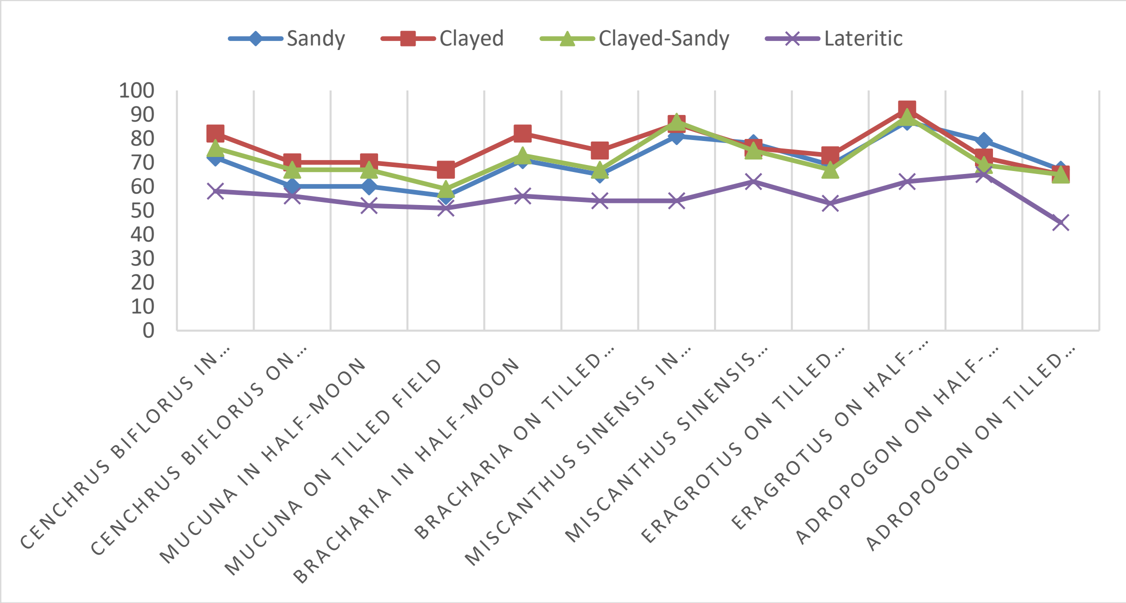

Figure 4.8 Grass Species Survival Rate by Soil Type after 45 Days of Dry sSpelt under Silvopastoral System.

Source: Author's Illustration 2023

Legend: the number on the figure describes the percentage survival rate per specie.

From this finding, all the mentioned fodder shrubs and trees seedlings survived more under business-based platform, the followed by Agri silviculture and then silvopastoral system. Survival rates were higher under the business-based platform compared with the Agri silviculture system.

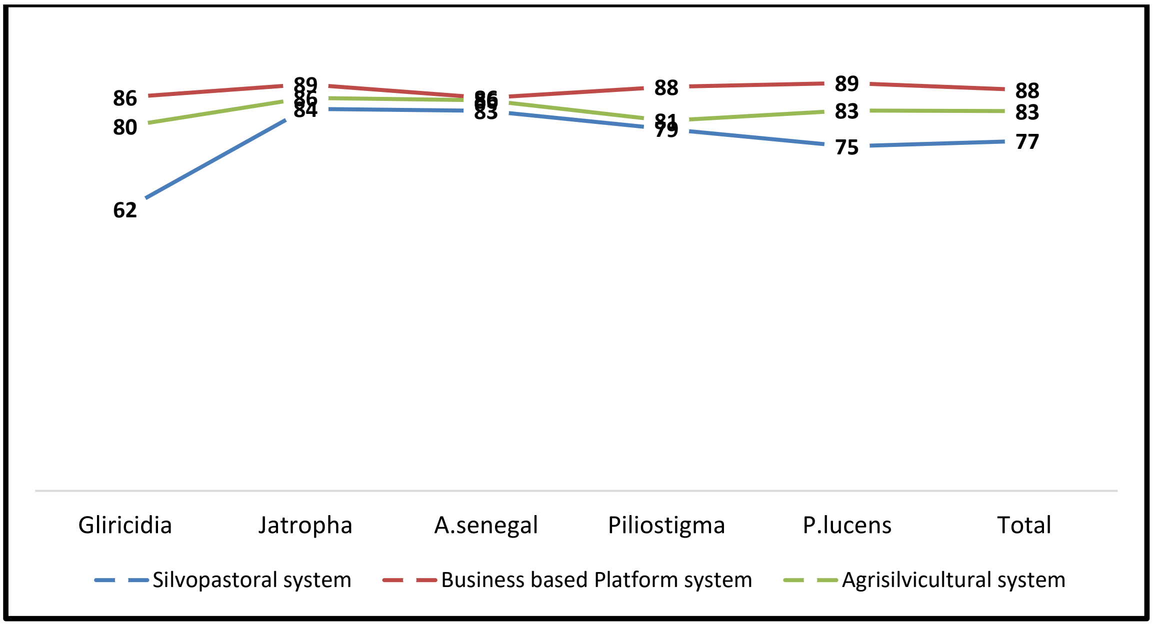

Figure 4.9 Fodder Shrubs and Tree Seedling Survival Rate after 45 Days of Dry Spell

Legend: the number on the figure describes the percentage survival rate per specie.

Source: Author's Illustration 2023

This result revealed that, the improved fruits trees seedling survived more under business-based platform compared to the agrisilvisultural system. Despite the differences, the survival rate was considered acceptable under both systems. *Andansonia digitata* had higher survival rate followed by Tamarindus indica and *Ziziphus mauritiana.*

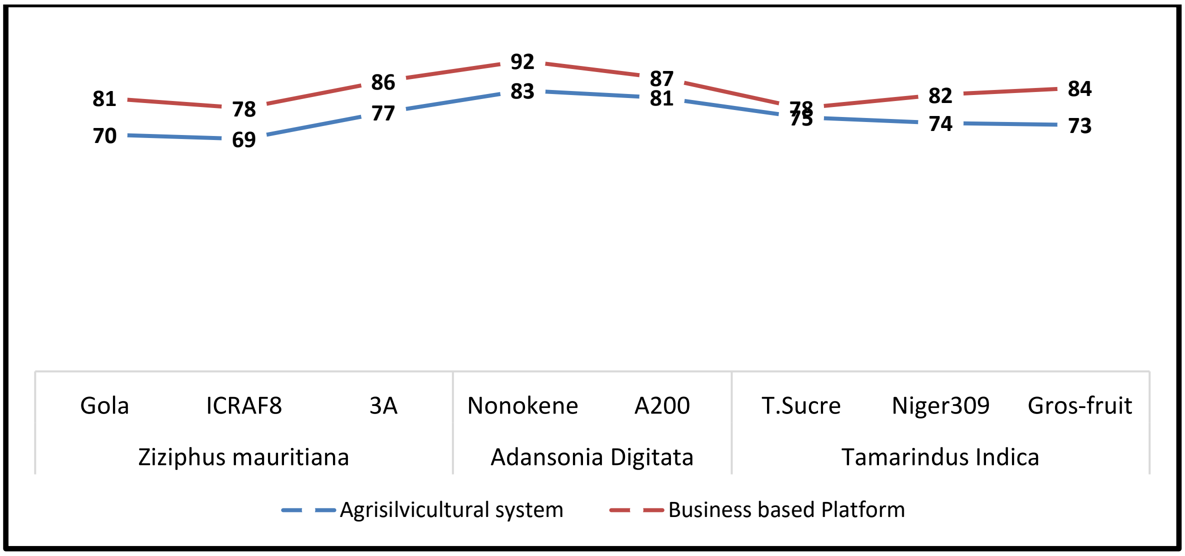

Figure 4.10 Improved Fruits Trees Seedling Survival Rate after 45 days of Dry Spell under Agri Silvicultural and Business-Based Platform Systems.

Source: Author's Illustration 2023

Objective 3

4.2.4. Ecosystem services from farmland restoration

The results shows that restoration of farmland strongly increased the supply of ES as perceived by the farmers. In general, the ecosystem potential of unrestored farmland was perceived as low by both men and women. Although degraded farmland had low productivity, there were still some harvestable goods that provided women with some income. The main product highlighted by women it was shea nut (*Vitellaria paradoxa*), which they collected even from degraded farmlands, although the number of trees is now much lower compared to that on restored farmlands. Some sell shea fruits directly in the domestic market or process it into shea butter, which is used locally as cooking oil or body ointment and is also exported for the cosmetics industry.

Restored farmland, on the other hand, had shown its a high (score 5) potential in supplying provisioning services to both men and women, whereas they benefitted to different extents. Men generally they received higher benefits than women. Women's benefits from plant-based products for sale were high compared to men and refer to particularly in terms of the use of shea for income generation. In addition, women perceived that in the restored farmland, assisted or planted trees produced fruits that they collected and partly transformed into sub-products to generate income and that contributed to household food security. In addition to Shea, *Ziziphus mauritiana* or commonly called "Jujube" or "tomono" in the local language is also appreciated for degraded and restored farmlands. This specie has been perceived differently in terms of its provisioning services potential by both men and women.

Regulating services were also perceived to be higher on restored compared to non-restored farmland, as they were providing relevant diverse maintenance and mediation services except for flood control which was not a common hazard in the area. Moreover, men perceived more benefits compared to women. This finding is attributed to the limited involvement of women in farmland restoration activities. It was found that restored farmland has a high potential in providing regulating services which is were supposed to moderate natural phenomena (flood, drought, and storm). This shows that the combination of Farmer Managed Regeneration (FMNR) with on-farm tree planting and drought resistance crop farming on the same plot can improve farmland's potential for regulating services in the face of natural hazards.

With regards to cultural services, both genders had common views on the low relevance of the physical and spiritual values of non-restored farmland while restored farmland highly contributed to the supply of educational, future preservation, and leisure time services. Thus, it can be assumed that they perceive more services compared to women.

the findings justified that the integration of FMNR, tree planting, and cultivation of drought resistance crops under agric silvicultural system has high potential in restoring degraded farmland through the provision of socio-ecological and cultural services and functions for livelihood improvement in the Sahel. But there is a need to integrate gender consideration in the implementation and profit-sharing so that equitable services can be generated from Agri silviculture systems for more resilience (see fig 4.11).

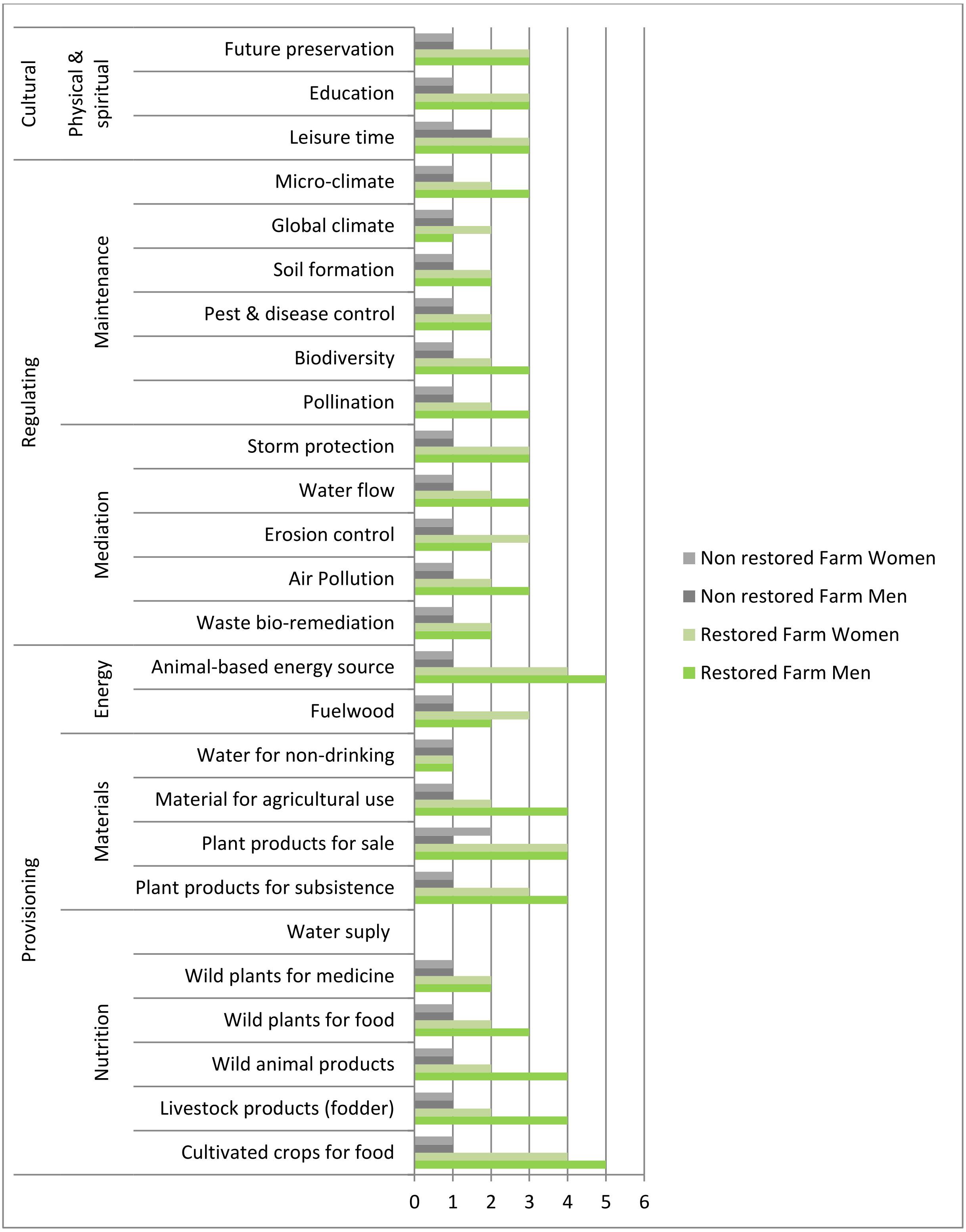

Figure 4.11 Ecosystem Services Perception from Restored and non-restored Farmland

Source: Author’s Illustration 2023

Legend: 0 (non-relevant potential) to 5 (very highly relevant potential)

4.2.5. Ecosystem services from pastureland restoration

Like farmlands, pasturelands also tended to provide higher ES overall once they have been restored. Restored pastureland recorded generally higher provisioning services, however, fuel wood, drinking and non-drinking water. However, provisioning services for wild plants used for medicine remains unchanged after restoration (figure 4.12). The rationale behind this is the limited consideration of these services in pastureland restoration interventions. Restoration interventions focused more on fodder while pastoralists need tree-based medicine, fuel wood, clean water, and animal-based mechanics energy for household needs.

The results clearly show a strong increase in fodder provision from restored pasturelands (see figure 4.12). It was found that there is a need to consider fuel wood, drinking and non-drinking water, and tree-based medicine supply. From the investigation, less research attention was paid on the drinking water supply consideration in the restoration intervention. Moreover, women perceived fewer provisioning services compared to men from pastureland restoration (see figure 4.12).

Thereby, inequality and non-consideration of clean water, tree-based medicine, and fuel wood are barriers pastureland restoration to address provisioning services. There is an urgent need to consider these gaps in pastureland restoration so that provisioning services can be provided sustainably in pastoral communities in the Sahel. Both men and women perceived that non restored pastureland has low potential in supplying regulating services while restored pastureland recorded a relevant potential. The main regulating services are erosion control and water conservation mechanism. Biodiversity, pest and disease control, soil formation, and microclimate regulation (Sinare & Gordon, 2015). Men opined that they perceived higher regulating services than women due to their high involvement in restoration activities. It was found that for restored pastureland to improve significant regulating services, there is a need for more time, gender, and tree species consideration in restoration strategies.

In line with the other service types, cultural values were perceived as weak in the non-restored pasturelands by both genders while restored areas provided significant services. The most relevant were education, leisure time, and future preservation. Most of the pastoralists met in the pasture when grazing their livestock. Thus, the pastureland is a place where they interact and exchange their experiences on landscape-related topics. They discussed the forecast of fodder availability, restoration interventions, pastureland management rules and regulations, water availability, bush fire occurrence, and other relevant topics. This opportunity for discussion enabled them to get prepared to face potential hazards. Thus, restored pastureland is considered as a location where they gather and discuss with extension workers frequently on management of restored pastureland. Culturally, restored pastureland is considered a location for education, and cultural exchange. It is considered an area that conserved their culture and their tradition for the future generation. It is obvious then that large-scale promotion of degraded pasture restoration interventions with gender consideration in the Sahel could improve pastoralist's education, reinforce their social network, and facilitate Early Warning on the pastureland vulnerability in the face of natural hazards (drought, flood, and storms). Moreover, it could also contribute to the culture and resources conservation for future generations.

Pastureland restoration has a great potential to provide ecosystem provisioning, regulating, and cultural services in livelihood specific. The figure 4.12 shows the perceived potential ecosystem services from both men and women perception as analyzed in the above narrative.

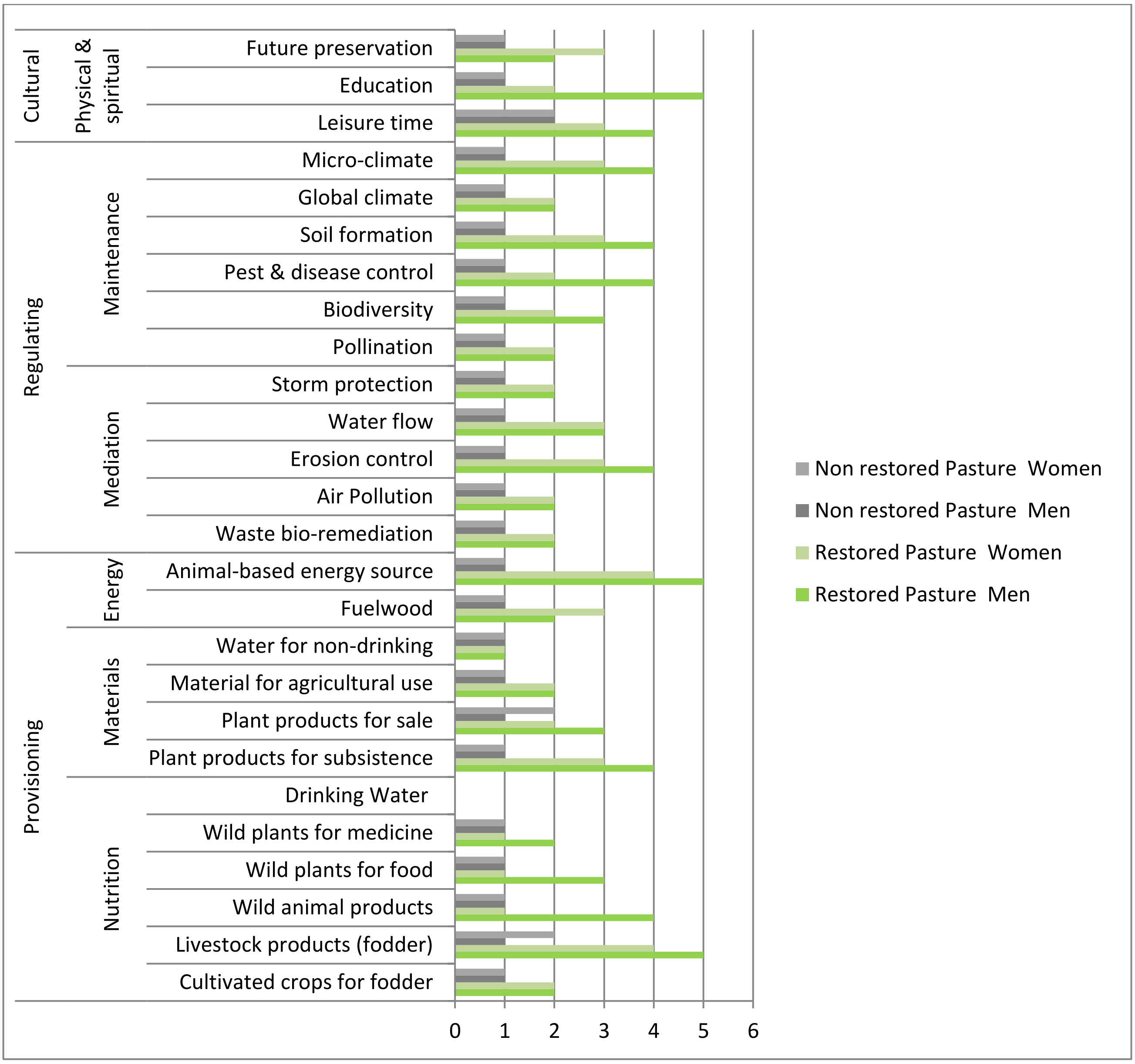

Figure 4.12 Ecosystem Services Perceived from Pastureland Restoration by Gender.

Source: Author's Illustration 2023

4.3. Test of Hypothesis

Based on the computed result using Pearson correlation analysis, a significant (p-value=0.005) correlation has been found between the decreases in wooded savannah and population growth. Thereby, the null hypothesis (Ho) is rejected while the alternative (H1) is accepted. The increase in wooded savannah is attributed to the population growth.

As finding from Pearson correlation, the increases in settlement (*p*-value = 0.005), and grass savannah (*p*-value = 0.03) cover are attributed to the decreases in wooded savannah with significance. Thereby, the null (Ho) is rejected while the alternative (H1) is accepted.

4.4. Discussion of findings

This study found a decline in wooded savannah area with an increase in settlement, farmland, and shrub savannah areas, which is in line with findings from similar studies in the Sahel (Oseph et al., 2003). This was mainly driven by expansion of smallholder agricultural, recurrent droughts, overgrazing, population growth, increases in cotton price and high needs of tree-based energy products. Other land use change happened primarily due to the unsustainable exploitation of trees. Thus, more research on integrated farming practices considering vegetation conservation and restoration needs to be conducted and respective recommendations added to the National Agriculture orientation law called LOA (in French) and Pastoral Charter (" Charte Pastorale") for the purpose of ensuring sustainable land use strategies for livelihood security for the local people.

Promotion of Agroforestry technologies could be one of the strategies to support farmers' livelihoods in the long term. This study focused on Mali, (it) has contributed to the understanding of wider land change drivers relevant to the Sahel region. Similar to the current study, other authors have also reported that climate change in general and increasing drought periods, in particular, negatively affect the livelihoods of rural communities in Sahelian West Africa (Adaawen, 2021; Sanogo et al., 2021) and that this pushes them towards expansion of cropland and alternative livelihoods (firewood, charcoal and timber), ultimately driving LULCC (e.g., loss of wooded savannah). Thereby, land management strategies need to consider climate friendly energy and timber sources for livelihood improvement in the Sahel (Elagib & Al-Saidi, 2020b).

Keeping more livestock through transhumance to meet the high meat and milk demand leads to overgrazing which has been considered as contributing factor to the decline of wooded, shrub and grass savannah by most local communities (Rahimi et al., 2021). Overgrazing, combined with trampling by livestock hooves and subsequent soil compaction, leaves bare land which is subsequently exposed to the hot sun during the dry period and, ultimately, leads to soil and wind erosion (Diawara et al., 2020). Unsustainable land use practices are attributed to the insufficient level of enforcement of the national pastoral charter and natural resources management policy. Few people are conscious of these policies and their implications for future land-based resources preservation for the next generation. This scenario was a lesson learned by the community that transhumance is not a long-term solution for grassland and shrub land restoration if it is not adapted to the carrying capacity of the ecosystem, as it may cause unexpected damage. The perception on transhumance is consistent with (Oloukoi, 2017), who finds that drought across Mali's north seriously affected transhumant populations, forcing pastoralists to remain near permanent water sources and leading to considerable overgrazing throughout the period of the time considered in this study. There is a need for grazing land to be restored through a combination of fodder trees, grass, and shrub planting, as well as controlled livestock populations for sustainable livelihoods in the pastoral communities in the Sahel.

The findings of this study, evidence suggests that increasing population density is one of the most important factors behind the declining use of fallows and increased land fragmentation in Burkina Faso (Fernández et al., 2007). Population pressure on resources could rise in the coming years and could threaten the survival of plant and animal species and eco-systems in addition to human well-being in Mali and beyond, especially in the current context of climate change (Olumba et al., 2022). This finding suggests a competing scenario between land uses without a proper landscape-level strategy. A good balance is needed between population growth and settlement cover through sustainable territorial planning which is sometimes conditioned by political will. Thereby, sustainable land management strategies should consider population projections in the short, mid-, and long terms for future stable and resilient natural resources and livelihoods for local communities.

Agriculture, through its related policies, is recognized as one of the major drivers of forest cover loss (FAO, 2020). This research found that in addition to the rapid population growth (and settlement), cotton price incentives contributed significantly to agricultural land expansion and reduced vegetation cover. This phenomenon was exacerbated by the national policy facilitating access to agriculture inputs for cotton farming (Falconnier et al., 2018). Similar results were observed in neighbouring countries, Burkina Faso (Okafor et al., 2019) and Senegal (Thiam et al., 2021).

It is therefore advocated that any new agriculture development policy or strategy (such as cotton price incentives) should always be accompanied by an assessment of their potential environmental impacts and the design of adequate mitigation measures to ensure sustainable land use. One existing opportunity to ensure implementation of such measures in the field is that the cotton sector in Mali and in other cotton-farming countries in the Sahel (for instance Burkina Faso) has generally a well-structured extension system with extension agents closely monitoring individual farms to ensure productivity. A remaining challenge is the design of a joint environmental standard to be enforced by extension agents at sub-regional level.

The result of this research shows that population growth, energy demand, drought and cotton price incentives were the main driving factors of LULCC (factors) that could potentially be persistent in a business-as-usual scenario. This could exacerbate the prevailing severe food insecurity and malnutrition in the area resulting in heightened conflict, terrorism, and jihadism (West et al., 2020). Security is the priority of the current Government of Mali, but this might be hampered if due attention is not paid to securing the livelihoods (of) for vulnerable populations, as emphasized by (William and Arun, 2012, who state that “Where hunger rules, peace cannot prevail”. Sustainable land management policies which consider the driving factors (population growth, incentives in cotton production (price), fuelwood extraction and drought) are urgently needed.

This research was limited to a certain study area, period (31 years) and context, it has, nonetheless, being able to advance the knowledge on land change drivers that can be relevant for the Sahel region. The results of this research include the lack of a clear distinction between underlying and direct drivers, which is often a challenge when comparing RS and GIS analyses with local perceptions; the non-inclusion of climate modelling data; and the level of detail in assessing each land use and specific change drivers that would enable more concrete recommendations for policymakers.

The non consideration of the above aspect was caused by the non-accessibility of accurate climate data from the met service. All these pose opportunities for further research.

The approach of using mixed methods has supported the understanding of how the dynamics of land cover changes could be explained by communities' perceptions of potential drivers. In the prevailing context of climate change, future studies could endeavour to evaluate to which extent such dynamics could be explained by specific climate factors through climate-impact modelling approaches. Moreover, it would be interesting, beyond communities' perceptions on the potential drivers, to explore what in their view constitutes alternative environmentally friendly livelihood options given the circumstances.

It has been found that, the proposed trees, shrubs and grass varieties do not have the same level of suitability under various agroforestry systems. Every specie suit based on people preference, soil type and climatic condition. Grass, fodder shrubs and trees were more suitable under business-based platform and silvopastoral systems than the Agri silvicultural system. The rationale reason behind this was attributed to the protective and care inputs (fertilisers, water, and defence system) species benefited from, under these systems. Moreover, harmonised co-production norms are another factor. Some grass species like Cenchrus biflorus, Miscanthus sinensis and Eragrotus cannot---delete (could not) cohabit with some crops on farmland due to the high competition for nutrient and water.

Regarding the fruits trees species, farmers highly appreciated their suitability under agrisilvicultural system and business-based platform because of their high survival rates. The high survival rates under Agri silvicultural and business platform systems are explained by their high adaptive capacities due to the robust protection facilities, nutrient and humidity availability, and maintenances (Duffy et al., 2021). Moreover, their limited exposure to the predator's attacks is a contributing factor. Therefore, proper attention should be put on species resistance under driest conditions on various systems.

Germination period is one of the critical factors which needs to be analysed when promoting species under various agroforestry systems in different soil types. To understand soil specific case, various grass and leguminous species have been demonstrated under silvopastoral system. The findings show that species germination is attributed to, firstly, to the soil type and then, the management practices. Germination days of all the species is low on sandy soil and increase respectively from clayed, to sandy-clayed and to lateritic soil. Lateritic soil has the highest germination days. All the species germinated quickly under half-moon management compared to tilled field practices. This may have been justified by the high potential of half-moon practice and the high exposure of the tilled field to the evaporation. Grass and leguminous species need sandy and humid soil for quick germination but survive more on clayed soil than sandy soil when planted into half-moon management practices (Dantas et al., 2020).
Species survival rate is related to the combination of factors, agroecological conditions. That factor needs to be understood for contextual dissemination. After an experimentation on the factor, generated output shows that the survival rate varies from one species to another and differently according to the soil types.

Grass, fodder shrubs and trees and fruits trees species survive more under clayed and sandy-clayed soils compared to the sandy and lateritic soils. Moreover, the fruits trees like *Adansonia digitata, Tamarindus indica and Ziziphus mauritiana* recorded a minimal survival rate of 70 and maximum of 90 percent under the driest condition in the Agri silvicultural system and business-based platform.

This finding corroborates the finding by Ky-Dembele et al., (2022) that of 80.0% survival rate with *A. digitata, F. albida, Z. mauritiana, and V. ̈paradoxa*. But from the result, survival rate differs from one species to the other in different soil and climatic condition scenarios. Therefore, species suitability is agroforestry systems, management practices, soil, and climatic condition specific in the Sahel/Mali. Every species orientation for livelihoods intervention should consider these contextual factors.

The integration of Farmer Managed Natural Regeneration (FMNR) with tree planting combined with drought resistance crops or grass has a great potential for ES that support smallholder farmer and pastoralist livelihood with very relevant capacity (Sinare & Gordon, 2015). Farmland restorations improve the provision of a diversity of livelihoods through the supply of nutritious food crops, livestock products, wild animal and plant products, materials for household consumption, for sale, and for satisfying energy needs (Tschakert, 2007). Moreover, it contributes to the maintenance and regulation of climate protection, control of crop pests and diseases maintaining hydrological flow, soil, and water conservation, and improving biodiversity (McVittie & Faccioli, 2020). This finding is in line with the findings by Chen et al., (2022) that landscape restoration contributes to an increasing trend in most of the provisioning, regulating and cultural services including fruit production, livestock production, sediment retention, carbon sequestration, habitat quality, aesthetic landscape value, learning and inspiration and outdoor recreation (Mehring et al., 2017).

It has also physical and cultural benefits through cultural preservation. The more farmland is restored the more social, economic, and environments related issues are overcame in the dry landscape areas (Jasaw et al., 2017).

Thereby, this is what motivates promoting degraded farmland restoration at a large scale could to improve smallholder livelihood sustainability in the face of environmental degradation and climate change in dry land areas like the Sahel Mali.

Pastureland restoration interventions are seeing not efficient due to the limited research evidence on its ecosystem potential (Bado et al., 2021). Its consideration gives more strength regarding the livelihood sustainability in the Sahel. Considering that, it was found that non-restored pastureland is perceived as areas with limited ES potential while restored lands are providing relevant ES in supporting pastoralists' and farmers' livelihoods needs (Butler & Oluoch-Kosura, 2006). Restored pastureland with natural regeneration combined with planting and assisting local shrubs and grass species improve the supply of fodder for livestock, and energy sources and contribute to climate protection, soil and water conservation, pest and disease control, and biodiversity conservation (Binam et al., 2017). But there is a need for a contextual and holistic scaling-up approach to the existing technologies and management practices in the Sahel Mali.

From both non-farmland and pastureland, 99.0% of the score is 1 (very weak potential to provide ES) while restored lands shows their high potential. This revealed the significance contribution of agroforestry technologies in providing ES for livelihoods improvement contextually (Castle et al., 2022).

Gender is one of the key pillars when analyzing livelihood sustainability in the rural context. Looking at that, the results show that, although, both men and women benefited from the restoration projects, more profits are generated by more benefits accrued to men than women's low involvement of women with restored lands and insufficient level of land access. Women were considered as indirect beneficiaries of the restoration interventions among the most vulnerable group facing the threats of farmland and pastureland degradation. Regarding this fact, promoting gender equity in land restoration strategies and facilitating women's access to farmland and pastoral land could strengthen their capacities and furthermore reinforce livelihood sustainability in the farming and pastoral communities in the face of environmental degradation and climate change in the Sahel. This result corroborates the point of view of Siqueira et al., (2021) that gender inclusion in ecological restoration could then be a win- win solution for promoting cross-cutting achievements of the Sustainable Development Goals (SDGs) and effectively demonstrate its broad positive benefits to promote diversity and equality.

As water is considered one of the livelihood issues in the Sahel due to severe climate threats, analysis was executed on this component. It was found that both restored farmland and pastureland did not have water supply potential which is crucial in livelihood support. It was also found that dried up water bodies that are supported to serve people and livestock are not considered in most of the restoration interventions (Sacande et al., 2021). People need to move far away in other communities looking for water for their own needs or to serve their livestock. This is a big gap that needs to be taken into consideration when implementing restoration for livelihood sustainability. This is often a source of conflict among pastoralists from different communities.

The more the degraded watersheds are rehabilitated, the more restoration interventions stabilize pastoralists and transhumance related conflicts (Olumba et al., 2022). About that fact, restoration interventions should consider watershed rehabilitation in pastoral and farming communities for livelihood sustainability in the Sahel (Woreda, 2022a).

Woreda (2022b) finds that watershed rehabilitation could bring major ecological changes such as decrease in soil erosion, increase soil fertility and agricultural productivity, increase forest cover and firewood availability.

As education is one of the key components for livelihood sustainability, an analysis has been carried out on that subject. As a component of the restoration package, training sessions on agroforestry technologies and management practices have contributed to the beneficiaries' knowledge improvement but once again, men benefitted more than women. The reason behind this is that women are marginalized by men in land management interventions. It was found that restoration contributes a lot to knowledge improvement because restored sites are considered areas where farmers and pastoralists meet to exchange ideas on the potential benefits, challenges, and perspectives of promotion (Baidu-Forson, 1997). Furthermore, communities without restoration interventions are attracted to learn from restoration beneficiaries for the purpose of scaling up. Thereby, Thus, the more the extent of farmland and pastureland restoration, the more the number of people (increases the more people will who are educated in ES sustainability in the Sahel.

Culture is considered one of the sensitive elements when implementing restoration interventions. This study took note of that fact and found that participatory restoration intervention sites are considered a culture conservation approach by farming and pastoral communities.

The more the extent of restoration of degraded farm and pastoral lands, the more the future generation will be in contact with their culture in implementing farming and pastoral activities (Picardi & Seifert, 1977). But without restoration interventions, environmental degradation and climate change will likely jeopardize future food, fodder, fibre, fuel wood, and pharmaceutical services (Binam et al., 2015). Finally, people's attraction to farming and pastoralism may diminish.

Thus, regarding farming and pastoralism cultural conservation, there is an urgent need for promoting agrisilviculture and silvopastoral systems as restoration options.

4.5. Problems encountered in the field.

While WASCAL facilitated fieldwork, certain issues hindered the optimal execution of activities. These include financial limitations; the allocated research budget was insufficient for extensive fieldwork required by some theses. Delays in disbursement also affected the implementation of the last two studies. Objective 2 and 3 relied on data from workshops and focus group discussions, which ideally should have been complemented with surveys or in-depth interviews. In objective 2, I used previous project work to assess plant species performance, employing a simplified approach in an experimental setup not specifically designed for that purpose. Additionally, the access to credible online libraries for literature review has been challenging.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Since some decades, land degradation is causing severe threat to the livelihoods of rural people in Mali. It has affected sectors, such as livestock production and natural resource management. One of commonly known indicators in the dry landscape is the loss of vegetation cover due to deforestation and land use changes have led to the degradation of pastureland and a decline in livestock productivity, which has further impacted the livelihoods of pastoralist communities.

To address these issues, a range of interventions have been implemented in Mali, including the promotion of sustainable land use practices, such as agroforestry, conservation agriculture, and sustainable rangeland management. These practices aim to improve soil health and fertility, reduce soil erosion, and promote the regeneration of vegetation cover, thereby increasing agricultural productivity, and improving livelihoods. But still less impacts are observed from the perception of local people's perception and documented. Moreover, promoted trees, shrubs and grass species suitability is observed as a contributing factor to the agroforestry-based interventions failure.

Thereby, this study investigated Land Use Cover Dynamic, attributed driving factors, species suitability analysis and ecosystem potential of AFS interventions using remote sensing, GIS technology, experimentation, and participatory design approaches (FGD and workshops) over three decades in Wacoro/Sahel Mali. The result found wooded savannah has been severely depleted and been converted into low productive farmland, settlement, shrubland and grassy steppe coverage.

Its driving factors were drought, energy's needs, increases in cotton production incentives and population growth. To address that, promoted livelihoods-oriented species suit when specifically prioritised under agroforestry systems by local people and resist differently soil, management practice and climatic conditions. Fruit trees and shrubs species suit under Agric silvicultural system while fodder trees, shrubs and grass are preferred under silvopastoral system but all suit under business-based platform (control site with adequate soil and water conservation mechanism). Moreover, under dry spell scenario, grass species germinate faster under sandy soil while survive more under clay soil. The same observation was recorded with fruits and fodder species. In terms of ecosystem potential, restored farmland and pastureland provide significant services when above parameters are considered but men perceived more services than women and insignificant water supply is perceived by both. With regards to the findings, this study recommends the promotion of Integrated Land Use System (ILUS) considering local people's species preferences under adequate soil type, soil, and water conservation technics in the face of erratic climatic conditions. This thesis calls for proper consideration of these parameters for sustainable livelihoods in the Sahelian context.

5.2 Conclusion

This study used Remote Sensing and GIS in integration with perception through mixed method for socio-ecological analysis of LULCC and contextual restoration interventions suitability for livelihoods improvement. It found that LULCC is observed over the last 31 years in Wacoro. Wooded savannah faced significant decreases and been converted into low productive farmland, grassy steppes and shrubs savannah and bad planned settlement. The driving factors are mainly attributed to the drought, energy's needs, increased incentives for cotton production and population growth.

Bivariate correlation shows that within the time frame (1990 to 2020), the increase in farmland significantly correlates with population growth (p-value = 0.04), whereas the decrease in wooded savannah correlates with the increase in settlements (p-value = 0.005) and the increase in grassland (p-value = 0.03). Moreover, a conversion of shrub savannah into grassland has also been recorded (p-value = 0.05). Degraded wooded savannah has been mainly converted into settlement, shrubs savannah and grassland savannah.

To address these driving factors, agroforestry systems could be an option for livelihoods reconciliation, but more attention need to be done in considering local people context specific species preferences, soil type and management practices in the face if erratic climatic conditions. People preferred fodder specific grass, shrubs, and tree species under silvopastoral systems at an appreciation score of ≥ 80% while fruits trees species are mainly appreciated under Agri silvicultural systems ≥ 60% and business-based platform recorded ≥ 70% a score for all the species. In term of germination, it was found that fodder grass species geminate faster when planted under half-moon management practice under sandy soil than open tilled land (3 to 7 days in soil specific in dry spell condition). Grasses and leguminous fodder recorded high survival rate when planted under clay soil followed by clay and sandy mixed soil (70 to 90 %) while low survival was noticed under sandy and lateritic soil. All the Fodder trees and shrubs recorded significant survival rate (≥ 80 %) under Business based platform system and Agri silvicultural system while fruits trees recorded (≥ 69 %). The consideration of these parameters increases the agroforestry system potential to provide adequate ecosystem services for livelihoods reconciliation in the Sahel Mali.

Thereby, agroforestry-oriented option by context approach strategies needs to consider the findings of this research for the successful dry-landscape restoration interventions for livelihoods security in the Sahel Mali.

5.3 Recommendations

- Government needs to promote Integrate Land Use Systems (ILUS) for the purpose of reconciling livelihoods in the rural communities in the Sahel Mali
- Livelihoods based agroforestry interventions need to consider local people's species or varieties preferences, soil type, climatic conditions, and land use type in their approaches to ensure socio ecological functions under ILUS in the Sahel Mali
- ILUS centred approach shall consider rural women implication and degraded water bodies restoration should be promoted as catalysts to ensure sustainable ecosystem services supply for livelihoods in the Sahel Mali.

5.4 Contributions to Knowledge

The study discovered rapid conversion of wooded savannah into unsustainable farming systems, low productive shrubland, grassland and unproper settlement distribution drove by incentive increased in cotton price, high energy demand and population growth in Wacoro/Sahel Mali.

Species suitability under agroforestry system depends on local people preferences, soil type, climatic conditions, proper soil type and adequate soil and water conservation practice implication in Wacoro/Sahel Mali.

Men perceived more ecosystem services from agroforestry-based land restoration interventions than Women and limited water supply is observed in Wacoro/Sahel Mali.

5.5 Suggestions for Further Studies

While this research was limited to a certain study area, time (31 years) and context, nonetheless, its findings was able to advance (the) knowledge on land change drivers that can be relevant for Mali, a Sahel region. Other limitations linked to this research include the lack of a clear distinction between underlying and direct drivers, which is often a challenge when comparing Remote Sensing and GIS analysis with local perceptions; the non-inclusion of climate modelling data; and the level of detail in assessing each land use and specific change drivers that would enable more concrete recommendations for policymakers. All these pose opportunities for further research.

Assessed ecosystem was limited at perception level, Assessment of ES was limited to perceptions, but a cost and benefit analysis could have improved the results of the study. This should be analysed in future studies.

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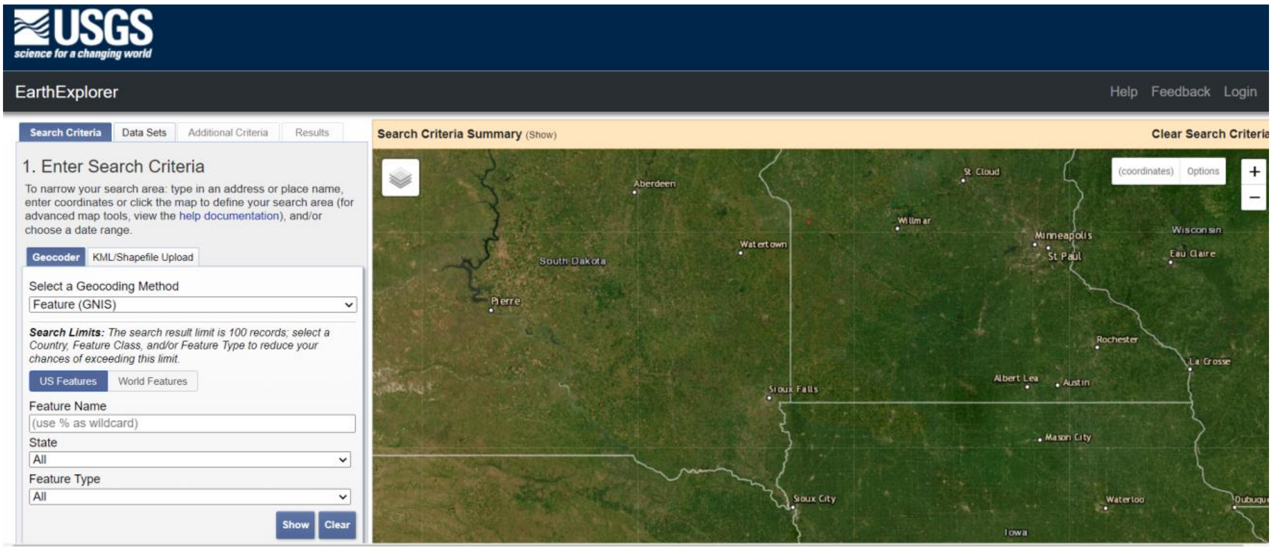
Appendices

Database explored for satellite images collection



Tools used for Mapping

Tool used for LULCC driving factors assessment

Scoring tool for Land Use Cover Driving Factors Assessment			
	1990-2000	2000-2010	2010-2020
Firewood Charcoal production Timber construction Agriculture expansion House construction Bushfires			
Poverty Population growth Low financial resources Lack of law enforcement High demand for Timber Drought Overgrazing Increase in coton price Topography Hydric Erosion Wind erosion			

Ecosystem service assessment tools (Common International Ecosystem Classification Tool)

Tool used for assessing Ecosystem Services Assessment Under Restored and Non-Restored Farmland and Pas

NB: This tool has been used separately under farmland and Pastureland based on the land use specific. 5 Like

ES based on the potential of each service

			Restored		Non restored	
			Men	Women	Men	Women
Provisioning	Nutrition	Cultivated crops for food				
		Livestock products (fodder)				
		Wild animal products				
		Wild plants for food				
		Wild plants for medicine				
		Water suply				
	Materials	Plant products for subsistence				
		Plant products for sale				
		Material for agricultural use				
		Water for non-drinking				
	Energy	Fuelwood				
		Animal-based energy source				
Regulating	Mediation	Waste bioremediation				
		Air Pollution				

		Erosion control				
		Water flow				
		Storm protection				
	Maintenance	Pollination				
		Biodiversity				
		Pest & disease control				
		Soil formation				
		Global climate				
		Micro-climate				
Cultural	Physical & spiritual	Leisure time				
		Education				
		Future preservation				

Legends:

Legends

0 = no effect, 1 = low effect, 2 = medium effect, 3 = relevant effect, 4 = very relevant effect and 5 = highly relevant effect.

NB: The same tool has been used to for Pastureland.

Tools used to assessment qualitative information from each ES under farmland and Pastureland.

Approvisionnement	Nutrition	1	Cultures cultivées	....
		2	Produits de l'élevage	....
		3	Produits d'animaux sauvages	....
		4	Plantes sauvages pour l'alimentation	....
		5	Plantes sauvages pour la médecine	....
		6	De l'eau à boire	....
	Materiaux	7	Produits végétaux de subsistance	....
		8	Produits végétaux à vendre	....
		9	Matériel à usage agricole	....
		10	Eau non potable	....

	Energies	11	Bois de chauffage	....
		12	Source d'énergie d'origine animale	....
		13	Énergie mécanique d'origine animale	....
				....
Regulation	Mediation	14	Bio-remédiation des déchets	....
		15	C-séquestration / pollution de l'air	....
		16	Médiation odeur/bruit	....
		17	Contrôle de l'érosion hydrique	....
		18	L'écoulement de l'eau	....
		19	Protection contre les inondations	....
		20	Protection contre les tempêtes	....
	Maintenance	21	Pollinisation	....
		22	Biodiversité	....
		23	Lutte contre les ravageurs et les maladies	....
		24	Formation du sol	....
		25	Global climate	....
		26	Microclimat	....
				....
Culture	Physique et spirituel	27	Temps libre	....
		28	Education	....
		29	Site patrimonial / culturel	....
		30	Esthétique	....
		31	Symbole religieux	....
		32	Future preservation	....
			Préservation future	....

Tool used for Germaination day assessement

Germination day and suvi				
Species	Sandy	Clayed	Clayed-Sandy	Lateritic
Cram-Cram dans Demi-Lune	5	10	8	15
Mucuna dans Demi-Lune	4	6	6	7
Bracharia dans Demi-Lune	3	5	5	6
Herbe a éléphant dans Demi-Lune	3	4	5	5
Cram-Cram en tapis Herbacé	5	6	6	6
Eragrotus en tapis Herbacé	3	4	4	5
Eragrotus ans Demi-Lune	3	3	4	5
Herbe a éléphant en tapis Herbacé	4	5	4	4
Adropogon	3	3	3	3

Species prioritization Tool with stockholders

Example of prioritization of promising climate smart agronomic practices at Bompari, Lawra district, Ghana.

Technology	Criteria (score from 0 (none/not at all) to 10 (excellent/highly suitable))							
	Food security		Adaptation	Mitigation	Others			
	Productivity	Income	Adaptation	Mitigation	Up-scaling	Economic viability	Ecosystem services	Total score
Tie ridges	10	8	9	8	10	9	7	61
Crop rotation	9	10	8	7	10	8	7	59
Earth-Bunding	9	8	7	7	9	9	8	57
Intercropping	9	9	8	7	10	7	5	55
Improved varieties	9	9	10	8	5	6	7	54
Crop residue retention	8	8	9	6	10	5	7	53
Composting	9	5	10	8	6	8	5	51
Minimum tillage	8	7	8	6	7	7	6	49
Mulching	5	6	7	7	8	7	7	47

Prioritized species experimentation

Experimentation processes

Agrisilvicult uralSystem under restoration

Business based platform under restoration