

UNIVERSITÀ CATTOLICA DEL SACRO CUORE

Sede di Piacenza

Dottorato di ricerca per il Sistema Agro-alimentare
Ph.D. in Agro-Food System

Cycle XXXVIII
Geography, Topography and Cartography



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Mitigating land conflicts and enhancing the adaptive capacities of agrarian landscapes through improved participatory mapping in Mbalmayo, CAMEROON

Coordinator:
Prof. Paolo Ajmone Marsan

Candidate:
Marcel Loyd MINKA
Matriculation n: **5215076**

Academic Year 2024/2025

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Dedication

I dedicate this PhD thesis to my unborn children, to my wonderful wife, and to my amazing mother. My wife Paola MINKA, from the first day we met in 2020, has always believed in me and has always encouraged me to get a PhD admission in an international university, and the completion of this PhD thesis is very significant to her. I love you, my dear wife. And ever since I started this PhD journey in 2022, my wife has always encouraged me to finish writing this PhD on time. For my mother Ms. Marie-Paul NGUIMBOUS, I would not be here writing this PhD thesis if she did not pay my tuition fees from primary school through high school up till my undergraduate and graduate studies at the Catholic University of Central Africa. My mother always told me that the "key to becoming a leader is education." As the proverb says, all readers are leaders. So, my mother believed that the best way for me to succeed was to get a good education. And during my high school in 2008, my mother brought me to church and taught me how to believe and trust in GOD. And from that day, GOD has always been faithful. I want to give a big thanks to both my wife and my mother for believing in me, even when nobody believed in me. This PhD thesis is proof that resilience, hard work, and prayers are the keys to every accomplishment. To my unborn children, Gabrielle Jireh and Yannis Emmanuel, I dedicate this PhD to you, and by the Grace of GOD, I promise you that you will receive the best education, care, love, and guidance in the world.

Declaration

I, Marcel Loyd MINKA, I do hereby declare that the work contained in this thesis is entirely my own work, except where it is attributed to other authors or sources (citations). This work has never been submitted for a degree in any other university

Dated at.....this.....day of 2026

Signed.....

The following amended thesis declaration is recommended to meet the requirements of electronic publication of PhD theses.

I Marcel Loyd MINKA hereby certify that this thesis, which is approximately 60,032 words in length, has been written by me, that it is the record of work carried out by me and that it has never been submitted in any previous application for a higher degree.

I was admitted as an executive PhD student in November, 2022 and as a candidate for the degree of PhD Agri-food Systems in 2022; the higher degree study for which this is record was carried out in the Università Cattolica del Sacro Cuore between 2022 to 2025.

Date Signature of candidate

I hereby certify that the candidate has fulfilled the conditions of the Resolution and Regulations appropriate for the degree of PhD in Agri-food Systems at the Università Cattolica del Sacro Cuore and that the candidate is qualified to submit this thesis in application for that degree.

Date Signature of supervisor

This serves as an agreed request by candidate and supervisor regarding the electronic submission of this thesis to the Agri system Student Service Office.

Acronyms and Abbreviations

AC – Adaptive Capacity

AET – Access and Entitlements Theory

CAS – Complex Adaptive Systems

DA2 – Data Analysis 2

DFS – Diversified Farming Systems

DRR – Disaster Risk Reduction

DSM – Digital Surface Model

ENEF – École Nationale des Eaux et Forêts

EDA – Euclidean Distance Analysis

FN – Farthest Neighbor

IPCC – Intergovernmental Panel on Climate Change

MLT – Measure Line Tool

NN – Nearest Neighbor

NTFP – Non-Timber Forest Products

QGIS – Quantum Geographic Information System

PM – Participatory Mapping

PRA – Participatory Rural Appraisal

PhD – Doctor of Philosophy

GIS – Geographic Information Systems

GNSS – Global Navigation Satellite System

SES – Social Ecological Systems

SLA – Sustainable Livelihoods Approach

RGB – Red-Green-Blue

RQ – Research Question

TAT – Transformational Adaptation Theory

UAV – Unmanned Aerial Vehicle

UN – United Nations

UTM – Universal Transverse Mercator

Abstract

Many agrarian landscapes in the world are experiencing exacerbated disturbances driven by climate change, such as increases in flooding, wildfires, and droughts, as well as warming river temperatures, with some of these extreme events being the most severe and intense (Palmer & Filoso, 2009). Resilience to climate change considers not just preventing disturbances in existing planning systems, but also concerns strengthening landscapes abilities in terms of building strong landmarks (Li, Degener, Gaudreau, Li, & Kappas, 2016) and strong structures of land management to increase its adaptive capacity (Eraydın & Taşan-Kok, 2013). In many customary or informal systems, land boundaries are defined by natural features (landmarks) such as creeks, rivers, slopes, swamps, plains, trees, bridges, grasses, un-paved roads, houses, hills, and mountains. These are the landmarks that we analyzed in this PhD research. The demarcation of land boundaries by these landmarks helps to secure the land rights of farmers and pastoralists. All these landmarks are found in the agrarian landscapes of Oyack, Ngalat, and Mbockulu in Mbalmayo. The destruction of these landmarks by climate disasters will destroy the markers and boundaries that delimit the various land parcels owned by farmers and pastoralists. The absence of these markers and boundary delimitations for each land parcel will cause more land conflicts. So, it becomes very urgent to protect these landmarks against climate disasters. The protection and preservation of these landmarks will not only help reduce land conflicts, but it will also help build the adaptive capacities of these landscapes, thereby rendering them resilient to climate hazards.

A landmark is a physical feature that stands out and helps people identify, navigate, or remember a place. The core problem which this PhD thesis addresses is: “the lack of efficient and accurate research frameworks that assess the various geographical features (landmarks) which helps to enhance adaptive capacity in an agrarian landscape. The theoretical frameworks which we examined in this PhD research were: the Resilience Theory (social-ecological systems theory); the Access and Entitlements Theory; the Transformational Adaptation Theory (TAT); and the Vulnerability Theory. With regards to our research methods, we used mixed methods research. This mixed methods research combines the collection and analysis of both quantitative data (numbers, measurements, surveys, statistics), and qualitative data (interviews, observations, open-ended responses). To collect quantitative data, we used survey questionnaires, drone mapping, and GPS/GNSS surveying. To collect qualitative data, we conducted interviews, and did participatory sketch mapping. The data we collected, provided us with some valuable information which we analyzed to establish relevant frameworks and determine key findings. To analyze these qualitative data we used symbol

recognition, visual analysis and the DSR Knowledge Contribution Framework (Gregor & Hevner, 2013). The DSR Knowledge Contribution Framework is derived from Design Science Research (DSR) (Visser, 2017) and is used to describe the type of knowledge that a design science study provides. The knowledge this PhD thesis provides is based on how agrarian landscapes function, adapt, and endure under environmental and human pressures. More so, to analyze our quantitative data, we used Cross-tabulation analysis, Landmarks Perceptions analysis, Spatial analysis, Euclidean Distance Analysis, Buffering and Proximity Analysis. Landmark Perceptions Analysis investigates how people detect, understand, recall, and emotionally respond to landmarks in a location. The Euclidean distance analysis was used to calculate the straight-line distance between two landmarks found on the drone maps. To calculate these distances, we used the following formula: $Distance = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$ (Lay, 2015). With this analysis, we determined the proximity (farthest and nearest distances) between the landmarks.

Our results and findings show that the four hypotheses of our research have been addressed. These four hypotheses are that: each participatory mapping method has a distinctive contribution; there exist many spatial relationships between farmlands and hydrographies; sketch maps have much potential in helping to perceive the role played by landmarks in enhancing adaptive capacities; and drone mapping data have a well-defined scope that illustrates the contribution of landmarks in reducing land conflicts and building resilience to climate change. The results of our research gave rise to four frameworks, each of which addressed one of the above hypothesis. These frameworks are : a methodological framework that shows the distinctive contributions of participatory mapping data collection methods ; a conceptual framework that determines the spatial relationships which exist between farmlands and hydrographies; an analytical framework that shows how landmarks enhance adaptive capacities through the lens of sketch mapping; and an empirical framework illustrating the landmarks which are vital for securing land tenure and building resilience to climate change through the scope of drone data. These four frameworks are new to the scientific discipline of Landscape Sustainability and Resilience Studies (LSRS). The novelty of this PhD thesis is that it provides a comprehensive and high-level grasp of environmental science, land use planning, social processes, and decision making. This high-level grasp makes it important for academics, policy and non-governmental organizations. In summary, our research teaches that the best way for landscapes to adapt to change (climate, economic pressure, or land conflicts) is when people's understanding of landmarks and land mapping improve meaningfully.

CHAPTER 1 : GENERAL INTRODUCTION

I. PROBLEM STATEMENT, JUSTIFICATION AND RELEVANCE

A. Problem Statement

The core problem which this PhD thesis addresses is: “the lack of efficient and accurate research frameworks that assess the various landscape structures and natural features (landmarks) which helps to enhance adaptive capacity in an agrarian landscape.” Appart from this core problem, there are four sub problems which had been addressed by our four research studies (field studies) in chapters 2, 3, 4 and 5. These four sub problems are:

- The lack of a methodological frameworks which helps to determine the distinctive contributions of participatory mapping methods in identifying land conflict prone areas in agrarian landscapes. [1st Research Study]
- The lack of a conceptual Framework that will describe the spatial relationships which exist between farmlands and hydrographies in agrarian landscapes. [2nd Research Study]
- The lack of an analytical Framework that will investigate the role of landmark features in enhancing the adaptive capacities of farmers, rural dwellers, peasants, and pastoralists. [3rd & 4th Research Study]
- The lack of an empirical Framework showing the landmark features which can be used to improve adaptive capacity in an agrarian landscape. [3rd & 4th Research Study]

This core problem and its four sub problems affect a category of people, and these people are the people who live in agrarian landscapes. These people are typically those whose income and livelihoods are closely tied to agriculture and rural life. Here's a breakdown of who they are :

a- Farmers: Amongst these farmers we have:

- Small-scale farmers: People who own or lease small plots of land to grow crops or raise animals, often for local consumption or subsistence.
- Commercial farmers: People who operate larger farms aimed at producing crops or livestock for sale in national or international markets.

- b- Agricultural Laborers:** In Cameroon, these are people who work on farms but do not own land. They may be: seasonal or migrant workers, permanent farmhands, or wage laborers.
- c- Rural Families and Villagers:** These are families who may not farm directly but are part of the rural community. They often engage in local trade, handicrafts, or animal husbandry. They may rely on the agricultural economy for employment and food.
- d- Local Service Providers:** Here are people who provide essential services to the agrarian community. In Cameroon, these local providers are: blacksmiths, carpenters, millers, teachers, nurses, shopkeepers, local traders and transporters.
- e- Indigenous or Traditional Communities:** In the agrarian landscapes of Cameroon, indigenous peoples or traditional communities have lived for generations, often practicing sustainable farming or agroforestry adapted to their local environments.

B. Justification & Relevance

There are six reasons which justifies and explains why it is important to address the above core problem of this PhD research. Each of these six justifications touches or handles a specific aspect of climate action and adaptation.

The first justification is about the resilience of rural communities. Addressing the above-mentioned core problem is very important, because the resolution of this problem will give rise to a good framework that will assess vulnerability at a landscape level, model climate risks across various land features, and recommend adaptive strategies like agroforestry, crop diversification, or water retention measures. These measures will therefore improve the resilience of rural communities and agricultural systems, thereby reducing the vulnerabilities of agrarian landscapes to droughts, floods, and changing weather patterns. Novel and innovative frameworks will give rise to a better assessment of vulnerability and adaptive capacity in different agricultural zones (Waseem & Rana, 2025).

The second justification concerns the Global Commitments to Climate Action (the SDGs). Developing effective frameworks that supports global commitments to sustainability and resilience is a good means to solve the core problem of this PhD research. The four frameworks which we will develop in this PhD research will

directly support the following SDGs: SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land). The advantage of these four frameworks is that they can be replicated across regions and contribute to climate-smart agriculture and land restoration.

The third justification focuses Adaptive Capacity to Climate Change. The development of accurate frameworks which will be used to identify vulnerable areas and suitable interventions (like agroforestry, contour farming, or water harvesting) will address the core problem of our PhD thesis. This is because the core problem of our PhD thesis is the lack of efficient and accurate frameworks that assess the role of landscape structures (landmarks) in enhancing the adaptive capacity of agrarian landscape. After solving this problem, the direct outcome will be that farmers and land managers will proactively adapt to extreme weather, droughts, floods, and shifting growing seasons.

The fourth justification concerns updated and informed Land-Use Planning in agrarian landscapes. The analytical framework developed in this PhD thesis will enable the creation of high-resolution spatial data and landscape analysis which would guide decisions on where to plant, conserve, or build infrastructure. These high-resolution spatial data and landscape analysis will directly lead to a sustainable land use thereby reducing degradation, erosion, and biodiversity loss.

The fifth justification deals with Data-Driven Agricultural Policy and Investment, whereby the frameworks we developed in this PhD thesis provides reliable data for local, regional, and national policymakers. These frameworks will have a great impact on agricultural Policies and Investments because the data we used facilitates evidence-based policies which are created for subsidies, insurance, and climate adaptation strategies.

Finally, it is very important to address the above core problem of this PhD research, because addressing this core problem will strengthen the Integration of indigenous and local knowledge in agrarian landscapes (Asare, Diko, Frimpong, Abunyewah, & Mensah, 2025). Our PhD thesis will develop frameworks that include participatory and spatially explicit methods that integrates traditional land-use knowledge. Through these frameworks indigenous and local communities will be able to put in place appropriate and locally accepted adaptation practices that will enhance the adaptive capacity of their agrarian landscapes.

II. RESEARCH GOAL, OBJECTIVES AND QUESTIONS

The overarching goal of this PhD research is to diagnose the extent to which sketch and drone mapping can help determine the role played by landmarks in mitigating land conflicts and enhancing the adaptive capacities of agrarian landscapes. This goal can be broken down into the following specific objectives:

- 1- To investigate the unique contributions of participatory mapping data collection methods in identifying land conflict prone areas in an agrarian landscape.
- 2- To analyze the kind of spatial connections which exist between farmlands and hydrographies in agrarian landscapes.
- 3- To develop a structure analysis which will help to determine the extent to which participatory mapping can help perceive and understand the contribution of landmarks in strengthening the adaptive capacities of agrarian landscapes.
- 4- To evaluate the extent to which drone mapping data can help illustrate and determine the contribution of landmarks in strengthening the adaptive capacities of agrarian landscapes.

Based on these objectives, the key research questions guiding this PhD thesis are:

RQ1: What are the distinctive contributions of participatory mapping data collection methods in identifying land conflict prone areas in an agrarian landscape? [1st Research Study]

RQ2: What type of spatial relationships exist between farmlands and hydrographies in agrarian landscapes? [2nd Research Study]

RQ3: How and to what extend can participatory mapping help perceive and understand the role played by landmarks in strengthening the adaptive capacities of agrarian landscapes? [3rd Research Study]

RQ4: How and to what extend can drone mapping help illustrate and determine the role played by landmarks in strengthening the adaptive capacities of agrarian landscapes? [4th Research Study]

III. RESEARCH APPROACH AND RESEARCH DESIGN

In this section, we will look at the research approach (McCarthy, Gupta, & Barker, 2025) (1) and the research design (2) which we used to write and conduct the four research studies of our PhD thesis.

A. Research approach

The research approach which we used here in our PhD thesis is an abductive research approach, which combines both inductive and deductive research methods. Our PhD thesis is made up of four research studies, each of them representing chapters 2, 3, 4, & 5. In the first and second research study, we used the inductive research method. While in the third and fourth research study, we used the deductive research method.

1. Abductive research approach

The abductive research approach is a methodological framework used in qualitative and mixed-methods research that combines elements of inductive and deductive reasoning. It is particularly useful when exploring complex and real-world phenomena where existing theories do not fully explain observations.

Abduction is a form of logical inference that starts with an observation or set of observations and seeks the most likely explanation. It was originally introduced by the philosopher Charles Sanders Peirce (Campos, 2011). In research, the abductive approach involves: observing an unexpected or puzzling phenomenon; seeking the best possible explanation by iteratively moving between theory and data; and developing or modifying theoretical frameworks to account for the observed reality.

Peirce introduced abduction as a logical operation that generates new explanatory ideas, and it is unique among inferences in that it introduces novel hypotheses. As he famously puts it: "Abduction is the process of forming explanatory hypotheses. It is the only logical operation which introduces any new idea" (McAuliffe, 2015)

a. Inductive research method

The inductive research approach is a method of reasoning and inquiry in which researchers move from specific observations to broader generalizations and theories. It's commonly used in qualitative research, where patterns, themes, and categories emerge from the data rather than being imposed (Priddle, 2010) by the researcher ahead of time (Thomas, 2006). To apply this inductive Research method, our chapters 2 & 3 followed a four step by step process, which comprises of:

Step 1 – Observation: During this phase, we collected detailed data through interviews, field notes, documents. This first step was the same for chapter 2 & 3.

Step 2 – Pattern Recognition: Here, we identify trends, similarities, or recurring themes in each study, in order to group them in categories.

Step 3 – Categorization: This phase was very important because it facilitated the answering of the research question in each chapter. Here we grouped similar data into categories or themes.

Step 4 – Theory Development: Based on the data we collected in step one and with the categorization which we did in step 3, we later on proceeded with the formulation of concepts, frameworks, and theories. This formulation also helped in answering the research questions (Maluleke, 2025).

b. Deductive research method

The deductive research approach is a method of conducting research that starts with a theory, then it designs a methodology (data collection and analysis) to test the validation of this theory. It is the opposite of the inductive approach, which begins with observations and then builds up to a theory. Deductive research moves from the general to the specific. It begins with a theory or general statement and tests whether this theory applies in specific instances. The deductive research method is : Quantitative in nature, theory-driven, uses structured methodology, and it usually focuses on testing rather than developing theories. To apply this deductive Research method, our chapters 4 & 5 followed a four step by step process, which comprises of:

Step 1 – Theory Development: This phase was developed based on existing knowledge or literature.

Step 2 – Formulation of Hypothesis: Here we formulated the hypothesis. Our hypotheses are testable predictions derived from the theory.

Step 3 – Research Design and Data Collection: This is a crucial phase, as it concerns the collection of data according to the research designs identified in our PhD thesis.

Step 4 – Data Analysis: To obtain results, we analyzed the data we collected in the previous phase. To analyze this data, we used some statistical and spatial tools to test the hypotheses.

Step 5 – Confirmation or Rejection of Hypothesis: The confirmation or rejection of our hypothesis means that, if data supports the hypothesis, the theory is strengthened (valid); if not, this theory may need to be revised.

These five steps of deductive research are repeated, and researchers may need to return to earlier steps if they find new information or new ways of looking at things. Inductive research and deductive research are two different types of research approaches with different starting points, goals, methods, and ways of looking at the data (Kumar & Ujire, 2024). Inductive research uses specific observations and patterns to come up with new theories. On the other hand, deductive research starts with a theory or hypothesis and tests it through data analysis. Both approaches have advantages as well as disadvantages and can be used in different types of research depending on the question and goals (Kumar & Ujire, 2024).

B. Research design

In this PhD, we used four types of research designs, which are correlational, case study, cross-sectional, and Mixed-Method Design. These four designs are been illustrated below and constituted the basis of our data collection process. Each of these designs was separately used in each chapter, to help us guide the study in order to answer every research question.

1. Correlational Design

A correlational design is a type of non-experimental research design used to determine the relationship between two or more variables. Unlike experimental designs, correlational studies do not involve manipulation of variables. Here, the researchers simply observe and measure variables as they naturally occur. In Correlational Design, there are: no manipulation of variables (no independent nor dependent variables in the experimental sense); and no random assignment or control groups (Cherry, 2006). Correlational Design focuses on measuring associations or relationships between variables, often used when experiments are unethical, impractical, or impossible. In few words, we can say that correlational design examines relationships between variables (Cherry, 2006). This was the research design we used to carry out the 2nd research study on spatial relations which is found in chapter 3 of this PhD thesis.

2. Case Study Design

Case study research design is a qualitative research approach used to explore complex phenomena within their real-life contexts. This is an in-depth study of a single subject or group (Eisenhardt, 1989). As an in-depth study, it analyses a particular research problem rather than a comprehensive comparative study. It is often used to narrow down a very broad field of research into one or a few examples. This research design is useful

for testing if a specific theory or model actually applies to a phenomenon in the real world. It is a useful design when not much is known about an issue or phenomenon. This was the research design (Nkabinde, 2024) we used to carry out the 1st research study on land conflicts mitigation, which is found in chapter 2 of this PhD thesis.

4. Cross-sectional

A cross-sectional research design is a type of observational study that involves analyzing data from a population, or a representative subset, at one specific point in time. It is commonly used in fields like psychology, sociology, public health, and education to assess prevalence, relationships between variables, or differences between groups (Kesmodel, 2018). This research design is good at examining data at one specific point in time. Here data is collected once (not over a period of time), to understand what is happening now, not how things change over time. It typically involves multiple subjects or groups, to explore multiples variables and compare subgroups, and can be either used for quantitative research, qualitative research, or both (Kesmodel, 2018). This was the research design we used to carry out the 3rd research study on enhancing adaptive capacities through participatory sketch mapping, which is found in chapter 4 of this PhD thesis.

5. Mixed-Method Design

Mixed-method research design is a type of research methodology that combines both quantitative and qualitative approaches within a single study. The goal is to provide a more comprehensive understanding of a research problem (Johnson, Onwuegbuzie, & Turner, 2007). This research design involves the collection, analysis, and integration of both quantitative data (e.g., numbers, statistics) and qualitative data (e.g., interviews, open-ended survey responses) within one study or within one research program. This design analyses and addresses research problems that requires: a real-life assessment or multi-level perspectives; and uses both quantitative & qualitative methods to address this research problem. Also, with this design, the strengths of one method can be used to overcome the weaknesses of another method (Johnson, Onwuegbuzie, & Turner, 2007). The advantage of this design is that a more complex problem can be investigated by using several methods. This was the research design we used to carry out the 4th research study on improving adaptive capacities through drone mapping, which is found in chapter 5 of this PhD thesis.

IV. STUDY AREA

Mbalmayo is a city (town) in Cameroon's Center region, inside the regional department of Nyong-et-So'o. The most recent census, which was conducted in the previous four years, indicates that Mbalmayo has 125,616 people living there (Liliane et al., 2022). Mbalmayo is characterized by the presence of the Nyong River which is halfway between Ebolowa and Yaoundé.

A. Biophysiographic Components of Mbalmayo

Firstly, the topography and geology of Mbalmayo is composed of its elevation and its soil. The elevation of Mbalmayo sits at approximately 335 m above sea level. The surrounding terrain varies between about 626 m and 760 m. The soils of Mbalmayo are typically ferralitic, acidic, permeable, and fertile, originating from schistose parent rocks. Their low-lying areas are hydromorphic with high water tables (Essombo Essombo, Seutche, Goune, Ekani, & Ben-Bolie, 2023). Regarding its hydrography, there is one major river in Mbalmayo, which is the Nyong River. This river that runs through Mbalmayo is approximately 690 km and is navigable from Abong-Mbang to Mbalmayo, with rapids at Mbalmayo and Déhané (Essombo Essombo, Seutche, Goune, Ekani, & Ben-Bolie, 2023). The river serves multiple roles, such as: transportation route, ecological corridor, and resource base for fishing and local economies. It's river basin in the broader Centre Region lies on the South Cameroon Plateau featuring numerous rivers with equatorial flow regimes, high water during the wet season, and low in the dry. The Nyong in particular is seasonally navigable and does not drain into the Sanaga river (Essombo Essombo, Seutche, Goune, Ekani, & Ben-Bolie, 2023). The agrarian landscapes (countryside) of Mbalmayo (Oyack, Ngalat and Mbockulu) are found within a couple of miles Mbalmayo and are composed of a mix of cropland (46%), grassland (22%), trees (19%), and shrubs (13%). Mbalmayo lie between the top Pan-African Mobile Zones (Owona, et al., 2011).

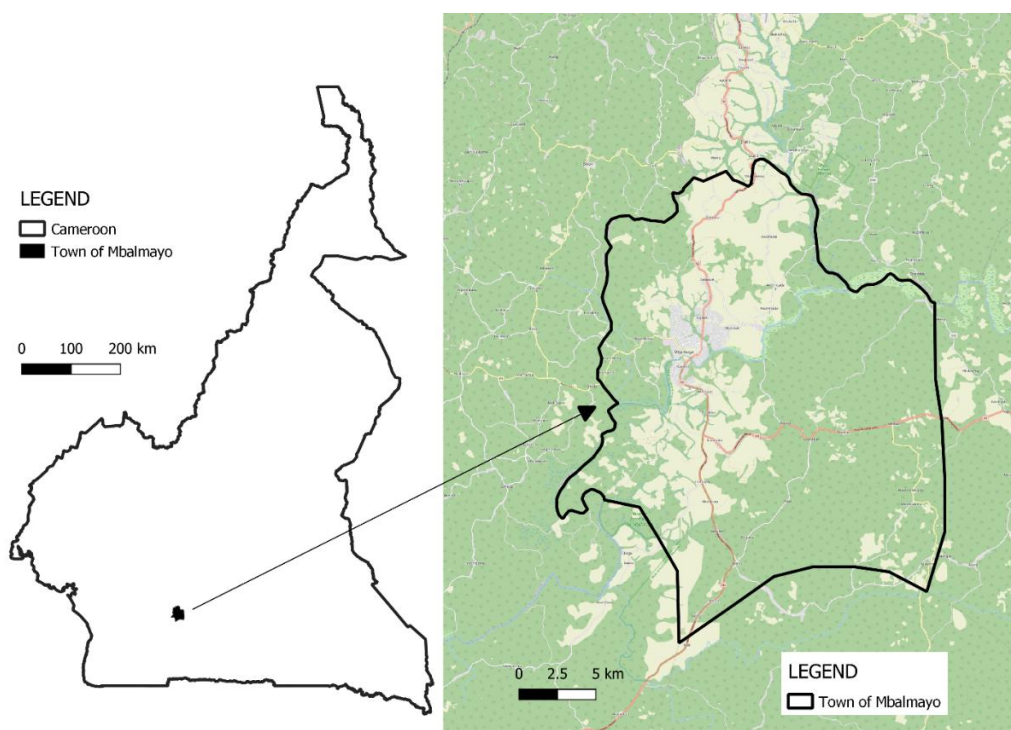


Figure 1 : *The geographical location of Mbalmayo on the Map of CAMEROON*

B. Climate Overview: Mbalmayo, Cameroon

Located in the humid equatorial zone of South-Cameroon's plateau, Mbalmayo experiences a typical Guinea-type equatorial climate: known to be consistently warm and humid, with distinct dry and wet seasons alternating throughout the year. Due to the fact that Mbalmayo falls under an equatorial climate, it receives between 1,600 and 1,700 mm of rainfall annually. Average temperatures range from 19–28 °C (Fang, et al., 2022). With regards to vegetation, Mbalmayo area lies within a bioclimatic zone characterized by dense, humid evergreen to weakly deciduous forests (Fang, et al., 2022). Every day in May, Mbalmayo has temperatures ranging from a high of 81°F (27°C) to a low of 70°F (21°C) (Zepner et al., 2021) and some could describe it as delightfully warm, humid, but cold (WMO, 2024).

C. Governance System of Mbalmayo

Mbalmayo is the capital of the Nyong-et-So'o division, situated in Cameroon's Centre Region, and is governed under a decentralized state framework with authority from the Ministry of Territorial Administration. The region is overseen by a governor, and each division (such as Nyong-et-So'o) is managed by a Divisional Officer

appointed by the Head of State (Monteh, 2021). At the local level, Mbalmayo is administered by the Mbalmayo Municipal Council. The mayor, currently Dieudonné Zang Mba Obele, has overseen initiatives that recently earned the commune the Feicom national award for innovative infrastructure management (notably building social facilities from recycled plastic bottles) (Monteh, 2021).

Traditionally, Mbalmayo is structured and composed of local authorities (e.g., patriarchs, community heads) among Beti and other groups, though their administrative power today is largely symbolic. The major tribe and ethnic group found in Mbalmayo is the Beti tribe and ethnic group (Mediebou & Gaspard, 2022). Civic engagement in governance has been encouraged; for instance, the UN Women held a "Café Genre (Gender Coffee) Forum" in Mbalmayo to support women's participation and leadership in local governance. Mbalmayo also serves as an active hub for civil society engagement, including workshops to increase accountability in climate policy and youth involvement in sustainable forestry management (Mediebou & Gaspard, 2022).

D. Socioeconomic Profile of Mbalmayo

Mbalmayo's primary economic activities include agriculture and forestry, and there is a plywood plant that is powered by electricity generated by the Edea Hydroelectric Power Station (Mounjouenpou et al., 2014). Mbalmayo is the epicenter of agricultural activity in Cameroon's central area, as agriculture is the primary source of income for its residents. Timber exploration, among other economic activities, is an important source of revenue for Mbalmayo and Cameroon in general (Mounjouenpou et al., 2014). One of Cameroon's oldest forest reserves is in Mbalmayo, which is also the most developed subdistrict along the main route that runs along the border of Cameroon, Gabon, and Central Africa between Yaoundé and Kye-ossi (Mounjouenpou et al., 2014). Subsistence farming and shifting slash-and-burn techniques are the primary agricultural methods used in Mbalmayo. Other cash crops grown there include palm oil, palm kernel oil, coffee, and cocoa (Liliane et al., 2022).

With regards to demographics, as of 2022, Mbalmayo had approximately 125,616 inhabitants, forming a diverse, largely Beti-origin community enriched by migrants from various regions of Cameroon. The urban commune of Mbalmayo spans about 650 km², comprising urban centers, 2 groupings, and 28 villages, with over 70% of its population residing in urban areas (Liliane et al., 2022). The major economic activities in Mbalmayo are agriculture and forestry. These two activities are the economic backbone, centered on timber

processing, cocoa, palm oil, and cocoa production. Mbalmayo has a plywood factory powered by energy from the Edea Hydroelectric Power Station. The town also supports mining, with a large stone quarry supplying construction materials for nearby Yaoundé (Monteh, 2021). The industrial activities in Mbalmayo extends to the bamboo and rattan sectors. Through an MoU between Cameroon's Ministry of Small and Medium Size Enterprises (SME) and INBAR, Mbalmayo aims to become a hub for bamboo and rattan crafts, equipping artisans, digitizing production, and structuring the value chain. Mbalmayo hosts the École Nationale des Eaux et Forêts (ENEF), a prestigious forestry and environmental training institution founded in 1949, as well as a university-affiliated Wood Technology Institute (Mediebou & Gaspard, 2022). Also, in Mbalmayo, Urban planning has begun incorporating GIS tools to restructure central urban areas, roads, railways, built environments, and waterways, addressing issues like informal settlements and flooding vulnerability. Basic infrastructure challenges are found in the rural communities around Mbalmayo, where fewer than half of the population have access to clean drinking water, increasing susceptibility to waterborne diseases. Additionally, HIV/AIDS remains a significant public health burden, with many children orphaned by the disease (Mediebou & Gaspard, 2022).

E. Overview of the Land System in Mbalmayo

In Cameroon, including areas like Mbalmayo, two main land tenure systems coexist: customary law (based on traditional, informal agreements) and statutory law (formal, state-recognized land titles). Customary tenure tends to be more accessible and widely used, given the complexity and cost of formal land registration. However, without a formal land title, land secured through customary agreements can be vulnerable to expropriation and offers limited legal protection (Belaunde, et al., 2010). Pertaining to urbanization and informal expansion, Mbalmayo has experienced unplanned urban growth, particularly with neighborhoods expanding into flood-prone and swampy areas. GIS tools and remote sensing have been used (Kent & Doug, 2023) to create cadastral "land maps" to support restructuring efforts and inform better urban planning in the city center (Mevoa, Tohozin, & Mouhamadou, 2015). Regarding the Environmental Characteristics, Mbalmayo lies about 45 km south-southeast of Yaoundé, featuring ferrallitic and acid-rich soils derived from schistose bedrock. These soils are very permeable, enabling groundwater recharge (Essombo Essombo, Seutche, Goune, Ekani, & Ben-Bolie, 2023). Lowland soils (e.g., in Ngalan, Nkolngok) show elevated levels of heavy metals (Cd, Pb, Zn), primarily associated with anthropogenic activities, industrial, agricultural, informal, and roadside contamination (Essombo Essombo, Seutche, Goune, Ekani, & Ben-Bolie, 2023).

The villages and agrarian landscapes of ZAMAKOE, OYACK, NGALAT, and MBOCKULU which we studied in the various chapters of this PhD thesis, are located in the country sides of MBALMAYO inside the Nyong-et-So'o regional department, in the center region of Cameroon, and belongs to the canton BANÉ (Mevoa, Tohozin, & Mouhamadou, 2015). This village of ZAMAKOE has a total population of 968 inhabitants. Among them, 475 are men and 493 are women. In 1963, Zamakoe had 574 inhabitants, but during the 2005 census, the population increased to 968 people (Mevoa, Tohozin, & Mouhamadou, 2015).

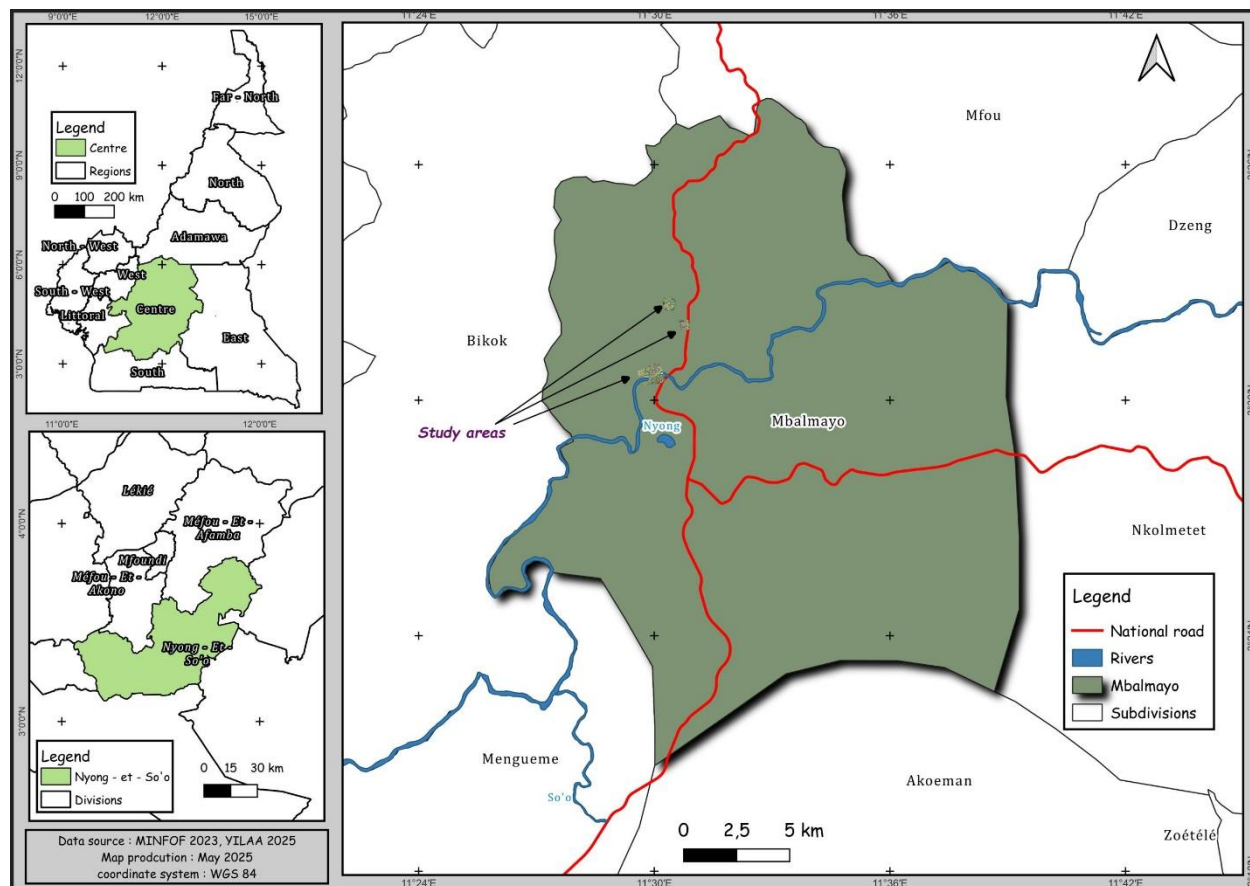


Figure 2 : The Map of Mbalmayo with its natural and man-made features

V. LITERATURE REVIEW AND RELATED WORKS

The purpose of this fifth section is to critically examine the body of literature relevant to the adaptive capacities (Deschamps, 2024) of farmers and pastoralists in agrarian landscapes. This literature review is

structured around: the contextualization of our research (1); the identification of gaps in literature (2); the establishment of the theoretical and methodological frameworks (3); and the justifications of our research questions (4). These four elements make up the four sub-sections which underpin our literature review.

A. Contextualizing our research to determine where it fits within existing literature

The concept of adaptive capacity was first used by Brooks & Adger (2004) in their paper titled « assessing and enhancing adaptive capacity ». According to them, adaptive capacity is a central concept of both vulnerability and adaptation analyses (Adger, 2006). It is defined as the ability of a system to adapt to climate-related hazards by designing and implementing new strategies or by expanding coping capacity to reduce vulnerability to these hazards. Few years after, Eakin and Luers (2006) said in their research that adaptive capacity is determined by human actions and influences both social and biophysical elements of a system (Eakin & Luers, 2006). This argument was supported by Folke et al., 2010 who considers adaptive capacity, as a process that confers resilience, as it is used to encourage new land use decision making in the pursuit of sustainability outcomes (Folke C. , et al., 2010). In this pursuit, adaptive capacity and resilience literature is agnostic to the normativity of property relations (Joseph, 2013).

Adaptive capacity is an important property since it describes a system's capacity to mobilize resources to respond to, recover from, and maintain functions in response to stresses and shocks (Choden, Keenan, & Nitschke, 2020). It portends the positive characteristics of a system which can decrease biophysical and socio-economic vulnerability associated with climate change (Engle N. L., 2011). There has been increased emphasis on governance, management and institutions, making the concept more translatable to decision makers (Choden, Keenan, & Nitschke, 2020). Adaptive capacity however is one of the lesser-researched topics within sustainability science and global change (Birkmann, et al., 2013). Vulnerability and adaptive capacity are increasingly regarded as context and scale-dependent requiring the understanding of the local-scale socio-economic impacts of climate change (Piya, Raihan, & Khan, 2019). The scale-dependent variability of adaptive capacity also needs to be considered for informed decision making (Marzi, Mysiak, & Santato, 2018). This is highlighted by Gupta et al., (2020) who found that adaptive capacity, exposure, sensitivity and vulnerability varied spatially within the Garhwal Himalaya region of India (Choden, Keenan, & Nitschke, 2020). In her study on assessing adaptive capacity to climate change in resource dependent communities, Kunzang Choden (2020) presents a multivariate approach for assessing the adaptive capacity of rural (Choden, Keenan, & Nitschke, 2020), agrarian-based households and communities at local and regional scales to inform the

development of locally relevant and effective adaptation policies and actions (Choden, Keenan, & Nitschke, 2020). Her approach is based on standard indicator-based methods integrated with social surveys and spatial data analyses to develop locally relevant indicators (Choden, Keenan, & Nitschke, 2020).

At its most basic level of definition, adaptive capacity is the capacity of a system to adapt if the original environment of that system changes. At this level it does not exclusively focus on vulnerabilities, as is the case in much of the research that highlights the intersection of climate and livelihood changes (Bohle, Downing, & Watts, 1994). The Intergovernmental Panel on Climate Change (IPCC) refers to adaptive capacity as the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behavior, resources and technologies (Parry, Canziani, Palutikof, van der Linden, & Hanson, 2007). On the other hand, a number of authors developed some systems and solutions which supports and enhances adaptive capacities. Amongst them we have Adam Calo (2020), who developed the Diversified Farming Systems (DFS). This DFS supports and contributes to the enhancement of adaptive capacities in order to confer resilience to agricultural systems. In his paper, he argues that a framework for DFS can efficiently enhance adaptive capacity only when adequately combined with the role played by farmland tenure in shaping food systems at both internally coherent and socially redistributive levels (Calo, 2020). Diversified Farming Systems (DFS) refers to agricultural practices that integrate multiple crops, livestock, and management strategies to enhance biodiversity, ecological resilience, and food system sustainability. These systems differ with monoculture or industrial farming by emphasizing diversity at multiple levels (Calo, 2020). Diversified Farming Systems (DFS) enhance adaptive capacities by increasing the ability of agricultural systems, communities, and ecosystems to respond to and recover from various stresses (Nyong, 2025), like climate change, market shocks, pests, and diseases (Calo, 2020).

The adaptive capacity of farmers is thus a function of farmers' perceptions and experience on signals of environmental change in relation to other stressors and opportunities they face and risk, (probability of undesirable outcomes, given the sensitivity of their assets and activities) associated with difficulties to take effective decisions (Eakin, Lemos, & Nelson, 2015). If the adaptive capacity of farmers is a function of farmers' perceptions and experience on the signals of environmental change, it is relevant to conduct research studies that will assess and determine farmer's perceptions on the role played by landmark's in enhancing their adaptive capacities. It was based on this need and relevance that we did this PhD research that assessed the perceptions that farmers and pastoralists have on the role played by landmark's in enhancing their adaptive capacities (Eakin, Lemos, & Nelson, 2015).

Although much of the actor-oriented adaptation literature has focused on the external resources and entitlements of actors in the face of emerging risks (Grothmann & Patt, 2005), a growing body of literature is highlighting the internal, perceptive and cognitive dimensions of adaptation to climate change. Perception and individual cognition has long been recognized as having an important influence on risk behavior (McDaniels, Axelrod, & Slovic, 1996). Recent scholars have expanded theories of cognition and adaptation, focusing on how individuals perceive information sources and internalize knowledge (Frank, Eakin, & López-Carr, 2011), how they perceive their own capacities (i.e., their self-efforts) as agents of change and how effective they believe their adaptation actions can influence the social and institutional context of decision-making (Burch & Robinson, 2007).

To measure the different cognitive dimensions of adaptive capacity, Hallie Eakin et al., (2015) established a series of scale items, designed to assess the respondents' attitudes about risk, change in water availability, entrepreneurship, experimentation, interest in learning, and attitudes about the location and community in which they were farming. These scaled items were closely based on the survey instruments that Marshall et al. (2012) had developed and tested, with some modification for specific language and socio-cultural contexts. Each subset of the scaled items was hypothesized to represent a specific component of capacity (e.g., attitudes about risk, entrepreneurship and experimentation), and they were later on tested for construct validity using Cronbach's Alpha (Hodbod & Eakin, 2015). Critical social scientists have long understood the profound influence that social and political contexts including formal institutional incentives, and available information have on individual perceptions regarding their self-capacities (Avelino & Rotmans, 2009). These perceptions are now being considered as core components of individual motivations in responding to exogenous change (Hodbod & Eakin, 2015).

In perceiving self or individual's capacity, mobility should be considered as a key component. Mobility is a key coping mechanism for pastoralists in dealing with seasonal resource variability and drought. In this context, any restriction on mobility negatively affects adaptive capacities and increase vulnerabilities (BurnSilver et al., 2008; Oba and Lusigi, 1987). Through their analyses Mara J. Goldman & Fernando Riosmena (2013) were able to provide insights about future adaptive capacities in relation to long-term climate change with direct implications for pastoral societies and relevant lessons regarding the adaptive capacities of other resource-dependent communities. Firstly, the Maasai pastoralists have developed new coping mechanisms to deal with climatic variability and extreme events in line with the current restrictions placed on their old coping strategies, namely mobility (Goldman & Riosmena, 2013). Secondly, adaptive capacity, as related to

entitlements and assets that cannot be defined by wealth and poverty alone, is being mobilized at the household level in uneven ways within and across communities. Through a case study looking at responses to a recent drought by Maasai pastoralists in northern Tanzania, Mara J. Goldman & Fernando Riosmena (2013) illustrated how pastoralists are adapting to multiple changes and stressors in addition to a climate change. They demonstrated that adaptive capacity is deployed through the use of new techniques to cope with drought within a changing landscape-institution nexus. This includes the decline in certain customary strategies (e.g., reciprocity), the adoption of new strategies (e.g., purchasing feed) and the transformation of old strategies, such as mobility (Goldman & Riosmena, 2013).

Alternatively, Sam Schramski & Grenville Barnes (2016) measured adaptive capacity as a direct function of a household's diversity of livelihood activities and its health in terms of prevalence of disease. They explore how households demonstrate adaptive capacity in relation to environmental change through varying reliance upon natural resources and linkages with other households. Rhoades and Thompson (1975) suggested two types of adaptive strategies in Andean communities (the tropical Andes). The first type of adaptive strategy is a "generalized type" in which a single population "through agropastoral transhumance directly exploits a series of micro-niches or eco-zones at several altitudinal levels" (Rhoades & Thompson, 1975). And the second type of adaptive strategy is a "specialized type" in which a population "locks themselves into a single zone and specializes in the agricultural or pastoral activities suitable to that altitude, thereby developing elaborated trade relationships with populations in other zones which are also involved in the same specialized production" (Rhoades & Thompson, 1975). Thomas, Winterhalder and McRAE, (1979) making reference to the multiple resource base and the behavioral flexibility of individuals and communities in the tropical Andes, distinguished five major " agricultural response types": rotation, regulations, cooperation, mobility, and storage (Thomas, Winterhalder, & McRae, 1979).

Finally, effective land tenure through DFS plays a great role in supporting and enhancing adaptive capacities. Christoph Stadel (2008) in his research suggest that centering the role of land tenure into the frameworks of DFS for adaptive capacity provides a lens to observe the power relations that mediates any benefits of agricultural diversification (Stadel, 2008). In his understanding of how land tenure functions, the power to decide (and therefore the capacity to adapt) is imbricated in socio-cultural notions of ownership and property (Stadel, 2008). This is how they have been shaped over time, and they are linked to the legal commitments that deliver access or ownership rights over land (Trauger, 2014). With this understanding of tenure, decision-making authorities are constantly gathered to effectively negotiate the existing interests and potential

resources that their communities can benefit from with the current land and environments surrounding them (Meinzen-Dick & Mwangi, 2008).

B. Identifying the gaps in the literature on adaptive capacities

Despite the existence of all of the above-mentioned research studies on adaptive capacity, several gaps in the literature remain. To identify these gaps in the literature, we conducted a critical analysis of all available research to determine what hasn't been studied and what remains unexplored in the field of adaptive capacities. This critical analysis consisted in highlighting what has been studied and identify the unanswered questions or problems that this existing research did not address. These unanswered questions enabled us to clearly determine the current gaps in the field of adaptive capacities.

The first gap we identified was the unanswered question that emerged from the research study conducted by Petersen-Rockney et al. (2020) (Calo, 2020). In their study, Petersen-Rockney et al. (2020) introduces a formulation whereby Diversified Farming Systems (DFS) supports the emergence of an equitable adaptive capacity (Calo, 2020) when applied across a variety of ecological, agronomic, and social dimensions (Petersen-Rockney, et al., 2021). In response to these threats, the authors of this research paper suggest that agricultural systems can move either by simplifying or diversifying pathways in pursuit of resilience (Petersen-Rockney, et al., 2021). The unanswered question that was left out by Petersen-Rockney's research is: does DFS rely on farm landmarks to supports the emergence of an equitable adaptive capacity? If it does, what are the farm landmarks on which DFS rely and what role does these landmarks play? The gap here is the role played by farm landmarks in supporting the emergence of equitable adaptive capacities in DFS.

The second gap we identified came forth due to the unanswered questions that we had from Fraser et al. (2003) in their study on natural resource reliance. Fraser et al. (2003) in their research tried to link natural resource reliance with adaptive capacity. Their empirical research suggests that household poverty is positively associated with reliance on natural resources (Fraser, Mabee, & Slaymaker, 2003). This is especially true for non-timber forest products (NTFP) in rural South Africa. In this paper, they tested the claim that poorer and less adaptive households are more reliant on natural resources (Fraser, Mabee, & Slaymaker, 2003). This concept of natural resource reliance in adaptive capacities developed by Fraser et al. (2003) gave rise to two unanswered questions, which are:

- i- To enhance a community's adaptive capacity, are there other landscape structures on which poorer and less adaptive households can rely other than natural resources?
- ii- Can poorer and less adaptive households be reliant on landmarks rather than natural resources for their adaptive capacities?

The third gap we detected was the unanswered question that emerged from the study conducted by Mara J. Goldman & Fernando Riosmena (2013). Their study examines the fact that the adaptive capacities of households vary within communities, and this variation depends on institutional and landscape changes. Their research presents qualitative and quantitative data from two Maasai communities who were differentially exposed to the devastating effects of the severe drought of 2009 in Northern Tanzania (Goldman & Riosmena, 2013). They showed how rangeland fragmentation combined with the decoupling of institutions and landscapes are affecting pastoralists' ability to cope with drought. Their data highlighted that mobility remains a key coping mechanism for pastoralists to avoid cattle loss during a drought (Goldman & Riosmena, 2013). The above research conducted by Mara J. Goldman & Fernando Riosmena (2013), gave rise to one question that remains unanswered. This unanswered question is: Apart from droughts, are there other devastating climatic events which necessitates the enhancement of a community's adaptive capacity?

Sensitivity and adaptive capacity are largely dominated by social markers that influence dimensions like access to and control over resources, type, and location of livelihood activities, as well as values assigned to different resources and activities. These social markers influence a person's vulnerability and their ability to adapt (Thompson-Hall, Carr, & Pascual, 2016). The literature on vulnerability and adaptation in agrarian landscapes in the global south has tended to focus on one social marker, which is « gender » (Carr & Thompson, 2014), thereby leaving out the other social markers. These left-out social markers created a fourth research gap in literature, which called for our attention. This research gap gave rise to two questions that remains unanswered. These two unanswered questions are :

- i- Apart from gender, what are the other social markers that influence the sensitivity and adaptive capacity of an agrarian landscape?
- ii- How do these social markers influence the control over resources and the implementation of livelihood activities in this agrarian landscape?

But in the Global North (Europe, North America, etc.), a large portion of today's climate change adaptation and development work attempts to capture a broad assemblage of social markers (social characteristics), such as gender, age, income, education level, land ownership, and others related to formal and informal institutions, in their vulnerability analyses (Winowiecki, et al., 2014).

Another gap we discovered emerged as a result of the unanswered question that we had from Freeman (1976) in his study on adaptive capacity in the face of environmental change through reliance upon another household. Throughout his study, Freeman (1976) attempted to determine whether households demonstrate adaptive capacity in the face of environmental change through reliance upon another household external to the community (Hannan & Freeman, 1977). This resilience takes the form of financial exchange, gifts, or information about disease, which he measured using social network analysis. Freeman (1976) used network centrality measurements, namely in-degree and out-degree, to gauge this (Hannan & Freeman, 1977). Their study gave rise to an unanswered question (gap) that our PhD research wants to address. This question is: in the domain of adaptive capacities, can a household rely on another landmark other than houses? In other words, according to Freeman (1976) "households can only demonstrate adaptive capacity in the face of environmental change through reliance upon another household". The unanswered question which came up is: In the domain of adaptive capacities, can a household rely on another landmark other than a house?

Finally, the last gap in literature we found was triggered by the unanswered question we raised from Adam Calo's (2020) research study on resilience thinking and adaptive capacities. He highlighted how resilience thinking focuses on a farmer's individual decision to build adaptive capacities, while abstracting the tenure circumstances in which these decisions are made (Calo, 2020). To articulate his opinion, Adam Calo's (2020) first examined the way resilience thinking and adaptive capacity tend to deemphasize or mischaracterize the role of land tenure (Calo, 2020). The unanswered question we ask ourselves here is: if resilience thinking helps farmers make effective decisions which will improve their adaptive capacities, can spatial perceptions be associated with resilience thinking to improve decision-making?

C. The theoretical and methodological foundations that underpins adaptive capacity

Adaptive capacity refers to the ability of a system, community, or individual to adjust to potential damage, take advantage of opportunities, or respond to consequences (Chand, et al., 2024). Several fundamental theories and frameworks for conceptualizing and measuring adaptive capacity have arisen in relation to

climate change, social-ecological systems, development, and disaster risk reduction (Ro, 2021). Below are some significant theories and frameworks related to adaptive capacity:

1. Resilience Theory (Social-Ecological Systems Theory)

According to this theory, adaptive capacity is a component of resilience because it strengthens the ability of a system to absorb disturbances while undergoing change. Resilience theory examines how systems, especially complex systems like adaptive systems (ecosystems and societies) respond to shocks, disturbances, or changes without collapsing or undergoing fundamental shifts (Holling, 1973). This theory applies to social-ecological systems (SES), which are interdependent systems composed of humans (social systems) and nature (ecological systems) (Holling, 1973). This theory was developed by three scholars: C.S. Holling; Brian Walker ; and Fikret Berkes.

Resilience Theory has four core concepts, which fall into two types. These four concepts are: the absorption of disturbances; self-organization ; Learn and adapt ; and maintaining identity and functions (Walker, Holling, Carpenter, & Kinzig, 2004). The two types are: "*Engineering resilience*", (Fekete & Fiedrich, 2018) which refers to how quickly a system returns to equilibrium after a disturbance. And "*Ecological resilience*" (Holling's concept), which refers to the amount of disturbance a system can absorb before it shifts into a different regime or structure (Otto, 2015).

Walker et al. (2004) defines resilience as "the capacity of a system to absorb disturbance and reorganize itself while undergoing change, so as to retain essentially the same function, structure, identity, and feedbacks" (Walker, Holling, Carpenter, & Kinzig, 2004). Resilience Theory is used or applied in six scientific fields, which are: environmental management, urban planning, disaster risk reduction (DRR), climate adaptation, agriculture and food systems, governance and policy-making (Walker, Holling, Carpenter, & Kinzig, 2004).

2. Access and Entitlements Theory

Access and Entitlements Theory (AET) is a framework developed to understand how people gain or lose access to essential resources, especially in times of crisis, such as famines or natural disasters. It was primarily developed by the economist Amartya Sen, who introduced it in the context of famine analysis in his groundbreaking work, titled "*Poverty and Famines: An Essay on Entitlement and Deprivation (1981)*" (Sen Amartya, 1981).

This theoretical framework on access and entitlements was used by Amartya to understand why some individuals or groups are more vulnerable to environmental and socio-economic shocks than others, even when facing similar hazards. In the context of adaptive capacity, the ability of individuals, communities, or systems to adjust to climate change, cope with shocks, and seize opportunities enabled the theory to provide critical insight into how power, institutions, and social structures shape people's ability to respond and adapt to disasters (Sen Amartya, 1981).

The access and entitlements theory were developed separately by two different scholars. The scholar Amartya Sen (1981) developed the *"Entitlements theory"*. This theory was originally developed to explain famine. This entitlement theory argues that hunger is often not caused by a lack of food but by people's inability to access food (Sen Amartya, 1981). The word "entitlement" comes from the fact that people can own assets, which they acquired through their employment income or through support from networks and institutions. Meanwhile, the *"Access theory"* was developed by Ribot and Peluso (2003). In this access theory, they built on Sen's work by highlighting that access is not only legal ownership or rights, but also includes the ability to benefit from resources (such as owning land), which is shaped by social, political, and economic processes (Ribot & Peluso, 2003).

In climate change and disaster studies, Access and Entitlements Theory (AET) helps explain why some people adapt better than others, even within the same geographic or climatic conditions. This difference in adaptive capacities is explained by the following three key points: differential access to resources; institutional power; and social identity (Gumel, 2022).

- **Differential Access to Resources:** This point argues that people have unequal access to land, water, information, technology, capital, education, and political representation. These inequalities affect their adaptive capacity (Gumel, 2022).
- **Institutions and Power:** With this key point, Gumel Danladi Yusuf (2022), in his paper *"Assessing Climate Change Vulnerability: A Conceptual and Theoretical Review"* meant that the power needed to adapt is defined by local and national institutions, as well as social norms and power relations (Gumel, 2022). They determine who gets what, when, and how by influencing access to resources needed for adaptation (e.g., subsidies, extension services, loans).
- **Social Identity and Marginalization:** Here gender, caste, ethnicity, age, and social class often determine entitlements and access. Marginalized groups may be systematically excluded from adaptation planning or resource distribution (Ribot & Peluso, 2003).

In conclusion, we can say that Access and Entitlements Theory (AET) reveals how adaptive capacity is shaped not just by physical exposure to climate risks but by the social, political, and economic relationships that govern access to resources (Williamson, McCordic, & Doberstein, 2023) and decision-making power. This perspective is crucial for designing just and effective climate adaptation strategies that recognize and address inequalities.

3. Transformational Adaptation Theory (TAT)

Transformational Adaptation Theory is a concept most commonly discussed in the context of climate change adaptation, but it also has broader applications in organizational change, sustainability transitions, and social systems (Lonsdale, Pringle, & Turner, 2015). Transformational adaptation refers to fundamental, systemic changes in response to climate or environmental challenges. It goes beyond incremental changes and instead seeks to alter the structures, functions, or goals of a system to make it more sustainable, equitable, and resilient (Gillard, Gouldson, Paavola, & Van Alstine, 2016).

The theoretical foundations of the Transformational Adaptation Theory (TAT) draw from resilience theory, complex adaptive systems, transition theory, and political ecology. There are three scholars who developed this transformational adaptation theory, each of them having a specific aspect of the theory which they developed (Gillard, Gouldson, Paavola, & Van Alstine, 2016).

- Kates et al. (2012), in their research developed and outlined the characteristics of transformational adaptation.
- Pelling (2011), on his path, emphasized on adaptation as a way to social transformation.
- Finally, O'Brien (2012), introduced the idea of "inner transformation" and "values-driven change".

The key elements of the transformational adaptation theory (O'Brien, 2012) are: systemic change, social justice & equity, long-term perspective, participatory governance and innovative thinking. The Transformational Adaptation Theory (TAT) can be applied and used in four scientific disciplines which are: "Climate Policy" for National Adaptation Plans (NAPs) and IPCC discussions; "Urban Planning" for redesigning cities to be carbon-neutral and climate-resilient; "Agriculture" for shifting from industrial monocultures to regenerative agriculture; and "Water Management" for restoring ecosystems instead of just building infrastructure (O'Brien, 2012).

Feature	Incremental Adaptation	Transformational Adaptation
Scale of change	Small adjustments	Fundamental/systemic changes
System structure	Maintains existing systems	Alters or replaces existing systems
Timeframe	Short- to medium-term	Long-term vision
Examples	Building a seawall	Relocating a coastal city
Drivers	Efficiency, risk reduction	Equity, justice, sustainability

Table 2 : *Transformational vs. Incremental Adaptation (O’Brien, 2012)*

4. Vulnerability Theory

The vulnerability theory of Turner et al. (2003) (King & Crews, 2013) is a widely cited framework in the field of human and environmental interactions (Kopnina & Shoreman-Ouimet, 2011), particularly in the study of vulnerability to environmental change (e.g., climate change, natural disasters, and land degradation). The framework was introduced in the paper *Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., & Schiller, A. (2003), A framework for vulnerability analysis in sustainability science, Proceedings of the National Academy of Sciences, 100(14), 8074–8079*. In this paper, the authors proposed a comprehensive, integrative framework that connects exposure, sensitivity, and resilience to understand the vulnerability of coupled human and environment systems (Turner, et al., 2003). This theory originates from Human-environment geography and sustainability science and its contribution to sciences emphasizes on the role of social, economic, and political structures (Gisevius, Niesters, & Braun, 2025) in shaping a community's ability to adapt to external stressors (Turner, et al., 2003).

Vulnerability theory is a framework primarily used in law, social sciences, and disaster studies to analyze how and why certain individuals, groups, or systems are more susceptible to harm than others. This theory helps explain inequities in how people experience risk, hardship, disaster, and the challenges associated to the assumptions that vulnerability is solely the result of individual failings (Turner, et al., 2003). Vulnerability theory and adaptive capacity are both core concepts in climate change research, disaster risk reduction, and socio-ecological resilience studies. They are closely linked but represent different aspects of how individuals,

communities, or systems respond to stressors like climate change or natural hazards (Adger, Jouni, Saleemul, & Mace, 2006).

Vulnerability theory seeks to explain why some people, communities, or systems are more susceptible to harm than others in the face of external stressors (e.g., climate change, economic shocks, and disasters). The key components of vulnerability are exposure, sensitivity and adaptive capacity (Tian & Lemos, 2018). Gallopín's framework views vulnerability as a function of exposure, sensitivity, and adaptive capacity (Gallopín, 2006). Exposure, sensitivity, and adaptive capacity are key building blocks in resilience theory and disaster risk reduction. Gallopín's vulnerability framework is structured around the interaction between human systems and environmental systems, focusing on the causal structure of vulnerability (Gallopín, 2006).

- **Exposure:** This concerns the stressors or perturbations that a system faces (e.g., droughts, floods, and market shocks). These stressors can be natural (like hurricanes) or anthropogenic (like policy changes). Exposure is therefore the degree to which a system experiences environmental or socio-economic stress (Gallopín, 2006).
- **Sensitivity:** Here the author evaluates how much a system is affected by exposure. For example, a farming community may be highly sensitive to drought due to dependence on rainfall. Sensitivity is therefore defined as the extent to which a system is affected by that exposure (Gallopín, 2006).
- **Adaptive Capacity:** Adaptive Capacity is the ability of a system (people living in a landscape) to cope, resist, or recover from the hazard. This ability defines a systems capacity to respond to and recover from stressors, includes coping mechanisms, learning, institutional support, and access to resources (Gallopín, 2006).

So, adaptive capacity is a component of vulnerability (Liao, Zou, Fang, Lei, & Zhong, 2025), because it is what reduces vulnerability (Paavola & Adger, 2006).

In Conclusion, these theoretical foundations like resilience theory provides the conceptual grounding for some frameworks such as the Adaptive Capacity Wheel, by offering key principles like learning, diversity, and transformation. Many adaptive capacity frameworks are similarly built on foundational theories from environmental science, sociology, and governance studies. Below is a table that shows the various theoretical foundations that influences and commonly supports one or two adaptive capacity frameworks.

Theoretical Foundation	Explanations of each Theoretical Foundation	Frameworks Influenced by each Theoretical Foundation
Social-Ecological Systems (SES)	Interconnected systems of humans and nature (Robertson, 2025) that co-evolve and influence each other	Ostrom's SES framework (<i>Ostrom 2007</i>), IPCC AR5 Adaptation Framework (<i>IPCC 2014</i>)
Complex Adaptive Systems (CAS)	Systems with multiple interacting parts that adapt to environmental changes	Resilience Alliance models (<i>Holling, C.S. 1973</i>), Adaptive Management approaches (<i>Walters 1986</i>), (<i>Gunderson, Holling & Light 1995</i>)
Institutional Theory	Institutions (rules, norms, routines) shape the ability to adapt	Adaptive Capacity Framework (ACF) (<i>Gupta et al. 2010</i>), (<i>Adger 2003</i>)
Political Ecology	Power dynamics and political influences affect vulnerability and adaptation	Social-Ecological Systems (SES) Resilience Framework (<i>Turner et al. 2003</i>), (<i>Leach et al. 2010</i>)
Sustainable Livelihoods Approach (SLA)	Focuses on capabilities, assets, and activities required for a means of living	DFID's Sustainable Livelihoods Framework (<i>DFID 1990</i>)

Table 3 : Theoretical foundations and adaptive capacity frameworks.

D. The missing or unsolved issues in literature that our research questions address

Identifying missing or unsolved issues in the literature on adaptive capacities was the second way for us to find gaps and contradictions, in order to verify the solidity of our research questions. This verification gives a form of validity to the research questions of our PhD thesis. These missing or unsolved issues formed the basis of our research questions. Ranging from DFS practices to generate adaptive capacity, to natural resource reliance without leaving out entitlements for adaptive capacity and units of exposure. We realized that each of these research concepts paved the way to the design of our research questions.

To determine how DFS practices can generate adaptive capacity, Adam Calo (2020) demonstrated that DFS practices that enhance adaptive capacity may be muted by restrictive land tenure regimes in many agricultural contexts: especially in contexts where farmers may be receptive to DFS but, with tenure

insecurity may not have the power to make adaptive changes (Calo, 2020). Secondly, for him, applying DFS for resilience alone may entrench unjust tenure regimes, whereby farming systems may succeed in diversification for resilience but, entrench the flow of their ecosystem services and other benefits to those that control land access mechanisms (Calo, 2020). With these demonstrations enumerated by Adam Calo (2020), we identified a missing element with regard to the role played by drone mapping in monitoring crop diversity, land use changes, and land use patterns (Okyere, Diko, Frimpong, Abunyewah, & Mensah, 2025) in DFS for improving adaptive capacities. Monitoring crop diversity, land use changes (Li, Chen, Zhao, & Zhai, 2024), and land use patterns is crucial for supporting adaptive capacities in a landscape, particularly in the face of climate change, socio-economic pressures, and environmental degradation. This missing element gave rise to a research question on the role of drone mapping in strengthening the adaptive capacities of agrarian landscapes where DFS is practiced. However, centering the role of farmland tenure allows researchers in pursuit of an equitable resilience to ask, “Who has the power to adapt?” In this way, an analysis of farmland tenure could help to observe the social relations that mediate any benefits of agricultural diversification (Calo, 2020). Here our research question tries to determine who has the power to adapt and which factors enhance the adaptive capacities of farmers in agrarian landscapes.

Concerning natural resource reliance, in their research, Sam Schramski & Grenville Barnes (2016) determined adaptive capacity by measuring the livelihood diversity score and health score of each household, which will be, in fact, the average between these two scores (Schramski & Barnes, 2016). In addition, he tested the natural resource reliance against both scores to investigate its relationship with adaptive capacity. Natural resource reliance is a composite of natural resources acquired by the household. These include items related to timber products and NTFP, water, fields, home gardens, and livestock (Schramski & Barnes, 2016). Next to this concept of « natural resource reliance » in adaptive capacities developed by Sam Schramski & Grenville Barnes (2016), our research questions gave rise to the concept of « landmark reliance » in adaptive capacities (that is reliance on landmarks for adaptive capacities).

With regards to entitlements for adaptive capacity, according to Mara J. Goldman & Fernando Riosmena (2013), adaptive capacity is based on the set of environmental, social, economic, and political entitlements (human rights) that particular individuals, households, or communities can mobilize to cope with risk (Goldman & Riosmena, 2013). Also, as per Adger (2006), entitlements are “the actual or potential resources available to individuals based on their own production, assets or reciprocal arrangements.” This includes livestock and other forms of wealth; farmland, reserve grazing areas, and tenure rights; gender norms,

education, knowledge, and reciprocal relations enabling access to resources (Adger, Jouni, Saleemul, & Mace, 2006). Altogether, entitlements are the set of alternative commodity bundles that a person can command in a society using the totality of rights and opportunities that he or she faces (Leach, Mearns, & Scoones, 1999). One of the missing entitlements available to individuals and useful to enhance adaptive capacities that was not cited by Adger (2006) is landmarks. These missing entitlements called landmarks, are been addressed by the research questions of our PhD thesis. These research questions address the role played by landmarks in strengthening the adaptive capacities of agrarian landscapes.

Finally, the missing elements in the concept of "*units of exposure in adaptive capacity*" developed by Marshall (2011), paved the way to our research questions. In the words of Marshall (2011) adaptive capacity should be assessed in relation to a particular "*unit of exposure*," e.g., the farm enterprise, or an entire industry (Marshall, Gordon, & Ash, 2011). Assessments of the social vulnerability of farm communities are often based on an assumption of natural resource dependence: farmers, as adapting actors, are vulnerable because the natural capital that is the foundation of their economic activities (crops and livestock, soils and water) is presumed to be highly sensitive to change and variability in climatic parameters such as rainfall and temperature (Eakin & Luers, 2006).

Apart from « farm enterprises » as a unit of exposure where adaptive capacities can be assessed, there are two other units of exposure that were left out by Marshall (Marshall, Gordon, & Ash, 2011). These two missing units of exposure have been highlighted and explained by our PhD research questions and research findings. These units of exposures highlighted and showcased in our PhD research questions are: natural and man-made hydrographies. The natural hydrographies are rivers, streams, creeks, lakes, ponds, wetlands, and swamps. Meanwhile, the man-made hydrographies are: fish ponds, canals, dams, aqueducts, and irrigation channels. The research questions of our PhD thesis assessed the adaptive capacities and the spatial relationships of these three units of exposure (farmlands, natural and man-made hydrographies).

VI. THESIS STRUCTURE AND COMPOSITION (thesis outline & plan)

Chapter 1: This chapter is the general introduction of our PhD thesis, and it sets the stage for the entire dissertation and helps orient the research. This chapter aims at defining and developing seven main sections. These sections are: introducing the research topic and its context; highlighting the importance and relevance

of the study; identifying the research gap that the thesis addresses; defining the research objectives; stating the research questions; developing the literature review; and outlining the structure of the thesis.

Chapter 2: This chapter is dedicated to assessing the contribution of participatory mapping data collection methods in detecting and mitigating land boundary conflicts in farm areas. Structured as a methodological framework, this chapter defines the methods of land data collection that facilitate land conflict mitigation by comparing the unique contribution that each method brings in identifying land conflict-prone areas. These distinctive contributions adopt an approach that combines farmland data from interviews, questionnaires, consultative meetings, field visits, demarcation of farm boundaries, recording of ground corner points using Catalyst DA2, UAV flights, and participatory mapping. Finally, in this chapter we discussed the usefulness and limitation of these methods.

Chapter 3: This chapter elaborates on the type of spatial relationships that exist between farmlands and hydrographies in agrarian landscapes. In this chapter, we addressed the absence of data on the spatial relationships that exist between farmlands and hydrographies in order to help address the issue of farmlands' exposure and vulnerabilities to climate change. Therefore, understanding the spatial relationships that exist between farmlands and hydrographies can help to strengthen climate mitigation strategies and reduce the exposure level of the farmlands. Here we identified seven different types of spatial relationships that exist between farmlands and hydrographies: adjacency, containment, connectivity, intersection, disjoint, overlapping, and same-space relationships.

Chapter 4: This chapter discusses the role played by participatory mapping in helping to perceive and understand the contribution of landmarks in strengthening the adaptive capacities of agrarian landscapes. In this chapter, farmers were asked to draw on a paper (sketch mapping) the landmarks found in the agrarian landscapes where they cultivate their crops as a means to assess their perception and understanding of landmark distribution and disparities. In addition to these sketch maps, farmers were asked through a questionnaire survey to describe how these landmarks help them to adapt to climate disasters and what relation the landmarks have with their agricultural practices. With the aim to improve the adaptive capacities of farmers, the method of participatory sketch mapping was successful because it provided deeper insights into how farmers conceptualize their environment.

Chapter 5: This chapter presents the extent to which drone mapping helps to illustrate and determine the role played by landmarks in strengthening the adaptive capacities of agrarian landscapes. Here we used drone

data to determine which landmark strengthened the most and how. This drone data was also used to understand how each landmark sustains the food crop cultivations and livestock farming activities even in the advent of severe climate-induced disasters. In addition to this drone mapping process, farmers were asked through a questionnaire survey to describe how these landmarks help them to adapt to climate disasters and what relation the landmarks have with their agricultural practices.

Chapter 6: This chapter concludes our PhD thesis and shows the similarities and connections between the four studies (in chapters 2, 3, 4 & 5) by explaining how these four studies addressed the literature gap and the unsolved issues that gave rise to many open and unanswered questions. This chapter provides summative perspectives, recommendations, and conclusions, and clarifies the contribution that this PhD brings to science. This last chapter also provides insights into the limitations of the study and presents recommendations for further research.



CHAPTER 2:

Assessing the contribution of participatory mapping data collection methods in detecting and mitigating land boundary conflicts on farm areas: A methodological framework

Author: Marcel Loyd MINKA

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1st PhD Research Study Conducted in Mbalmayo – Cameroon from August 2023 to November 2023

Assessing the Contribution of Participatory Mapping Data Collection Methods in Detecting and Mitigating Land Boundary Conflicts on Farm Areas: A Methodological Framework



Marcel Loyd MINKA

Università Cattolica del Sacro Cuore, Faculty of Agricultural, Food and Environmental Sciences,
Department of Animal, Nutrition and Food Sciences (DiANA)

ABSTRACT: Land conflict is a serious and sensitive issue in Africa. Disputes about land occur at all levels, which are: Conflicts between neighbors about field boundaries; between pastoralists and farmers; between states and indigenous peoples; etc. (Wardell & Lund, 2006). These conflicts are a serious threat to agricultural and land productivity. Now our days there exist several methods of land data collection which facilitates land conflict mitigation, and each of these methods are been explained in various papers. However, none of these papers have compared these methods to bring out their unique contribution as a means to assist practitioners in identifying land conflicts prone areas. Our research is centered around the question: what is the distinctive contribution of each land data collection methods in identifying land conflict prone areas during participatory mapping? Using a case study of three villages in Mbalmayo (Cameroon), our research adopts an approach that combines farmland data from interviews, questionnaires, consultative meetings, field visits, demarcation of farm boundaries; recording of Ground Corner Points using Catalyst DA2, UAV flights, and participatory mapping. In this paper, we discuss the usefulness and limitation of each method, highlighting their unique contribution to the holistic understanding of the context of Mbalmayo and the mitigation of land conflicts. The study was conducted from June to October 2023. The results of our analysis show that amongst the eight methods used to collect farmland data, six of these methods had a distinctive contribution that facilitated the mitigation process by precisely identifying the land boundary conflicts zones. The ideas provided by this paper can serve as guidelines for researchers and practitioners interested in mitigating land conflicts through participatory mapping approaches.

KEYWORDS: Participatory mapping; Land conflicts; Mitigation; Data collection methods.

ABBREVIATIONS

DSR – Design science research

GIS – Geographic Information Systems

GCPs – Ground Control Points

GNSS – Global Navigation Satellite System

IG – Indirect Georeferencing

LIS – Land Information Systems

PM – Participatory Mapping

QGIS – Quantum Geographic Information System

SDL – Spatial Data Layer

TMM – Trimble Mobile Manager

UAV – Unmanned Aerial Vehicle (Drones)

VGGT – Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security

I. INTRODUCTION

Now our days in Africa, people increasingly competing to get access to arable land and pastures, and open land conflicts are becoming more and more common across the continent. (Lund, Odgaard, & Sjaastad, 2006). Disputes and conflicts about land occur at all levels: Conflicts between neighbors about field boundaries; between men, women, and generations about their respective land rights; between pastoralists and farmers; etc. (Lund, Odgaard, & Sjaastad, 2006). Also, in sub-Saharan Africa, land conflicts have been increasing and are seriously affecting the wellbeing and safety of people and properties (Ringo, 2023). According to Micky Thambikeni land conflicts can be mitigated by improving the operations of Land Information Systems (LIS) thereby making land information and land services more available in support of urban and rural economic development for farmers and pastoralists (THAMBIKENI, 2015).

Participatory mapping is a group-based qualitative research method which is known to mitigate land conflicts (Evans, 2018) and this practice of land conflict mitigation is been used by many communities in the world, especially in Africa. Participatory mapping is based on the recognition that men and women in local communities are the main experts in the geography of their lands (Smith, Ibanez, & Herrera, 2017). The experience I have acquired while working as land governance and participatory mapping specialist for the African NGO named Youth Initiative for Land in Africa (YILAA), gave me the necessary knowledge I needed to conduct this research study. YILAA is a non-state actor involved in mitigating land conflicts in multi-cultural and multi-lingual contexts. Non-state actors are organizations and individuals that are not affiliated with, directed by, or funded through the government.

The voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (VGGT) give some recommendations to non-State actors. These recommendations stand as principles and good practices which every State and Non-State actor should implement in their activities as a means to promote and encourage the responsible governance of Tenure of Land, Fisheries and Forests in the world (FAO, 2012). This research we carried out in Mbalmayo was focused on the implementation and promotion of eight different principles and recommendations written in the VGGT. These eight principles are found in guideline number 6.9 on delivery of services; guidelines number 9.10 and 9.12 on community's customary tenure rights; guidelines number 12.13 on investments; guidelines number 22.2 on transboundary matters; guidelines number on 24.5 on natural disasters; guidelines number 25.1 and 25.3 on conflicts in respect to tenure of land, fisheries and forest; and guidelines number 26.5 on the promotion, implementation, monitoring and evaluation of these VGGT (FAO, 2012). Though all the above-

mentioned guidelines (6.9, 9.10, 9.12, 12.13, 22.2, 25.1, 25.3 and 26.5) are related to our research study, we placed more emphasis on implementing and promoting guideline numbers *9.10, 9.12, 12.13, 24.5, 25.1* and *25.3* when conducting our research work from June to October 2023 in Mbalmayo. So, on this ground, I can say with assurance that our research on land conflicts mitigation in Mbalmayo contributed in improving community's customary tenure rights; contributed in guaranteeing the tenure rights of local people in the phase of large investments; and also contributed in reducing conflicts in respect to tenure on land, fisheries and forests as stipulated by the VGGT (FAO, 2012).

The problem this research wants to address is the lack of a comparative analysis which brings out the distinctive contribution of each data collection method used. The most recent census, which was conducted in the previous two years, indicates that Mbalmayo has 125,616 people living there (Liliane, Romain, Caroline, Abigaëlle, & Loic, 2022). This research study was conducted from June to October 2023 in the villages of Zamakoue, Asanza and Medzong in Mbalmayo. Our research question is “what is the distinctive contribution of each land data collection method in identifying land conflict prone areas during participatory mapping?”. This paper investigates the distinctive contribution of each data collection method used during participatory mapping to design a framework that will help participatory mapping practitioners to choose the best methods for identifying land conflict prone areas for land conflicts mitigation in multi-cultural contexts. To answer the above research question, our method will be based on a series of sequential steps which forms a funnel. These sequential steps are five steps that will convey us to the answer of our research question. These five steps are: the presentation of each method used for data collection (step 1); the outcome of the data collected by each method (step 2); the similarities between these methods (step 3); the differences between these methods (step 4); and the use of the DSR Knowledge Contribution Framework to establish the distinctive contribution of each method (step 5). These five steps constitute the generalized solution developed by our research to bring out the distinctive contribution of each data collection method used to identify land conflicts prone areas during participatory mapping. This generalized solution can serve as a framework for practitioners who because of limited resources have to choose a reduced number of data collection methods during participatory mapping to mitigate land conflicts by identifying land conflict prone areas in multi-cultural contexts.

II. METHODS USED FOR DATA COLLECTION DURING PARTICIPATORY MAPPING TO DETECT POTENTIAL LAND CONFLICT PRONE AREAS

To mitigate these land conflicts, we used eight methods to collect qualitative and quantitative data. These qualitative and quantitative data we collected enabled us to detect and show potential land conflict prone areas. The eight methods we used were: in-depth Interviews (1), SW Maps (2), Trimble Catalyst DA2 Receiver (3), UAV Flights (4) Sketches on drone image (5), Kobo Collect (6), Map processing on QGIS (7) and Post-Participatory Mapping Interviews (8). Below are the explanation and details of these eight methods I used to collect both qualitative and quantitative data during participatory mapping.

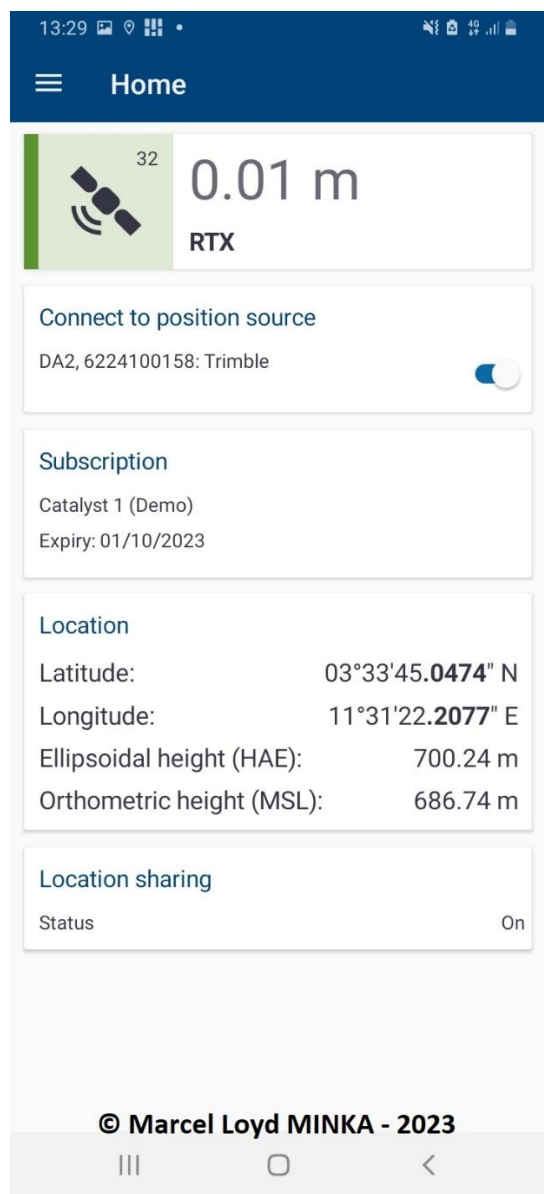
A. Method 1: Pre-Participatory Mapping Interviews (In-depth interviews)

We conducted in-depth interviews with farmers during a farm visit using a framework of questions to determine the intensity, seriousness and consequences of these land boundary conflicts. These interviews were carried out by us and each interview, lasted between 30 to 40 minutes and were conducted with each of the farm tenants who felt comfortable participating in the interview. A total of twelve interviews were conducted. These in-depth interviews were the first step in gathering information with farmers and they were done in conjunction with the farm tours we organized. During these farm tours and interviews, we realized that none of these farms have ever been captured by drone (UAV) images. So, these farmers had no idea on what is a drone (UAV) image. These farms did not have UAV images from previous years, because such a study had never been done before on these farms nor with these farmers. These interviews revealed the existence of land boundary conflicts which we will see in section 3 below.

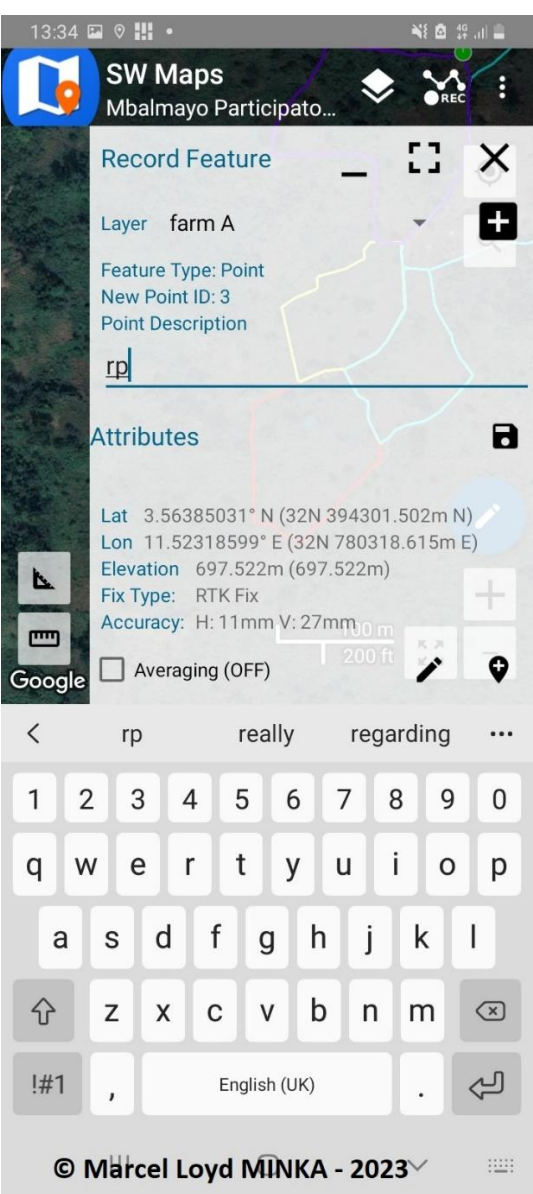
B. Method 2: SW Maps with Trimble Catalyst DA2 Receiver for the delimitation of farms boundaries

The Trimble Catalyst DA2 is a GNSS receiver that collects spatial data with a centimetric accuracy ranging from 3 to 1 cm. It is compatible with Android and IOS systems. To collect this spatial data with Catalyst DA2, we used an Android terminal where we installed Trimble Mobile Manager (TMM) and SW Maps. TMM and SW Maps are two software's which helped me to collect all the GCPs (Ground Control Points). The android terminal (smart phone) was used as the main terminal coupled to the DA2 catalyst in order to operate and manage its signal in particular through the TMM and SW Maps applications. SW Maps is a GIS and topography application mainly used for real-time terrain data collection. Therefore, in order to collect the GCPs we went through the following process: we downloaded and installed the TMM application on our android terminal,

then we created a TMM account through which we were able to subscribe to the Trimble 1 package, which gives us access to centimetric accurate data.



Picture 1: TMM interface showing the centimetric accuracy used in collecting the spatial data



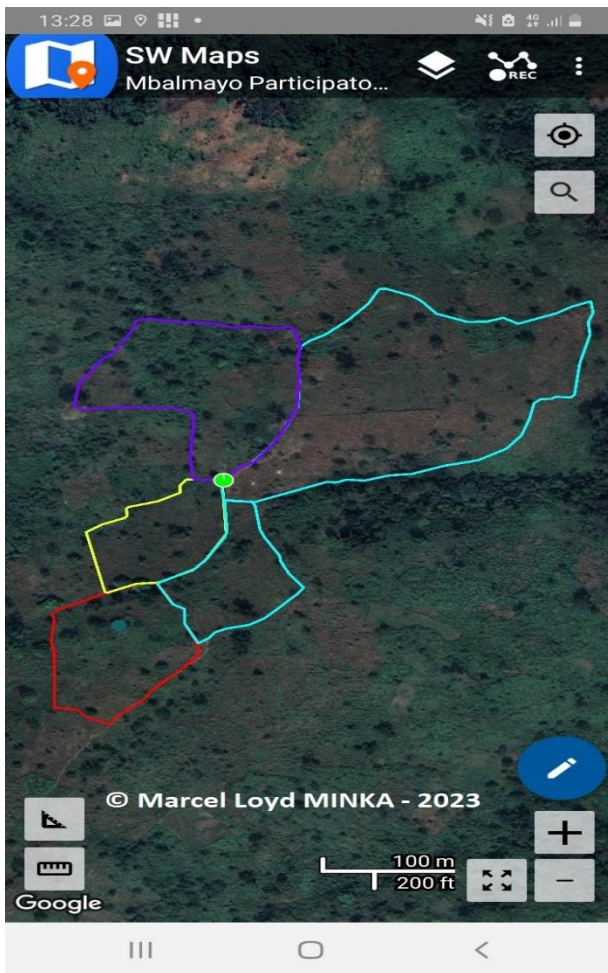
Picture 2: SW maps interface showing the accuracy in GPS/GNSS measurements

In this way, we were able to share this precision with all the other location-aware applications on our android terminal, including the SW Maps data collection application. Once in the field, we georeferenced the

boundaries of the various plots using the SW Maps application, tracking them on foot around the 10 different farm plots. This enabled us to mark the delimitation of farms and place the ground control points (GCPs).



Picture 3: *Delimitation of farm limits using Trimble Catalyst DA2*



Picture 4: *Boundaries of farms delimited on SW Maps*

C. Method 3: Trimble Catalyst DA2 Receiver for placing Ground Control Points (GCP)

As soon as we characterized the various limits, the next step was to place the ground control points (GCPs) on the field that would serve as the physical boundaries between the farms and also serve as control points for the future drone missions. After placing the ground control points, we had to collect coordinates of their positions with the help of the Trimble catalyst DA2 in order to have good accurate data that will be used to demarcate and define each farm boundary.



Picture 5: *Placing Ground Control Points (GCPs) on each farm corner*



Picture 6: *Placing Ground Control Points (GCPs) on each farm corner*

D. Method 4: UAV Flights

During these UAV flights, no farm was too large to be mapped by the drone in a single visit. After the UAV flights conducted by the drones, the images were transformed into a map layout in ArcMap (version 10.3) and printed on A3 paper. This data collection aimed at seeing the limits and boundaries of each farm on an orthophoto. This drone mapping activity provided exciting insights into the ability UAV to identify farms and farm boundaries. Relevant local government stakeholders were notified and informed about the data collection process.



Picture 7: *Programing of the UAV flight for mapping the potential land conflicting farms identified during the delimitation of farm boundaries*

E. Method 5: Sketches and drawings on drone image

These sketches done with a visible bold marker are overlaid property lines on satellite images, which will make it easier to reorganize farm boundaries. These drawings help to increase the visibility of each farm, enabling for the identification of potential areas with a high concentration of farms for an effective detection of some land conflict prone areas caused by unclear and invisible boundaries. The spatial and temporal resolution of the background satellite images is a very important aspect to consider when creating the map. In this process, we also used the orthophoto obtained from the UAV images to detect the exact conflicting farm boundaries. The older the orthophoto, the more problems the community might have in recognizing specific objects which helps them do the sketching. Similarly, the season can also play a role in certain areas, as the landscape can look very different in the rainy and dry seasons or in summer and winter (Dr. Claudia Stöcker & Kaspar Kundert, 2022). The spatial resolution (pixel size) of the orthophoto is also crucial.



Picture 8: Cameroon. Sketches on Satellite images for the participatory drawing of each farm boundary to mitigate the existing land boundary conflicts



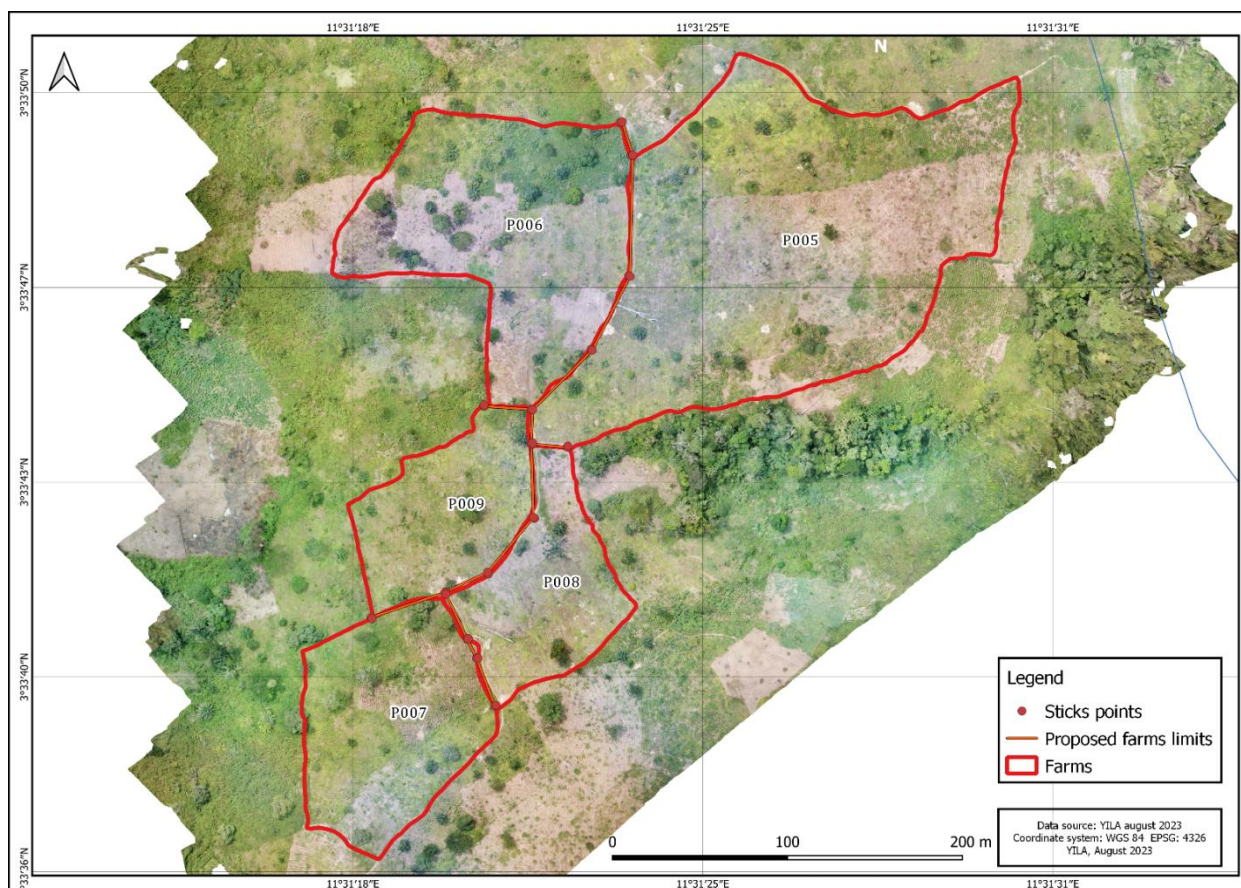
Picture 9: Sketches on Satellite images for the participatory drawing of each farm boundary to mitigate the existing land boundary conflicts

F. Method 6: Kobo Collect

With this method, we collected attribute data to help mitigate the boundary land conflicts. These attribute data are paramount knowledge in land administration and might or might not have caused the land boundary conflict. On Kobo toolbox, we built a questionnaire, then later we deployed and sent the questionnaire to mobile devices from which the survey was made. Through this questionnaire, we were able to collect qualitative data on land ownership, land rights, land use. The questions on kobo toolbox were primarily closed questions for which we provided propositions to guide the farmers and avoid them from feeling the weight of many questions. This questionnaire helped to gather data which could have been left out through the interviews. The Questions were separated into four categories, which included: questions on the demography; questions on the agriculture practices; questions on the Land ownership, land rights and land use; and questions on of the nature of the land conflict.

G. Method 7: Map processing on QGIS

Once farm boundaries are sketched and that the questionnaires on kobo collect are filled, the farmers had to agree with the sketches on the orthophoto which enabled us to draw on QGIS the final farm boundary lines for the mitigation of the land conflicts. These agreed boundary lines on the orthophoto were traced by the mapping assistant on top of the ballpoint pen lines with a black marker, coupled with a line width of 1 mm - 2 mm to yield reliable results in the automatic line extraction process. To process the maps on QGIS in order to obtain the final shape and size of the farms, we photographed the sketched orthophoto map using the SmartLandMaps Digitizer application (Claudia, Auriol, Gergely, Kaspar, & Angela, 2023). Here the orthophoto map needed to be aligned in a landscape format on a flat surface such as a big table or a tiled floor. Here, we were recommended to tape the edges of the map to the ground to ensure that it was completely flat. In this process, the pictures of the map were taken in passive daylight conditions without shadows. Then as soon as the mobile device was connected to internet, all these pictures were uploaded automatically to the SmartLandMaps cloud and the automatic processing of the Map on QGIS automatically started.



Picture 10 (orthophoto): Final sizes, shapes and boundaries of farms processed on QGIS after agreeing with the participatory farm boundary lines drawn on the drone images

H. Method 8: Post-Participatory Mapping Interviews

These interviews were done after the participatory mapping sessions. These interviews aimed at determining the level of satisfaction of farmers with regards to the strategy we used to detect and mitigate the boundary land conflicts. These interviews we did lasted between 20 to 40 minutes, and were done one month after we had finished the participatory mapping exercises. It was important to do these interviews after having the new farm boundary lines agreed by all the farmers. Majority of the farmers said that one of the major improvements which this study brought to their farms, was the easy access to each farm due to the creation of new unpaved road paths which separates the five farms. The implementation of these road paths was a mitigation strategy which we proposed to the farmers to reduce the outbreak of future land boundary conflicts.



Pictures 11: Presentation of the final farm boundaries to the conflicting parties for an evaluation of the participatory mapping exercise used a strategy to mitigate the land conflicts



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Pictures 12: Discussions with the farmers on the new unpaved road paths implemented to mitigate the existing conflicts and prevent the outbreak of future land boundary conflicts.

III. DESCRIPTION OF THE QUALITATIVE AND QUANTITATIVE DATA COLLECTED BY THESE EIGHT METHODS

Below is a table listing and describing the data collected by each of the eight methods. Each of these qualitative and quantitative data help us to detect potential land conflict prone areas.

Methods used to Data Collect	Spatial Data Layer (SDL) types	Data Collected	Description of Data
In-Depth Interviews	- Croplands. - Natural habitats - Agroforestry	Existence of Land conflicts (verbal affirmations of farms boundaries deficiencies which causes land conflicts)	These are qualitative data which confirms the presence of boundary land conflicts amongst majority of the neighboring farmers, with a 90% YES to the answer on the existence of land conflicts and a frequency of 9 YES amongst the 10 respondents.
SW Maps with Trimble Catalyst DA2 Receiver	- Croplands. - Natural habitats - Agroforestry	Shapes and boundaries of farms (farm boundaries detection lines)	These are quantitative geographic data which when collected appears in the form of maps on the SW Maps software. (see picture 4 above)
Trimble Catalyst DA2 Receiver	- Croplands. - Natural habitats - Agroforestry	Ground Control Points (GCPs)	GCPs are specific places on the earth's surface with known referenced locations that are used to georeferenced an area. GCPs can be used as reference data for the boundaries of a farmland.
UAV Flights	- Croplands. - Natural habitats - Agroforestry	Georeferenced drone Images of the farms	These are hundreds of slightly overlapping pictures that covers every square inch of the farms, from the property edges to the tops of trees. Each of these pictures are georeferenced. For example, every time a drone takes a picture, it records the precise coordinates (longitude and latitude) in the image's in EXIF data.
Sketches on drone image	- Croplands. - Natural habitats - Agroforestry	Sketches and drawings of farm boundaries on drone images (the provisional shapes and sizes of farms)	These sketches and drawings of farm boundaries on drone images are overlaying property lines which helps to better visualize and rearrange the farm boundaries on a drone image. These drawings are done with a visible bold marker. These drawings help to improve the visibility of the boundary lines of each farm in order to detect and mitigate potential land

			conflicts which arose because of unclear and invisible boundaries.
Kobo Collect	- Croplands. - Agroforestry	Attribute data (Land ownership ; Land rights ; Land use ; etc.)	Attribute data are used to describe vector features. These attributes don't have to be visible things, but they can describe things we don't know about the farmlands, such as the name of the owner, the legal aspects of the farm, the year the farming activity started, etc. The attribute data revealed that majority of the farmers are tenants and only a few of them are owners of the farmland
Map processing on QGIS	- Croplands. - Natural habitats - Agroforestry	Final farms shapes and sizes	These farm shape and sizes are vector data whose shapes are represented using geometry. within the GIS environment. The geometry is made up of one or more interconnected vertices (vertex). The data of these maps on QGIS are made up of the following detailed elements: The Title in detail; the Map Border in detail; the Map Legend in detail; the North arrow in detail; the map Acknowledgment in detail; the Graticule in detail; and the Name of the map projection in detail.
Post-Participatory Mapping Interviews	- Croplands. - Natural habitats - Agroforestry	Satisfaction level of farmers about the mitigation strategy used in this study	These are qualitative data obtained from farmers through interviews. This data assesses the effectiveness of the mitigation process by obtaining the satisfactory responses of farmers three months after the new boundary lines had been drawn on the field. Added to these new boundary lines was the creation of unpaved road paths which separates the five farms.

Table 1: Table Describing the qualitative and quantitative data collect by each of the eight methods

IV. SIMILARITIES BETWEEN THESE DATA COLLECTION METHODS USED TO DETECT LAND CONFLICT PRONE AREAS

To determine the similarities between the above eight data collection methods, we carried out a two-step process. The first step consisted in identifying which of the eight methods collected similar data (4.1). And

the second step consisted in detecting which of these eight methods followed the same implementation process on the field during the data collection period (4.2).

A. Similarities in data collected

Methods 2, 5 and 7 collected similar data during the participatory mapping. These data collected was the shape and sizes of the five farms, which can be seen in pictures 4 and 10 above. These data on the shape and sizes of farms were obtained by tracing and marking the boundary lines and corner points of each farm on SW Maps. Also, through the sketches of all the farm boundaries on the orthophoto, we also had an idea on the shape and sizes of each farm. This data enabled us to identify the land conflicting neighboring farms by detecting the error in the boundary lines of these neighboring farms.

More so, methods 3 and 4 collected similar qualitative data. These data collected were the georeferenced drone images with GCPs. The combination of these GCPs with the geo georeferenced drone images gives rise to what is called Indirect Georeferencing (IG). IG is a precise technique for georeferencing aerial photography. It uses Ground Control Points (GCPs) to assist Aero-Triangulation (AT) and achieves accuracies of 0.02 m (Joan-Cristian, Francisco-Javier, Jordi, & Xavier, 2019).

B. Similarities in the implementation process

In this sub-section, I will explain the similarities which exist between the various methods with regards to the implementation process we followed on the field to collect data using each of the eight data collection methods. For example, in this research study, methods 2 and 3 have the same implementation process because to implement these methods on the field, we used the same boundary detection software and the same measuring tool. The software we used to implement these two methods was SW Maps (see picture 2 above). And the measuring tool we used was Trimble Catalyst DA2 Receiver (see picture 1 above) which gave us an accuracy of 0.01 m for each farm boundary line.

Also, methods 5 and 7 have the same implementation process because to collect data on the field through these methods, we used the same settings. These settings were a drone image and an orthophoto on which the farmers could do the participatory drawing of each farm parcel in order for these farmers to agree on each farm boundary line that was drawn. The unanimous agreement on the participatory drawing of these farm boundary lines mitigated the land conflict by giving rise to the final boundaries of each farm.

Finally, methods 1, 6 and 8 are similar in their implementation process, because the implementation of these methods demanded the presence of all the farmers involved in the land conflict, who had to answer our questionnaires in the form of interviews.

V. DIFFERENCES BETWEEN THE DATA COLLECTION METHODS USED TO DETECT LAND CONFLICT PRONE AREAS IN MBALMAYO

Apart from the above similarities, these eight methods of data collection also have some differences when applied during participatory mapping. Therefore, to determine the differences between the above eight data collection methods, we carried out a two-step process. The first step aimed at identifying which of the eight methods collected different data (5.1). And the second step aimed at detecting which of these eight methods had different implementation process on the field during the data collection period (5.2).

A. Differences in data collected

To mitigate these land boundary conflicts between these five farms, we collected two different types of data, which were qualitative and quantitative data. It's through these different types of data collected that we illustrated the differences between our eight data collection methods. Methods 1, 6 and 8 were used to collect qualitative data (interviews) in the form of verbal affirmations of farms boundaries deficiencies; and in the form of attribute data on land ownership and land rights. Whereas methods 2, 3, 4, 5, and 7 were used to collect quantitative data (figures) in the form of farm shapes; farm sizes; GCPs; georeferenced UAV images; and farm boundaries detection lines. (see Table 1 above)

B. Differences in the implementation process

In this sub-section, we will illustrate the differences which exist between these eight methods with regards to the implementation process we put in place to collect data in Mbalmayo–Cameroon. At the level of the step needed to apply each data method collection method, the steps of methods 2, 3, 5, and 7 were longer than the steps of methods 1, 6 and 8.

Another implementation difference was at the level of the software and measuring tools we used when implementing these data collection methods. We witness many differences when implementing methods 2, 3 and 7. To implement these methods, we did not use the same software nor measuring tool for the boundary

detection, shape configuration and size determination of the five conflicting farms. In method 7, we used the Geodesic Measure Tool icon on QGIS by doing a left-mouse click on the map to get measurements between corner points that helped to define the map size and boundaries. Whereas in method 2 and 3, we used SW Maps and Trimble Catalyst DA2 to get the farm corner points for the boundary detection, shape configuration and size determination.

Finally, we observed and noted a significant implementation difference between methods 2, 3, 5 and 7 at the level of the settings put in place to carry out these methods on the field in Mbalmayo. The settings of method 2 and 3 were farm settings, where we did farm tours to place GCPs. Whereas the setting of method 5 and 7 were drone images and orthophotos on which we did the participatory drawing of each farm boundary line.

VI. THE DISTINCTIVE CONTRIBUTION OF THE ABOVE DATA COLLECTION METHODS IN DETECTING POTENTIAL CONFLICTING BOUNDARY LINES

In this sixth and last section, we will discuss the distinctive contribution of the above eight data collection methods in detecting and mitigating land conflicts during participatory mapping. To determine and bring out the distinctive contribution of these data collection methods we used the DSR Knowledge Contribution Framework (Gregor & Hevner, 2013). The application of the DSR Knowledge Contribution Framework as seen in figure 1 below, revealed that only six methods out the eight methods above had a distinctive contribution in detecting potential conflicting boundary lines for an effective mitigation of the land conflict.

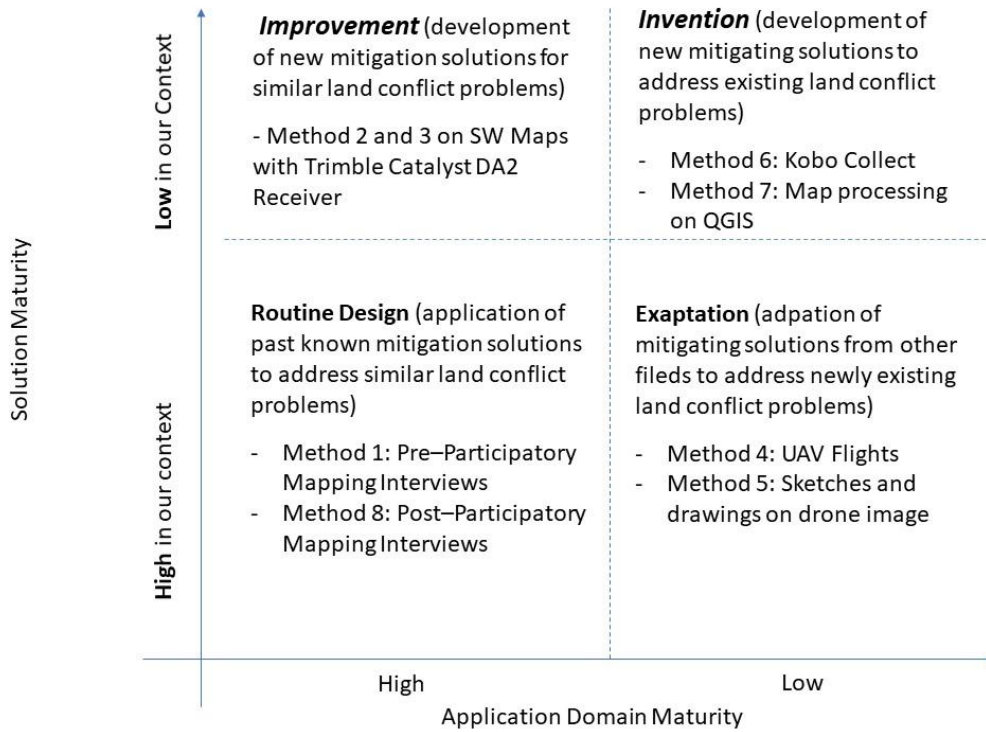


Figure 1: DSR Knowledge Contribution Framework (Gregor & Hevner, 2013) showing the distinctive contribution of each data collection method in terms of: improvement, invention, routine and exaptation.

A. Distinctive contribution of methods 2 and 3 in fostering improvements for mitigating land boundary conflicts

Trimble Catalyst DA2 (Trimble, 2021) is a different type of low-cost GNSS receiver developed in 2021 as a new solution to foster the improvements of participatory mapping in mitigating land conflicts. Its distinctive contribution is that: this method of Trimble catalyst DA2 helped to survey each farm parcel boundary lines by 0.01 cm accuracy for a perfect detection of the conflicting boundary lines between the five farm parcels. Also, during the mitigation process, Trimble Catalyst DA2 makes it easy to observe the proximity between the ground markers and GNSS derived GCPs coordinates (Israel, Sunday, & Matthew, 2023).

B. Distinctive contribution of methods 6 and 7 in promoting innovative inventions for land boundary conflicts mitigation

Methods 6 and 7 are innovative methods which helps to identify double allocation of land. Double allocation of land is an important factor which causes land conflicts. The allocation or sale of the same parcel of land to two different people (double allocation) is a serious land conflict because when it occurs, two or more people find themselves claiming the same plot of land, each of them having a valid certificate right of occupancy (THAMBIKENI, 2015). So, the use of kobo collects to obtain data on land ownership and the formalization of this land ownership on a QGIS software to produce the map for land titling is an effective mitigation strategy which we used in Mbalmayo to prevent this problem of double allocation of the same land parcel.

C. Distinctive contribution of Methods 4 and 5 in the reimagining existing solutions for land boundary conflicts mitigation

Method 4 on UAV flights is significant in determining the type of land use in an area. Drones (UAV) are a unique tool which helps to visualize what activities are been carryout on a land. UAV flights are therefore crucial for land use planning and management. Land use planning is used as a land conflict mitigation strategy by certain communities in Cameroon. So, the combination of UAV flights with sketches on drone images helps to clearly define and visualize the boundary lines of each land parcel, even when these land parcels have the same land use. “Land use” is the term used to describe the human use of land. It represents the economic and cultural activities (e.g., agricultural, residential, industrial, mining, and recreational uses) that are practiced at a given land parcel (EPA, 2024).

VII. CONCLUSION

In conclusion, this paper outlines a comprehensive framework for determining the unique and distinctive contribution of participatory mapping data collection methods in mitigating land conflicts. In this paper we place an emphasis on the pivotal role played by each of these eight methods in mitigating existing land boundary conflicts amongst farmers. The type of data layers present in these farms were significant in determining which method have similar data with another. The similarities between these methods of data collection clearly shows that to mitigate land boundary conflicts these methods cannot be dissociated from

one another, thereby showing their inter-linkages. But even though these inter-linkages exist, the differences portrayed by these methods in terms of data collected and, in the implementation, process made us to develop a framework that will bring out the unique contribution of each data collection method (Gregor & Hevner, 2013). To bring out these unique (distinct) contributions, we grouped these data collection methods in four categories: improvements; inventions; routine and exaptation. Methods 2 and 3 distinctive contributions are that the data they collect help to enrich the mitigation process by giving a virtual representation of the boundary lines which are inexistent on the field. Meanwhile the data obtained from methods 4 and 5 showed to the conflicting parties a visual representation of what their farms look like without boundaries thereby identifying the root cause of the conflict. And finally, the peculiar contribution of methods 6 and 7 in the mitigation process was the detection of boundaries deficiencies. The identification and combination of all these distinctive, unique and peculiar contributions enables us to understand the role played by each of these data collection methods when using participatory mapping to mitigate land boundary conflicts. With this appropriate understanding outline in our research paper, we hope that our paper will serve as guidelines for researchers and practitioners interested in mitigating land conflicts through participatory mapping approaches.

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INFORMED CONSENT STATEMENT

Informed consent was obtained from participants involved in the data collection process.

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X. CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; nor in the collection, analyses, nor in the interpretation of data; nor in the writing of the manuscript.

XI. REFERENCES

- Claudia, L., Auriol, D., Gergely, V., Kaspar, K., & Angela, S. (2023). The SmartLandMaps Approach for Participatory Land Rights Mapping. *Land, MDPI*, vol. 12(11), 1-21.
- EPA, U. S. (2024). *What are the trends in land use and their effects on human health and the environment?* Washington, DC: epa.gov.
- Evans, J. D. (2018). A Reciprocal Triangulation Process For Identifying And Mapping Potential Land Use Conflict. *Environmental Management Journal*, Volume 62, pp. 777–791.
- FAO. (2012). *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security*. Rome: Food and Agriculture Organization of the United Nations.
- Gregor, S., & Hevner, A. R. (2013). Positioning and Presenting Design Science Research for Maximum Impact. *Management Information Systems Research Center, University of Minnesota*, pp. 337-355.
- Israel, O. T., Sunday, O. O., & Matthew, O. I. (2023). *Comparative Analysis of GNSS-derived Ground Control points on UAV Orthomosaic Accuracies; A Case Study of The Federal Polytechnic Ado-Ekiti, Nigeria*. Akure: Remote Sensing and Geoscience information System Department, Federal University of Technology, Akure, Ondo State, Nigeria.
- Joan-Cristian, P., Francisco-Javier, M., Jordi, P., & Xavier, P. (2019). Comparison of four UAV georeferencing methods for environmental monitoring purposes focusing on the combined use with airborne and satellite remote sensing platforms. *International Journal of Applied Earth Observation and Geoinformation*, volume 75, March 2019, 130-140.
- Liliane, M. D., Romain, N. J., Caroline, M. S., Abigaëlle, T., & Loic, T. T. (2022). Quantifying Forest Loss in the Mbalmayo Forest Reserve (Center Region, Cameroon). *Journal of Geoscience and Environment Protection*, Vol.10, pp. 271-288.
- Lund, C., Odgaard, R., & Sjaastad, E. (2006). *Land Rights and Land Conflicts in Africa: A review of issues and experiences*. Denmark: Danish Institute for International Studies.

- Ringo, J. (2023). Roles of village land councils in mitigation of land conflicts in Ngorongoro district, Tanzania. *Heliyon - Cell Press, Volume 9, Issue 4, E15132, APRIL 2023*, 8 pp.
- Smith, D. A., Ibanez, A., & Herrera, F. (2017). The Importance of Context: Assessing the Benefits and Limitations of Participatory Mapping for Empowering Indigenous Communities in the Comarca Ngäbe-Buglé, Panama. *The International Journal for Geographic Information and Geovisualization, Volume 52 Issue 1, Spring 2017*, pp. 49-62.
- Socpa, A. (2011). New Kinds of Land Conflict in Urban Cameroon: the Case of the 'landless' Indigenous Peoples in Yaoundé. *Cambridge University Press, Africa , Volume 80 , Issue 4*, pp. 553-572.
- THAMBIKENI, M. (2015). Analysis of ICT application in mitigating land conflicts: case study oftanzania. *nternational Journal of Computer Science and Information Security (IJCSIS), Vol. 13, No. 11*, 6 pp.
- Trimble, C. G. (2021). *GIS/GNSS Data Collection with Trimble DA2 and Subscription-Based Catalyst*. Colorado: Trimble Geospatial.
- Wardell, D. A., & Lund, C. (2006). Governing Access to Forests in Northern Ghana: Micro-Politics and the Rents of Non-Enforcement. *ELSEVIER World Ddevelopment Journal, Volume 34, Issue 11*, pp. 1887-1906.



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CHAPTER 3:

Spatial relationships between farmlands and hydrographies in agrarian landscapes: A case study of two agrarian landscapes in OYACK – MBALMAYO, CAMEROON

Author: **Marcel Loyd MINKA**

African Journal on Land Policy and Geospatial Sciences (AJLP & GS)

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SPATIAL RELATIONSHIPS BETWEEN FARMLANDS AND HYDROGRAPHIES IN AGRARIAN LANDSCAPES: A CASE STUDY OF TWO AGRARIAN LANDSCAPES IN OYACK – MBALMAYO, CAMEROON.

¹Marcel Loyd MINKA

¹ Catholic University of Central
Africa,
loyd.minka@yahoo.fr
Yaoundé, Cameroon.

²Università Cattolica del Sacro
Cuore,
Faculty of Agricultural, Food and
Environmental Sciences,
Department of Animal, Nutrition
and Food Sciences (DiANA).
marcelloyd.minka01@icatt.it

ABSTRACT

Context and background

Climate induced disasters, human involvement, and changes in natural cycles have all had a profound, complex, and difficult-to-understand impact on rural landscapes, especially agrarian landscapes. Most of these negative impacts are been felt on farmlands and hydrographies. The term “spatial relationships” refers to the way objects are arranged in relation to one another in geographic space. For example, we can describe them as adjacency, contiguity, overlap, and proximity. The spatial arrangement of natural landscapes, human settlements, and infrastructure plays a critical role in influencing: the occurrence and intensity of climate-induced disasters; the exposure and vulnerability of populations; and the effectiveness of mitigation and adaptation strategies.

Objective and research questions:

While farmlands and hydrographies try to survive and resist to the negative impacts of climate induced disasters, no research has ever tried to find out the type of spatial relationships which exist between farmlands and hydrographies in an agrarian landscape. Our research is centered around the question: what type of spatial relationships exist between farmlands and hydrographies in agrarian landscapes? The absence of data on the spatial relationships which exist between farmlands and hydrographies is a gap which this study wants to fill in order to address the problem of farmlands exposure and vulnerabilities to climate change.

Methodology:

Understanding the spatial relationships which exist between farmlands and hydrographies in space can help to strengthen climate mitigation strategies and

	reduce the exposure level of the farmlands. In this paper, we provided analysis on the type of spatial relationships which exist between the farmlands and hydrographies found in the villages of Ngalat and Mbockoulu in the district of Mbamayo. Then we also provided some analysis on the use of map object relations through existing literature. Results: The results of our work identified seven different types of spatial relationships which exist between farmlands and hydrographies. These seven types of spatial relationships are : adjacency ; containment ; connectivity ; intersection ; disjoint ; overlapping ; and same space. Keywords: Spatial relationship, farmland, hydrography, landmark, agrarian, landscape, agriculture, geographical feature.
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I. INTRODUCTION

In spatial relationships, *“everything is related to everything else. But near things are more related than distant things”*, said Waldo R. Tobler. In analyzing spatial relationships, adequate representation of cartographic knowledge is required if maps are to be made in an automated manner. Part of this expert knowledge is comprised of structural knowledge embedded in the relationships between the objects depicted on a map, as these define the structures and patterns of the corresponding real-world objects that should be preserved and emphasized in the cartographic generalization process (Steiniger & Weibel, 2007).

Spatial object and spatial relationship are two basic concepts of GIS. Spatial object is the digital representation of a geographical entity or phenomenon, which forms the basis for data management and analysis. Meanwhile spatial relationship is the connection between spatial objects when geometric properties are considered. The commonly used classification of spatial objects as points, lines and areas, and they are suitable for data management (Renzhong, 1998). A good classification model (model representing the spatial relationships between two objects) should not only be good for representing real entities, but also good for revealing spatial relationships, therefore good for formalizing spatial analyses (Renzhong, 1998).

Spatial relationships between objects, such as buildings, vegetation, water bodies, transportation networks, and land use can significantly improve climate adaptation strategies by identifying more targeted, efficient, and context-sensitive actions (Chang, Anthony, & Anqi, 2020). For example, in the domain of climate-smart agriculture, the spatial relationships between soil types, crop patterns, topography, and water availability can help to: reduce emissions; improve precision agriculture; and ameliorates agroforestry planning by considering and analyzing the proximities between natural vegetation, farmlands and hydrographies. Secondly, in the domain of Disaster Risk Reduction (DRR) and Climate Adaptation, researches on spatial relationships between hydrographies, farmlands and human settlements will help to improve floodplain mapping (Chang, Anthony, & Anqi, 2020). Realizing an efficient floodplain map is very important because it will help to direct people on where to avoid new developments or relocate existing ones. Spatial relationships are therefore very crucial for aligning climate adaptation with the physical and human geography of a place. This leads to smarter land use, efficient infrastructure, and effective nature-based solutions (Mudashiru, Sabtu, Ismail, & Waheed, 2021).

Also, the spatial relationships between spatial objects illustrates how these different objects like buildings, forests, water bodies, and farmland are organized in a landscape. This arrangement can significantly influence

how exposed farmlands and people are to the impacts of climate change. By understanding and analyzing these spatial relationships, our study helps to reduce exposure and increase resilience (Anyu, Adrian, Maxime, & Sami, 2015). The data which we collected through this research in Ngalat and Mbockoulu (two villages of Mbalmayo) can be used to reduce exposure and increase resilience by conducting Hazard Mapping and Risk Zoning. This hazard and risk mapping can be done using GIS together with the spatial data we collected, in order to identify areas of high risk of drought and flooding. Aside from conducting hazard and risk mapping, the spatial data we collected and the results of this research can help improve land use planning in order to avoid high-risk zones. In summary, with regards to exposure to climate induced disasters, we say that managing spatial relationships helps reduce climate change exposure by: placing protective features (like forests) between hazards and vulnerable areas; Siting farms and communities strategically away from high-risk zones; Enhancing natural resilience (e.g., through water flow management and biodiversity); and facilitating better planning and response systems using spatial data. The results of our work identified seven different types of spatial relationships which are: adjacency; containment; connectivity; intersection; disjoint; overlapping; and same space. Though these seven spatial relationships, we noticed through this study that the intersection between farmlands and hydrographies can either be overlapping, within, disjoint, equal or bordering.

II. METHODS AND MATERIALS

A. Existing theories that inspired our study on spatial relationships

1. Tobler's Laws of Geography

Tobler's First Law in Geography states: "everything is related to everything else, but near things are more related than distant things." This principle, formulated by geographer Waldo Tobler in 1970, highlights the importance of spatial proximity in geographic relationships (Goodchild, Luc, Richard, & Barbara, 2000). It suggests that spatial phenomena are not randomly distributed; instead, there's a strong tendency for similar or related features to occur near each other. For example, two neighboring cities are likely to share similar climate patterns, economic connections, and cultural traits compared to cities that are farther apart (Goodchild, Luc, Richard, & Barbara, 2000). This foundational idea supports the logic behind spatial autocorrelation and underpins many methods in geographic information science (GIS), urban planning, and spatial analysis.

Though Tobler only formally articulated one "law," geographers often refer to his ideas collectively as "Tobler's Laws of Geography." These include concepts implicit in his work, such as the influence of scale, the role of spatial interaction, and the importance of modeling geographic patterns using mathematical or computational methods (Nigel, 2017). These broader "laws" emphasize that distance, direction, and spatial arrangement significantly influence how physical and human processes operate across space. Together, they provide a conceptual framework for understanding geographic phenomena and guide how we analyze, interpret, and visualize spatial data (Nigel, 2017).

2. Network Theory

The network theory is a framework used to analyze and understand how things are connected. In the context of spatial relationships, it focuses on how locations or places are linked through pathways or networks, such as roads, railways, rivers, or communication systems (Andris & O'Sullivan, 2021).

This theory treats spatial systems as networks of nodes (places) and links (connections). The key concepts in this network theory are: nodes (vertices), edges (links), network structure, and distance. Nodes are distinct points in space, often representing places of interest or critical junctions (Andris & O'Sullivan, 2021). Edges are the links or connections that allow movement or flow between nodes. In spatial network theory, edges often have attributes like distance, travel time, or cost associated with them. This allows for modeling not just connectivity but also the quality or efficiency of connections. The spatial arrangement of nodes and edges influences patterns of accessibility and movement (Andris & O'Sullivan, 2021).

A fundamental concept in network theory is connectivity, which measures how well nodes are linked to each other. Highly connected networks allow easy movement or communication between nodes, while poorly connected ones may have isolated points. Accessibility refers to the ease of reaching a particular node from others, influenced by the number and quality of connections. In spatial terms, accessibility affects everything from transportation planning to service delivery junctions (Andris & O'Sullivan, 2021).

As part of the review, the information, and data on the key challenges on securing women's land rights in these sub-regions have been analyzed. In addition, the identification of best and promising practices has been examined. The review also mapped out institutions in the land and policy sectors to help understand how power is distributed and assess the decision-making mechanism for strengthening women's land tenure security. Finally, the desk review provided important information and knowledge on the many challenges

confronting women as they seek to improve their livelihoods and access land for housing, agricultural production, and other uses. Land relations and governance systems are contingent on customary and statutory regulations, laws, and practices which shape how women and men access land in their families and communities. The context of access regimes is critical in identifying best practices and crucial lessons that can be drawn from varied locations.

B. Spatial data collection through UAV (aerial photography) with RGB and multispectral cameras

To define spatial relationships between objects, we collected data that capture the location, orientation, and interactions between features (landmarks) in the two agrarian landscapes. To collect these spatial data, we used drone mapping. This method of drone mapping involves using drones (unmanned aerial vehicles –UAVs) equipped with sensors, typically cameras, LiDAR, or multispectral sensors, in order to capture data. This data was then processed to create maps or 3D models.

1. The four steps applied to collected data

The data collection using drone (UAV) consisted in four basic steps. The first step is aerial imagery and GNSS data collection of the study area. The second step is the processing of the aerial imagery acquired during UAV flight using SfM (Structure from Motion) software, which is used to generate photogrammetric products. The image processing steps we used were: image alignment; sparse and dense point cloud generation; DSM; DOM; and 3D model production. The third step is spatial feature data extraction, using the produced 3D models, point clouds, and DSM spatial data. The last step aimed at using directly generated photogrammetry products and the extracted spatial feature data to build a spatial database to provide data support for the restoration.

2. The UAV style and platform

The UAV georeferenced images were collected by a Drone Phantom 4 pro. A total of 192 georeferenced images were obtained on a total surface area of 90 hectares for the two agrarian landscapes. A clear methodology was used to arrive at a final result which enabled us to generate the DSM and the Orthophoto. To obtain the 192 georeferenced images, we did the following three steps:

- a- **Automatic flight planning:** Here we made a delimitation of the area to be covered by the drone and we used the remote of the drone to set an automatic flight.
- b- **Preparation of the aircraft and mission:** the mission being scheduled, the flight parameters were checked and the drone was put on mission. This drone mission lasted 14 and 15 minutes, with an altitude of 50 meters from the starting point.
- c- **End of mission and image extraction:** at the end of the mission, the images were extracted to make room for photogrammetric processing.



Image 1. *The Drone Phantom 4 pro We Used*

UAV parameters & specifications	OYACK A	OYACK B
Number of images	413	385
Flying altitude	118 m	120 m
Ground resolution	3.94 cm/pix	4.01 cm/pix
Coverage area	0.285 km ²	0.121 km ²
Camera stations	412	385
Tie points	414,485	101,444
Projections	1,298,070	323,012
Reprojection error	1.34 pix	2.42 pix

Table 1. *Some UAV Meta Data of the automatic flights in the two agrarian landscapes (OYACK A & B)*

3. Aerial and ground mapping process

To properly carry out this study, the photogrammetry methodology was used in combination with cartography and field observations. Aerial and ground mapping was conducted on each of the two agrarian landscapes. The data collection process took place in the field from the 27th of April to the 22nd of May 2025. The following tools were used to conduct this study:

- Drone Mavic Platinum Professional: the drone was used to map all the sites. The area mapping was done at a fly altitude of 60m from home point within an average time of 20 minutes per site.
- Smartphones: they were used to record videos and capture images of strategic features (landmarks).
- GPS app: the GPS app (mobile topographer) was used to collect ground control points in the field and other important elements.
- Vehicles: public transport was used to easy movement in and out of the field.

Camera parameters & specifications	OYACK A	OYACK B
Camera Model	FC220 (4.73mm)	FC220 (4.73mm)
Camera Type	Frame	Frame
Resolution	4000 x 3000	4000 x 3000
Focal Length	4.73 mm	4.73 mm
Pixel Size	1.57 x 1.57 μm	1.57 x 1.57 μm
Precalibrated	No	No
Coordinate system	WGS 84 (EPSG::4326)	WGS 84 (EPSG::4326)
Rotation angles	Yaw, Pitch, Roll	Yaw, Pitch, Roll

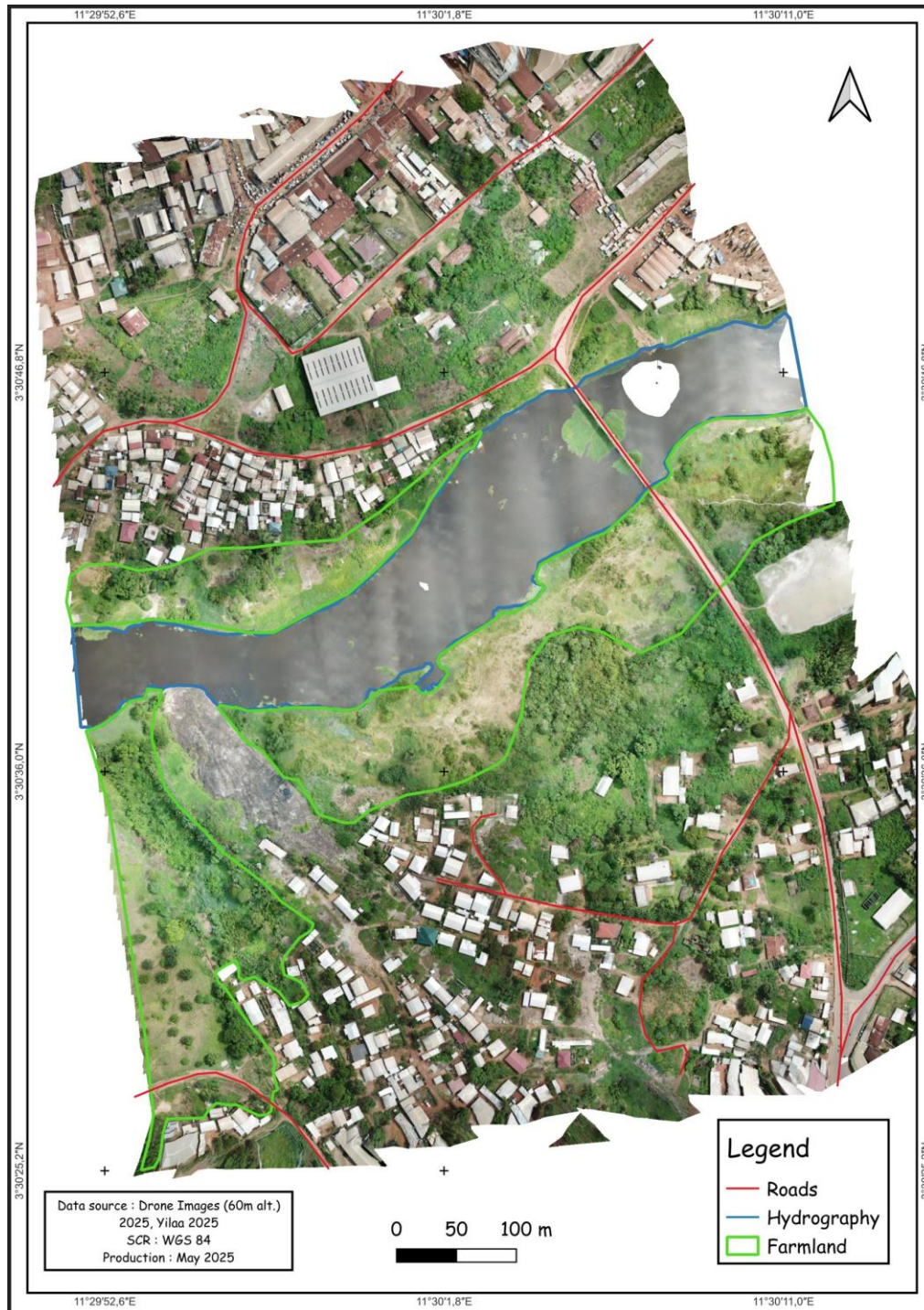
Table 2. *Aerial Photos Meta data of the two agrarian landscapes (OYACK A & B)*

C. Aerial drone maps of farmlands and hydrographies in the two landscapes

To define the spatial relationships, we used the data from the two aerial drone maps of OYACK A and OYACK B.

1. Drone map showing the farmlands and hydrographies in Landscape OYACK A

Approximatively, 50 hectares were mapped and considered as Oyack A. On this landscape, hydrographies like, rivers, creeks, ponds, swamps, floodplains, wells and farmlands were mapped. As we can see on the map below (fig. 1), presenting Oyack A our study site, we see that, the Nyong river (the main river) crosses the site in the middle. This main river is surrounded by farmlands with some high humid areas.



2. Drone map showing the farmlands and hydrographies in Landscape OYACK B

Approximatively, 40 hectares was mapped and considered as Oyack B. This site is situated at the western site of the Oyack A. On this landscape, hydrographies like creeks, ponds, swamps, floodplains, wells and farmlands were identified. As we can see on the map below (fig. 2), presenting OYACK B, the Nyong river also crosses the site in the middle. This Nyong river is surrounded by farmlands and other hydrographies with some areas likely to be flooded during rainy season. On this site, the farmlands are located in majority at the east of the site.

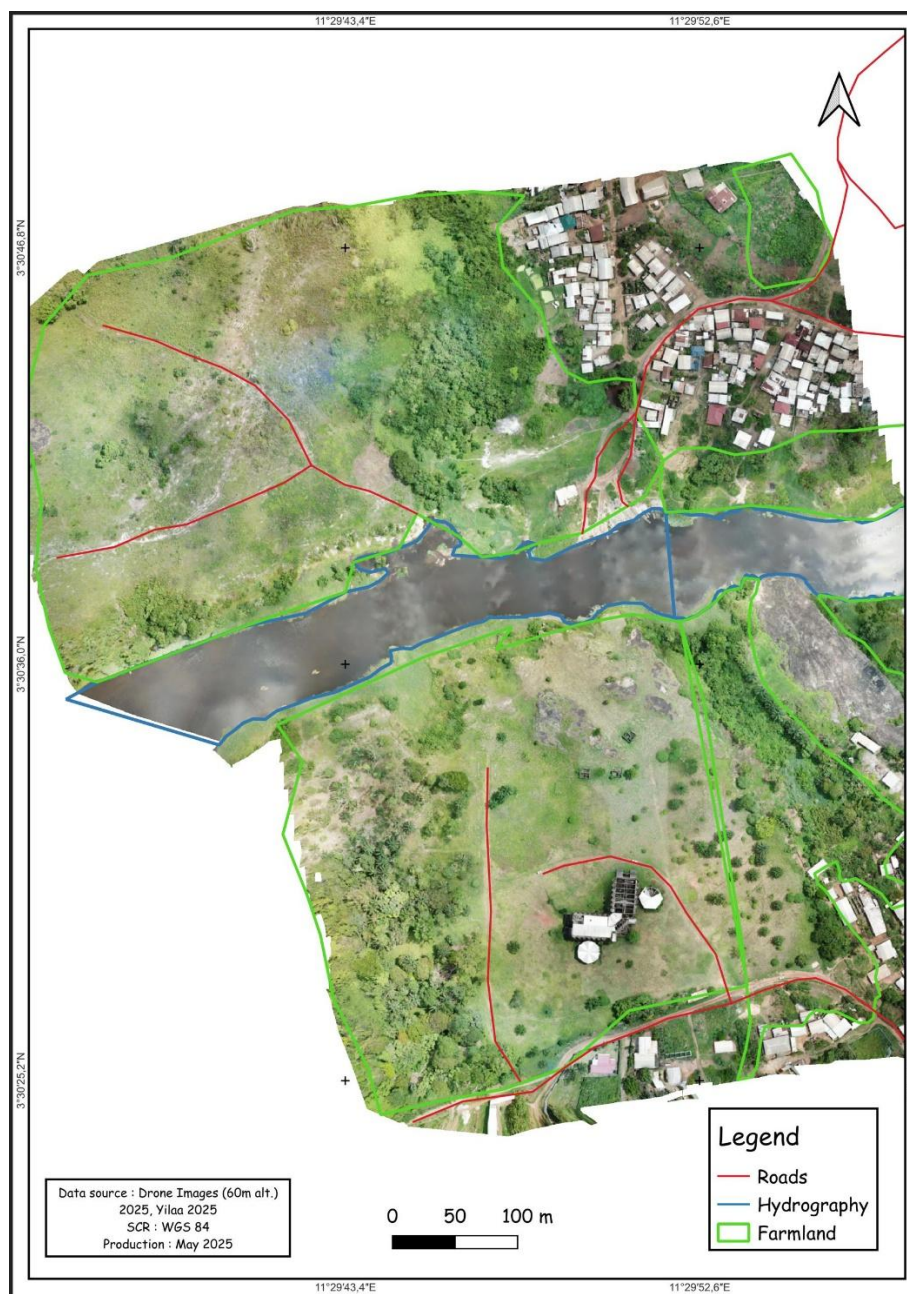


Fig. 2: The Aerial Drone Map of Oyack B with its farmlands and hydrographies

D. Digital elevation models of oyack a & b

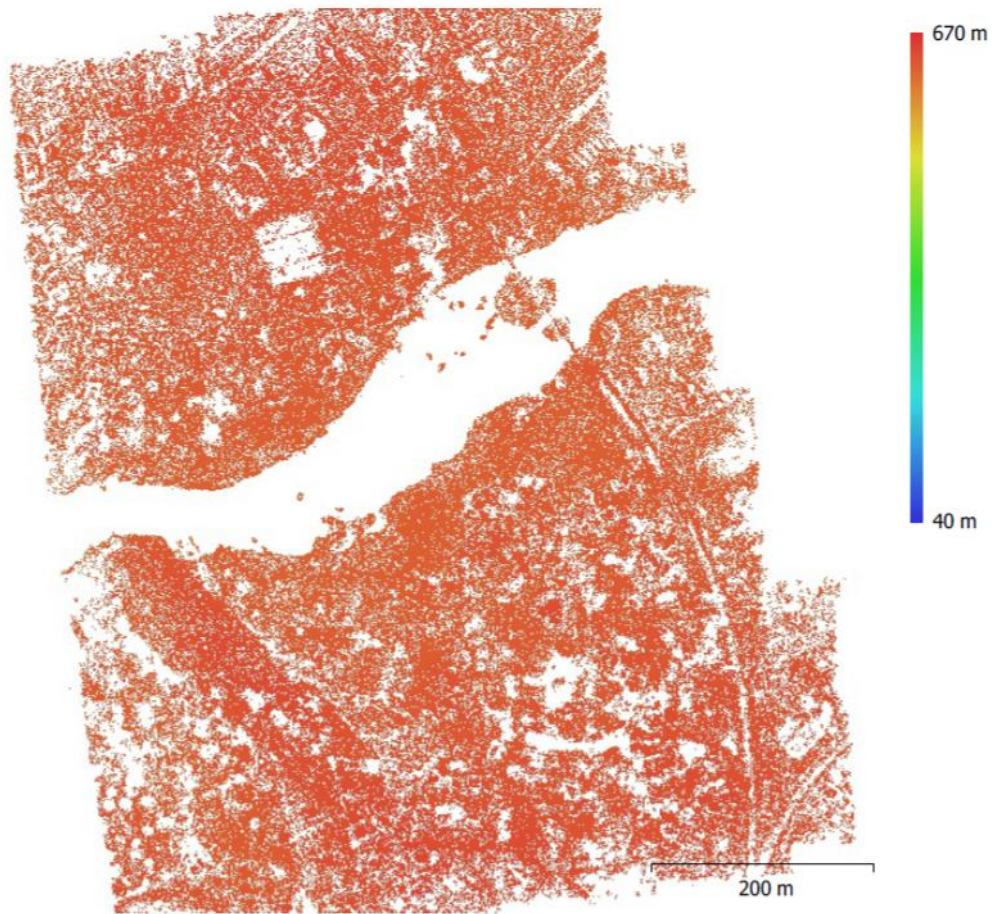


Fig. 3. Digital elevation model of OYACK A

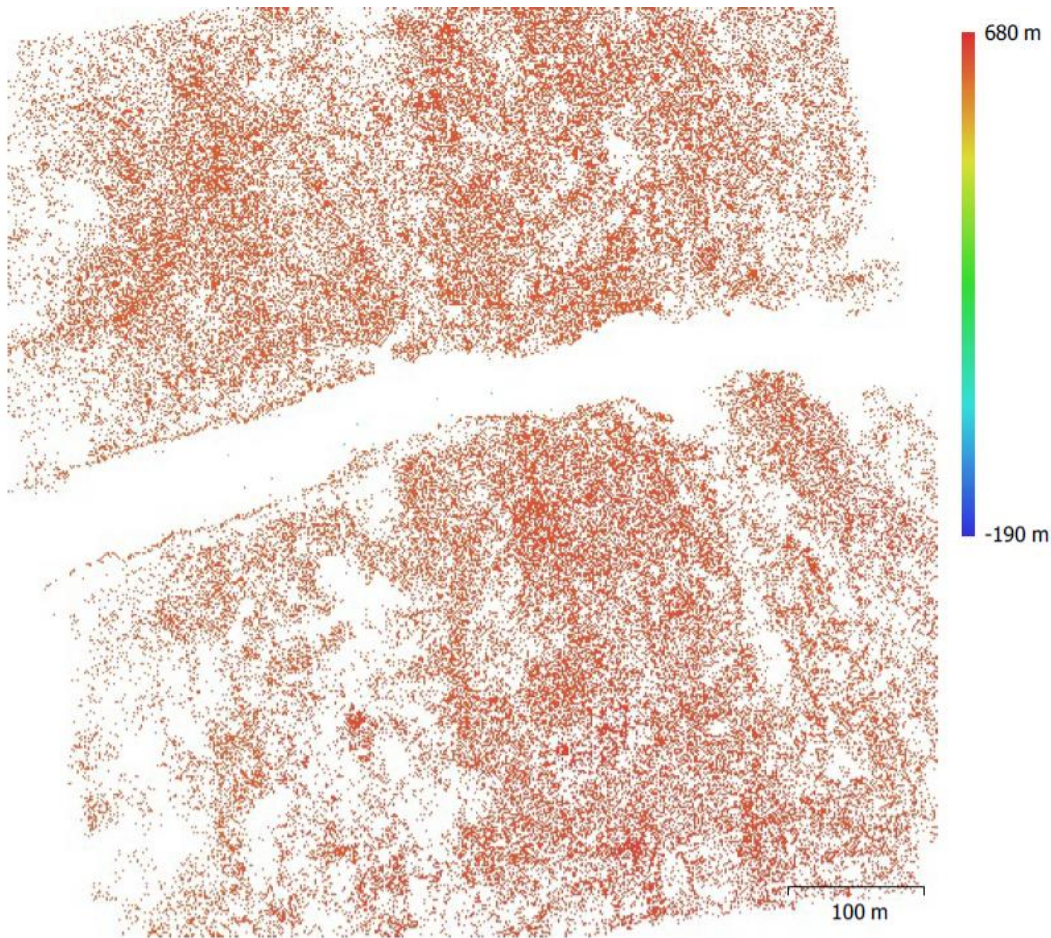


Fig. 4. *Digital elevation model of OYACK B*

III. DATA ANALYSIS

To define the spatial relationships between objects, we used the topological analysis. This topological analysis is a spatial analysis method particularly found in Geographic Information Systems (GIS) or spatial databases. The topological analysis is the most common types of analysis used to define spatial relationships.

A. Topological analysis

Topological analysis in spatial relationships is a method used in geographic information systems (GIS) and spatial data science to understand how geographic features relate to one another independently of their exact locations or distances. It focuses on the qualitative aspects of spatial relationships, that is how

geographic features are connected, adjacent, or contained within each other, rather than on their precise coordinates (Schneider & Behr, 2006).

In simple terms, topology is the mathematics of spatial relationships ($A \cap B = \{x | x \in A \text{ and } x \in B\}$). In GIS, it's used to model the relationships between different spatial features, such as: Points, Lines, and Polygons. It ensures data integrity (e.g., that polygons don't overlap incorrectly or the lines connect properly) and supports various types of spatial queries and analyses (Theobald, 2010).

The Topological analysis we did here consisted in verifying each drone maps (oyack A & B) and verifying the type of topological relationships that farmlands and hydrographies have. This verification was done on QGIS and it consist in the use of four geometric tools, which are the:

a- Topology Checker: After uploading the raster layer of each drone map (oyack A & B) on QGIS, we used this tool called Topology Checker to verify on QGIS software if farmlands and hydrographies share common boundaries.

b- Spatial Join: This spatial analysis tool checks whether geometry A (feature A) is completely inside geometry B (feature B). If this tool finds out that A is completely inside B, this means that all points of A lie within B, and none are on the boundary or outside (Jacox & Samet, 2007).

The scientific expression used to describe this type of relation is = ***within ()***. For example, ***A is within () B***

In QGIS, a Spatial Join is a GIS operation that combines attributes from one layer to another based on their spatial relationship. It's commonly used when you want to answer spatial relationship questions like: "Which polygon does this point fall into?" and "Which features are nearest to each other?" (Jacox & Samet, 2007).

c- Topological Validation: In QGIS, topological validation is used to verify if map features (like lines or polygons) are connected at a node or at a point called the "Topological Validation". In this type of spatial relations, the line or polygons of the two map features (farmlands and hydrographies) should be connected properly, with no gaps nor overlaps between their polygons. And the boundary lines of these farmlands and hydrographies should meet at nodes (Alderson, Li, Willinger, & Doyle, 2005).

The scientific expression used to describe this type of relation is: *connected at a node or at a point*. For example, *A is connected to B at a node*.

In spatial or topological terms, when we say "A is connected to B at a node," it usually means: A and B share a common point (node), which serves as the location where the two spatial entities are joined or intersect (Alderson, Li, Willinger, & Doyle, 2005).

d- Topology Rules: In the QGIS software, to verify if the map features do not share space (i.e., do not overlap or intersect) we used the tool or function called "Topology Rules". In this analysis, we used the Topology Rules on QGIS to determine three outcomes in the spatial relationships between farmlands and hydrographies (Schneider & Behr, 2006). These three outcomes are :

- farmlands and hydrographies overlap or touch;
- farmlands and hydrographies do not share same space;
- farmlands and hydrographies partially share same space.

Therefore, in QGIS, we set up (plugged) the topology rules in the following three terms:

- i- Must not overlap: To check if polygon features overlap each other.
- ii- Must not intersect: For line or polygon features to ensure they don't cross or overlap.
- iii- Must not have gaps: To ensure polygons share edges without gaps.

In the landscape of OYACK A and OYACK B, there are six types of hydrographies and four types of farmlands. These six types of hydrographies are Rivers; Creeks; Ponds; Wetlands (swamps); Floodplains; and Wells. Meanwhile the four types of farmlands are Arable Land; Pastureland (Grazing Land); Orchard or Plantation Land; and Mixed Farming Land. Therefore, the spatial relationships which we analyzed and determined through the above topological analysis are the spatial relationship which exist between the above six types of hydrographies and four types of farmlands. The results below (spatial relationship matrix) clearly illustrates the various spatial relations which exist between these types of hydrographies and farmlands in the agrarian landscapes of OYACK A and OYACK B.

IV. RESULTS

A. The spatial relationship matrix

	Rivers	Creeks	Ponds	Swamps	Floodplains	Wells	Arable Land	Grazing Land	Orchard Land	Mixed Farming Land
Rivers	—	A	A	C	A	E	E	E	E	E
Creeks	A	—	C	A	A	E	A	A	E	E
Ponds	A	C	—	C	A	E	A	E	E	A
Swamps	C	A	C	—	B	E	A	A	E	A
Floodplains	A	A	A	B	—	E	A	A	E	A
Wells	E	E	E	E	E	—	F	F	F	F
Arable Land	E	A	A	A	A	F	—	D	D	B
Grazing Land	E	A	E	A	A	F	D	—	B	C
Orchard Land	E	E	E	E	E	F	D	B	—	D
Mixed Farming Land	E	A	A	A	A	F	B	C	D	—

The meaning of the Codes (A, B, C, D, E, F, —) used in the above spatial relationship matrix:

A = Adjacency (Features share a common boundary)

B = Containment (One feature is completely inside another)

C = Connectivity (Features are connected at a node or point)

D = Intersection (Features overlap or touch)

E = Disjoint (Features do not share space)

F = Overlapping (Features partially share space)

— = Same space (Features completely share space)

B. Visual representation of the seven spatial relationships

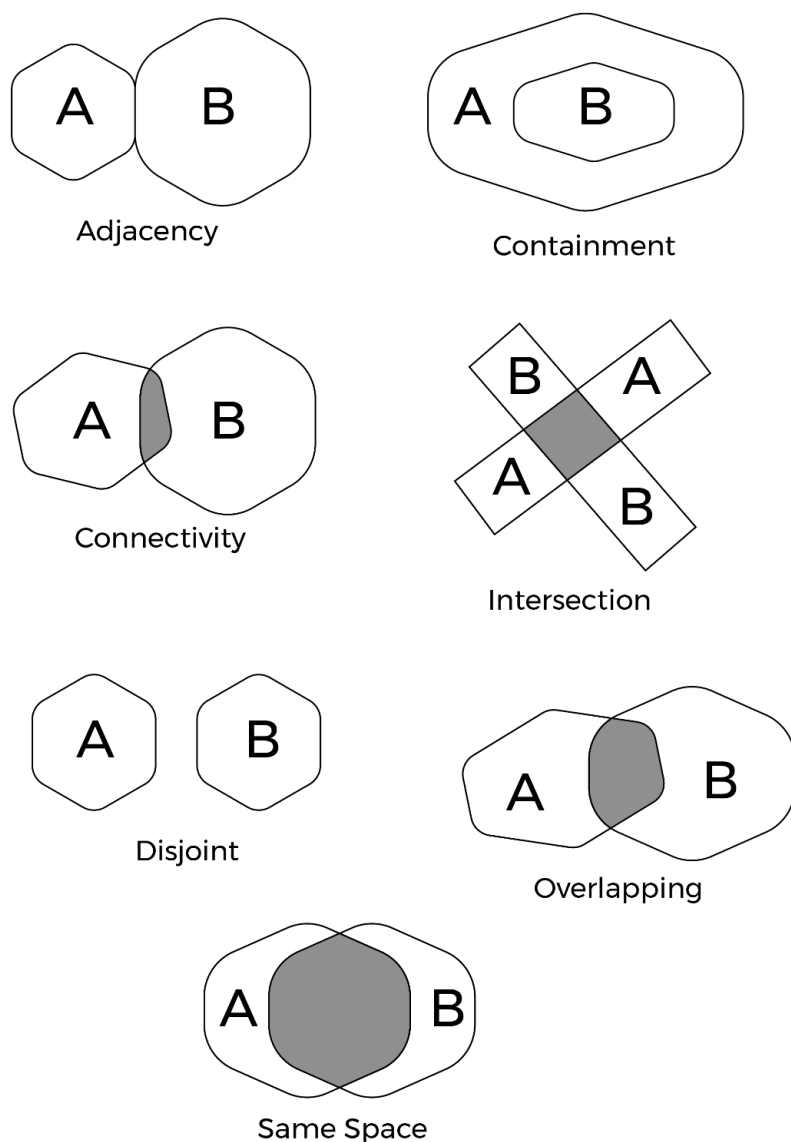


Fig. 5. Visual representation of the seven spatial relationships which exist between the hydrographies and farmlands in the two agrarian landscapes of OYACK.

C. The conceptual frameworks

These conceptual frameworks are based on the spatial relationships which exist between the various types of hydrographies and farmlands. In the agrarian landscapes of OYACK A and OYACK B, there are six types of hydrographies which are: rivers, creeks, ponds, swamps, floodplains, and wells. On the other hand, the farmlands are divided into four types, which are: arable lands; grazing lands, orchard lands; and mixed farming lands. Each of the relationships between the above types hydrographies and farmlands is been defined by a spatial concept which exist in spatial sciences. These spatial concepts have been developed by some authors, amongst which we have Egenhofer Max and Franzosa Robert. The spatial concepts which these two authors developped are : Disjoint, Containment, Overlap, Same space, Intersection, and Adjacency. Egenhofer & Franzosa (1991) introduced the *9-Intersection Model (9IM)* to define topological relationships like containment, disjoint, overlap, and adjacency (Egenhofer & Franzosa, 2007).

The spatial concepts found in the three conceptual frameworks below helps us to understand the type of spatial relationships which exist between these various types of hydrographies and farmlands. The first conceptual framework illustrates the spatial relationships which exist between the six types of hydrographies (Fig. 1). Meanwhile the second conceptual framework illustrates the spatial relationships which exist between the four types of farmlands (Fig. 2). And finally, the third conceptual framework illustrates the spatial relationships which exist between the six types of hydrographies and the four types of farmlands (Fig. 3).

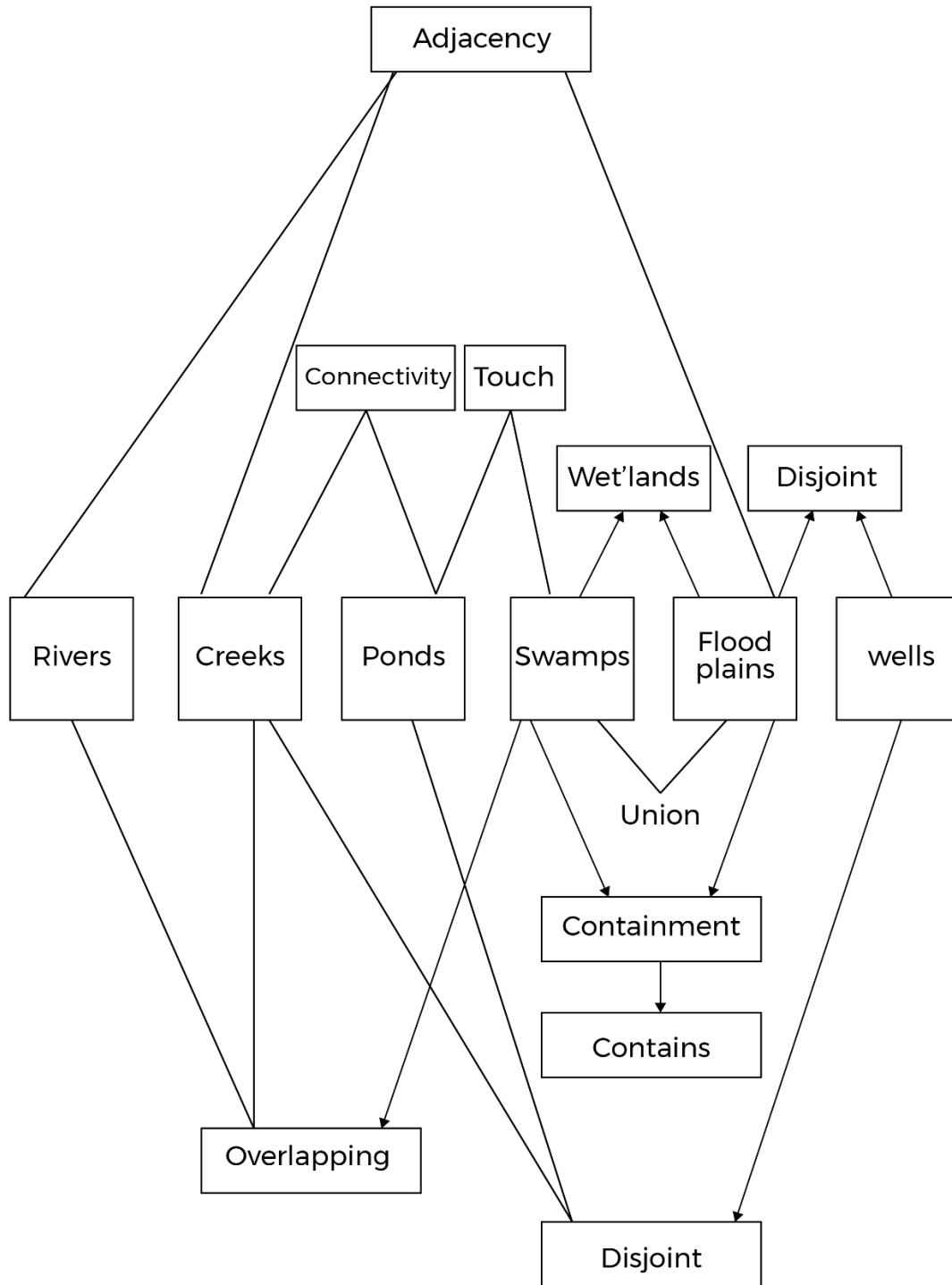


Fig. 6. Conceptual Framework on the spatial relationships which exist between the six types of hydrographies in the two agrarian landscapes of OYACK

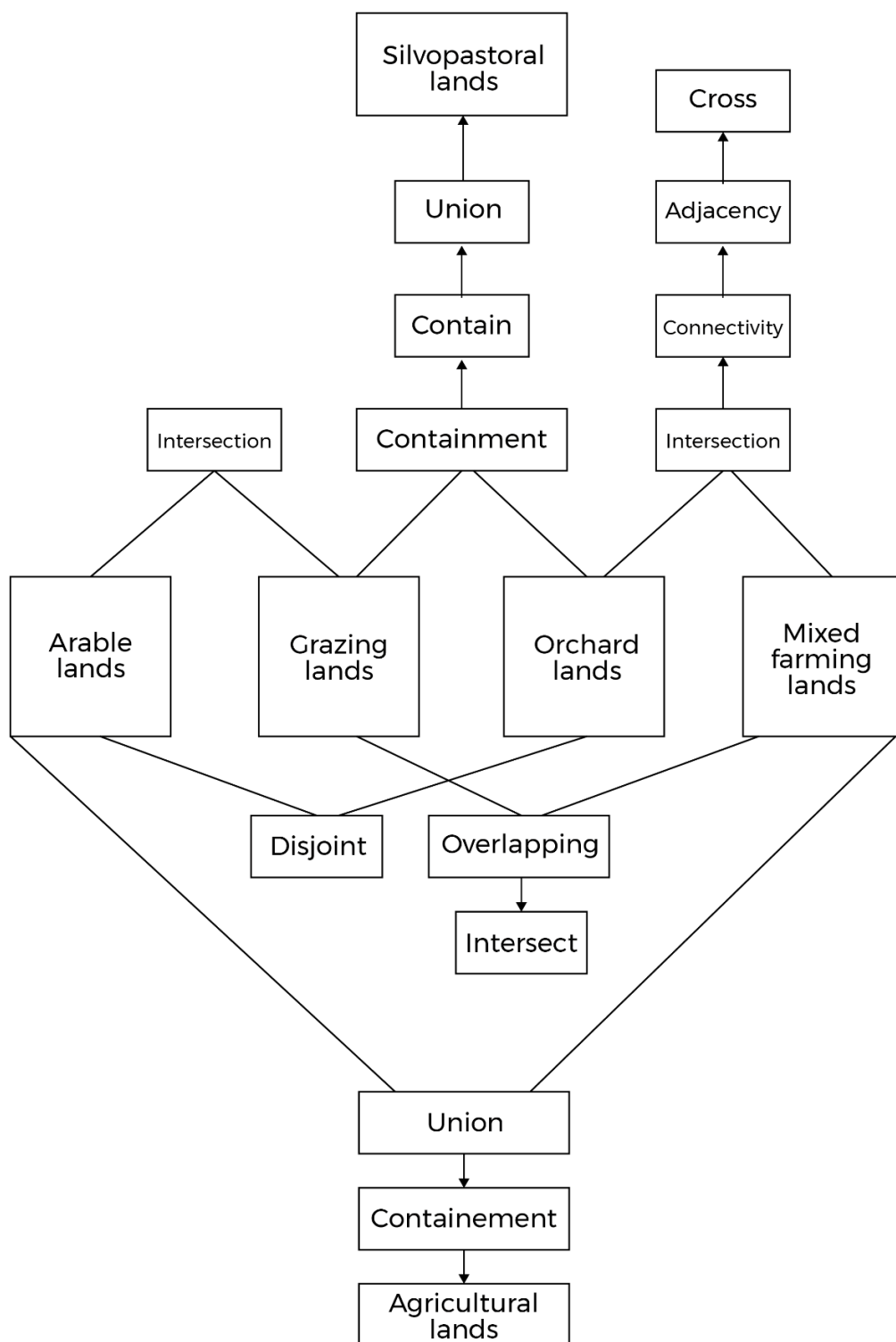


Fig. 7. Conceptual Framework on the spatial relationships which exist between the four types of farmlands in the two agrarian landscapes of OYACK

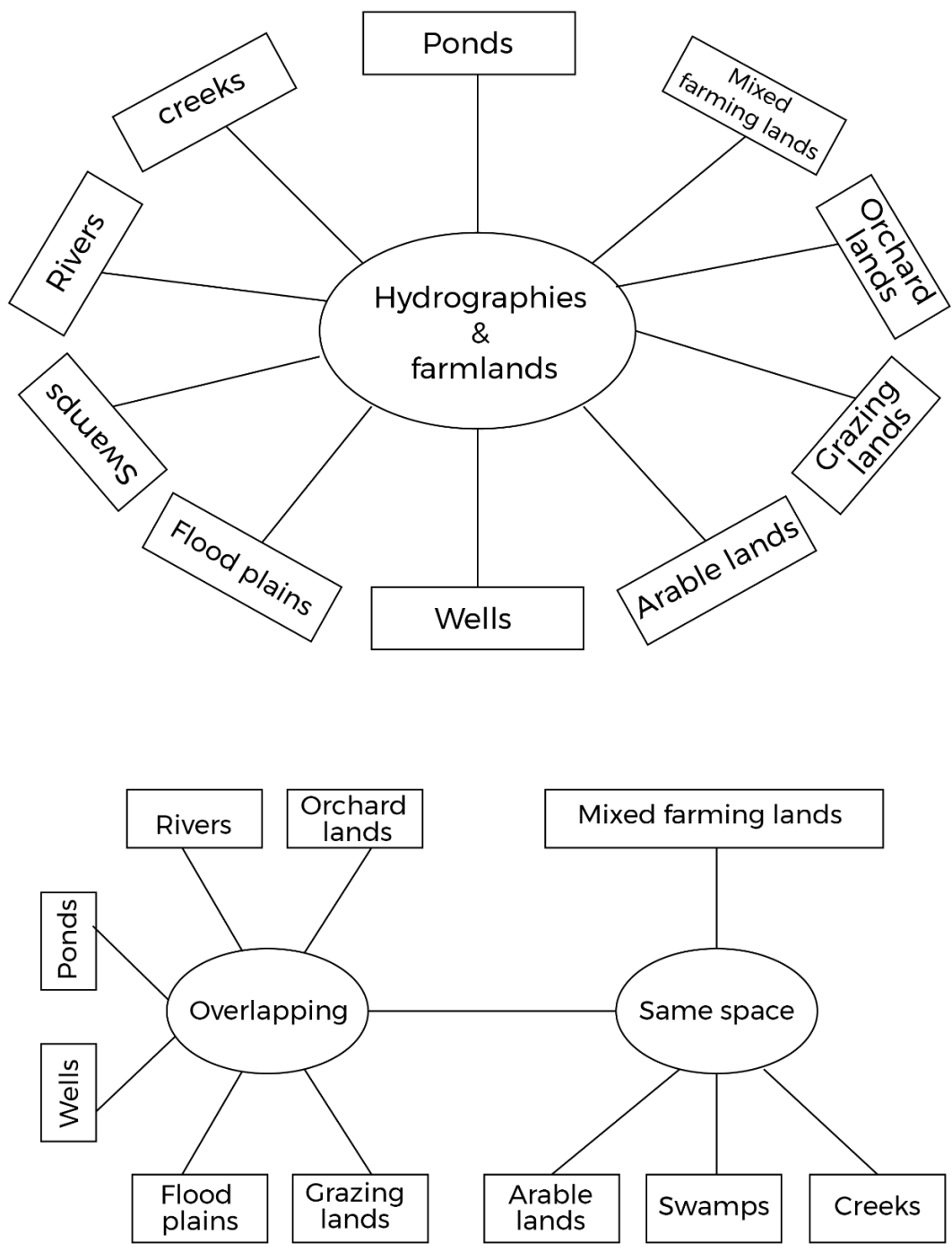


Fig. 8. Conceptual Framework on the spatial relationships which exist between the hydrographies and farmlands in the two agrarian landscapes of OYACK

V. DISCUSSION

Our conceptual framework on spatial relationships provides a systematic way to understand how things are positioned and interact in space. It integrates all the foundational concepts that describes the typology of the relationship, with real-world applications, making it essential for disciplines concerned with space, movement, and human-environment interactions. One of the most concerned applicable scientific disciplines here are : physical geography, geospatial science, cartography, environmental science, regional planning, and cognitive science. In Everyday life (real-world applications), the identification and analysis of these spatial relationships between hydrographies and farmlands can help to reduce crop destruction, soil erosion, waterlogging, livestock loss, damage to infrastructure, etc. For example, the identification of a spatial relationship concept like "near," "within," or "intersects" between hydrographies and farmlands, can help understand the factors which led to an increase in flood zones overlapping residential areas. In this section, we discuss each relational concept and identify some consequences that these spatial relationships had on the agrarian landscapes of OYACK A and B.

A. The relational concept of "Adjacency"

The relationship concept that defines the spatial relationship between river and creeks is adjacency, meaning that in the agrarian landscape of OYACK (in Mbalmayo, Cameroon), river Nyong and the creeks share a common boundary. This closeness (common boundary) will give rise to increased runoff in the event of a heavy rainfall. "Topology-based proximities in spatial systems" considers adjacency and proximity relations as spatial partitions and this describes how adjacency can be formalized in spatial topology or dual graphs (Bera & Claramunt, 2003).

The relational concept of adjacency refers to the idea of closeness or immediate connection between two elements within a structured set. In Spatial Sciences, the relational concept of adjacency refers to the spatial relationship between entities based on their proximity or shared boundaries. Rather than treating space as an absolute framework (as in Euclidean geometry), the relational approach emphasizes how spatial objects relate to each other, in this case, whether they are "adjacent" or not (Bera & Claramunt, 2003).

For example, in early 2022, Eastern Australia experienced prolonged and intense (heavy) rainfall, which saturated the Wilsons River. This river saturation occurred near a creek and this give rise to an increased runoff. This river saturation was caused by saturated soils and already high river levels due to previous rainfall,

combined with more heavy rain, leading to significant runoff and flooding (Reid, 2025). The runoff overwhelmed smaller creeks and tributaries, causing flash floods and riverbank overflows. After days of heavy rain, the Wilsons River overflowed, fed by saturated catchments and excessive runoff from surrounding land and smaller creeks. The flooding broke records and inundated homes and infrastructures, with many areas experiencing catastrophic flooding (Reid, 2025).

Also, in some cases the concept of adjacency has been used to define the spatial relationship between orchard land and mixed farming lands. This is the case in India, where there is a wide variety of climatic zones, allowing for both orchards (like mangoes, apples, bananas) and mixed farming (crops + livestock). In the hilly and rural regions of China, orchards (e.g., apples, peaches) border mixed farming zones. And in the mediterranean regions of Spain, olive and citrus orchards exist near mixed farms (Monfreda, Ramankutty, & Foley, 2008).

Components	Orchard Land	Mixed Farming Land	Spatial Relationship/Interaction
Use	Fruit/nut trees	Crops + livestock	Often adjacent
Terrain	Slopes, valleys	Flat or gently sloped	Complementary placement
Resource use	Water, labor	Water, labor	Shared/competing
Integration	Can be part of mixed farms	Often includes small orchards	Interlinked in land management

Table 3: Observed components on the spatial relationship between orchard land and mixed farming lands in OYACK, Mbalmayo – Cameroon.

B. The relational concept of "Containment"

In the agrarian landscapes of OYACK, in Mbalmayo, this relational concept describes the spatial relationship which exist between: swamps & floodplains; Grazing land & Orchard land; and between arable land & mixed farming land. This spatial relationship is very important because it enables the fusion (combination) of the agrarian landmarks who are in the relationship. The combination of these two landmarks gives rise to a new landmark. According to our results, containment means one landmark is completely inside another (what we describe as fusion of the agrarian features). While Massey (2023) does not usually use “containment” in a strictly topological sense, she strongly argues that space is relational, multiple, processual. Her relational conception of space implies that bounded and enclosed spaces (i.e. “containers / territories”) are not fixed

but socially produced, contested and penetrated by flows, relations, and power geometries (Werner, Lave, Christophers, & Peck, 2018).

For example, the spatial relationship between swamps and floodplains is described by the concept of containment. This containment (fusion) between swamps and floodplains gave rise to a new landmark (or new feature) called "wetland". Next to this first example, is the second spatial relationship between Grazing lands & Orchard lands which we conceptualized as containment. Unlike the first example whose fusion gave rise to wetlands, the containment (fusion) relationship between Grazing lands and Orchard lands gave rise to a new landmark in Mbalmayo called "Silvopastoral Lands". This silvopastoral lands are a new type of farmland that emerged in the agrarian landscapes of OYACK since 2018.

Silvopastoral land refers to land where trees, forage (grasses or legumes), and livestock are intentionally integrated into a single system for mutual benefits. It's a type of agroforestry specifically designed to combine silviculture (tree cultivation) with pastoralism (livestock grazing). Silvopasture, is therefore an integrated land use practice that combines trees, forage and livestock (Jose & Dollinger, 2019).

Finally, the last example in our results which illustrates the relational concept of containment is the spatial relationship between arable land & mixed farming land. In this spatial relationship most arable lands in the landscapes of OYACK are completely found inside mixed farming lands. To be specific, all the mixed farming lands in OYACK are arable lands. The mixture or containment of these two lands gave rise to a well known and existing type of land which is called "agricultural land". Agricultural lands make up 70% of the total landscape of OYACK, thereby confirming the agrarian nature of this landscape. The major activity practiced in OYACK and in Mbalmayo is agriculture. Mbalmayo is the epicenter of agricultural activity in Cameroon's central area, as agriculture is the primary source of income of the inhabitants. (*Mounjouenpou et al., 2014*). Subsistence farming and shifting slash-and-burn techniques are the primary agricultural methods used in Mbalmayo. Other cash crops grown there include palm oil, palm kernel oil, coffee, and cocoa (*Liliane et al., 2022*).

C. The relational concept of "Connectivity"

The relational concept of connectivity defines a spatial relationship in which two features are connected at a node or point. This connection at a node characterizes the connection between objects or elements in a physical space (Olson & Olson, 2000). The relational concept of connectivity is characterized as a face-face relationship (see fig. 5 above in results section), where the connection is mostly sequential at the level of the

rings or nodes. Here the node is a point at the boundary of the landmarks (geographical features). This node also serves as intersection between the two geographical features. In spatial sciences, two nodes are connected if there is a path between them (Olson & Olson, 2000).

In the agrarian landscapes of OYACK, there are five geographical features (landmarks) whose spatial relationship is connectivity. This connectivity characterizes the spatial relationship between: Creeks and Swamps; Creeks and Ponds; Grazing lands and Mixed farming lands; Orchard lands and Mixed farming lands.

In summary, the relational concept of connectivity, tells us that when two landmarks are connected at a node in spatial sciences, it means that these two landmarks share a common point in space and are topologically connected. This connection creates an enabling movement, flow and interaction between these two features at a particular location (see fig. 5 above in results section). In his book titled "*The Rise of the Network Society*", Castells (1996) introduced the idea of "space of flows", where connectivity between landmarks is defined by networks of communication, capital, and power. He emphasizes that connectivity is a social and technological construct, shaping how cities and regions function (Castells, 1996).

D. The relational concept of Intersection

In this spatial relationship, the landmarks meet, touch or even overlap at a certain area of their shape. Their intersection is the part (area) which they have in common, for example two roads crossing at a point, their intersection is the point where they meet (Egenhofer, Mark, & Herring, 1994). In GIS or geometry, if you have two spatial objects "A" and "B", the intersection is: the set of all points that belongs both A and B. In mathematics it is represented as: $A \cap B = \{x | x \in A \text{ and } x \in B\}$.

Max J. Egenhofer & John Herring (1994) developed the 9-Intersection Model (9IM) and related intersection relationship frameworks (interiors, boundaries, exteriors) to categorize how regions only meet, overlap, and are contained (Egenhofer, Mark, & Herring, 1994).

In the agrarian landscapes of OYACK, which is our area of study, we succeeded to identify two spatial relationships whom are intersectional. These two spatial relationships are: Arable lands & Grazing lands; and Orchard lands & Mixed farming lands.

Practically, in OYACK, in Mbalmayo, when arable land and grazing land intersect or overlap, it creates a shared land-use zone where both farming (crop production) and grazing (animal pasture) potentially occur. This has important implications in land management, planning and resource sustainability. This shared land-use zone

is called "mixed-use agriculture" or "mixed farming land". Here the mixed land is used for both crops and livestock at different times. After harvesting grain, livestock graze on the remaining stubble. Apart from this mixed land, the intersection between arable lands and grazing lands has some negative consequences on community life. This negative consequence is land-use conflicts. In the landscapes of OYACK, the point of intersection at which arable lands and grazing lands meet causes land-use conflicts. To be specific, this mixed-use agriculture causes land conflicts between farmers and pastoralist. Land-use conflicts are the competing interest between crop farming and grazing and this competing interest can lead to soil degradation, overuse and disputes. This is what happens in OYACK, every time when cattle damages young crops.

E. The relational concept of "Disjoint"

In spatial relationships, *disjoint* refers to a condition where two or more geometric objects (such as points, lines, or polygons) do not share any points in a physical space. This means they have no intersection because they are completely separate from each other (*Anthony Galton, 2009, Spatial and temporal knowledge representation*). For example, two circles that are far apart and do not touch nor overlap are considered disjoint. The concept is commonly used in geographic information systems (GIS) and spatial databases to determine how landmarks relate to one another in a physical space (Galton, 2009).

Max J. Egenhofer & Robert D. Franzosa (2007) defined spatial relations between regions (sets) using intersections of interiors, boundaries, exteriors, etc. One of the relations they discuss is disjointness: which means that two regions have no point in common (Egenhofer & Franzosa, 2007). Their “n-intersection” or “9-intersection model” is another standard in GIS and spatial reasoning, in which “disjoint” is one of the topological relations (Egenhofer & Franzosa, 2007)..

In the agrarian landscapes of OYACK, there are eight landmarks (geographical features) that are in a disjoint spatial relationship. These disjoint spatial relationships concern the relationship that wells have with every hydrographies and farmlands. These hydrographies and farmlands that are in a disjoint relationship with "wells" are: rivers, creeks, ponds, swamps, floodplains, arable lands, grazing lands, orchard lands, and mixed farming lands.

Also, our spatial analysis and the observations we carried out on the field revealed that in the landscapes of OYACK, the arable lands and orchard lands do not share the same space and do not intersect. This means that the arable lands and orchard lands have a disjoint spatial relationship. When we looked at the GIS layer

of land use found in the spatial dataset of OYACK A & B, we noticed that arable land polygons and orchard land polygons are close each other, but not adjacent nor overlapping, but rather disjoint.

Being disjoint is important in spatial analysis because it helps identify landmarks that are spatially independent. This can be useful in many applications, such as urban planning, environmental monitoring, or navigation. For instance, if two land parcels are disjoint, it indicates that they do not touch and can be treated as separate entities for zoning or ownership purposes.

F. The relational concept of "Overlapping"

Overlapping in spatial relationships refers to the visual phenomenon where one object partially covers or obscures another. This creates a sense of depth and relative positioning in space, as the object that overlaps is perceived to be closer to the viewer than the one being overlapped. This relational concept is widely used in visual arts, design, architecture, geomatics and geography.

In geographical contexts, overlapping can also describe how different spatial entities, such as land uses, zones, or features on a map interact when they occupy the same area or when they intersect. For example, a flood zone may overlap with residential neighborhoods, highlighting areas of potential risk (Egenhofer & Franzosa, 2007). In this way, overlapping helps in understanding complex spatial dynamics by illustrating how different elements coexist within a shared space. Max J. Egenhofer & Robert D. Franzosa (2007) also worked on the relational concept of overlapping. They worked on point-set topological relations, defining relations between sets (regions) in GIS, including intersections of interiors, boundaries etc. Overlapping in their frameworks is captured via intersecting interiors, boundaries under the DE-9IM related models (Egenhofer & Franzosa, 2007). Overlapping is one of the relations definable under their model. It occurs when interiors intersect, but are not contained wholly (fully) in one another.

In the agrarian landscapes of OYACK, there are two main hydrographic landmarks that overlap. These landmarks are: Rivers and Swamps. The spatial relationship of overlapping between rivers and swamps improves biodiversity, natural habitats and nutrient exchange. The connection or connectivity between rivers and swamps creates diverse habitats for fish, amphibians, birds, and other wildlife. Here fishes can migrate between the river and swamps for spawning, feeding and refuge. Swamps serves as nurseries and shelters for many aquatic and semi-aquatic species. Finally, nutrients from the river water can enter the swamps, enriching the soil and supporting diverse plant life. Organic matters from the swamp (like decaying plants)

can enter the river, thereby supporting aquatic lives. On the other hand, the farmlands that overlap are grazing land and mixed farming land.

G. The relational concept of "Same Space"

In spatial relationships, the term "same space" refers to the condition where two or more objects, people, or landmarks occupy or exist within the same area (Carniel, 2024). This can mean sharing the exact location or overlapping within a defined boundary. The term "same space" in the context of spatial relationships usually refers to the idea that two or more objects or landmarks occupy the same physical area or location within a given reference frame or environment (Carniel, 2024).

In this study, we categorized landmarks in the relational concept of same space if these two shapes or points of the landmarks are said to occupy the same location. In coordinate systems, it could mean having the same coordinates (x, y, z) , that is having the same exact position (Carniel, 2024).

In the agrarian landscape of OYACK A, the northern part of the river Nyong and floodplains found before the bridge, completely share the same space, and have the same coordinate systems which are: $(X, Y) = (11.50091, 3.51121)$.

Also, in this same agrarian landscape, a particular grazing land and an orchard land completely share the same area, thereby having the same coordinate systems. These coordinate systems are : $(X, Y) = (11.50217, 3.51059)$.

VI. CONCLUSION

In conclusion, the spatial relational concepts of connectivity, overlapping, disjoint, intersection, containment, and adjacency offer essential insights into the interactions between farmlands and hydrographies within agrarian landscapes. These relationships form the basis for understanding how water systems influence: agricultural productivity, land management practices, and ecological sustainability. By systematically analyzing these spatial interactions, it becomes possible to assess the potential for water sharing, flood risks, and nutrient flow between land and water bodies. This will help determine factors that are critical to both short-term farming success and long-term landscape resilience.

Our research demonstrates that the spatial relational concepts of connectivity and intersection between farmlands and hydrographic landmarks often correlate with both opportunity and vulnerability, as proximity to water can support irrigation but also increase exposure to runoff, floods and contamination. Meanwhile, containment and overlapping relationships may signal areas of integrated land-water systems that require nuanced governance, particularly where farmland encroaches upon riparian zones or wetlands. Disjoint and adjacent relationships, while seemingly less interactive, still play a role in determining accessibility to water resources and in shaping conservation buffer strategies.

Ultimately, applying these spatial relational concepts allows for more precise, data-driven approaches to land-use planning and environmental monitoring in agrarian regions. Such analysis supports decision-makers in optimizing agricultural productivity while mitigating environmental degradation. As climate change and land-use pressures intensify, leveraging spatial relationships between farmlands and hydrographies will become increasingly vital to ensuring both food security and watershed health in rural landscapes.

By applying spatial analysis tools to map and quantify these relationships, our study provides a framework for assessing landscape functionality in agricultural contexts. Understanding the spatial dynamics between farmlands and hydrographies can inform more integrated and sustainable land management practices, particularly in regions facing increasing climatic and environmental pressures. Future research works from colleagues should incorporate temporal data and hydrological modeling to further explore how these spatial relationships evolve and impact long-term agrarian resilience.

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to empower local universities, promote research, management innovation and agricultural systems (e.g. via tracks like Management & Innovation; Agri-Systems), fostering socio-economic development in Africa.

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IX. AUTHOR CONTRIBUTIONS

Individual authorship

X. REFERENCES

- Alderson, D., Li, L., Willinger, W., & Doyle, J. C. (2005). Understanding Internet Topology: Principles, Models, and Validation. *IEEE/ACM Transactions on Networking*, Vol. 13, No. 6, December 2005.
- Andris, C., & O’Sullivan, D. (2021). Spatial Network Analysis. *Handbook of Regional Science*, 1727–1750.
- Anyà, B., Adrian, M., Maxime, A., & Sami, B. (2015). Describing Spatial Relationships between Objects in Images in English and French. *Association for Computational Linguistics*, 104-113.
- Bera, R., & Claramunt, C. (2003). Topology-based proximities in spatial systems. *Journal of Geographical Systems*, Vol. 5, Issue 4, 353-379.
- Carniel, A. C. (2024). Defining and designing spatial queries: the role of spatial relationships. *Journal of Geospatial Information Science*, Volume 27, issue 6, 1868-1892.
- Castells, M. (1996). *The Rise of the Network Society*. Springer Nature Link.

- Chang, X., Anthony, G.-O. Y., & Anqi, Z. (2020). Analyzing spatial relationships between urban land use intensity and urban vitality at street block level: A case study of five Chinese megacities. *Landscape and Urban Planning, Volume 193, January 2020, 103669*.
- Egenhofer, M. J., & Franzosa, R. D. (2007). Point-set topological spatial relations. *International Journal of Geographical Information, 161-174*.
- Egenhofer, M. J., Mark, D. M., & Herring, J. (1994). *The 9-Intersection: Formalism and Its Use for Natural-Language Spatial Predicates*. UC Santa Barbara: National Center for Geographic Information and Analysis.
- Galton, A. (2009). Spatial and temporal knowledge representation. *Journal of Earth Science Informatics, Volume 2 Number 3, 169-187*.
- Goodchild, M. F., Luc, A., Richard, P. A., & Barbara, H. H. (2000). Toward Spatially Integrated Social Science. *International Regional Science Review, Vol. 23(2), 139-159*.
- Jacox, E., & Samet, H. (2007). Spatial Join Techniques. *ACM Transactions on Database Systems, Vol. 32, No. 1*.
- Jose, S., & Dollinger, J. (2019). Silvopasture: A sustainable livestock production system. *Agroforestry Systems, 93(1), 1–9*.
- Monfreda, C., Ramankutty, N., & Foley, J. A. (2008). arming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles, Volume22, Issue1*.
- Mudashiru, R. B., Sabtu, N., Ismail, A., & Waheed, B. (2021). Flood hazard mapping methods: A review. *Journal of Hydrology, Volume 603, Part A, December 2021, 126846*.
- Nigel, W. (2017). Tobler's First Law of Geography. *Wiley Online Library*.
- Olson, G. M., & Olson, J. S. (2000). Distance Matters. *HUMAN-COMPUTER INTERACTION, 2000, Volume 15, A Journal of Theoretical, Empirical, and Methodological Issues of User Science and of Sytem Design, 139–178*.
- Reid, K. J. (2025). A Multiscale Evaluation of the Wet 2022 in Eastern Australia. *Journal of Climate, Volume 38, Issue 4, 909-929*.
- Renzhong, G. (1998). Spatial Objects and Spatial Relationships. *Geo-spatial Information Science, Vol. 1, No. 1, 38-42*.
- Schneider, M., & Behr, T. (2006). Topological relationships between complex spatial objects. *ACM Transactions on Database Systems, Vol. 31, No. 1, 39-81*.
- Schneider, M., & Behr, T. (2006). Topological relationships between complex spatial objects. *ACM Transactions on Database Systems, 39-81*.

- Steiniger, S., & Weibel, R. (2007). Relations among Map Objects in Cartographic Generalisation 34(3). *Cartography and Geographic Information Science*, 175-197.
- Theobald, D. M. (2010). Topology revisited: representing spatial relations. *International Journal of Geographical Information Science*, 689-705.
- Werner, M., Lave, R., Christophers, B., & Peck, J. (2018). Introduction: Spatializing Power: Doreen Massey on Space as Domination and Potential. *Agenda Publishing*, 205 - 210.



CHAPTER 4:

Enhancing the adaptive capacities of agrarian landscapes through participatory sketch mapping and spatial perceptions on landmark's distribution and disparities

Author: **Marcel Loyd MINKA**

African Journal on Land Policy and Geospatial Sciences (AJLP & GS)

AJLP & GS is a journal that publishes research activities carried out in the field of geospatial sciences and land governance. It aims to encourage innovation and promote the exchange of knowledge and scientific outcomes related to its themes. The journal's target community is made-up of researchers, professors and media professionals.

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ENHANCING THE ADAPTIVE CAPACITIES OF AGRARIAN LANDSCAPES THROUGH PARTICIPATORY SKETCH MAPPING AND SPATIAL PERCEPTIONS ON LANDMARK'S DISTRIBUTION AND DISPARITIES

¹Marcel Loyd MINKA

¹ Catholic University of Central
Africa,
loyd.minka@yahoo.fr
Yaoundé, Cameroon.

²Università Cattolica del Sacro
Cuore,
Faculty of Agricultural, Food and
Environmental Sciences,
Department of Animal, Nutrition
and Food Sciences (DiANA).
marcelloyd.minka01@icatt.it

ABSTRACT

Context and background

Agrarian Landscapes are the natural basis for the survival and development of people in rural communities. Participatory sketch mapping refers to the collection of data (spatial, land use and land rights data) through the hand map drawing of study areas or relevant landmarks by stakeholders and community members in order to provide insights into the physical context and spatial dynamics of a study (Hamlin, 2022). By involving a range of interested parties, participatory sketch mapping facilitates their active participation, favors knowledge contribution, and helps to highlight important landmarks and resources in a study area.

Objective and research questions:

Now our days there are very few investigations on the adaptive capacities of agrarian landscapes, especially riverine landscapes, which makes it difficult for science to understand, analyze and provide solutions to the numerous agro-environmental challenges faced by the farmers and pastoralist living in these landscapes. Also, the absence of current, consistent and spatially-explicit data on the adaptive capacities of agrarian landscapes constitutes a gap which our research wants to fill. Our research is centered around the following questions: How and to what extend can participatory mapping help perceive and understand the role played by landmarks in strengthening the adaptive capacities of agrarian landscapes?

Methodology:

Using the method of participatory sketch mapping, farmers were asked to draw in groups the two agrarian landscapes found in OYACK in Mbalmayo. In

	addition to these sketch maps, farmers were asked through a questionnaire survey to describe how these landmarks helps them to adapt to climate disasters and describe which relation these landmarks have with their agricultural practices. Also, through this questionnaire survey, farmers where ask to describe how they percieve the disparities and distributions of these landmarks. Results: Through this study we detect the most exposed and sensitive landmarks and we determined the abilities of farmers to perceive, identify and understand the dynamics of these landmarks found in the agrarian landscapes. With the aim to improve the adaptive capacities of famers, the method of participatory sketch mapping was successful because it provided deeper insights into how farmers conceptualize their environment. Finally, these sketch maps improved the spatial representations that farmers had on these agrarian landscapes as a means for them to easily comprehend the complexities and dynamics of agrarian change. Keywords: adaptive capacities; agrarian landscapes; participatory sketch mapping geographic feature; landmarks; spatial perceptions; landmark's distribution; landmark's disparities; rural communities; farmers; pastoralists.
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I. INTRODUCTION

Sketch maps are hand-drawn abstract representations of spatial information considered to be externalization of one's acquired spatial knowledge. They have wide-ranging applications across multiple domains. In environmental psychology, sketch maps are used to analyze how individuals perceive their environment (Charu, Jakub, & Angela, 2024). And in Agricultural sciences, sketch maps are used to portray the land rights and land uses in a rural area. In Africa, there is a growing need to capture land use and spatial data in both urban and rural regions through sketch mapping. According to some experts, up to 70% of land uses in many developing countries is not recorded in national land registries (Lemmen, 2010). At the same time countries such as Cameroon, which experienced rapid rural development still have millions of parcels which remain administratively unrecognized, leaving behind many agrarian landscapes inhabitants such as farmers and pastoralist insecure (Lemmen, 2010). To help alleviate some of the technological challenges linked to this problem of non-administrative recognition faced by agrarian landscapes, a system called the "Smart Sketch Maps Land Tenure Recording Tool" was developed by Malumbo Chipofya to support a bottom-up approach to land tenure recording. Without a proper administrative recognition of all the land parcels in an agrarian landscape, it will be difficult to determine the adaptive capacities of the inhabitants living in these agrarian landscapes. This will be more difficult with farmers and pastoralist who practice agriculture on unrecognized and unperceived lands.

The method of participatory sketch mapping which we used here falls under the category of "volunteered geographic information tools" which are used to collect data for disaster management, urban and rural planning (Charu, Jakub, & Angela, 2024). Sketch maps have been increasingly used in conjunction with digital mapping tools in land management research to help delineate (define) neighborhood boundaries and perceive space (Claudia, Jill, Tsui, & Marilyn, 2001). Participatory sketch mapping assesses spatial aspects of crime perception and fear (Curtis, et al., 2014) and understand variations in spatial knowledge in a community (Mondschein, Blumenberg, & Taylor, 2010). Although early studies required participants to map their perceptions in a free drawing format using a blank sheet of paper, in recent years sketch maps have been integrated as digital tools in Geographic Information Systems (GIS) frameworks (Cheung, et al., 2016). In this case we refer to sketch maps as hand-drawn representations of land features (landmarks) with the use of a pen and paper either by analog free-hand sketching or analog sketching. In analog free-hand sketching, sketch maps are produced without any underlying topographic map or aerial image as guidance, setting them apart

from other participatory mapping methods. Meanwhile analog sketching uses topographic map or aerial image as a support base to draw each land feature (landmarks).

The landmarks which we analyzed in this study are the different varieties of physical elements found in the agrarian landscapes of Mbalmayo. These physical elements are : Creeks (variety 1); rivers (variety 2); slopes (variety 3); swamps (variety 4); plains (variety 5); Trees (variety 6); Bridges (variety 7); Grasses (variety 8); Farm un-paved roads (variety 9); Houses (variety 10); Hills (variety 11); and Mountains (variety 12). In this paper we conducted investigations to determine: the agrarian landscapes which have more landmarks than the others; the type of food crops cultivate on these agrarian landscapes; the level of exposure and sensitivity to climate induced disasters of landscapes; the type of livestock farming practiced in these agrarian landscapes; the type of nature-based adaptive measures useful to build resilient landscapes; and the type of climate induced disasters found on these agrarian landscapes. Using participatory sketch mapping, survey questionnaires, geotagging, and landmark coordinate systems, we succeeded to collect good quantitative and qualitative data. The results which came out from the analyzes of these data showed us that amongst the twelve landmarks, there are ten landmarks which represents the main pillars used by the farmers and pastoralist to build effective adaptive capacities on these agrarian landscapes. These adaptive capacities are very important because they help to reduce the people's vulnerabilities to climate change, with regards to their foods crops and livestock farming. Our study on these landmarks also enabled the detection of some nature-based adaptation measures which these farmers and pastoralist will use to adapt to severe droughts, heatwaves, heavy precipitation, devastating floods, hurricanes, and wildfires.

II. MATERIALS AND METHODS

A. Data collection

To properly carry out this study, we collected both quantitative and qualitative data through five different methods. These methods were: study area; landscape perceptions through perceptive values; questionnaire surveys on kobo toolbox; GNSS and coordinate systems for georeferenced data; and participatory sketched maps for spatial data like information on customary land boundaries, land use, sacred areas, and other spatially significant features as viewed by the community. Then we conducted in-depth data analysis to determine how the above data could support the enhancement of adaptive capacities in agrarian landscapes. This in-depth analysis consists in two types of analysis: cross-tabulation analysis and spatial analysis. The

cross-tabulation analysis was used to analyze all the survey data collected through kobo toolbox questionnaires. The spatial analyses consisted in: the analyzes of the landmarks found on each participatory sketch map; the spatial heterogeneity or homogeneity of the landmarks in both Landscapes; and the analysis of Landmarks Perceptions. To collect this data, we used a sample study. A sample study is research where data is collected from a selected group of individuals to represent and draw conclusions about the whole population. The sample here is a group of farmers and pastoralist who live in the landscapes of OYACK.

1. Questionnaire Survey on Kobo Toolbox

The data we collected from survey responses is primary research data, and as such, it is one of the most reliable and accurate research data we had in this study (in this research project). Collecting data with surveys was useful in gathering accurate information about both large and small groups living on the agrarian landscapes of Oyack A and Oyack B in Mbalmayo. The analysis of this data will help us draw conclusions and inform important decision-making processes. A questionnaire is a research tool that has a series of questions designed to elicit meaningful information from respondents (Rowley J. , 2014). Therefore, questionnaire surveys are a strategy for acquiring statistical information about a population's characteristics, beliefs, or activities using a predefined set of questions (Rowley J. , 2014). In this study, we created survey questionnaires using Kobo Toolbox. Kobo Toolbox is a suitable open-source tool for simplifying data collection. It allows users to develop and distribute forms as well as collect data over a variety of channels, including webforms, mobile devices, and tablets (Selva Das, 2024). Kobo toolkit is essential for accuracy, speed, data quality, and cost effectiveness (Lakshminarasimhappa, 2021). Field data is collected using this open-source data collection tool (kobo collect) by using mobile devices such as phones and tablets, but it can also be collected via online forms (using <https://www.kobotoolbox.org/>). Therefore, through Kobo toolbox, we collected quantitative data to determine the major landmarks to which the farmers and pastoralists in Oyack are entitled to in terms building resilience against climate disasters to secure the use and benefits of their lands (tenure security). The survey questions in this questionnaire were addressed and given to a sample of 119 (one hundred and nineteen) farmers and pastoralist, who live in the agrarian landscapes of OYACK A and OYACK B. This is a subset of the larger population of farmers and pastoralist in OYACK.

2. Georeferenced data with coordinate systems

The georeferenced data collected here referred to any spatial data (images) that has been linked to a real-world coordinate system, such as latitude and longitude. To detect, locate and perceive each landmark on each landscape, we collected data on the georeferenced digital images with an android application called "GPS Map Camera". These digital and georeferenced images were obtained through one means, which was android phone apps: GPS Map Camera.

The georeferenced images we collected with GPS Map Camera, contain the following data types:

- **Point Data:** This data are single locations with associated information. For example, the geotagged photos.
- **Line Data:** These are data representing a path or route over time. For example, the GPS tracks of the walking, biking, or driving route. Another example of data here are the routes (paths) we discovered during our field work.
- **Raster Data:** These are geotagged images that can be overlaid on maps. For example, the photos (pictures) taken with our smartphones. These photos (pictures) have automatically stored with latitude and longitude coordinates.

3. Participatory Sketched Maps (drawings) of Landscapes

Participatory sketched maps are visual tools created collaboratively, often between community members and researchers, planners, or designers—to represent landscapes, land use, resources, and spatial relationships from the perspective of local knowledge. They are widely used in participatory rural appraisal (PRA), community mapping, environmental planning, and Indigenous land rights documentation. Participatory sketched maps are Freehand drawings created by participants to depict their environment. These maps are often made on paper, the ground (with sticks or chalk), or on digital tablets. These sketched maps are non-cartographic but spatially informative, meaning they prioritize local understanding of space over precise geographic accuracy.

The two sketch maps of the agrarian landscapes of Oyack A and Oyack B were drawn on pieces of paper by farmers and pastoralists. For them to draw these two sketch maps, we gathered them in two different halls. In the first hall we gathered 20 farmers and 20 pastoralists from the agrarian landscape of Oyack A. In the

second hall we gathered 14 farmers and 14 pastoralists from the agrarian landscape of Oyack B. During this week for the participatory mapping exercise, the farmers and pastoralists in the agrarian landscape of Oyack B were more available and willing than those of Oyack B. These 68 farmers and pastoralists who drew the participatory sketch maps are a representative of the 119 farmers and pastoralists who responded to our survey questionnaire on Kobo Collect.

With this method of participatory sketch mapping, we succeeded to collect spatial and non-spatial data. The **spatial data** we collected are geographical data on the following four geographical elements:

- i- **Landmarks:** Schools, clinics, rivers, forests, mountains, roads, sacred sites, etc.
- ii- **Boundaries:** Village borders, land ownership, community resource zones, and administrative divisions.
- iii- **Routes and Paths:** Travel routes, footpaths, common transportation, and migration routes.
- iv- **Land Use and Land Cover:** Agricultural fields, forest areas, grazing land, and residential zones.

On the other hand, we also used participatory sketch mapping to collect four types of non-spatial data which are socio-cultural data; environmental data; perceptual data; governance and ownership data.

The **socio-cultural data** which we collected are data on:

- i- **Culturally Significant Sites:** Sacred groves, burial grounds, and ceremonial areas.
- ii- **Historical or Conflict Zones:** Places of past disputes, colonial boundaries, and war-affected areas.
- iii- **Local Institutions:** Religious centers, community halls, and markets.

The **environmental data** which we collect are data on:

- i- **Natural Resources:** Water sources, forests, wildlife areas, and fishing zones.
- ii- **Environmental Changes:** Areas affected by erosion, deforestation, flooding, or other environmental issues.

The **perceptual data** which we collected are data on:

- i- **Risk Areas:** Places considered unsafe or dangerous (e.g., for women, at night, or during floods).
- ii- **Resource Access Points:** Where people go to collect water, firewood, etc.
- iii- **Community Perceptions:** How community members perceive different areas (e.g., fertile vs. infertile land ; and safe vs. unsafe zones).

And finally, the **governance and ownership data** which we collected are data on:

- i- **Land Ownership:** Communal vs. private lands, and contested lands.
- ii- **Decision-Making Sites:** Locations where local governance or community decisions are made.

B. Data analysis

1. Cross-tabulation analysis

To determine the extent to which landmarks help enhance the adaptive capacities of agrarian landscapes, we conducted a cross-tabulation analysis on the survey data obtained through kobo toolbox. This data was collected from a sample of 32 households found in the two agrarian landscapes of OYACK, called OYACK A and OYACK B. These two agrarian landscapes are found on the banks of river Nyong, in the south of Mbalmayo.

Cross tabulation is the summarization of categorical data into a table with each cell in the table containing the frequency (either raw or proportional) of the observations that fit the categories represented by that cell. The survey data which we collected and analyzed in this section was based on six variables, which we classified as: independent and dependent variables. The two independent variables which we manipulated were: the agrarian landscapes; and the climate induced disasters. Meanwhile the four dependent variables which we measured were: the distribution & disparities of Landmarks; the food crops cultivated; the livestock farming practiced; and the type of nature-based adaptive measures adopted.

The cross-tabulation analysis of the survey data which we collected gave rise to 21 tables, each of them corresponding to at least two or more variables measured.

2. Analysis of Landmarks Perceptions

The landmarks which we analyzed in this study are the different varieties of physical elements found on the agrarian landscapes of Mbalmayo. These physical elements are Creeks (variety 1); rivers (variety 2); slopes (variety 3); swamps (variety 4); plains (variety 5); Trees (variety 6); Bridges (variety 7); Grasses (variety 8); Farm un-paved roads (variety 9); Houses (variety 10); Hills (variety 11); and Mountains (variety 12).

The perceptions that farmers have on these landscapes varies in numbers between 2; 1; 0; 1; 2; +1; and +2. This gives a scale of **2** to **+2**. Each of the number on this scale has a perceptive value. These perceptive values are: devastative; destructive; neutral; static; progressive; attractive; and productive.

Below are the perceptive values that each number on the scale represents:

- | | |
|--------------------------|------------------------|
| - 2 = Devastative | +1 = Attractive |
| - 1 = Destructive | +2 = Productive |
| 0 = neutral | |
| 1 = static | |
| 2 = progressive | |

The above seven perceptive values (devastative; destructive; neutral; static; progressive; attractive; and productive) were developed by Buendía et al. (2021).

3. Spatial analysis of the participatory sketch map data

Here, we will conduct spatial analysis to understand how the participants (landscape inhabitants) perceive and use the spaces found in their landscapes. This spatial analysis will comprise in the following three steps below:

- **1st step:** the identification of key landmarks, resources, hazards, or culturally significant areas on the sketch maps.
- **2nd step:** identifying matching landmarks and resources on both sketch maps and digital georeferenced images.
- **3rd step:** computing and comparing the landmarks and resources found on sketch maps with the one on the digital georeferenced images.

a- Symbol Recognition and Visual Analysis of the participatory sketch maps

On the other side, to facilitate the identification of key landmarks on the participatory sketched maps, we used "symbol recognition" and "visual analysis". These two types of analysis enabled us to identify many existing landmarks (houses, farmlands, schools, etc.). Symbol Recognition is a method of spatial analysis on

sketch maps which was used by Santosh et al., (2011) in their paper titled *“Symbol Recognition using Spatial Relations”* (Santosh, Bart, & Laurent, 2012). This method consists in reading and understanding the symbols used on the map, to enable the identification of landmarks like schools, churches, roads, vegetation, etc. The main tools used here were a map legend and spatial languages used when drawing the visual elements. Here we did a kind of spatio–structural description of the sketched maps (Santosh, Bart, & Laurent, 2012).

Meanwhile visual analysis is a method which consist in the basic observation of the map’s layout, symbols, labels, and spatial relationships. This method was used to easily recognizable features like rivers, roads, mountains, settlements, etc. Visual analysis employs visualization tools to aid in the discovery and interpolation of highly complex patterns and features in specific geographical data (Santosh, Bart, & Laurent, 2012). The key advantage of this method is that it delivers information in an easy and understandable way using spatial data interpretation elements.

b- Identifying matching features (landmarks) in the two sketch maps

Given the fact that most inhabitants rely on one or two of the twelve landmarks for their adaptive capacities, identifying matching landmarks is very important to determine if these landmarks have been properly perceived (spatial perception) by the inhabitants when drawing the landmarks during the participatory sketch mapping exercise. This analysis will also help determine if the spatial identify of the landmarks are the same in the two maps. Spatial identity is a result of a connection between people, physical elements of places, and activities associated with them (Damayanti & Kossak, 2016).

c- Computing and comparing the total number of landmarks in each sketch map

To count the total number of landmarks found on sketch maps, we first of all identified and categorized all the landmarks (e.g roads, rivers, houses, trees). Secondly, we marked each landmark with a tally mark as it is counted. And finally, we summarized and counted the tallies to get the total number for each variety of landmark and the overall total.

Meanwhile, to count the total number of landmarks found on aerial drone maps, we use the method of GIS-based feature extraction (Vectorization). This method consisted in first converting the raster maps (images) into vector data (polygons, lines, points). Then after we used pre-classified orthomosaic, then we vectorize the landmarks using "Polygonize" in QGIS, and finally we used attribute table to count total features (Anugya & Kamal, 2020). After obtaining the total number of landmarks in both maps, we compared the total number

of landmarks of the sketch map to that of the aerial drone map, to see if the spatial perceptions of the local inhabitants were correct. That is, where the local inhabitants able to perceive all the landmarks when doing the participatory sketch maps.

III. RESULTS

A. Cross-tabulation tables

Value	Frequency	Percentage
Trees	27	19.29
Houses	18	12.86
Grasses	17	12.14
Rivers	14	10.00
Slopes	11	7.86
Agricultural fields	11	7.86
Farm un-paved roads	10	7.14
Creeks	9	6.43
Plains	7	5.00
Swamps	6	4.29
Bridges	5	3.57
Hills	5	3.57
TOTAL	140	100

Table 1: The frequency at which each landmark is found or seen on the two riverine landscapes?

Value	Frequency	Percentage
Trees	19	19.39
Rivers	12	12.24
Houses	12	12.24
Swamps	10	10.20
Agricultural fields	9	9.18
Grasses	9	9.18
Creeks	8	8.16
Slopes	7	7.14
Farm un-paved roads	4	4.08
Plains	4	4.08
Bridges	3	3.06
Hills	1	1.02
TOTAL	98	100

Table 2: The landmarks which are more exposed to climate induced disasters

Value	Frequency	Percentage
Trees	15	17.86
Swamps	13	15.48
Houses	12	14.29
Rivers	11	13.10
Creeks	8	9.52
Agricultural fields	7	8.33
Grasses	5	5.95
Plains	4	4.76
Slopes	4	4.76
Bridges	2	2.38
Farm un-paved roads	2	2.38
Hills	1	1.19
TOTAL	84	100

Table 3: The landmarks which are more sensitive to climate induced disasters

Value	Frequency	Percentage
Rivers	16	23.19
Trees	16	23.19
Creeks	9	13.04
Swamps	9	13.04
Slopes	5	7.25
Agricultural fields	4	5.80
Grasses	4	5.80
Houses	2	2.90
Plains	2	2.90
None	1	1.45
Farm un-paved roads	1	1.45
TOTAL	69	100

Table 4: The landmarks which best sustains and strengthens the food crops cultivated

Value	Frequency	Percentage
Rivers	14	19.72
Trees	10	14.08
Grasses	9	12.68
Swamps	7	9.86
Creeks	7	9.86
Slopes	6	8.45
None	5	7.04
Agricultural fields	5	7.04
Houses	3	4.23
Plains	3	4.23
Farm un-paved roads	2	2.82
TOTAL	71	100

Table 5: The landmarks which best sustains and strengthens the livestock farming practiced

Value	Frequency	Percentage
Trees	20	28.57
Grasses	13	18.57
Creeks	13	18.57
Rivers	10	14.29
Slopes	6	8.57
Swamps	4	5.71
Plains	2	2.86
None	2	2.86
TOTAL	70	100

Table 6: The most-cited landmarks which are most likely to regenerate naturally in twenty-years without human intervention

Value	Frequency	Percentage
More often	23	82.14
Less often	2	7.14
Much more often	2	7.14
Once	1	3.57
TOTAL	28	100

Table 7: The frequency at which these landmarks appear on the banks of River Nyong

Value	Frequency	Percentage
Scattered	13	39.39
Grouped	9	27.27
Unevenly spaced	9	27.27
Uniform	2	6.06
TOTAL	33	100

Table 8: The form (type) of distribution observed amongst these landmarks

Value	Frequency	Percentage
Distinct	13	41.94
Unequal	8	25.81
None	4	12.90
Heterogeneous	3	9.68
Disproportionate	2	6.45
Inconsistent	1	3.23
TOTAL	31	100

Table 9: The form (type) of disparities observed amongst these landmarks

Value	Frequency	Percentage
20 meters	24	63.16
50 meters	12	31.58
200 meters	2	5.26
TOTAL	38	100

Table 10: The most observed and common distances between the landmarks?

Value	Frequency	Percentage
Landscape - OYACK A	14	51.85
Landscape - OYACK B	13	48.15
TOTAL	27	100

Table 11: The agrarian landscape with highest and lowest number of landmarks

Value	Frequency	Percentage
Severe droughts	22	36.67
Heatwaves	13	21.67
Heavy precipitation	12	20.00
Devastating floods	11	18.33
Wildfires	1	1.67
Hurricanes	1	1.67
TOTAL	60	100

Table 12: The most frequent climate induced disasters to which the landmarks are constantly expose to

Value	Frequency	Percentage
Severe droughts	22	36.67
Heavy precipitation	14	23.33
Heatwaves	14	23.33
Devastating floods	9	15.00
Wildfires	1	1.67
TOTAL	60	100

Table 13: The most recurrent climate induced disasters to which the landmarks are constantly sensitive to

Value	Frequency	Percentage
Plantain	24	17.39
Cassava	23	16.67
Maize	21	15.22
Peanut	18	13.04
Banana	13	9.42
Yam	7	5.07
Cocoyam	6	4.35
Beans	6	4.35
African Pear	6	4.35
Cocoa	4	2.90
Sugar Cane	4	2.90
Tangerines	3	2.17
Oranges	2	1.45
Others	1	0.72
TOTAL	138	100

Table 14: The type of food crops cultivated in these agrarian landscapes and their classification from the most to the least cultivated?

Value	Frequency	Percentage
Cassava	23	20.72
Maize	19	17.12
Plantain	16	14.41
Peanut	14	12.61
Banana	8	7.21
Cocoyam	5	4.50
Yam	5	4.50
Beans	5	4.50
Cocoa	4	3.60
African Pear	4	3.60
Sugar Cane	3	2.70
Tangerines	3	2.70
Oranges	2	1.80
TOTAL	111	100

Table 15: The type and proportion of food crops which are more exposed to climate induced disaster

Value	Frequency	Percentage
Maize	19	18.81
Cassava	18	17.82
Peanut	16	15.84
Plantain	15	14.85
Banana	9	8.91
Yam	6	5.94
Cocoa	4	3.96
Beans	4	3.96
Sugar Cane	3	2.97
African Pear	3	2.97
Tangerines	2	1.98
Oranges	1	0.99
Cocoyam	1	0.99
TOTAL	101	100

Table 16: The type and proportion of food crops which are more sensitive to climate induced disaster

Value	Frequency	Percentage
Poultry farming	12	34.29
Pig farming	9	25.71
Others	8	22.86
Small ruminant farming (goats and sheep)	4	11.43
Aquaculture	1	2.86
Dairy farming	1	2.86
TOTAL	35	100

Table 17: The type and most practiced livestock farming activities in these landscapes?

Value	Frequency	Percentage
Poultry farming	11	34.38
Others	8	25.00
Pig farming	7	21.88
Small ruminant farming (goats and sheep)	4	12.50
Aquaculture	1	3.13
Cattle farming	1	3.13
TOTAL	32	100

Table 18: The type and proportion of livestock farming which are more exposed to climate induced disaster

Value	Frequency	Percentage
Poultry farming	9	28.13
Pig farming	8	25.00
Others	7	21.88
Small ruminant farming (goats and sheep)	5	15.63
Aquaculture	2	6.25
Cattle farming	1	3.13
TOTAL	32	100

Table 19: The type and proportion of livestock farming which are more sensitive to climate induced disaster

Value	Frequency	Percentage
Agroforestry	14	23.33
Forest and Tree Planting	11	18.33
Soil Protection	9	15.00
Dikes and flood walls	6	10.00
Coastal Ecosystem Reforestation	5	8.33
Others	4	6.67
Green infrastructures	4	6.67
Wetland restorations	4	6.67
Mangroves Planting	3	5.00
TOTAL	60	100

Table 20: The Nature-based adaptive measures which best sustain and protect food crops against climate hazards

Value	Frequency	Percentage
Agroforestry	14	24.56
Wetland restorations	10	17.54
Coastal Ecosystem Reforestation	6	10.53
Forest and Tree Planting	6	10.53
Soil Protection	5	8.77
Dikes and flood walls	5	8.77
Others	4	7.02
Mangroves Planting	4	7.02
Green infrastructures	3	5.26
TOTAL	57	100

Table 21: The Nature-based adaptive measures which best sustain and protect livestock farming against climate hazards

B. Bar graph and chart results of the cross-tabulation analysis illustrating the data relationships and trends between the variables in percentages (%)

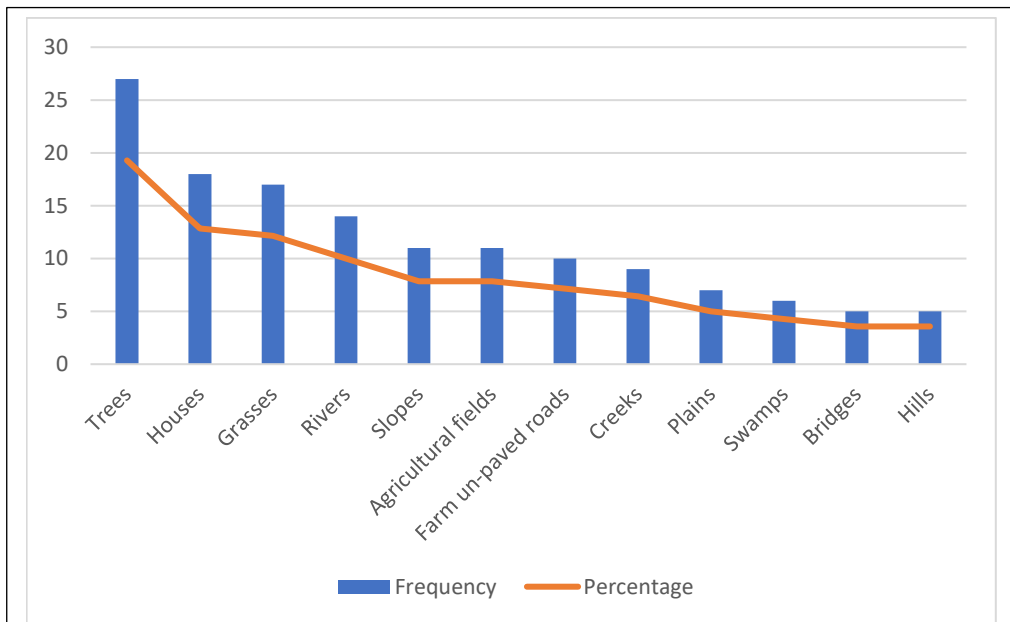


Figure 1: Bar graph showing the most observed landmark to the least observed landmark in the two agrarian landscapes.

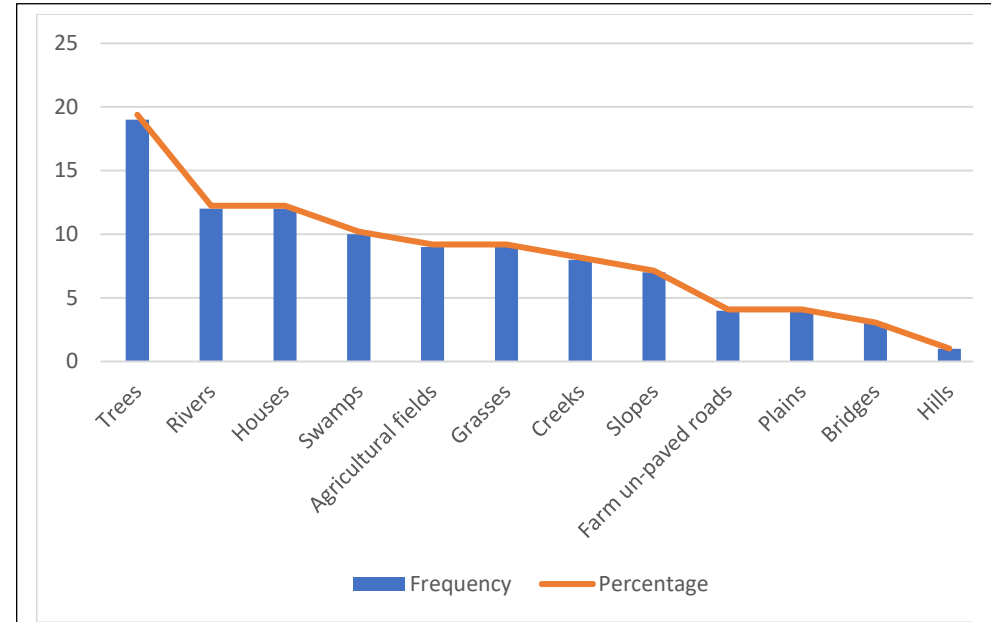


Figure 2: Bar graph unveiling the landmarks which are more exposed to climate induced disasters in the area.

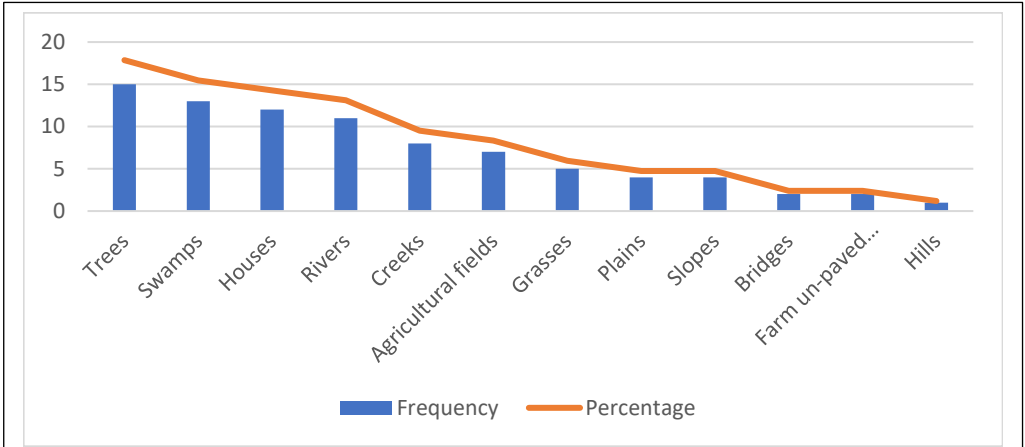


Figure 3: Bar graph unveiling the landmarks which are more sensitive to climate induced disasters in the area.

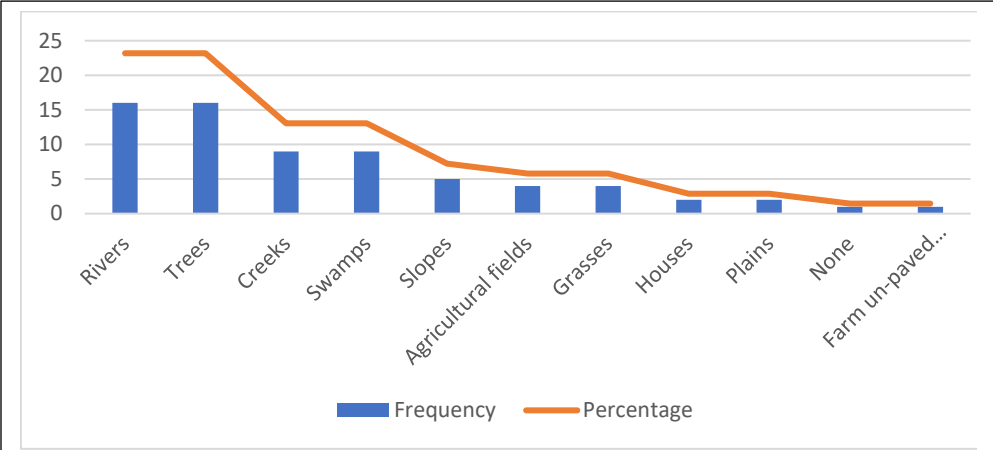


Figure 4: Bar graph revealing the landmarks which best sustains and strengthens the food crops cultivated in these agrarian landscapes.

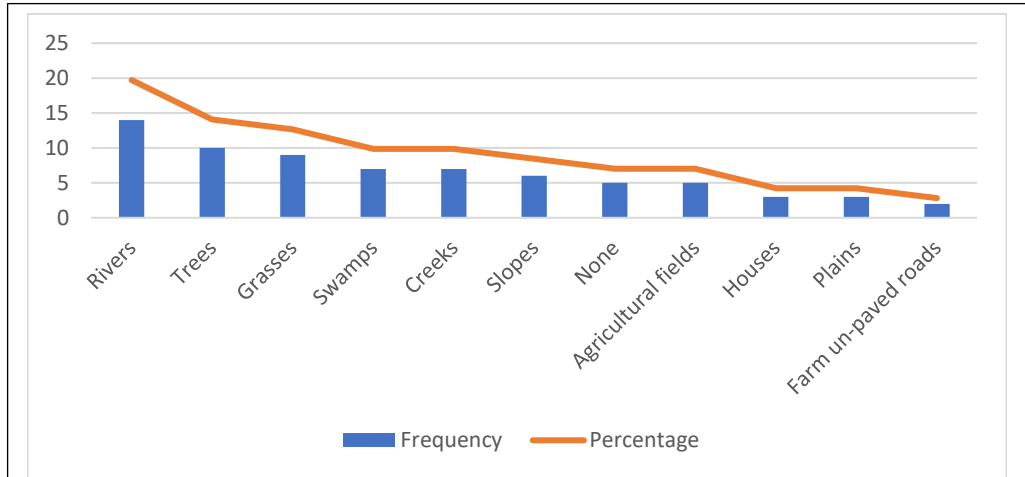


Figure 5: Bar graph revealing the landmarks which best sustains and strengthens the livestock farming practiced in these agrarian landscapes.

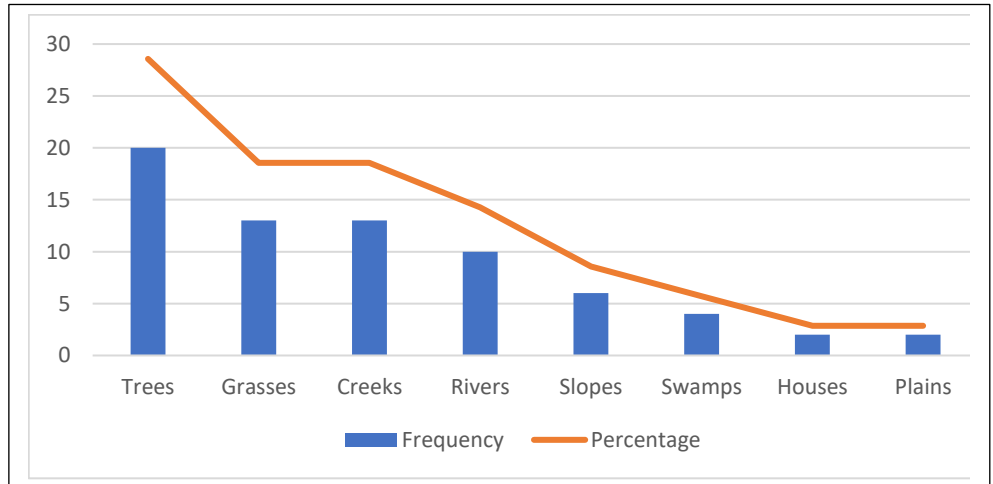


Figure 6: Bar graph revealing the landmarks which are most likely to regenerate naturally in twenty-years without human intervention.

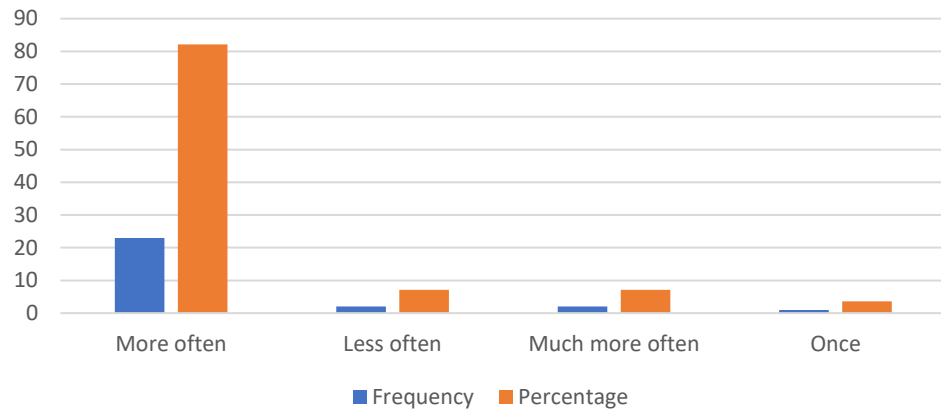


Figure 7: Bar graph showing the frequency rate (Less often; often; more often; much more often) at which landmarks appear the area.

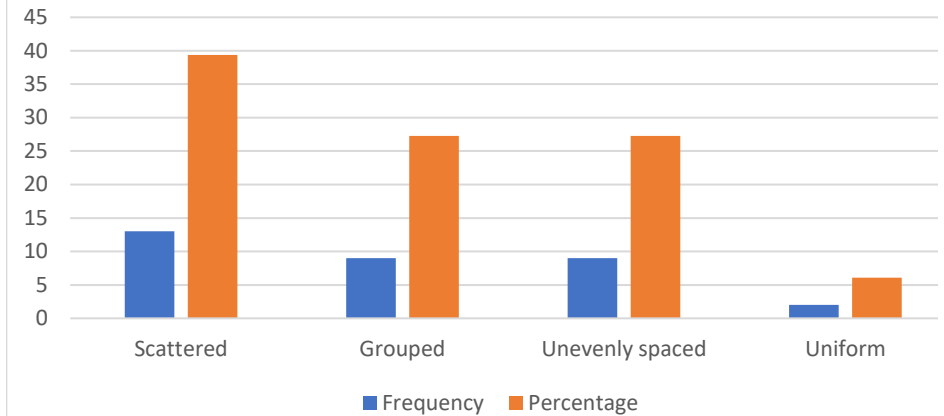


Figure 8: Bar graph showing the major type landmark distribution in the area.

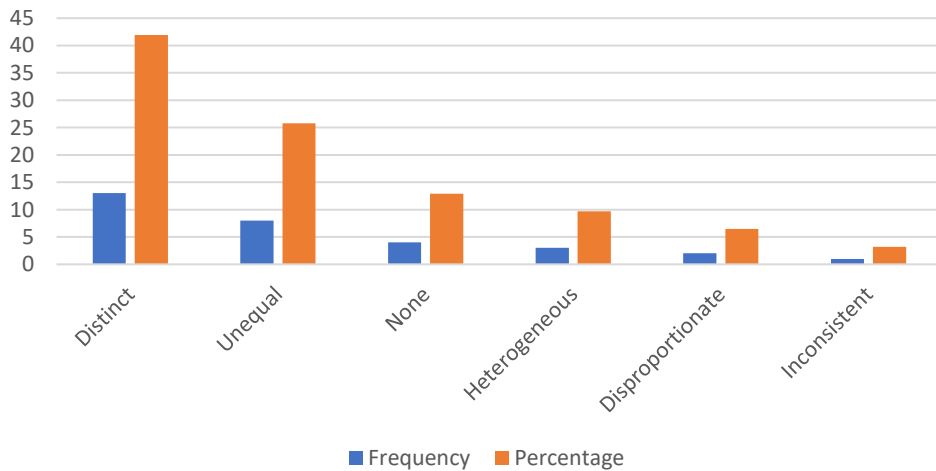


Figure 9: Bar graph illustrating the major form of landmark disparities in the area.

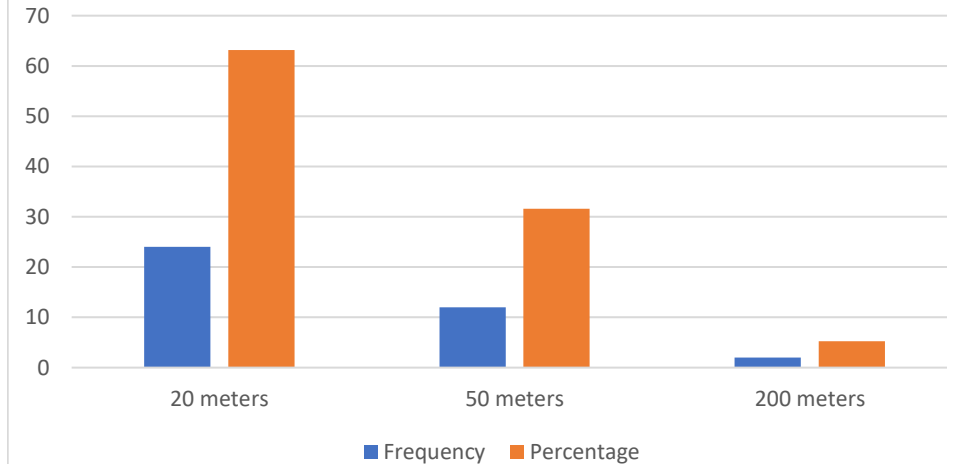
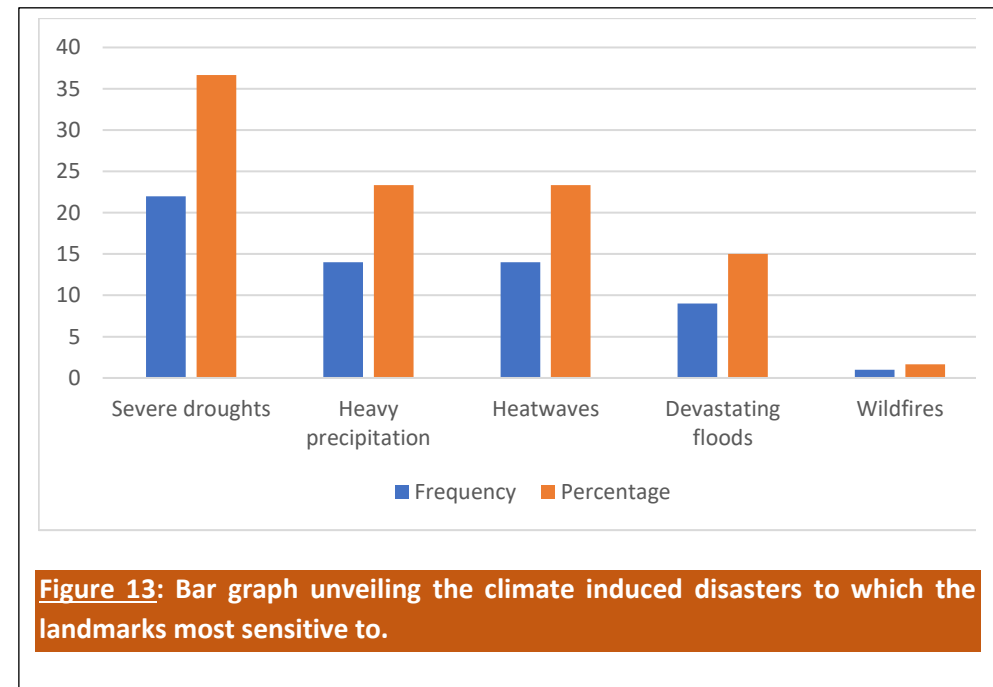
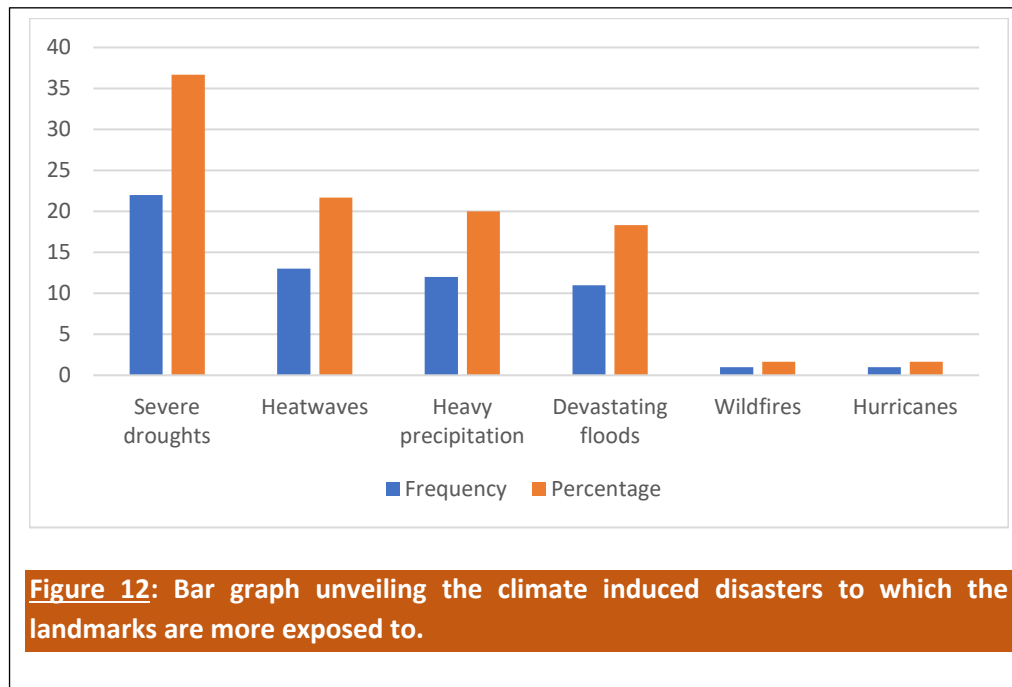
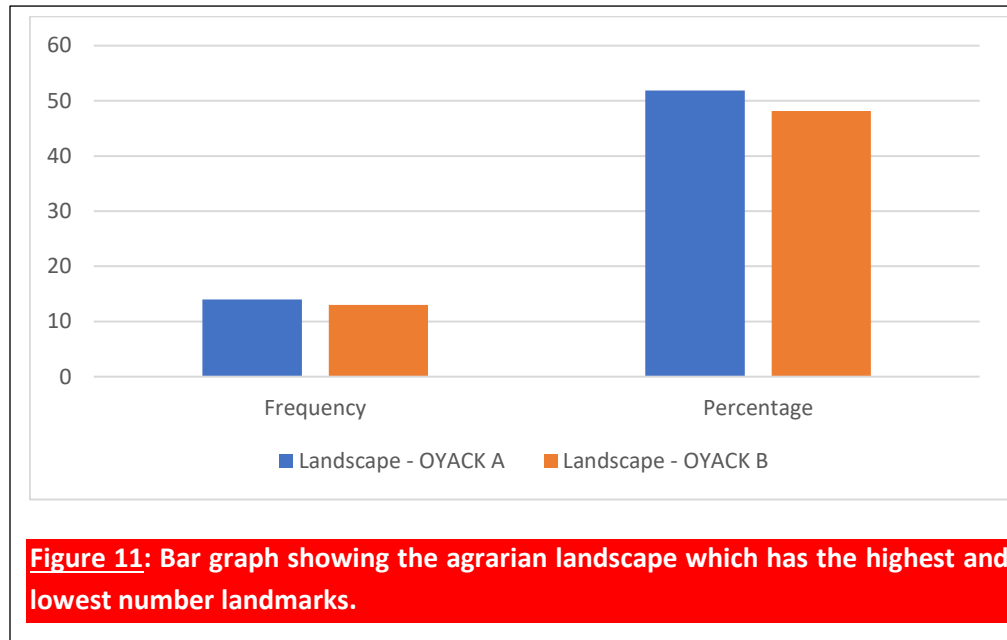


Figure 10: Bar graph illustrating the most observed and common distances between the landmarks in the area.



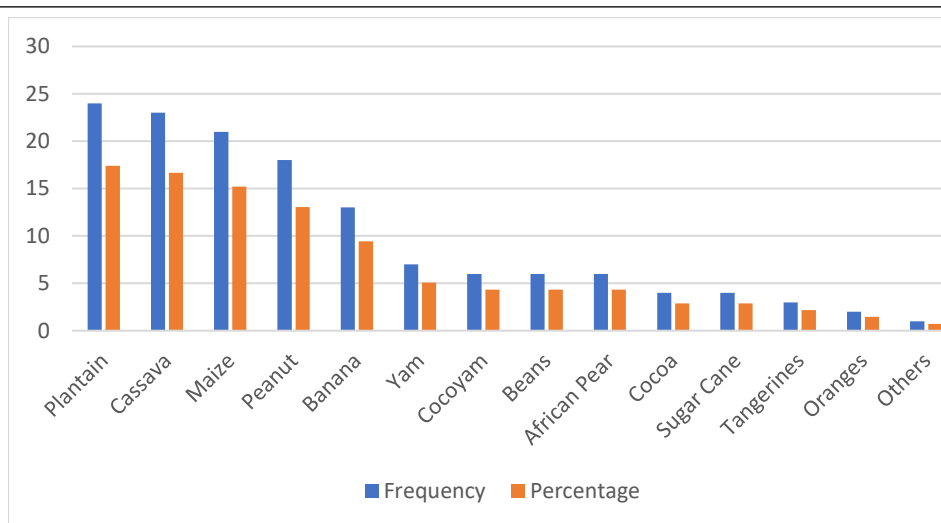


Figure 14: Bar graph displaying the type of food crops cultivated in these agrarian landscapes.

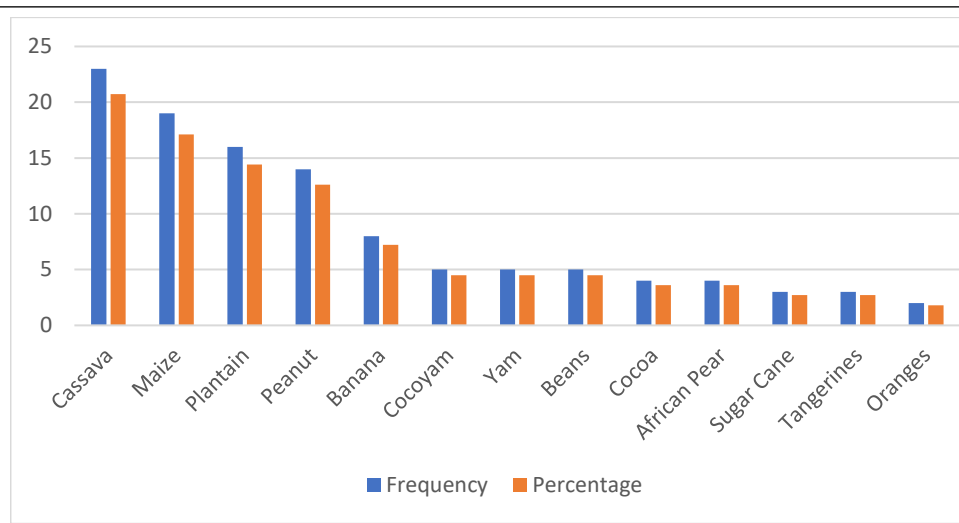


Figure 15: Bar Chart displaying the type of food crops which are more exposed to climate induced disaster in these agrarian landscapes.

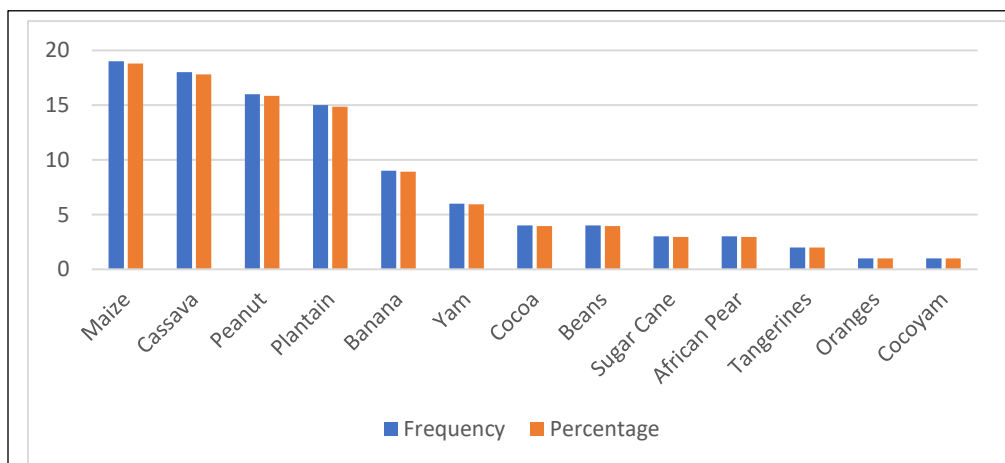


Figure 16: Bar Chart unveiling the type of food crops which are more sensitive to climate induced disaster in these agrarian landscapes.

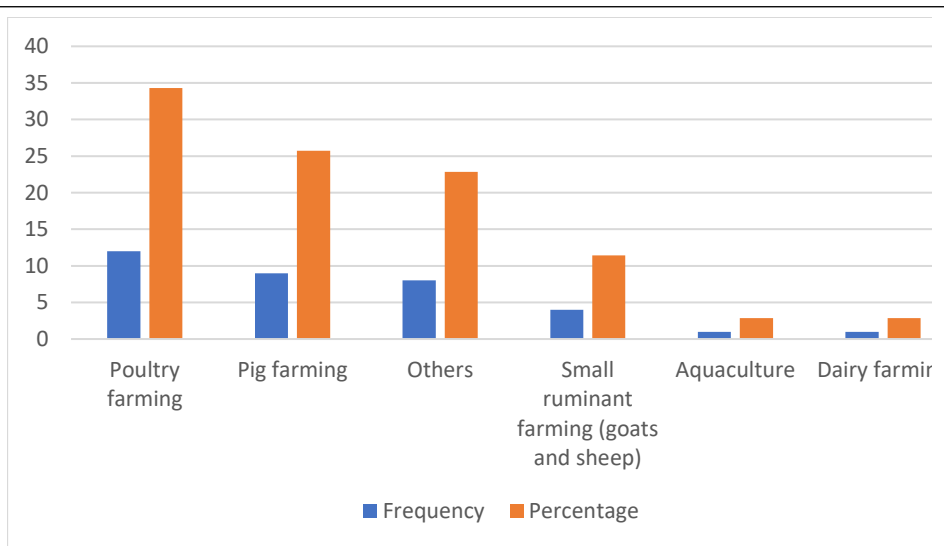


Figure 17: Bar graph showing the type of livestock farming activities in these agrarian landscapes.

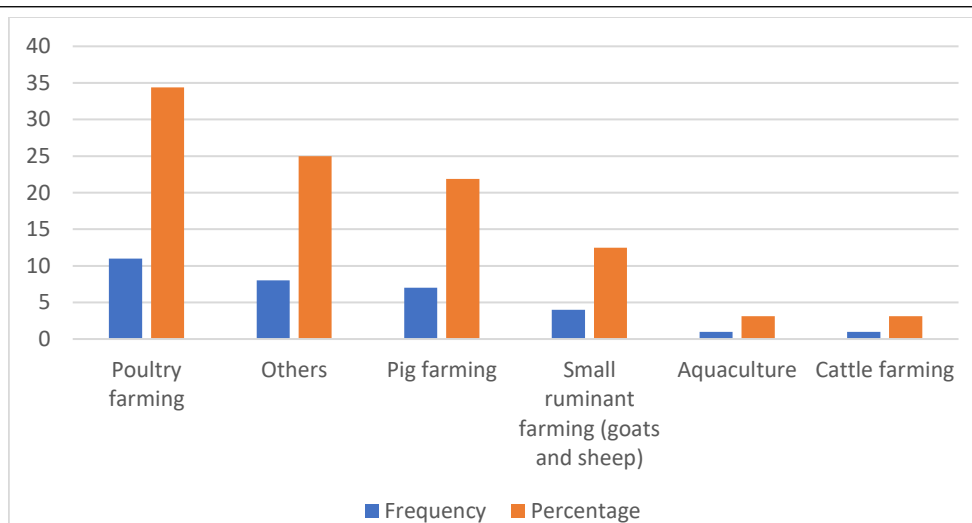


Figure 18: Bar graph showing the type of livestock farming which are more exposed to climate induced disasters in these agrarian landscapes.

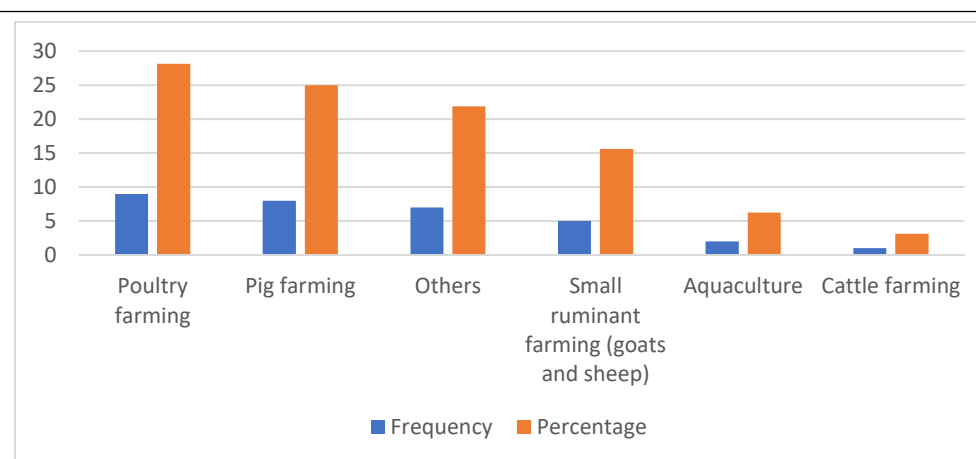


Figure 19: Bar graph showing the type of livestock farming which are more sensitive to climate induced disaster in these agrarian landscapes.

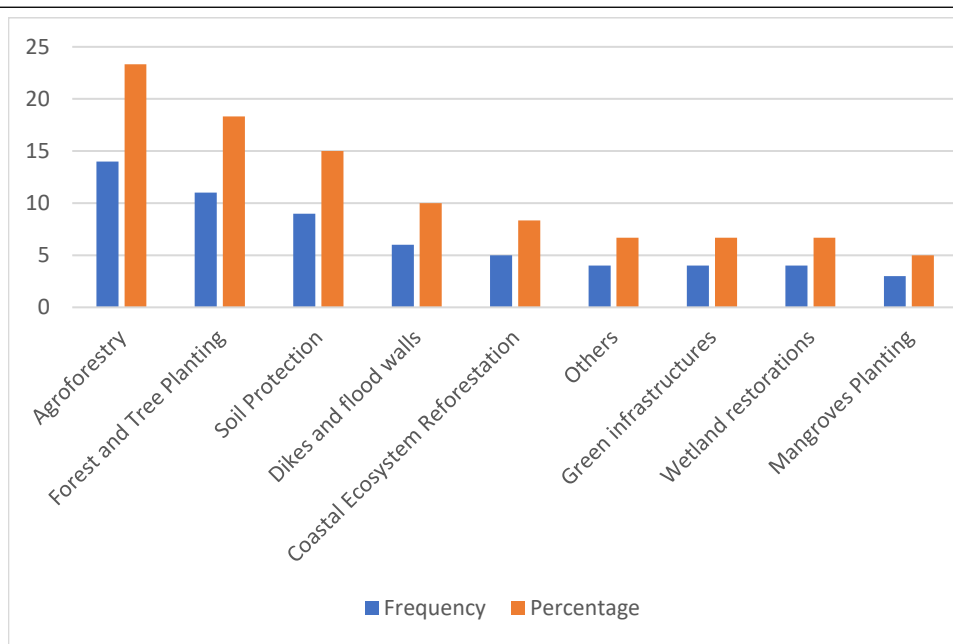


Figure 20: Bar Chart displaying the Nature-based adaptive measures which best sustain and protect food crops against climate hazards in these agrarian landscapes.

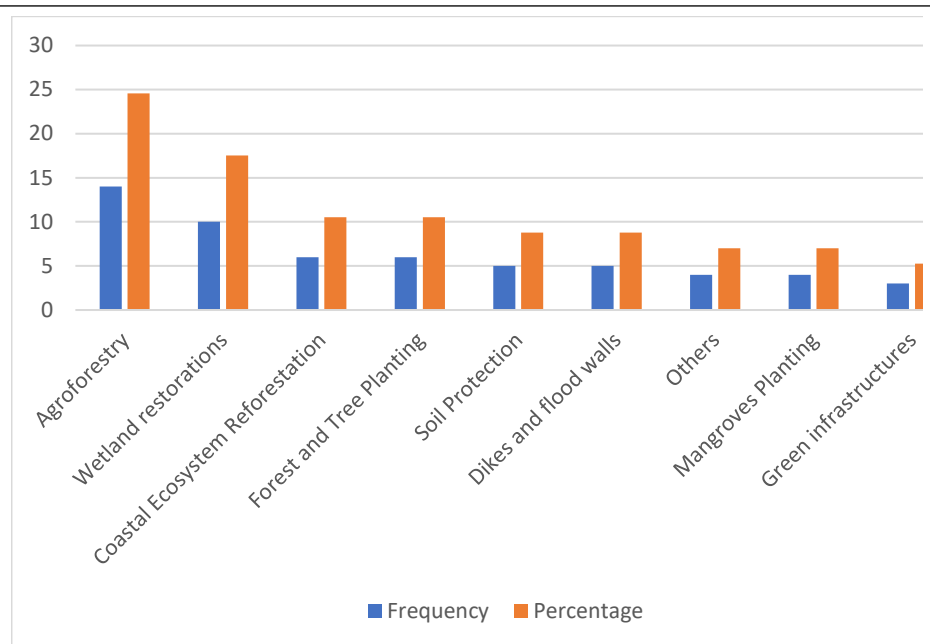


Figure 21: Bar Chart displaying the Nature-based adaptive measures which best sustain and protect livestock farming against climate hazards in these agrarian landscapes.

C. Landmarks perceptions: responses and comments by perceptive values

Landmarks	Aged Group	Number of Respondents	Perceptive values	Perceptive number (-2, -1, 0, 1, 2, +1, +2)
Creeks	35 - 65	10	Productive	+2
Rivers	35 - 65	6	Productive	+2
Slopes	35 - 65	9	Attractive	+1
Swamps	35 - 65	6	Progrssive	2
Plains	35 - 65	10	Progrssive	2
Trees	35 - 65	13	Productive	+2
Bridges	35 - 65	7	Static	1
Grasses	35 - 65	3	Productive	+2
Un-paved roads	35 - 65	10	Static	1
Houses	35 - 65	22	Progrssive	2
Hills	35 - 65	9	Neutral	0
Agricultural fields	35 - 65	14	Productive	+2
TOTAL Number of Respondents	/	119	/	/

Table 22: Perceptive values from farmers and pastoralists on the landmarks the are more entitled to in terms of climate resilience and land tenure security

Percpetive Values	Percentages	Landmarks
Devastative	0 %	/
Destructive	0 %	/

Neutral	8.33 %	Hills
Static	16.68 %	Bridges & Un-paved roads
Progressive	25 %	Swamps; Plains & Houses
Attractive	8.33 %	Slopes
Productive	41.66 %	Creeks; Rivers; Trees; Grasses; Agricultural fields
TOTAL	100 %	

Table 23: Percentages obtain on each perceptive values with regard to various landmarks

On the field, respondents gave their opinions and the perceptions the have on each landmark, by giving different perceptive values according to how these landmarks contribute in enhancing adaptive capacities on the agrarian landscapes. The perceptive value with the most responses was “productive” with 41.66%, while “progressive” followed with 25%. The third perceptive value of landmarks stated by the farmers was “static” with 16.68% (see table 23 above).

By choosing “productive”, the inhabitants meant their adaptive capacities is increasing and improving thanks to the support of landmarks. Also, the second perceptive value in terms of responses was “progressive”. By choosing “progressive”, the inhabitants meant the is a positive evolution in their adaptive capacities thanks to the support of landmarks. Then finally, for the respondents who choose “static” as their perceptive value, they meant that the presence of landmarks does not bring any change in their adaptive capacities. Respondents also expressed their views and perceptions by choosing other perceptive values such as: neutral and attractive (see table 23 above).

D. Sketched Maps (drawings) on paper of the two agrarian landscapes

The participatory mapping exercise which we conducted in the districts of OYACK A and OYACK B, resulted in the design and drawing of two sketched maps, which are: the sketch map of the agrarian landscape in OYACK A (1), and the sketch map of the agrarian landscape in OYACK B (2). To draw these sketch maps, we used the analog free hand sketching method, which consist in drawing a sketch map without using any kind of visual

(Image) nor digital support. This participatory sketch mapping aimed at understanding how the participants (landscape inhabitants) perceive and use the spaces found on their landscapes.

1. Sketch Map on paper of Landscape OYACK A



Figure 22: *The Participatory Sketched Map of Oyack A (the 1st agrarian landscape)*

With the help of the symbol recognition and visual analysis conducted on the sketch map of OYACK A, we obtained the following results and information: the identification of long-term (lasting) landmarks and short-term (easily movable) landmarks, which we illustrated below as natural and man-made landmarks.

a- Natural Landmarks

- **Rivers:** The main river hear is the river Nyong, which shape valleys and ecosystems over geologic timescales.

- **Plains:** The plains in this agrarian landscape represent long-standing landforms shaped by uplift and erosion.
- **Trees and Grasses:** These natural landmarks represent the green areas of the landscape, and they are a habitat for many terrestrial animals.
- **Creeks and Swamps:** These are the natural landmarks which represent the small water bodies of the landscape. They are a habitat for many aquatic animals.
- **Mountains & hills:** These mountains were formed by tectonic activity, and they persist for millions of years, although slowly eroded over time.

b- Human-Made Landmarks:

- **Road Networks:** These roads were built by the government to help the inhabitants move from one area of the landscape to another in a short time.
- **Houses:** These are the main shelters of the farmers and pastoralist. They live in their houses with their families.
- **Farmlands:** These are farm plots where the farmers grow their food crops for subsistence and commercial purposes (subsistence and commercial farming).
- **Markets:** These are the areas where the farmers and other produces come to sell their food crops.
- **Bridges:** The bridge in this landscape is a structure which was built to span the river Nyong, and enable people, vehicles, or bicycles to cross from one side to the other. The key purposes are for transportation, accessibility and trade.
- **Un-paved roads:** These are non-built roads, mainly made of sand, mud, and crushed stones which helps to create access to other corners or parts of the landscape.
- **Schools:** The main schools here are public primary and secondary schools, owned by the government.

2. Sketch Map on paper of Landscape OYACK B



Figure 23: *The Participatory Sketched Map of Oyack B (the 2nd agrarian landscape)*

With the help of the symbol recognition and visual analysis conducted on the sketch map of OYACK B, we obtained the following results and information: the identification of long-term (lasting) landmarks and short-term (easily movable) landmarks, which we illustrated below as natural landmarks; human-made landmarks; and rural infrastructures.

a- Natural Landmarks:

- **Fertile agricultural fields:** these are large expanses of cultivated land where farmers can grow wheat, corn, rice, etc.
- **Hedgerows:** these are lines of shrubs or trees marking field boundaries, providing shelter and biodiversity.
- **Water Bodies:** these are rivers, creeks, streams, irrigation canals, or ponds used for irrigation.
- **Soil Types:** these are fertile soils like loam or swampy areas which are key for natural resource.

- **Topography:** these are gently rolling hills or flat plains, ideal for machinery and crop growth.

b- Human-Made Landmarks:

- **Farmhouses:** these are homes where farmers and their families live. These are different from the houses found in OYACK A, because they are built with temporary materials like bamboo, mud, Plastic Sheets and wood.
- **Barns and Sheds:** these are structures for storing and keeping equipments, feed, or even housing animals.
- **Fences and Gates:** these are build to help manage livestock and protect crops.
- **Irrigation Systems:** these systems are pipes, ditches, or sprinklers to water crops.
- **Tractor Tracks:** these are visible lines or paths made by farm machinery.

c- Rural Infrastructures :

- **Country Roads or Farm Lanes:** these are access routes connecting fields, farms, and rural towns.
- **Agricultural Markets:** these are places where farm seeds are bought and where harvested food crops are sold locally.
- **Livestock Pens:** these are built up areas where pigs are been raised.
- **Food crop store houses:** these are storage areas where farmers store their harvested food crops.

E. Georeferenced images of all the landmarks (natural and man-made features) identified in the above sketch maps

There are twelve landmarks which were identified in the above sketch maps, and each of these landmarks were captured in georeferenced images with their respective coordinate systems (longitude and latitudes). We will first outline the georeferenced images of the landmarks identified in the sketch map of OYACK A (1), then we will outline and present the georeferenced images of the landmarks found in the sketch map of OYACK B (2).

1. The georeferenced images of the landmarks identified in the sketch map of OYACK A



Image 1: Georeferenced image of **Trees**

Image 2: Georeferenced image of **Swamps**

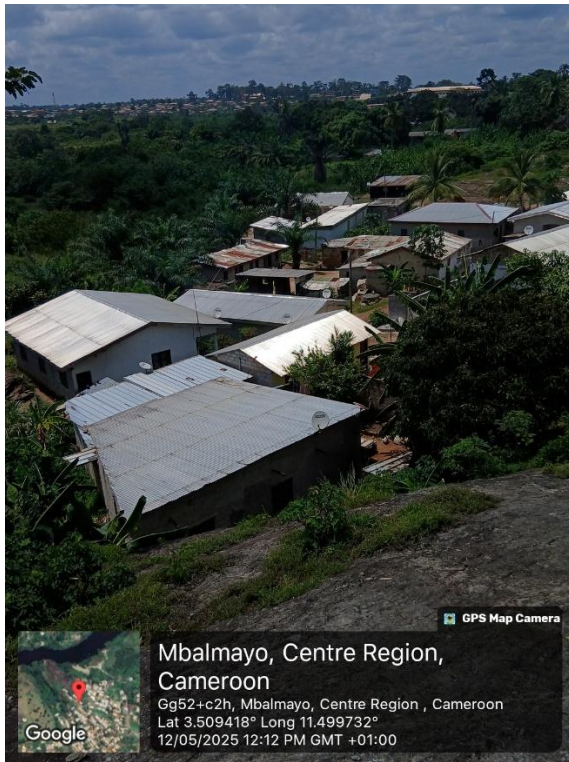


Image 3: Georeferenced image of **Houses**



Image 4: Georeferenced image of the **river**

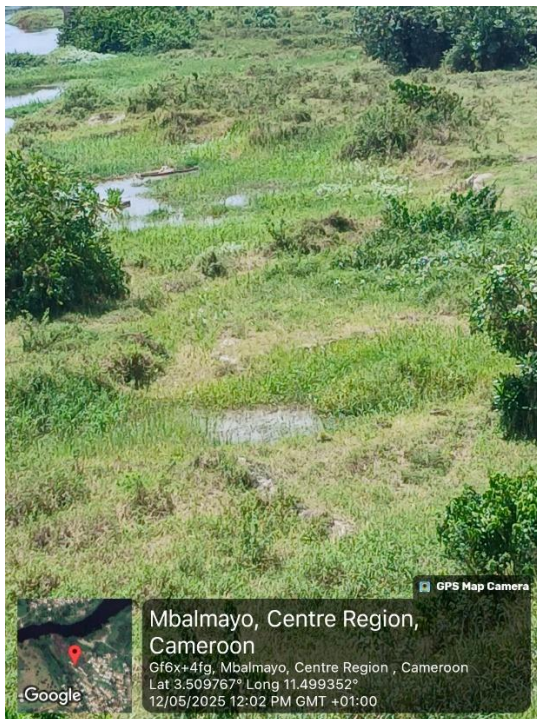


Image 5: Georeferenced image of the **Creek**



Image 6: Georeferenced image - **Agricultural field**

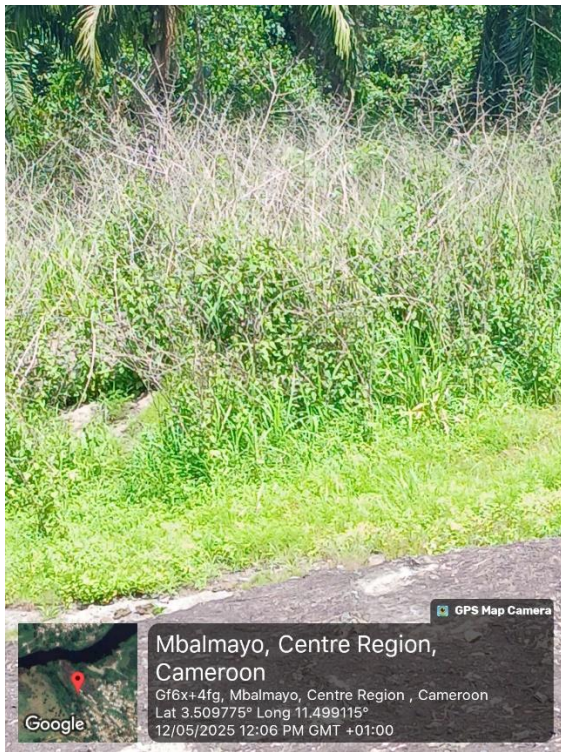


Image 7: Georeferenced image of **Grasses**

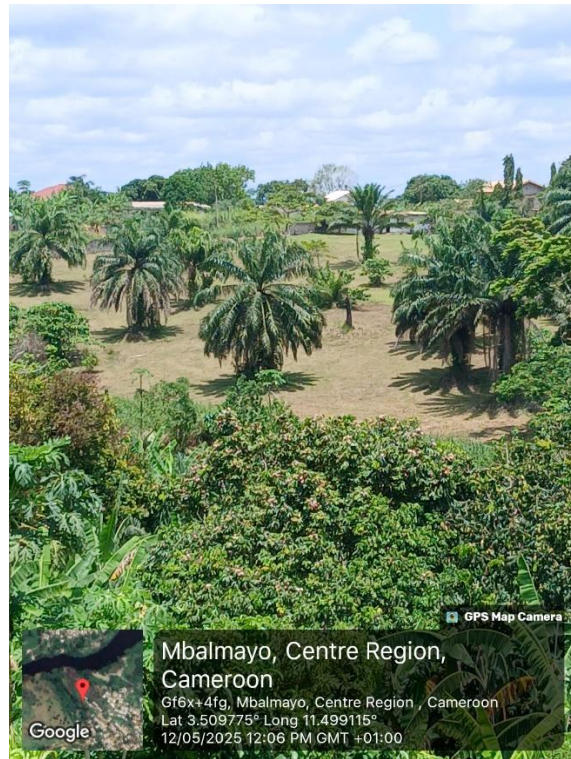


Image 8: Georeferenced image of **Plains**

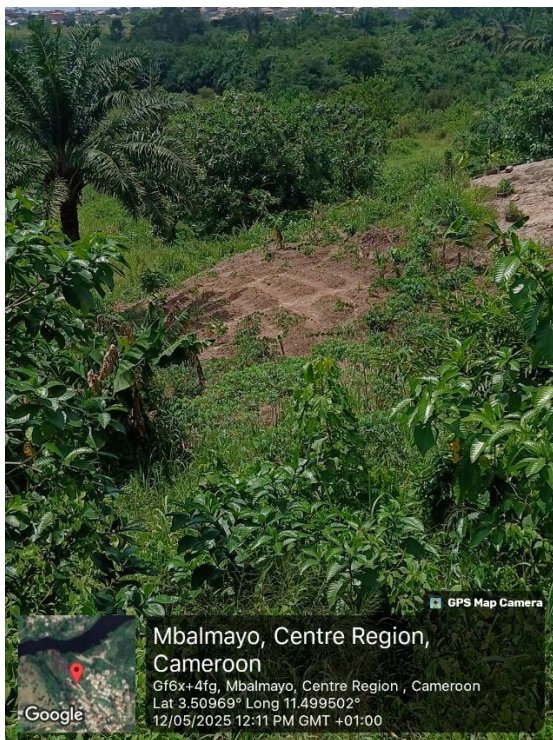


Image 9: Georeferenced image of the **Slope**

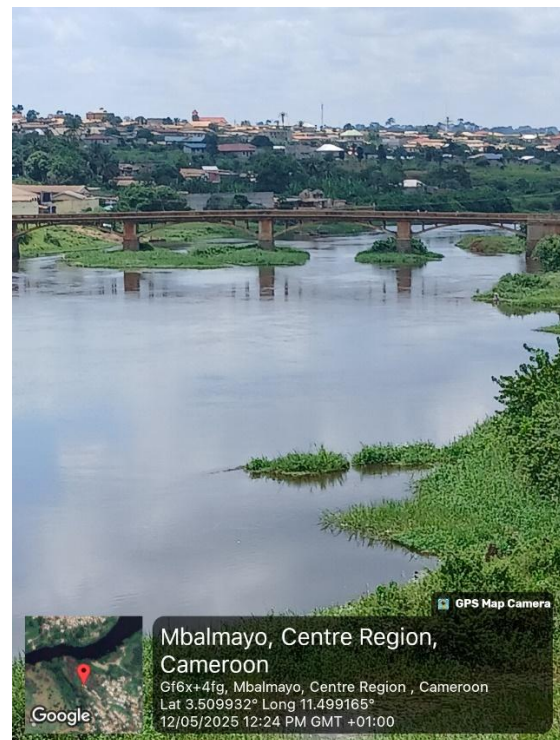


Image 10: Georeferenced image of the **Bridge**

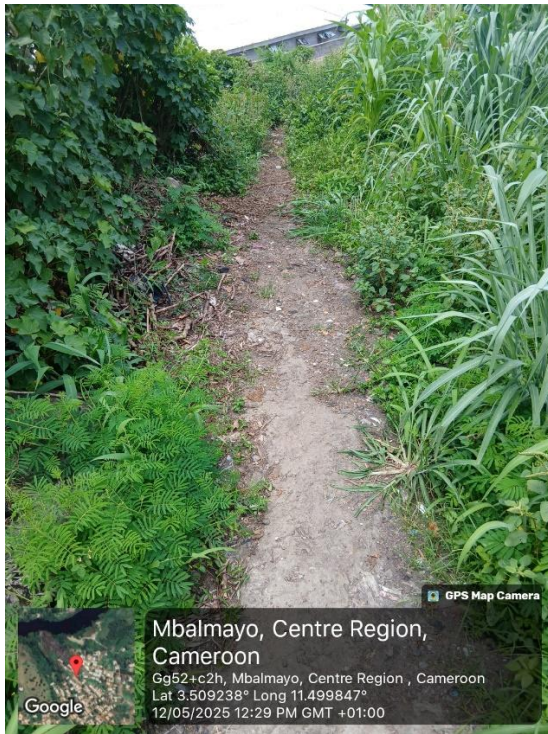


Image 11: Georeferenced image – Un-paved road

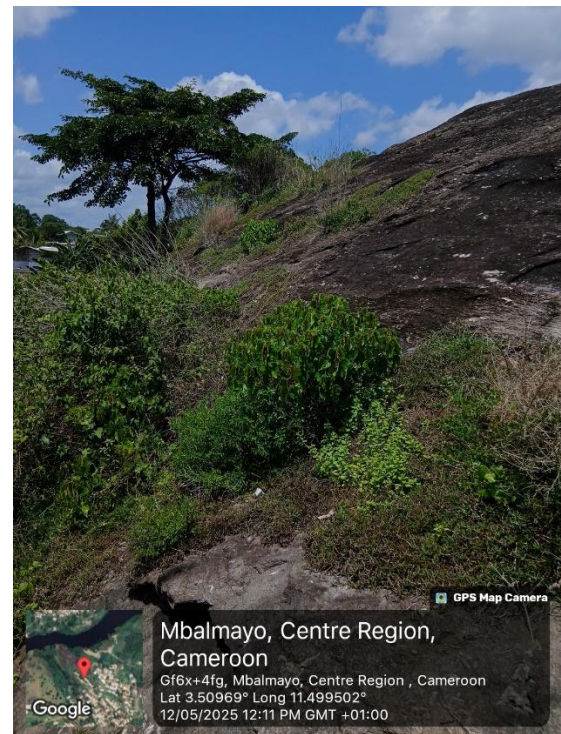


Image 12: Georeferenced image of the Hill

2. The georeferenced images of the landmarks found in the sketch map of OYACK B

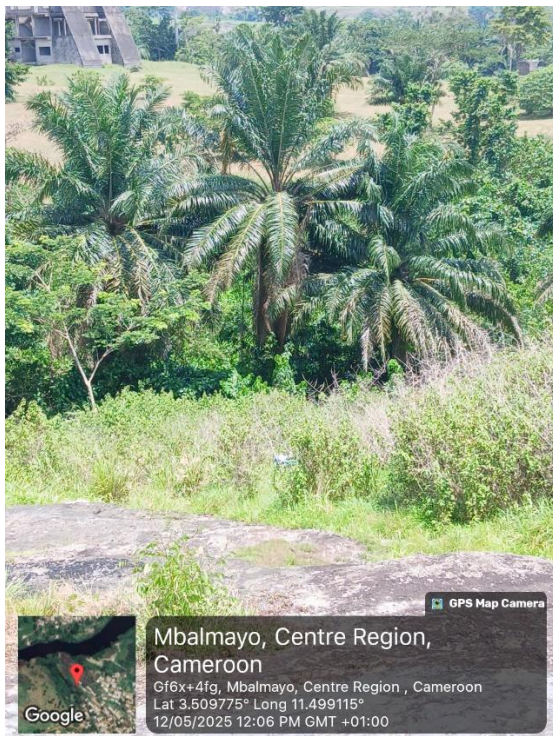


Image 1: Georeferenced image of Trees



Image 2: Georeferenced image of Swamps

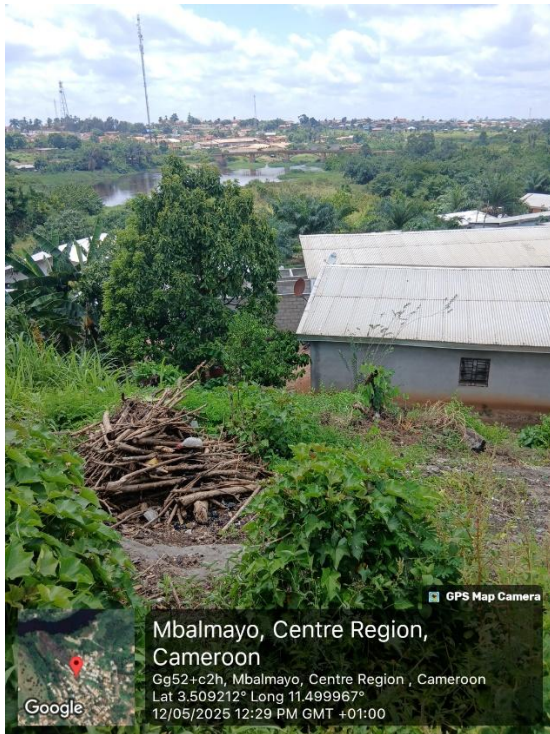


Image 3: Georeferenced image of **Houses**

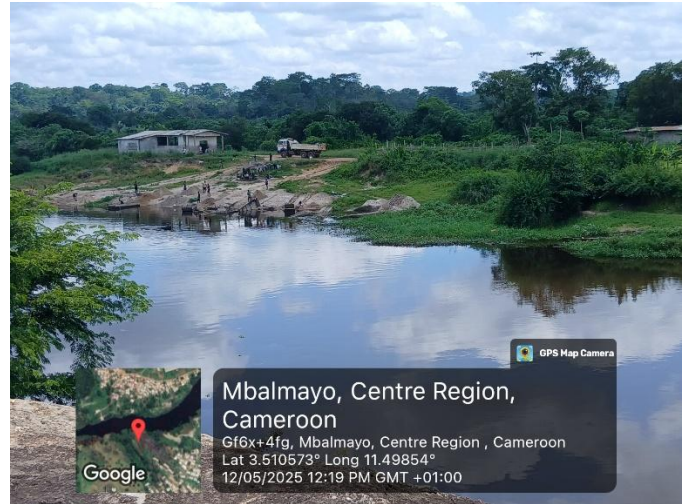


Image 4: Georeferenced image of the **river**

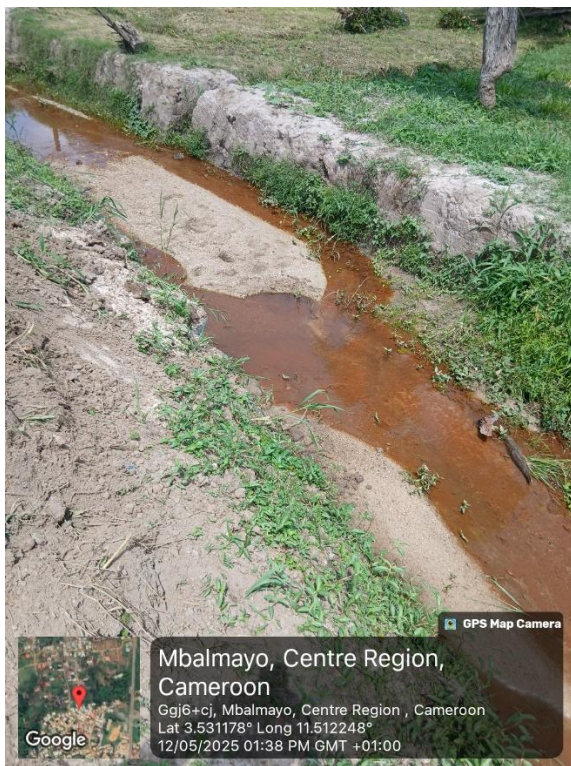


Image 5: Georeferenced image of the **Creek**



Image 6: Georeferenced image – **Agricultural field**

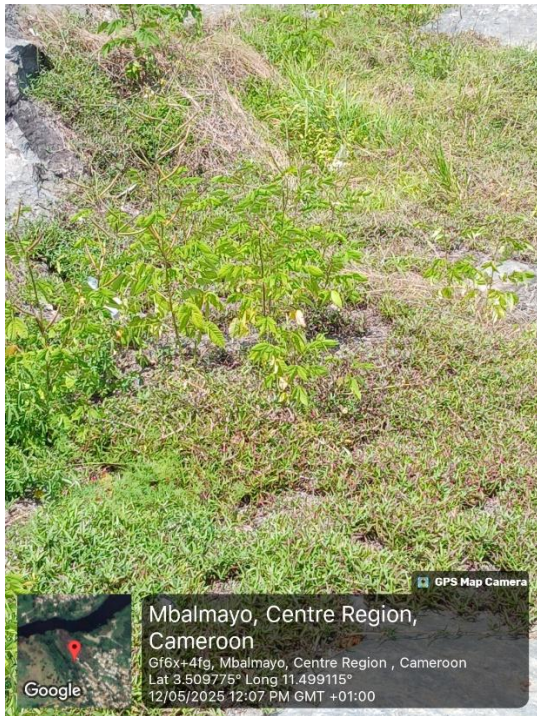


Image 7: Georeferenced image of **Grasses**

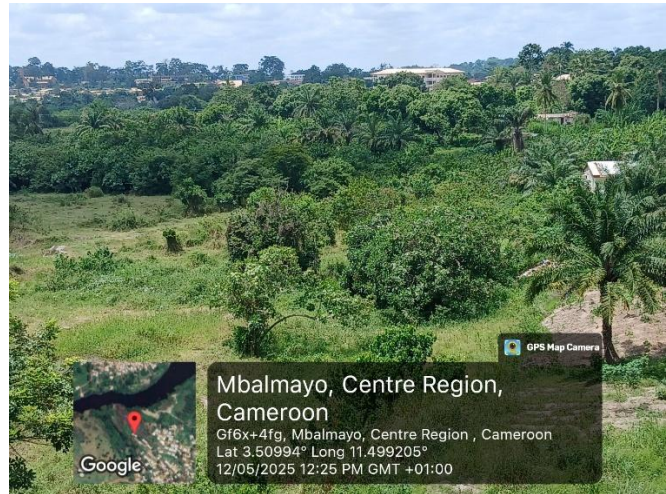


Image 8: Georeferenced image of **Plains**

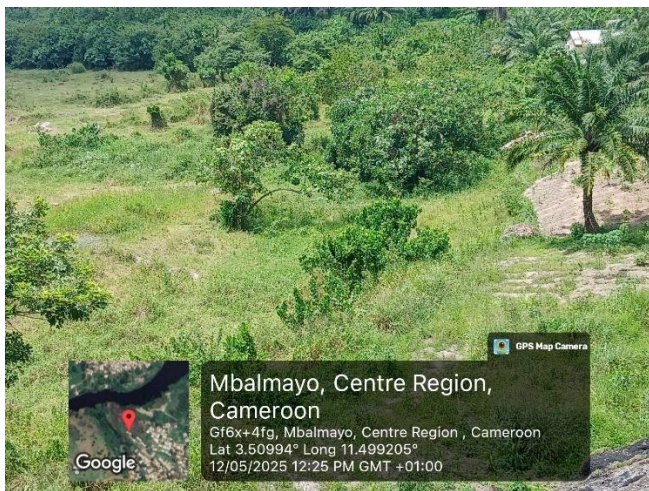


Image 9: Georeferenced image of the **Slope**

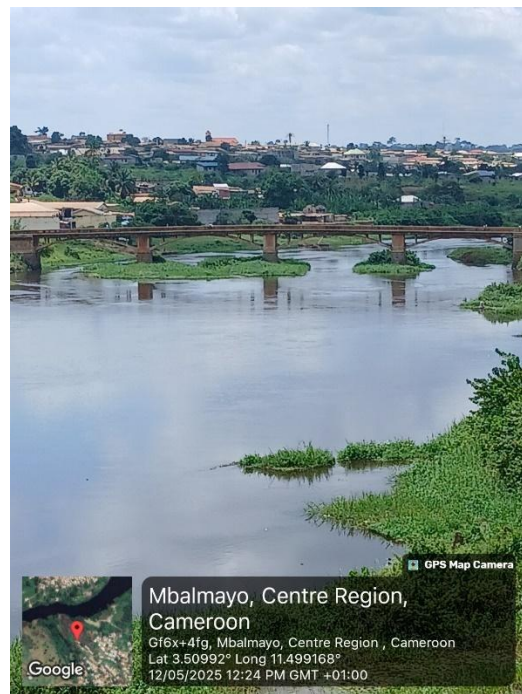


Image 10: Georeferenced image of the **Bridge**

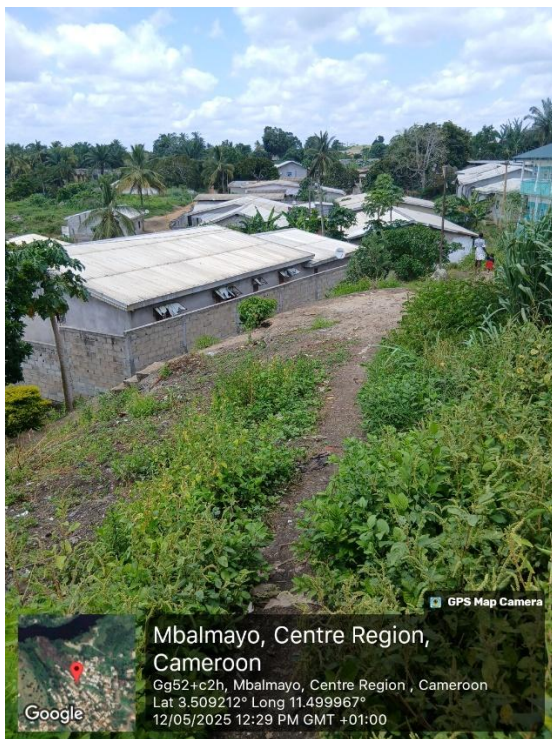


Image 11: Georeferenced image of the **Farm**
Un-paved road



Image 12: Georeferenced image of the **Hill**.

IV. DISCUSSION

In this section, we will discuss the contributions and impact of these various landmarks in addressing the key agro-environmental challenges that affects the productivity, sustainability, and livelihoods of farmers and pastoralists in the agrarian landscapes of OYACK A & B.

A. The contribution of landmarks in addressing water scarcity and poor water management in OYACK

In general terms, water scarcity covers all aspects related to water availability. According to the European Union (2007) water scarcity is defined as a situation where insufficient water resources are available to satisfy long-term average requirements. Similarly, Van Loon and Van Lanen (2013) considered that water scarcity represents the overexploitation of water resources, especially when demand for water is higher than water availability (María, Abel, Javier, Teodoro, & Javier, 2015).

In the agrarian landscapes of OYACK, there are five landmarks which helps to address water scarcity. These landmarks are: rivers, creeks, swamps, ponds and wells. In the agrarian landscapes of OYACK, the availability of fresh water from rivers, ponds and wells supports humans by providing water for drinking, agriculture, and industrial purposes, as well as for fish and waterfowl production. Rivers and lakes provide essential water for crop irrigation, especially during dry seasons or droughts. This contribution of rivers is called irrigation.

Droughts are a perturbation in the natural climatic and hydrologic regime, and they can affect the determinants of water quality in multiple ways. For example, low flows of water levels observed during hydrological droughts increase the residence time and reduce the flushing rate of water bodies (Mosley, 2015). Water sources for irrigation, including surface and groundwater, are declining in quality and quantity.

Greater annual crop yields can shift short-term profitability to the monoculture system, but long-term sustainability is likely to depend on environmental benefits and water savings achieved by integrated systems (Allen, Baker, Segarra, & Brown, 2007). Dryland agriculture will increase with the remaining water diverted to other uses including livestock, municipalities, manufacturing, and energy generation. Technological advances can increase water savings but can also decrease system resilience with dependence on no sustainable external buffers (Allen, Baker, Segarra, & Brown, 2007).

Wetlands help maintain groundwater levels and soil moisture, and this helps to prevent land degradation. This contribution of wetlands is called soil moisture retention. The significance of wetland ecosystems is thoroughly discussed amongst professionals in Cameroon, thereby demonstrating its numerous ecological services that range from wildlife habitat providing to water purification and flood control. Additional benefits of wetlands included reduced soil erosion, lower chemical inputs including a 40% reduction in N fertilizer, improved soil microbial and enzymatic activities, enhanced C sequestration, and greater rainfall infiltration (Allen, Baker, Segarra, & Brown, 2007).

The future challenges pertaining to food, clean water, energy, well-being of humans, natural disaster risk reduction, and climate change resilience can be met by preserving the wetlands. Wetlands are a crucial aspect of life on earth as they provide majority of services related to the sustainability of ecosystems. For instance, besides maintaining biodiversity, wetlands mitigate floods, protect the coastal areas from erosion, provide nurseries for aquatic and terrestrial life, improve and preserve water quality, recharge groundwater aquifers, serve as sinks, and produce food and energy for human use (Arunima & Brij, 2022).

In the agrarian landscape of OYACK, pastoralists rely on natural water bodies for their herds. Here, landmarks like rivers, creeks, swamps, ponds and wells help in providing Livestock watering. This contribution helps to maintain water in herbs for growth and nutrients. The region of Mbalmayo where we have the agrarian landscapes of OYACK was previously a grazing land ecosystem, which provided chances for pastoral systems who benefited from diversification.

B. The role of landmarks in addressing land degradation and soil erosion in the agrarian landscapes of OYACK

In Oyack, there are three landmarks which play a great role in addressing Land degradation and Soil erosion. These landmarks are: mountains, hills, slopes, and the topography of the landscape. Mountains often serve as catchment areas, promoting rainfall and feeding rivers or streams. This contribution of mountains enables rainfall catchment. Mountain regions supply a large share of the world's population with fresh water. Most of the rivers on this planet have their sources in mountain regions. The discharge which builds up there is transported via river systems to lower lying areas where it is often used for irrigation and, thus, for producing food (Viviroli & Weingartner, 2004).

Mountains and highlands are often called the world's natural "water towers" because they provide essential freshwater for populations both upstream and downstream. Despite this, knowledge about the significance of mountains in the hydrological cycle is still uncertain. Experts at an international conference on mountains held in Lima in 1995 stated that: "in the world, 80% of running freshwater originates from mountain areas". This astonishing figure, which is of major political importance was viewed as the emerging water crisis in the 21st century, and was originally scheduled for publication by the 1997 Special UN General Assembly on Agenda 21 (Daniel, Rolf, & Bruno, 2003).

Mountains constitute the source of much of the world's water resources, yet have less knowledge on hydrology and people know less about mountains on a global scale than about plains, hilly regions, and other areas. Meybeck et al. (2001) seemed to contest these claims concerning the hydrological significance of mountains: on the basis of a 0.5° grid, they determined that on a global scale the surface discharge from mountains was 32%. Their study is of great interest for the definition of mountains from a hydrological point of view (Daniel, Rolf, & Bruno, 2003).

Terracing of hillsides allows the cultivation of crops planted at specific altitudes, usually useful to diversify production. This contribution of hills gives rise to Altitude-based farming. Improving land productivity is essential to meet increasing food and forage demands in hillside and mountain communities. Tens of millions of smallholder terrace farmers in Asia, Africa, and Latin America who earn one to two dollars per day do not have access to peer-reviewed knowledge of best agronomic practices, though they have considerable traditional ecological knowledge. Terrace farmers also lack access to affordable farm tools and inputs required to increase crop yields (Tejendra & Manish, 2017).

Terrace farmers are agricultural workers who practice terrace farming. Terrace farming is a method of growing crops on the slopes of hills or mountains by creating step-like flat surfaces, called terraces, on the slopes. This method is especially used in hilly or mountainous regions where flat land is scarce. Terrace farming or terracing is a major source of livelihoods for a large section of hillside farmers across the world. In terracing, the hilly or mountainous terrains are divided into narrow but graduated steps, typically two to three meters wide and fifty to eighty meters long across the slopes, to facilitate growth of field crops, horticultural crops, fodder, and other crops that require specific management practices (e.g., irrigation), alone or associated in agroforestry systems (Tejendra & Manish, 2017).

Sloped areas may serve as grazing grounds when lowland areas dry out. Slopes facilitates the availability of pastures. The effects of livestock grazing on surface runoff and soil erosion at varying slopes were studied in pasture lands within Ginchi watershed, Ethiopia. The results showed that livestock grazing in the watershed followed distinct seasonal and spatial patterns. During the rainy season, grazing pressure was greatest on the upper slopes (>5% slope) while the pressure shifted to the lower slopes during part of the dry season (Mwendera, M. A. Saleem, & Dibabe, 1997).

There is an increasing interest in the development of livestock grazing management strategies that achieve environmental sustainability and improve the long-term production capacity of commercial grazing systems. This shift is driven by concerns over land degradation, climate change, biodiversity loss, and water quality, along with the need to support the livelihoods of producers (Dorrough, et al., 2004). Finally, topography affects water runoff, helping prevent waterlogging or erosion if managed well (e.g., contour plowing). This process gives rise to natural water drainage thereby avoiding soil erosion.

C. The support provided by landmarks in addressing biodiversity loss and climate extremes in OYACK

Landmarks such as trees and forest contribute a lot in addressing biodiversity loss and climate extremes in OYACK. Forests and trees act as windbreaks, reducing wind erosion. This action done by forest and trees is called Windbreaks. Windbreak is one of the key factors for making agriculture systems successful through reduced wind erosion, increased biodiversity, and improved production of timber and agricultural crops (Zdeněk, et al., 2018). Even though windbreak occupies only a small part of agricultural landscape, its advantages on the ecological and economical perspective are quite high (Zdeněk, et al., 2018).

Wind erosion is considered as one of the main processes of land degradation in different parts of the world. Among the most effective ways to control wind erosion, we have the action of covering land surface with natural vegetation areas (David, Tomáš, Josef, Jan, & Martin, 2017). Wind erosion is a dynamic process, which enables soil particles to be detached and relocated by the erosive forces of wind. Wind erosion starts at the time when wind forces exceed the threshold value of soil resistance to erosion. The speed of this type of erosion are influenced by geological, climatic, and anthropogenic factors. One of the ways to permanently prevent soil loss removal is to reduce wind speed and remove the intensity of wind erosion by windbreaks (David, Tomáš, Josef, Jan, & Martin, 2017).

On the other hand, trees provide shade for livestock and crops, mitigating heat stress. This second contribution of trees is referred to as Shade and shelter. Breeds that adapt to warm climates have provided an alternative means to mitigate the effects of heat stress on animal production. The non-availability of shades and shelters, creates serious cattle heat stress. Cattle heat stress causes billions of dollars is projected to become more severe in the future due to climate change. Tree establishment in pastoral livestock systems have the potential to reduce cattle heat stress and therefore provide nature-based adaptation solutions. Trees hold the greatest potential to reduce cattle heat stress in higher latitudes and altitudes, with minor benefits in the lowland tropics. Some scholars projected that the future contributions of current trees in mitigating climate change impacts will be mostly felt on dairy and beef herds (Daniel, Zachary, Donna, & Sandra, 2024). Therefore, the presence of many trees in OYACK will help mitigating climate change impacts on dairy and beef herds.

Shades and shelters may provide protection from cold and heat stress, during prolonged or seasonal drought. These shades and shelters may also provide essential nutrients, increased pasture, improved crop production

and improved landscape health to farmlands in the agrarian landscapes of OYACK. It is clear that shade and shelter in the correct locations provide a range of benefits to livestock and farmlands (Masters, et al., 2023).

Also, forests support pollinators, thereby enhancing crop productivity. While some forest loss can be beneficial to pollinators by enhancing habitat complementarity, too much can result in the near-elimination of forest-associated species. There are strong evidences from studies focusing on multiple crop types, which says that forest cover can substantially increase yields in adjacent habitats, at least within the foraging ranges of the pollinators involved. The literature also suggests that forests may have enhanced the importance of pollinators both in the present and in the future, given their role in mitigating the negative effects of pesticides and climate change. Many questions remain about the amount and the configuration of forest cover required to promote the diversity of forest-associated pollinators and their services within forests and neighboring habitats (Ulyshen, Urban-Mead, Dorey, & Rivers, 2023).

And finally, in the agrarian landscapes of OYACK and in the Mbalmayo Forest Reserve, forests help mitigate climate change effects by sequestering carbon. This process of carbon sequestration is called Carbon sink. Forests worldwide currently absorb billions of tons of CO₂ globally every year. This is an economic subsidy worth hundreds of billions of dollars, especially if an equivalent sink had to be created in other ways (Josep G. Canadell and Michael R. Raupach, 2008). A key opportunity in the agrarian landscapes of OYACK is the reduction of carbon emissions from deforestation and degradation.

D. The part undertaken by landmarks to address overgrazing and food shortages in OYACK

Landmarks play a great role in addressing low soil fertility and seasonal food insecurity in OYACK. These landmarks are: grasses and grasslands. Natural grasslands support a range of grasses and legumes for animal nutrition. This support brought by grasslands give rise to fodder diversity. These ecosystems are essential for pastoralists, providing grazing areas for livestock.

The global importance of grasslands is found in their nature and their characteristics. These grasslands comprise of 26% of total land area, whereby 64% is made up of agricultural land. The majority of grasslands are located in tropical developing countries where they are particularly important for the livelihoods of many poor peoples. Grasslands clearly provide the feed base for grazing livestock and thus numerous high-quality foods, but these livestock also provide products such as fertilizer, transport, traction, fiber and leather. In

addition, grasslands provide important services for water catchments, biodiversity reserves, recreational needs, and serves potentially as a carbon sink to alleviate greenhouse gas emissions (Boval & Dixon, 2012).

Grasslands, mixture of grass, leguminous species, dicotyledonous, herbs and shrubs, highly contribute in the struggle against erosion and to the regularizing of water regimes, for the purification of fertilizers and pesticides. They also contribute to biodiversity and they have an aesthetic role and recreational function as far as they provide public access that other agricultural uses do not do (Teague & Barnes, 2017).

Grassland will continue to be an important form of land use in Africa, even in the presence of increased diversity in management objectives and systems used. Besides its role as basic nutrient for herbivores and ruminants, grasslands provide opportunities for adding value by exploiting positive health characteristics in animal products from grassland and through the delivery of environmental benefits (Carlier, Rotar, Vlahova, & Vidican, 2009). And finally, in the agrarian landscape of OYACK, seasonal flooding may also regenerate pasture grasses by providing the needs of livestock production with environmental conservation. This regeneration process gives rise to what we call sustainable grazing.

V. CONCLUSION

Our study emphasizes the importance of participatory sketch mapping and spatial perception analysis in improving the adaptive capacity of agrarian landscapes. By directly engaging local stakeholders in mapping exercises, communities not only communicated their spatial knowledge, but also revealed the complex understandings of landmark distribution, land use dynamics, and socio-environmental vulnerabilities. These findings contributed to bridging the gap between scientific spatial analysis and lived experiences, resulting in a more inclusive approach to landscape planning and resource management. Disparities in landmark recognition and perceptions across demographic and geographic groupings revealed underlying inequalities in resource access and decision-making. Such discrepancies frequently go unreported in top-down planning approaches, but become obvious through participatory methodologies. This means that incorporating local spatial knowledge is more than just a tool for data gathering; because it provides a means to more egalitarian and resilient land-use planning, particularly in the face of climate change. Finally, our study concludes that collaborative and spatially grounded approaches can considerably improve adaptive capability in agrarian settings. Local knowledge is respected and integrated into planning frameworks, allowing communities to better anticipate, absorb, and adapt to climate change effects. As a result, future agrarian landscape

governance plans must integrate and take into account research results from participatory mapping and spatial perception studies on agrarian landmarks as critical components of adaptive and inclusive development policies.

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VIII. AUTHOR CONTRIBUTIONS

Individual authorship

IX. REFERENCES

- Allen, V. G., Baker, M. T., Segarra, E., & Brown, C. P. (2007). Integrated Irrigated Crop–Livestock Systems in Dry Climates. *Agronomy Journal of Texas Tech University, Volume 99, Issue 2*, 346-360.
- Anugya, S., & Kamal, J. (2020). Automatic extraction of urban land information from unmanned aerial vehicle (UAV) data. *Earth Science Informatics, Volume 13*, 1225–1236.
- Arunima, N., & Brij, B. (2022). Wetland Ecosystems and Their Relevance to the Environment: Importance of Wetlands. *Handbook of Research on Monitoring and Evaluating the Ecological Health of Wetlands*, 16 pp.
- Boval, M., & Dixon, R. M. (2012). The importance of grasslands for animal production and other functions: a review on management and methodological progress in the tropics. *Cambridge University Press, Animal , Volume 6 , Special Issue 5*, 748-762.
- Carlier, I., Rotar, i., Vlahova, m., & Vidican, R. (2009). Importance and Functions of Grasslands. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, volume 37, issue 1*, 25-30.
- Charu, M., Jakub, K., & Angela, S. (2024). An algorithmic approach to detect generalization in sketch maps from sketch map alignment. *PLoS One. 2024 Jun 26;19(6)*.
- Cheung, W., Houston, D., Schubert, J. E., Basolo, V., Feldman, D., Matthew, R., . . . Luke, A. (2016). Integrating resident digital sketch maps with expert knowledge to assess spatial knowledge of flood risk: A case study of participatory mapping in Newport Beach. *California. Applied Geography, 76, , 56–64*.
- Claudia, J. C., Jill, E. K., Tsui, C., & Marilyn, S. (2001). Mapping Residents' Perceptions of Neighborhood Boundaries: A Methodological Note. *American Journal of Community Psychology, 29(2):371-383*.
- Curtis, J. W., Shiau, E., Lowery, B., Sloane, D., Hennigan, K., & Curtis, A. (2014). The Prospects and Problems of Integrating Sketch Maps with Geographic Information Systems to Understand Environmental Perception: A Case Study of Mapping Youth Fear in Los Angeles Gang Neighborhoods. *Environment and Planning B: Planning and Design, 41(2), , 251-271*.
- Damayanti, R., & Kossak, F. (2016). xamining spatial identity of kampungs through young adults' perception in Surabaya – Indonesia. *Journal of Architecture and Urbanism, 40(1), 18–28*.
- Daniel, R., Zachary, D., Donna, G., & Sandra, L. (2024). Tree contributions to climate change adaptation through reduced cattle heat stress and benefits to milk and beef production. *Global Change Biology, Volume 30, Issue 5*.

- Daniel, V., Rolf, W., & Bruno, M. (2003). Assessing the Hydrological Significance of the World's Mountains. *Mountain Research and Development Journal*, Vol. 23, issue 1, 32-40.
- David, Ě., Tomáš, K., Josef, K., Jan, V., & Martin, P. (2017). Effect of Windbreaks on Wind Speed Reduction and Soil Protection against Wind Erosion. *Journal of Soil & Water Resilience*, 12, 2017 (2), 128–135.
- Dorrough, J., Yen, A., Turner, V., Clark, S. G., Crosthwaite, J., & Hirth, J. R. (2004). Livestock grazing management and biodiversity conservation in Australian temperate grassy landscapes. *Australian Journal of Agricultural Research* 55(3), 279-295.
- Hamlin, M. (2022). Participatory Sketch Mapping for Policy: A Case Study of Reentry Housing from Chicago. *The Professional Geographer*, Volume 74, Issue 1.
- Josep G. Canadell and Michael R. Raupach. (2008). Managing Forests for Climate Change Mitigation. *Science*, Vol 320, Issue 5882, 1456-1457.
- Lemmen, C. (2010). The Social Tenure Domain Model: A Pro-Poor Land Tool. *FIG Publication No. 52*.
- María, P. M., Abel, S., Javier, F., Teodoro, E., & Javier, P.-A. (2015). A review of water scarcity and drought indexes in water resources planning and management. *Journal of Hydrology*, Volume 527, 482-493.
- Masters, D. G., Dominique, B. A., Lockwood, A. L., Shane, C. ., D, M., Norman, H. C., . . . Hancock, C. (2023). Shelter and shade for grazing sheep: implications for animal welfare and production and for landscape health. *Animal Production Science*, Volume 63, issue 7, 623-644.
- Mondschein, A., Blumenberg, E., & Taylor, B. D. (2010). Accessibility and Cognition: The Effect of Transport Mode on Spatial Knowledge. *Urban Studies*, 47(4), 845-866.
- Mosley, L. M. (2015). Drought impacts on the water quality of freshwater systems; review and integration. *Earth-Science Reviews*, Volume 140, 203-214.
- Mwendera, E. J., M. A. Saleem, M., & Dibabe, A. (1997). The effect of livestock grazing on surface runoff and soil erosion from sloping pasture lands in the Ethiopian highlands. *Australian Journal of Experimental Agriculture* 37(4) , 421-430.
- Rowley, J. (2014). Designing and using research questionnaires. *Management Research Review*, 37(3), 308–330.
- Santosh, K. C., Bart, L., & Laurent, W. (2012). Symbol Recognition using Spatial Relations. *Pattern Recognition Letters*, Volume 33, Issue 3.
- Teague, R., & Barnes, M. (2017). Grazing management that regenerates ecosystem function and grazingland livelihoods. *African Journal of Range & Forage Science* Volume 34, Issue 2, 77-86.
- Tejendra, C., & Manish, N. R. (2017). Agronomic Challenges and Opportunities for Smallholder Terrace Agriculture in Developing Countries. *Front. Plant Sci., Sec. Agroecology*, Volume 8 – 2017, Department of Plant Agriculture, University of Guelph, Guelph, ON, Canada.

- Ulyshen, M., Urban-Mead, K. R., Dorey, J. B., & Rivers, J. W. (2023). Forests are critically important to global pollinator diversity and enhance pollination in adjacent crops. *Biological Reviews*, Volume 98, Issue 4, 1118-1141.
- Viviroli, D., & Weingartner, R. (2004). The hydrological significance of mountains: from regional to global scale. *Hydrology and Earth System Sciences*, Volume 8, issue 6, , 14 pp.
- Zdeněk, V., David, Ř., Jan, C., Stanislav, V., Tomáš, K., Ram, P. S., . . . Vladimír, P. (2018). Windbreak Efficiency in Agricultural Landscape of the Central Europe: Multiple Approaches to Wind Erosion Control. *Journal of Environmental Management*, Volume 62, 942–954.



CHAPTER 5:

Improving the adaptive capacities of agrarian landscapes through drone mapping and spatial analysis of landmark's distribution and disparities

Author: **Marcel Loyd MINKA**

African Journal on Land Policy and Geospatial Sciences (AJLP & GS)

AJLP & GS is a journal that publishes research activities carried out in the field of geospatial sciences and land governance. It aims to encourage innovation and promote the exchange of knowledge and scientific outcomes related to its themes. The journal's target community is made-up of researchers, professors and media professionals.

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IMPROVING THE ADAPTIVE CAPACITIES OF AGRARIAN LANDSCAPES THROUGH DRONE MAPPING AND SPATIAL ANALYSIS OF LANDMARK'S DISTRIBUTION AND DISPARITIES

¹Marcel Loyd MINKA

¹ Catholic University of Central Africa,
loyd.minka@yahoo.fr
 Yaoundé, Cameroon.

²Università Cattolica del Sacro Cuore,
 Faculty of Agricultural, Food and Environmental Sciences,
 Department of Animal, Nutrition and Food Sciences (DiANA).
marcelloyd.minka01@icatt.it

ABSTRACT

Context and background

Adaptive capacity is a system, region, or community's ability to adjust to the impacts or consequences of climate change. Enhancing adaptive capacity is a realistic way of dealing with changes and uncertainties in climate (Burton, 1997). Therefore, improving adaptive capacities of agrarian landscapes will decrease vulnerabilities to climate change and sustain agri-food systems. Spatial perception is the ability to perceive spatial relationships in respect to the orientation of one's body despite distracting information. It consists of being able to perceive and visually understand outside spatial information such as features, properties, measurement, shapes, position and motion (Tiwari, 2024).

Objective and research questions:

The research gaps or research problem that this study addressed is the lack of drone mapping data that illustrates and examines the role played by landmarks in strengthening the adaptive capacities of agrarian landscapes, especially swampy and fish pond landscapes. Our research is centered around the following two questions: How and to what extent can aerial drone mapping help illustrate and determine the role played by landmarks in strengthening the adaptive capacities of agrarian landscapes? And how can data help us determine which landmarks strengthens the most and how?

Methodology:

Using aerial drone mapping, we collected georeferenced data (Geotagging, GPS and GNSS) and aerial distance data to understand how each landmarks sustains the food crops cultivations and livestock farming activities even in the advent of severe climate induced disasters. By applying the Buffering and Proximity

Analysis on these Aerial Drone Maps, we succeeded to identify many existing features (houses, farmlands, schools, etc.) that also play a great role in strengthening adaptive capacities. In addition to this drone mapping process, farmers were asked through a questionnaire survey to describe how these landmarks helps them to adapt to climate disasters and which relation the landmarks have with their agricultural practices. Also, through this questionnaire survey, farmers where ask to describe the distribution and disparities which exist amongst these landmarks.

Results:

The results of this study shows that the most exposed and sensitive landmarks were creeks, rivers, swamps, plains, trees, Grasses and Tulip fields. In the surveys, the respondents mentioned that the implementation of adaptive measures like floodplains, agroforestry, Mangroves Trees and wetland restorations will protect and sustain the cultivation of watermelon, maize, wheat, rice, cassava and sugarcane. This is because, the cultivation of these six food crops in Mbalmayo is sustained by landmarks such as creeks, rivers and swamps. Most landmarks are sensitive and exposed to droughts, heatwaves, heavy precipitation and flooding.

Keywords: Adaptive capacities; Agrarian Landscapes; drone mapping; aerial imagery ; Landmarks; Spatial analysis; proximity ; Nearest neighbors ; Landmark’s distribution; Landmark’s disparities; Farmers; Pastoralists.

I. INTRODUCTION

Climate change poses a significant threat to Cameroon's sustainable development. Responding to climate change from both mitigation and adaptation perspectives requires strategic approaches from legislative, regulatory, and institutional frameworks and capacities. Rivers provide a special suite of goods and services valued highly by the public that are inextricably linked to their flow dynamics and the interaction of flow with the landscape. Yet most rivers are within watersheds that are stressed to some extent by human activities including development, dams, or extractive uses. Climate change will add to and magnify risks that are already present through its potential to alter rainfall, temperature, runoff patterns, and to disrupt biological communities (Palmer & Filoso, 2009). Many rivers of the world are experiencing exacerbated disturbances driven by climate change, such as increases in flooding, wildfires, and droughts, as well as warming river temperatures, with some of these extreme events being the most severe and intense. As changing climate alters the inputs to rivers and human modification alters the morphology and connectivity of rivers, restoration increasingly considers how to enhance adaptive capacities (Wohl, et al., 2024). River corridors consist of a dynamic mosaic of spatial elements and ecological processes arrayed hierarchically. As such, they fit comfortably within the framework of landscape ecology, defined by Turner (1998) as the study of interactions between spatial patterns and ecological processes in the context of spatial heterogeneity across a range of scales.

Resilience to climate change considers not just preventing disturbances in existing planning systems, but also concerns strengthening government abilities in terms of building structures of land distribution and functions in order to increase its adaptive capacity to disturbances (Eraydin & Taşan-Kok, 2013). Adaptive capacity refers to the ability of a region/area/system to deal with environmental and social disturbances in order to maintain resilience (Folke, et al., 2002). The main environmental disturbances in Cameroon are: floods, droughts, wildfires, and landslides. Systems with high adaptive capacity are able to re-organize and renew themselves against disturbances without significant structure changes. The loss of adaptive capacity is the loss of opportunity for resilience, and “gaining from the disturbances” becomes a new path of perceiving resilience (Smit & Wandel, 2006). In practical terms, adaptive capacity is the ability to design and implement effective adaptation strategies, or to react to evolving hazards and stresses so as to reduce the likelihood of the occurrence and/or the magnitude of harmful outcomes resulting from climate-related hazards. The

adaptation process requires the capacity to learn from previous experiences to cope with current climate, and to apply these lessons to cope with future climate, including surprises (Barnett, 2001).

The landmarks which we analyzed in this study are the different varieties of physical elements found on the agrarian landscapes NGALAT and MBOCKULU in Mbalmayo. These landmarks are Creeks (variety 1); rivers (variety 2); slopes (variety 3); swamps (variety 4); plains (variety 5); Trees (variety 6); Bridges (variety 7); Grasses (variety 8); Farm un-paved roads (variety 9); Houses (variety 10); Hills (variety 11); and Mountains (variety 12). The problem this research wants to address is the lack of spatial data and spatial analysis illustrating the role played by landmarks in building adaptive capacities fish pond and in agrarian landscapes. This research study was conducted from April to August 2025 in the fish pond and agrarian landscapes of NGALAT and MBOCKULU in Mbalmayo. To solve the above problem, we asked ourselves the following research questions: How and to what extend can aerial drone mapping help illustrate and determine the role played by landmarks in strengthening the adaptive capacities of agrarian landscapes? And what type of data helps determine which landmarks strengthens the most and how? Our paper carried out investigations on both landmarks and agrarian landscapes. Concerning landmarks, our paper investigated: the varieties of landmarks which are found in NGALAT and MBOCKULU; how often these landmarks appear; their form of distribution and disparities; their exposure and sensitivity to climate induced disasters; the type and number of landmarks which will regenerate naturally without human intervention; and the type of climate induced disasters which destroys these landmarks, food crops and livestock farming.

II. METHODS AND MATERIALS

A. Data collection

To properly carry out this study, we collected both quantitative and qualitative data through five different methods. These methods were: Questionnaire Surveys on Kobo Toolbox; Georeferenced data with coordinate systems; geometry; aerial distances; and Drone mapping. Then we conducted in-depth data analysis to determine how the above data could support the enhancement of adaptive capacities in the agrarian landscapes of NGALAT and MBOCKULU. This in-depth analysis consists in three type of analysis which were: cross-tabulation analysis; Buffering analysis; Proximity analysis of aerial drone maps; and Euclidean Distance Analysis (using the Euclidean distance formula). To collect this data, we used a sample study. A sample study is research where data is collected from a selected group of individuals to represent and draw

conclusions about the whole population. The sample here is a group of farmers and pastoralist who live in the landscapes of NGALAT and MBOCKULU.

1. Questionnaire Survey on Kobo Toolbox

The data we gathered from this survey is primary research data, making it one of the most dependable and accurate data we had in this study. These surveys were effective in getting precise information about both large and small groups living on the agrarian landscapes of NGALAT and MBOCKULU in Mbalmayo. The analysis this survey data will allow us to make conclusions and guide crucial decision-making processes. A questionnaire is a research tool that has a series of questions designed to elicit meaningful information from respondents (Rowley J. , 2014). Therefore, questionnaire surveys are a strategy for acquiring statistical information about a population's characteristics, beliefs, or activities using a predefined set of questions (Rowley J. , 2014). In this study, we created survey questionnaires using Kobo Toolbox. Kobo Toolbox is a suitable open-source tool for simplifying data collection. It allows users to develop and distribute forms as well as collect data over a variety of channels, including webforms, mobile devices, and tablets (Selva Das, 2024). Kobo toolkit is essential for accuracy, speed, data quality, and cost effectiveness (Lakshminarasimhappa, 2021). Field data is collected using this open-source data collection tool (kobo collect) by using mobile devices such as phones and tablets, but it can also be collected via online forms (<https://www.kobotoolbox.org/>). Therefore, through Kobo toolbox, we collected quantitative data to determine the major landmarks to which the farmers and pastoralists in NGALAT and MBOCKULU are entitled to in terms building resilience against climate disasters to secure the use and benefits of their lands (tenure security). The survey questions in this questionnaire was addressed and given to a sample of 122 (one hundred and twenty-two) farmers and pastoralist, who live in the agrarian landscapes of NGALAT and MBOCKULU. This is a subset of the larger population of farmers and pastoralist in NGALAT and MBOCKULU.

2. Georeferenced data with coordinate systems and geometry

The “Georeferenced data with coordinate systems” which we collected here refers to the information (location and shape) of any natural or human-made characteristic (landmark or geographic features) which is found in the districts of NGALAT and MBOCKOULU in the department of Nyong-et-So'o, found in the center region of Cameroon.

Firstly, with regards to the **location**, the data here comprises of the **geographical coordinates (Latitude and Longitude)** of each landmark found in the districts of NGALAT and MBOCKOULU.

- **Latitude:** Measures how far north or south a point is from the Equator (0° latitude).

Range: from -90° (South Pole) to +90° (North Pole)

- **Longitude:** Measures how far east or west a point is from the Prime Meridian (0° longitude).

Range: from -180° to +180°

A typical example can be the location of Mount Everest, which is approximately:

Latitude: 27.9881° N

Longitude: 86.9250° E

Secondly, with regards to the shape, the data here comprises of the **geometry** of each landmark found in the districts of NGALAT and MBOCKOULU. In geographic information systems (GIS), the **geometry** here is often described using:

- **Vectors** — such as points, lines, and polygons that define shapes.
- **Polygons** — commonly used to represent areas like lakes, parks, or countries.
- **Lines** — for linear features like rivers, roads, or boundaries.
- **Points** — for specific locations like landmarks, districts or cities.

To obtain this geometry data (shape of the landmarks), we uploaded the aerial drone map of NGALAT and MBOCKOULU (the two agrarian landscapes) on QGIS software, in order to draw and bring out the vectors, polygons, lines and points of each landmark. Therefore, by determining (bringing out) the shape of these landmarks, we provided their geometric representation.

Thirdly, used the coordinate systems (longitudes and latitudes) of each landmark to obtain the physical distances between each landmark.

3. Drone Mapping and aerial distances data between landmarks

This aerial distance is the straight-line distance between two landmarks found on the drone map. This is especially useful for surveying, agriculture, construction, and logistics planning. The data obtained here will

be the Straight-line distance (in meters) between two or more landmarks (waypoints). To obtain these ground distance data, we uploaded the drone maps in a particular mapping software or GIS tool which was “QGIS”, then, we measured the ground distance between each landmark. To measure these ground distances between two or more landmarks, we used the Measure Line Tool on QGIS to draw and compute distances. This measure line tool was used to calculate the distances (straight-line) between these landmarks. By using this measure line tool, we obtained high accurate ground distance data with precise coordinates.

In each of the two agrarian landscapes of NGALAT and MBOCKOULU, we calculated on the QGIS software the following ground distances:

- **Paved Roads facilitating access to landmarks:** the ground distance from the main paved road to each of the twelve landmarks (to the nearest and farthest neighbors, with regards to each of the twelve landmarks).
- **Un-paved roads granting access to landmarks:** the distance between the nearest un-paved road to the nearest landmark (nearest neighbors).
- **Agricultural Fields (farmlands):** the total length of farm boundaries. Here we calculated the length (ground distances) of each farm.
- **The ground distance (Nearest and Farthest Neighbors) between the following landmarks:**
 - Fish Ponds and Main Road; Fish Ponds and Houses; Fish Ponds and Hospital.
 - Crop farms and Main Road; Crop farms and Houses; Crop farms and Hospital.
 - Swine farm and Main Road; Swine farm and Houses; Swine farm and Hospital.
 - Small ruminant farm and Main Road; Small ruminant farm and Houses; Small ruminant farm and Hospital.
- **The ground distances between every twelve landmarks:** Ground distance between creeks; rivers; slopes; swamps; plains; trees; bridges; grasses; farm un-paved roads; houses; hills; and mountains in the agrarian landscapes of NGALAT and MBOCKULU.
- **Water bodies (fish ponds, rivers, lakes, etc.) and Landmarks:** the ground distances (Nearest and Farthest Neighbors) between the water bodies and every landmark.

B. Data analysis

1. Cross-tabulation analysis

To analyze the survey data which we collected with kobo toolbox, we used cross-tabulation analysis. This method of cross-tabulation analysis is the best method because the survey data which we collected aims at determining the existing relationship between the four variables of our study. These variables are: distribution, disparities and ground distance between landmarks (*Independent variable*); adaptive capacities of agrarian landscapes (*Dependent variable*); type of agrarian landscapes; the type of climate induced disasters; and type of nature-based solutions (*Controlled/Constant variable*); unexpected climate induced disasters occurring in the agrarian landscapes which deteriorates and destroys the landmarks; type and volume of food crops cultivated; the type and amount of livestock farming practiced (*Extraneous Variables*). In this study, we used cross-tabulation analysis (often called crosstab) as a statistical tool to analyze the relationship between the above four variables by displaying the data in a matrix or table format. This analysis helped us to visualize how the values of one variable relate to the values of another, thereby helping us to identify patterns, trends, or correlations.

The cross-tabulation analysis of the survey data which we collected gave rise to 21 tables, each of them corresponding to at least two or more variables measured.

2. Buffering and Proximity Analysis of Drone Maps

To facilitate the identification key features on the drone maps, we used Buffering and Proximity Analysis on QGIS. This type of analysis enabled us to identify many existing features (houses, farmlands, schools, etc.). This Buffering and Proximity Analysis method was used to identify features within a certain distance from a point, line, or landmark. For example, finding all schools within 1 mile of a highway road. The tool we used here is Buffer creation on QGIS software.

In this study, buffer creation was used as a GIS operation that created a zone (called a buffer) around a map feature (landmark) at a specified distance. The purpose of this buffer creation analysis was to identify the total area within a certain distance from one landmark to the other, in order to determine if this total area is a flood risk zone or if it can be used as an adaptation area to climate change. For example, in this study, we created a 500-meter buffer around the following landmarks: wetlands, Mangroves, mountains, forests,

floodplains, grasslands and highlands. We created a buffer zone around these landmarks because these landmarks are most observed natural features that provide resilience to climate induced disasters in these two districts (NGALAT and MBOCKOULU).

With this buffer creation, we will also be able to identify all the movement or transportation obstacles which are found within 500 meters of the hospitals or main roads in NGALAT and MBOCKOULU. The identification of these transportation obstacles will help improve all the emergency and anticipatory actions in the event of a climate disaster.

3. Euclidean Distance Analysis

The Euclidean distance analysis calculates the ground distance between two points. Euclidean distance is a fundamental concept in geometry and data analysis that measure the straight-line distance between two points found on a drone map. It's widely used in many fields such as machine learning, image processing, spatial analysis, and clustering. With this analysis, we determined the proximity between the twelve landmarks.

Firstly, with this euclidean distance formula, we measured and determined the ground distance between every twelve landmarks (creeks; lakes; slopes; swamps; plains; forest; trees; grassland; houses; unpaved roads; hospitals, and hills) in the agrarian landscape. The distances in meters obtained through this euclidean distance formula were placed in matrix tables. These distances in meters will enable us to know which landmark is closer to which one thereby determining each landmark Nearest Neighbor (NN). This information will also help improve the adaptive capacities of these landscapes given the fact that the inhabitants rely mostly on landmarks for their adaptive capacity. Therefore, because these twelve landmarks had projected coordinate system (like UTM, meters), we used the formula below:

Euclidean distance formula:

$$\textit{Distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

where: (X₁, Y₁) and (X₂, Y₂) are the coordinates of the two landmarks (locations):

- **X₁** and **Y₁** are the coordinates of the first landmark.
- **X₂** and **Y₂** are the coordinates of the second landmark.

-
- D is the distance between the two landmarks.

The calculation of the **closest distance (Nearest Neighbor)** through the above Euclidean distance formula gave rise to some **distance matrix tables on Excel**. These distance matrix tables represent the result of our analysis which we presented in the next section (results section).

Creating a distance matrix table manually in Excel involves calculating the ground distance between pairs of points (usually coordinates). Here's how we did it step by step:

- The 1st step was to identify the coordinate systems of the landmarks whose distance we wanted to calculate and put these coordinate systems in a table with respect to their longitude (X) and latitude (Y). That is, input our data in the cells of the table, from cells A2:C4 of the excel table.
- The 2nd step was to set up the Matrix Headers starting from E1. Here we created the headers horizontally and vertically with the landmark's names. That is, we placed the landmarks names "A", "B", "C" in F1, G1, H1 and in E2, E3, E4 respectively.
- The 3rd step was to calculate the distance between each landmark by applying the **Euclidean distance formula** in every cell of the excel table. The Euclidean distance formula we used in Excel was:

$$= \text{SQRT}((x2 - x1)^2 + (y2 - y1)^2)$$

Secondly, we also used the euclidean distance analysis to calculate the ground distance from every fish pond or farm (crop farm or livestock farm) to the nearest main road, hospital and house, in order to determine the rapidity (speed) of an adaptation action in the event of a climate induced disaster. The two main adaptation actions which are referring to here are: *Determining nearest and closest distances to improve planting times in order to match shifting growing seasons*; And *bringing healthcare services closer to effectively manage new climate-related diseases*. Each of these fish ponds, farms, roads, hospital or houses represents a specific point which was marked in 2D on the drone map. Therefore, through these euclidean distance analysis, we determine how close the fish pond and farms are to the healthcare services for an accurate management of new climate-related diseases. An example of such *climate*-related diseases is Schmallenberg virus infection which is found in cattle and sheeps.

Thirdly (finally), with the ground distances (results) obtained from this second euclidean distance analysis, we determined which of the major farming activity (fish pond, crop farm or livestock farm) is closer to the

main road and hospital. These results will help to improve emergency and adaptation actions in the event of a sudden climate induced disaster. Examples of sudden or unexpected climate disasters which usually happens in Mbal Mayo are: landslides, wildfires, and Flash Floods. Therefore, by knowing which fish pond or farm is the closer to the main road, and by knowing what are the distances between these farms and the main roads, the farmers will be able to easily escape from any sudden climate disaster.

For this second and third euclidean distance analysis, we applied the following euclidean distance formula on the QGIS's Field Calculator:

$$= \text{SQRT}((x2 - x1)^2 + (y2 - y1)^2)$$

III. RESULTS

A. Cross-tabulation tables

Value	Frequency	Percentage
Grasses	32	13.22
Trees	32	13.22
Swamps	29	11.98
Creeks	26	10.74
Houses	24	9.92
Rivers	21	8.68
Agricultural fields	21	8.68
Farm un-paved roads	19	7.85
Slopes	18	7.44
Plains	12	4.96
Bridges	5	2.07
Hills	5	1.24
TOTAL	242	100

Table 1: The frequency at which each landmark is found or seen in the fish pond and agrarian landscapes

Value	Frequency	Percentage
Swamps	28	16.47
Trees	27	15.88
Rivers	22	12.94
Houses	19	11.18
Agricultural fields	19	11.18
Creeks	17	10.00
Grasses	14	8.24
Slopes	13	7.65
Plains	6	3.53
Farm un-paved roads	3	1.76
Bridges	2	1.18
TOTAL	170	100

Table 2: The landmarks which are more exposed to climate induced disasters in the fish pond and agrarian landscapes

Value	Frequency	Percentage
Trees	26	17.33
Swamps	25	16.67
Rivers	22	14.67
Creeks	18	12.00
Agricultural fields	18	12.00
Houses	17	11.33
Slopes	11	7.33
Grasses	11	7.33
Farm un-paved roads	1	0.67
Bridges	1	0.67
TOTAL	150	100

Table 3: The landmarks which are more sensitive to climate induced disasters in the fish pond and agrarian landscapes

Value	Frequency	Percentage
Swamps	27	22.50
Rivers	12	18.33
Agricultural fields	18	15.00
Creeks	16	13.33
Trees	15	12.50
Slopes	12	10.00
Grasses	6	5.00
Plains	3	2.50
Bridges	1	0.83
TOTAL	120	100

Table 4: The landmarks which best sustains and strengthens the food crops cultivated

Value	Frequency	Percentage
Swamps	22	20.00
Rivers	20	18.18
Creeks	15	13.64
Grasses	12	10.91
Tress	11	10.00
Agricultural fields	11	10.00
Slopes	10	9.09
Plains	4	3.64
Houses	3	2.73
Bridges	1	0.91
Farm un-paved roads	1	0.91
TOTAL	110	100

Table 5: The landmarks which best sustains and strengthens the livestock farming practiced

Value	Frequency	Percentage
Trees	33	23.91
Grasses	28	20.29
Creeks	23	16.67
Swamps	19	13.77
Rivers	16	11.59
Slopes	9	6.52
Plains	4	2.90
Farm un-paved roads	3	2.17
Houses	2	1.45
Agricultural fields	1	0.72
TOTAL	138	100

Table 6: The most-cited landmarks which are most likely to regenerate naturally in twenty-years without human intervention

Value	Frequency	Percentage
More often	26	55.32
Less often	17	36.17
Much more often	2	4.26
Once	2	4.26
TOTAL	47	100

Table 7: The frequency (recurrent) at which these landmarks appear in the two agrarian landscapes

Value	Frequency	Percentage
Grouped	33	66
Scattered	9	18
Aligned	4	8
Unevenly spaced	3	6
Uniform	1	2
TOTAL	50	100

Table 8: The form (type) of distribution observed amongst these landmarks

Value	Frequency	Percentage
Distinct	14	33.33
Unequal	12	28.57
None	7	16.67
Heterogeneous	6	14.29
Disproportionate	3	7.14
TOTAL	42	100

Table 9: The form (type) of disparities observed amongst these landmarks

Value	Frequency	Percentage
20 meters	29	67.44
50 meters	10	23.26
200 meters	2	4.65
100 meters	1	2.33
500 meters	1	2.33
TOTAL	43	100

Table 10: The most observed and common distances between these landmarks?

Value	Frequency	Percentage
Landscape of NGALAT	38	82.61
Landscape of MBOCKULU	8	17.39
TOTAL	46	100

Table 11: The agrarian landscape (Ngalat and Mbockulu) with the most landmarks

Value	Frequency	Percentage
Severe droughts	32	36.78
Heatwaves	24	27.59
Devastating floods	16	18.39
Heavy precipitation	14	16.09
Wildfires	1	1.15
TOTAL	87	100

Table 12: The most frequent climate induced disasters to which the landmarks are constantly expose to

Value	Frequency	Percentage
Severe droughts	32	36.78
Heatwaves	24	27.59
Devastating floods	16	18.39
Heavy precipitation	14	16.09
Wildfires	1	1.15
TOTAL	60	100

Table 13: The most recurrent climate induced disasters to which the landmarks are constantly sensitive to

Value	Frequency	Percentage
Maize	38	18.54
Plantain	32	15.61
Cassava	27	13.17
Banana	26	12.68
Peanut	21	10.24
Beans	12	5.85
Yam	11	5.37
Cocoyam	10	4.88
Oranges	7	3.41
Tangerines	6	2.93
Cocoa	5	2.44
Sugar Cane	4	1.95
African Pear	3	1.46
Others	3	1.46
TOTAL	205	100

Table 14: The type of food crops cultivated in these agrarian landscapes and their classification from the most to the least cultivated?

Value	Frequency	Percentage
Maize	35	19.89
Plantain	28	15.91
Cassava	27	15.34
Peanut	18	10.23
Banana	18	10.23
Beans	10	5.68
Cocoyam	9	5.11
Yam	8	4.55
Oranges	6	3.41
Sugar Cane	5	2.84
Tangerines	5	2.84
Cocoa	4	2.27
African Pear	3	1.70
TOTAL	176	100

Table 15: The type and proportion of food crops which are more exposed to climate induced disaster

Value	Frequency	Percentage
Maize	34	20.86
Plantain	28	17.18
Cassava	25	15.34
Banana	19	11.66
Peanut	17	10.43
Beans	9	5.52
Cocoyam	8	4.91
Yam	8	4.91
Oranges	5	3.07
Tangerines	5	3.07
Cocoa	3	1.84
Sugar Cane	2	1.23
TOTAL	163	100

Table 16: The type and proportion of food crops which are more sensitive to climate induced disaster

Value	Frequency	Percentage
Aquaculture	18	22.22
Small ruminant farming (goats and sheep)	17	20.99
Poultry farming	14	17.28
Pig farming	13	16.05
Cattle farming	10	12.35
Others	7	8.64
Dairy farming	2	2.47
TOTAL	81	100

Table 17: The type and most practiced livestock farming activities in these landscapes?

Value	Frequency	Percentage
Aquaculture	18	22.78
Small ruminant farming (goats and sheep)	17	21.52
Poultry farming	14	17.72
Pig farming	11	13.92
Cattle farming	10	12.66
Others	7	8.86
Dairy farming	2	2.53
TOTAL	79	100

Table 18: The type and proportion of livestock farming which are more exposed to climate induced disaster

Value	Frequency	Percentage
Aquaculture	16	22.22
Small ruminant farming (goats and sheep)	14	19.44
Poultry farming	13	18.06
Pig farming	11	15.28
Cattle farming	10	13.89
Others	7	9.72
Dairy farming	1	1.39
TOTAL	72	100

Table 19: The type and proportion of livestock farming which are more sensitive to climate induced disaster

Value	Frequency	Percentage
Wetland restorations	23	23.96
Agroforestry	20	20.83
Forest and Tree Planting	13	13.54
Soil Protection	13	13.54
Mangroves Planting	9	9.38
Dikes and flood walls	7	7.29
Others	6	6.25
Coastal Ecosystem Reforestation	3	3.13
Green infrastructures	2	2.08
TOTAL	96	100

Table 20: The Nature-based adaptive measures which best sustain and protect food crops against climate hazards

Value	Frequency	Percentage
Wetland restorations	23	27.06
Agroforestry	19	22.35
Forest and Tree Planting	11	12.94
Soil Protection	9	10.59
Dikes and flood walls	7	8.24
Others	6	7.06
Mangroves Planting	4	4.71
Coastal Ecosystem Reforestation	4	4.71
Green infrastructures	2	2.35
TOTAL	57	100

Table 21: The Nature-based adaptive measures which best sustain and protect livestock farming against climate hazards

B. Bar graph and chart results of the cross-tabulation analysis illustrating the data relationships and trends between the variables in quantitative coordinate (%)

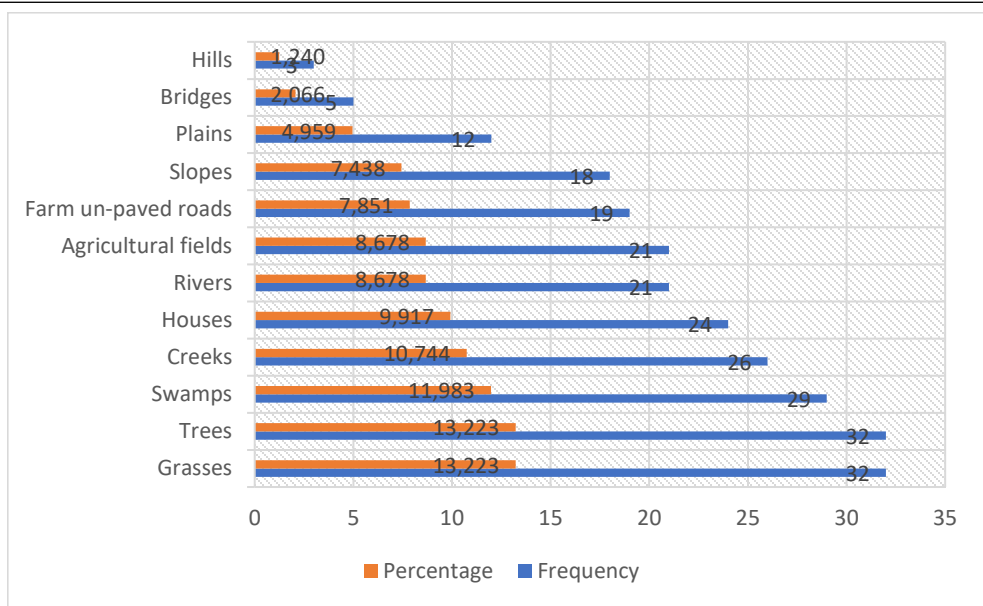


Figure 1: Bar graph showing the amount of landmark found in the agrarian landscapes of Ngalat and Mbockulu.

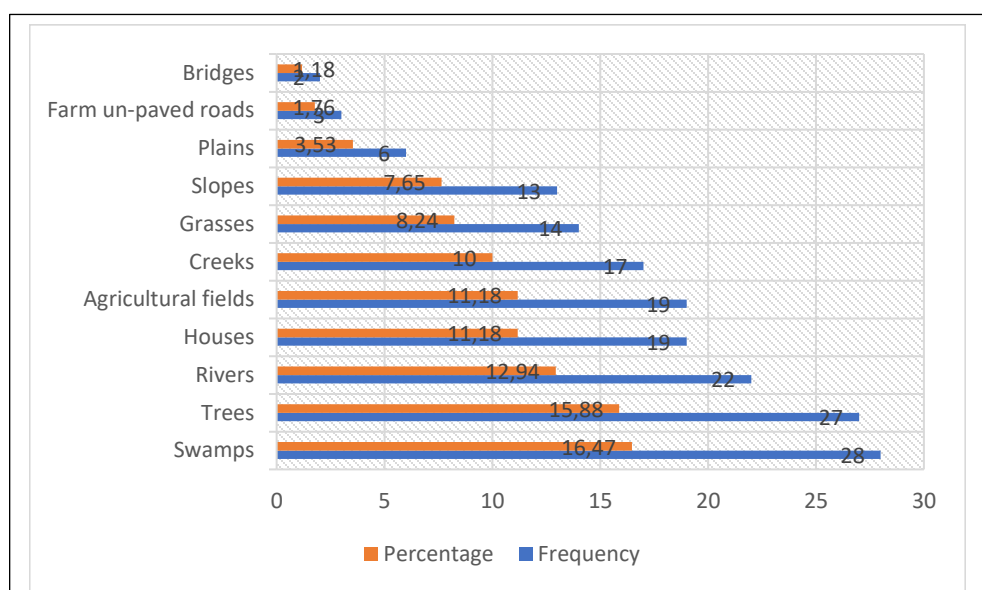


Figure 2: Bar graph unveiling the landmarks which are more exposed to climate induced disasters in the agrarian landscapes of Ngalat and Mbockulu

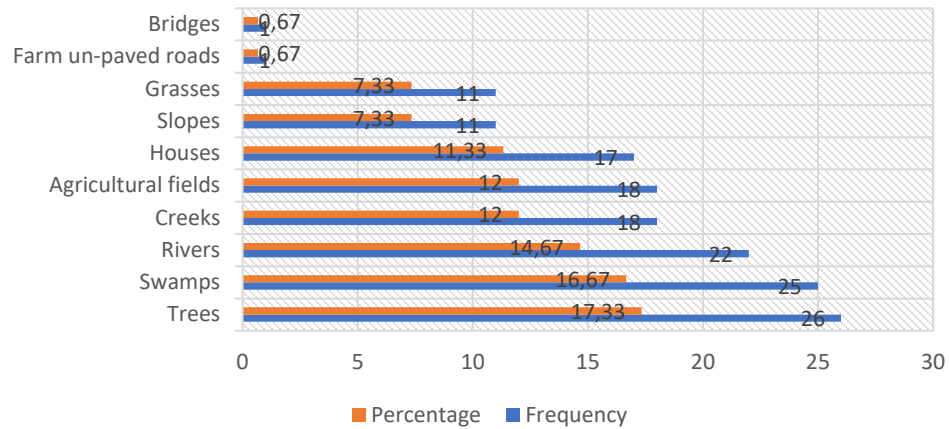


Figure 3: Bar graph unveiling the landmarks which are more sensitive to climate induced disasters in these two agrarian landscapes

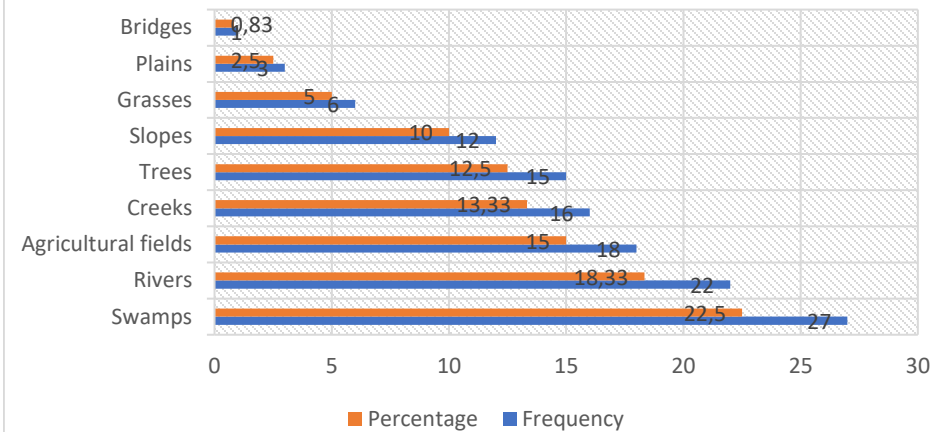


Figure 4: Bar graph revealing the landmarks which best sustains and strengthens the food crops cultivated in these two agrarian landscapes.

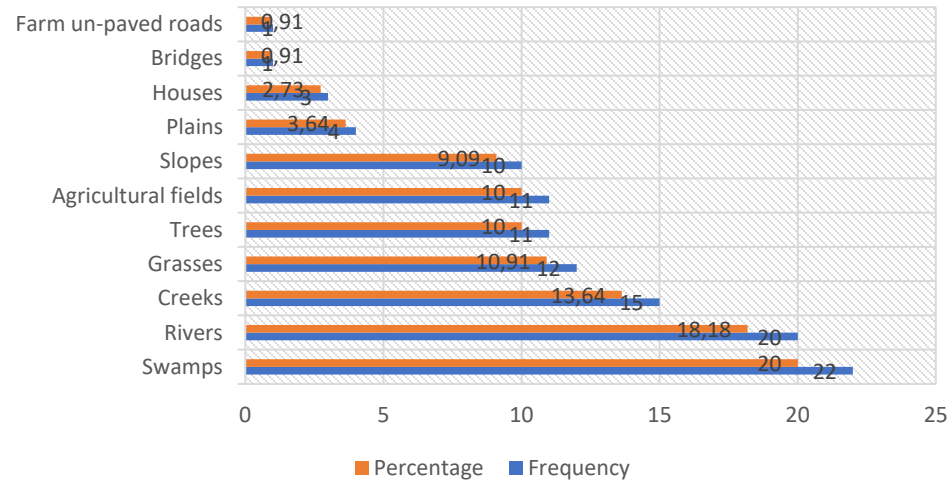


Figure 5: Bar graph revealing the landmarks which best sustains and strengthens the livestock farming practiced in these agrarian landscapes.

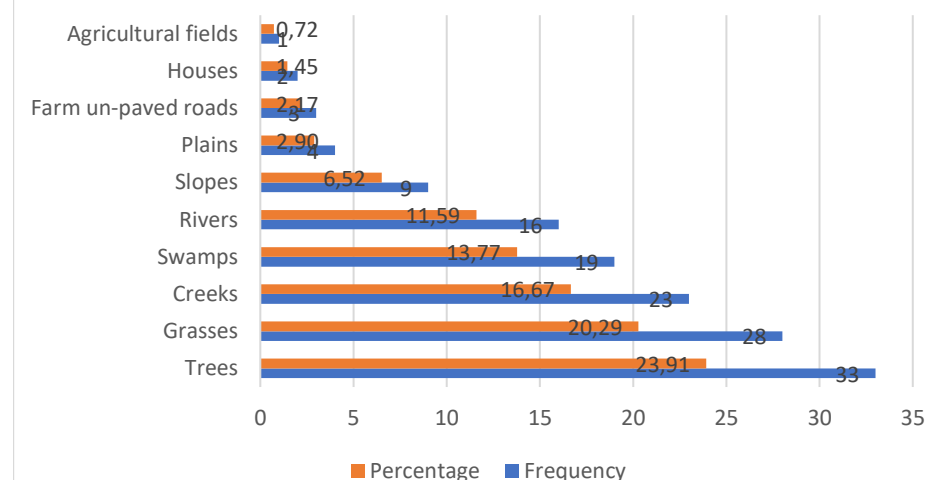


Figure 6: Bar graph revealing the landmarks which are most likely to regenerate naturally in twenty-years without human intervention.

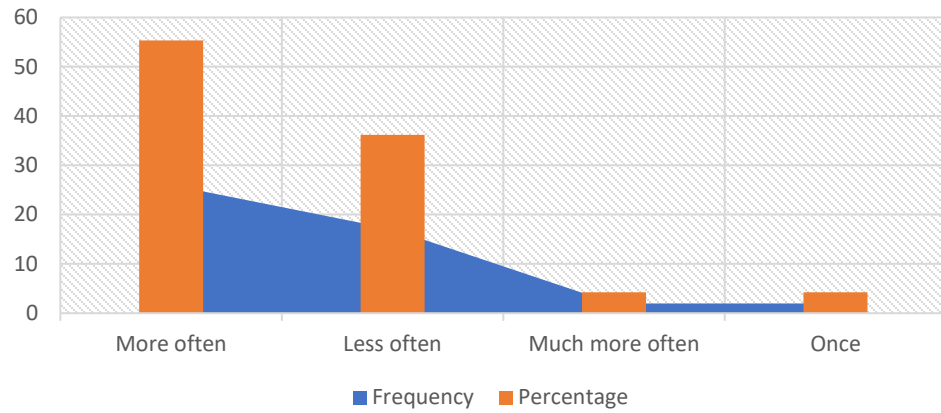


Figure 7: Bar graph showing the most frequency rate (Less often; often; more often; much more often) at which landmarks appear the area.

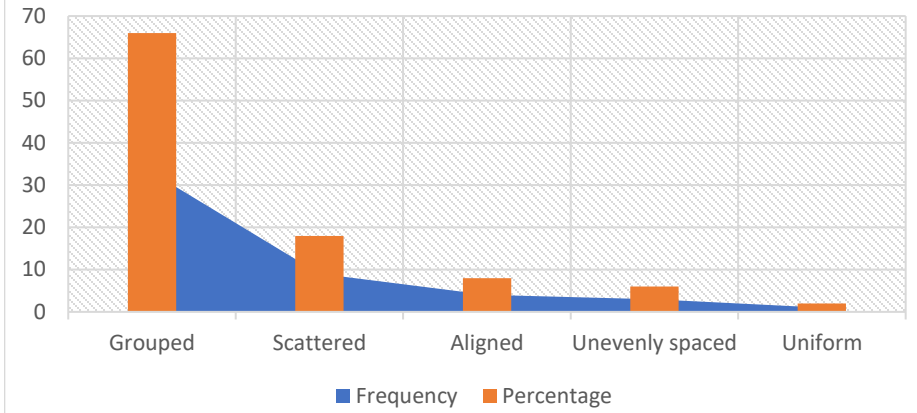


Figure 8: Bar graph showing the major type landmark distribution in the agrarian landscapes of Ngalat and Mbockulu.

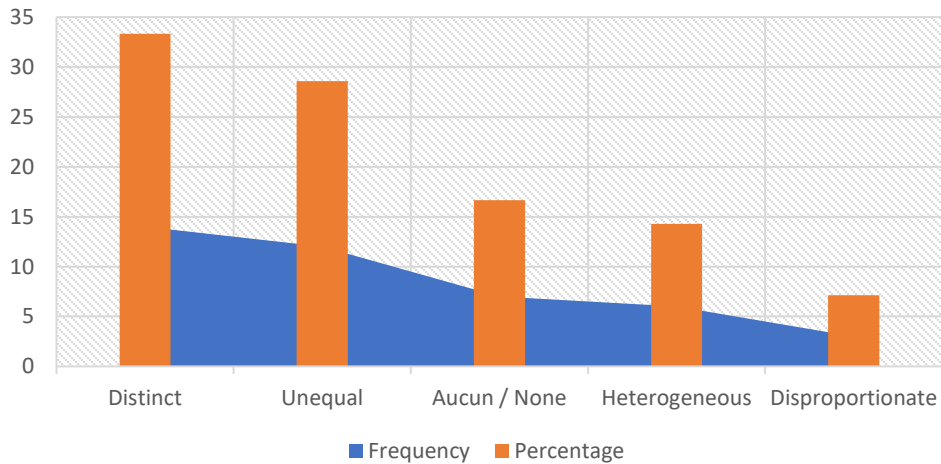


Figure 9: Bar graph illustrating the major form of landmark disparities in the agrarian landscapes.

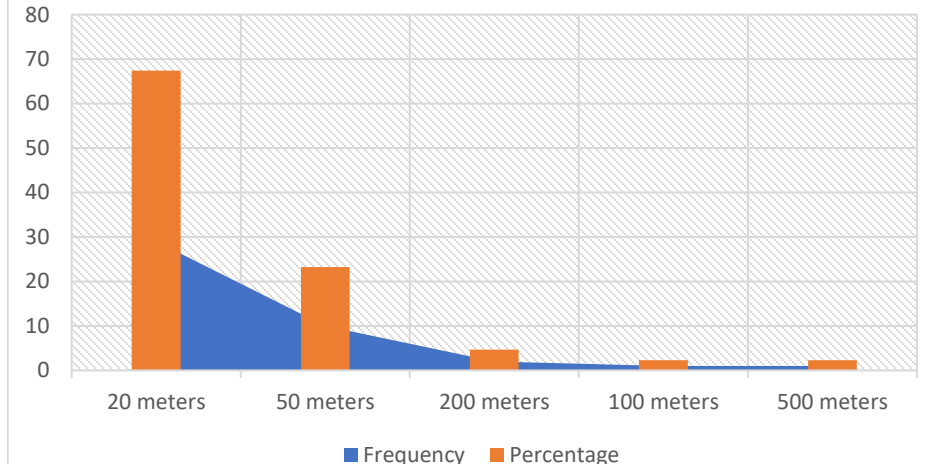
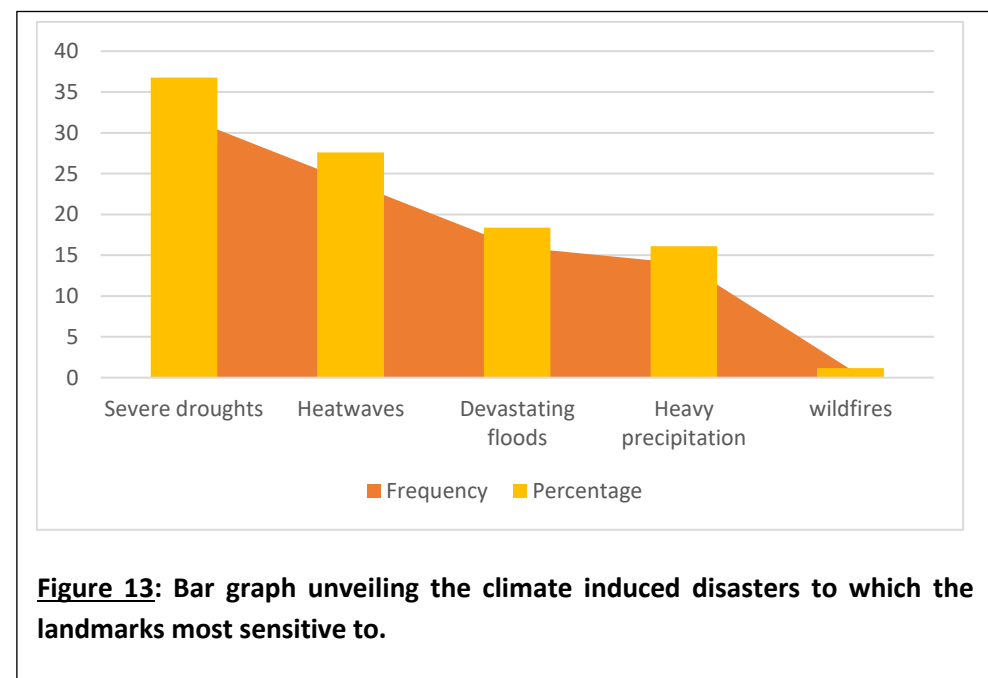
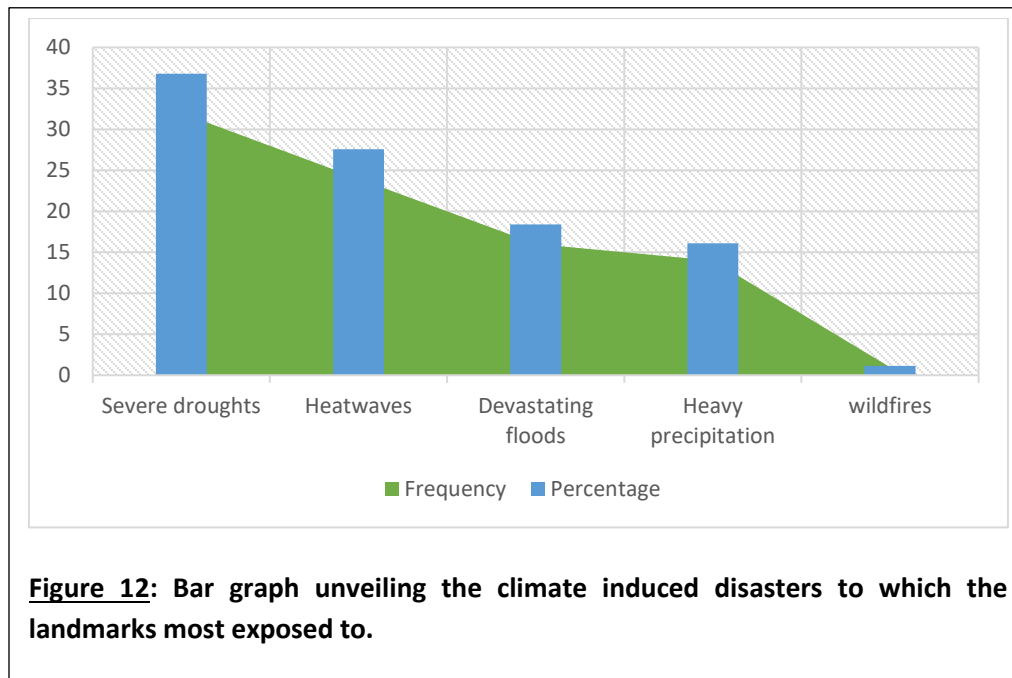
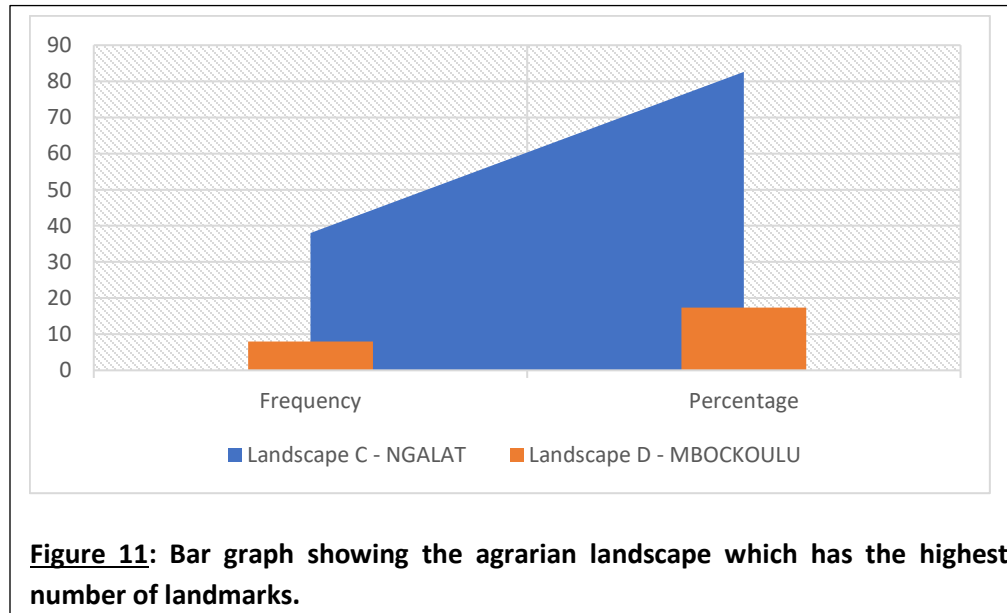


Figure 10: Bar graph illustrating the most observed and common distances between the landmarks in the agrarian landscapes.



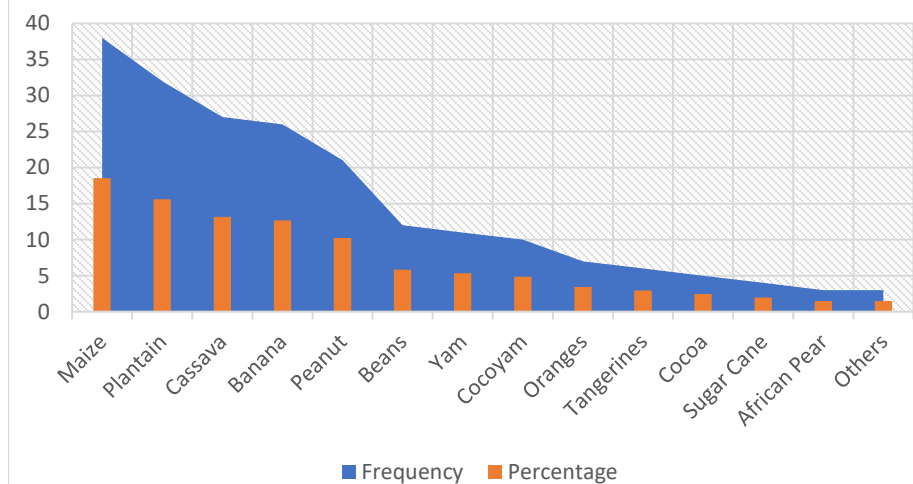


Figure 14: Bar graph displaying the type of food crops cultivated in these agrarian landscapes.

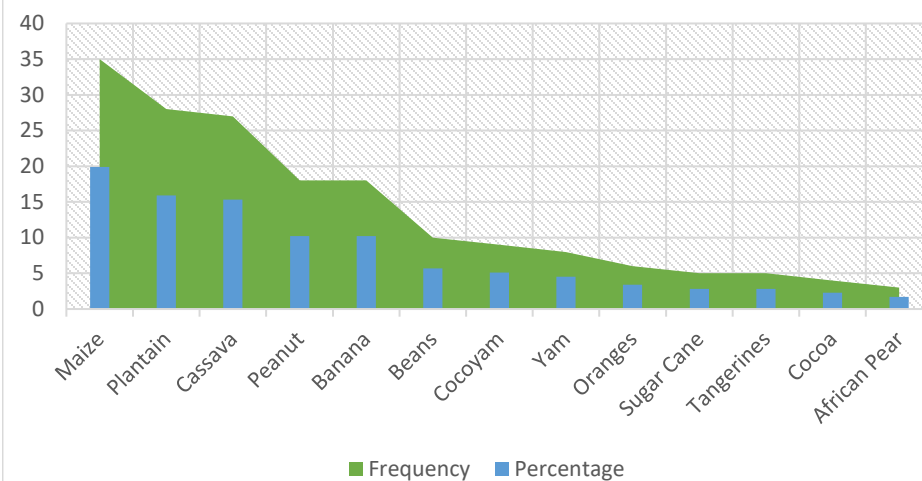


Figure 15: Bar Chart displaying the type of food crops which are more exposed to climate induced disaster in these agrarian landscapes.

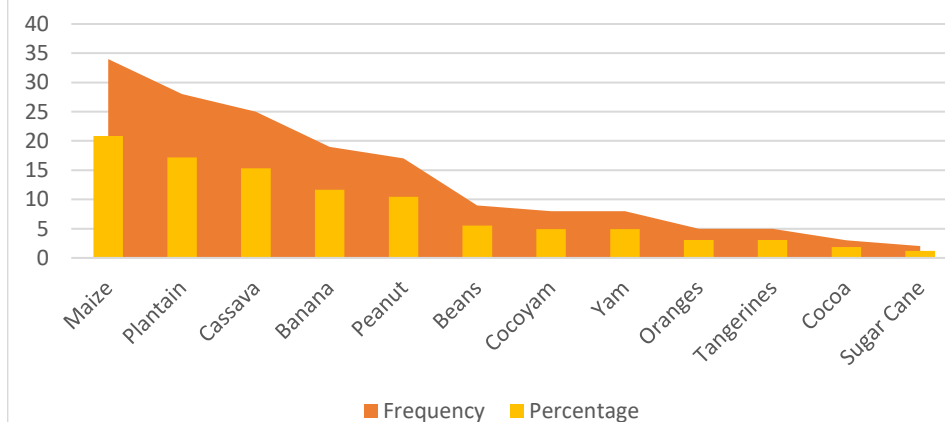


Figure 16: Bar Chart unveiling the type of food crops which are more sensitive to climate induced disaster in these agrarian landscapes.

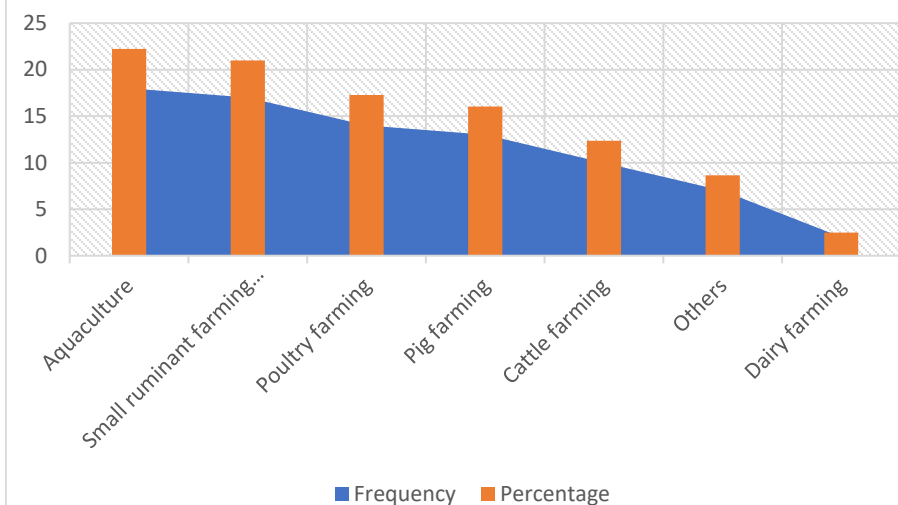


Figure 17: Bar graph showing the type of livestock farming activities in these agrarian landscapes.

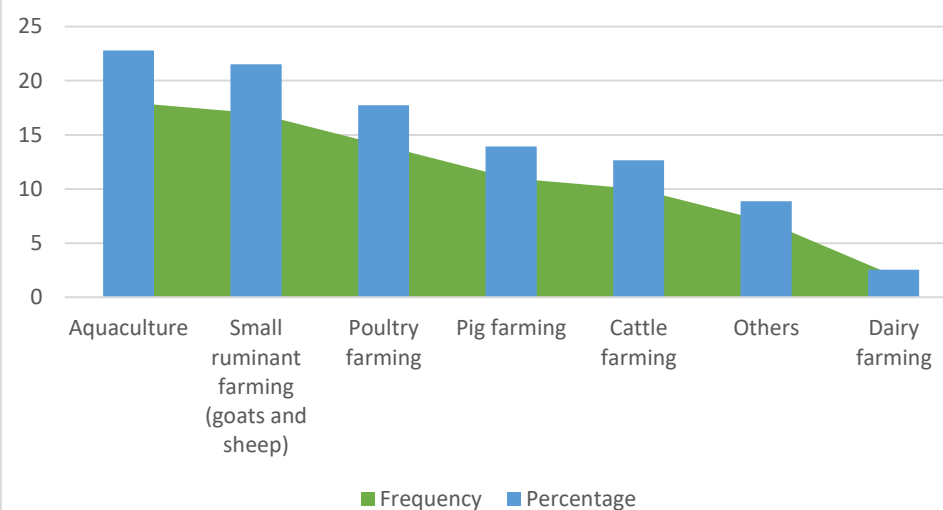


Figure 18: Bar graph showing the type of livestock farming which are more exposed to climate induced disasters in these agrarian landscapes.

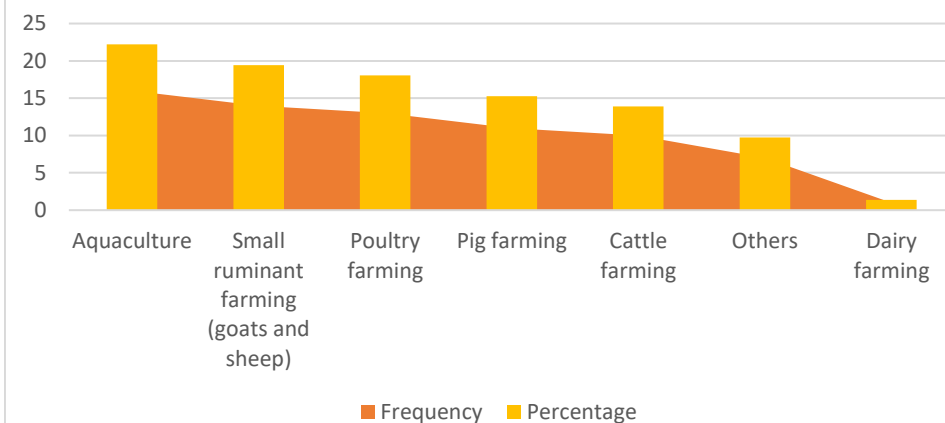


Figure 19: Bar graph showing the type of livestock farming which are more sensitive to climate induced disaster in these agrarian landscapes.

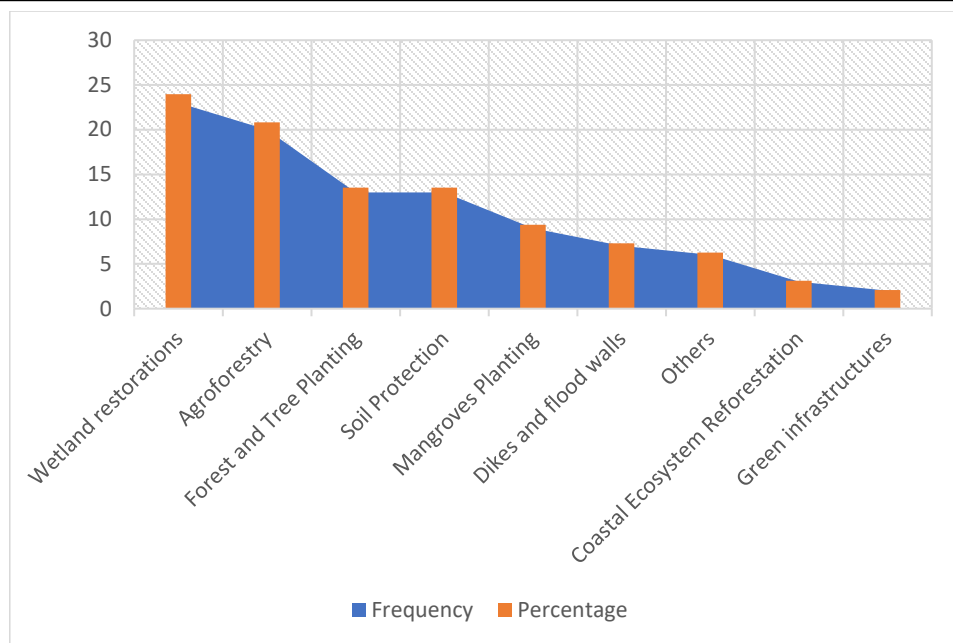


Figure 20: Bar Chart displaying the Nature-based adaptive measures which best sustain and protect food crops against climate hazards in these agrarian landscapes.

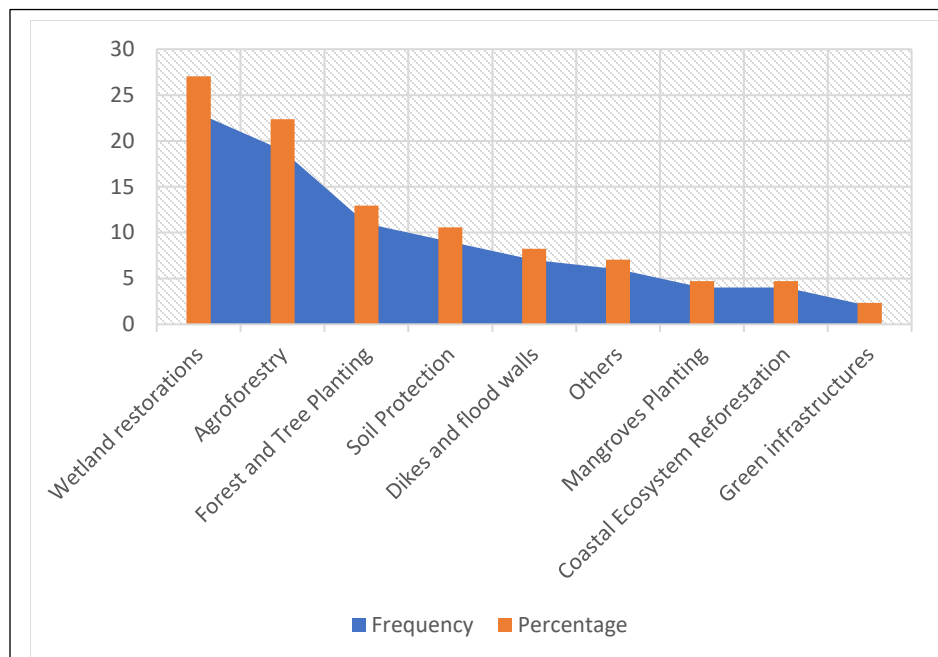


Figure 21: Bar Chart displaying the Nature-based adaptive measures which best sustain and protect livestock farming against climate hazards in these agrarian landscapes.

C. Drone maps of the agrarian and fish pond landscapes in NGALAT and MBOCKOULU

1. Drone Map of the agrarian and fish pond Landscape in NGALAT

Approximatively, 15 hectares of landscape was mapped in the district of NGALAT. NGALAT is a district in Mbalmayo located near to the national road Number 2. On these 15 hectares of landscape, we have landmarks like roads, houses, hospitals, trees, grasses, hills, fish ponds, swamps, farmlands, etc. As it can be seen on the map below (figure 22), the NGALAT landscape is a fish pond landscape which has two major fishing sites, one at the east and the other one at the west. The fishing site in the east has five fish ponds, meanwhile the fishing site in the western side of the drone map has four fish ponds, which makes a total of nine fish ponds. Due to this high number of fish ponds present in this NGALAT landscape, the district leaders named it as a fish pond landscape. The farmlands in this landscape are mainly found in the middle of the landscape as it can be seen in the map below.



Figure 22: The aerial drone map of the agrarian and fish pond landscape in Ngalat

2. Drone Map of the agrarian and fish pond Landscape in MBOCKULU

The agrarian landscape in MBOCKULU is made up of approximately 25 hectares of land, which we mapped out as an agrarian and fish pond landscape given the numerous numbers of fish ponds and farms found in the area. This landscape is also considered by the community as a fish pond landscape because the primary activity after crop cultivation is fishing. Fishing is the most important agrarian activity in this landscape after crop cultivation. This agrarian landscape is situated at the north-east part of Mbalmayo. On this landscape, we have landmarks such as roads, houses, mountains, forest, grasses, hills, fish ponds, swamps, farmlands, creeks etc. As you can see on the map below (figure 23), presenting the landscape of MBOCKULOU, there is a small stream that passes in the middle of the landscape. Aside from this small stream, we have four main fishing sites, with each of these fishing sites having at least two fish ponds. The crop farms are found both in the Northern and in the southern part of the landscape.

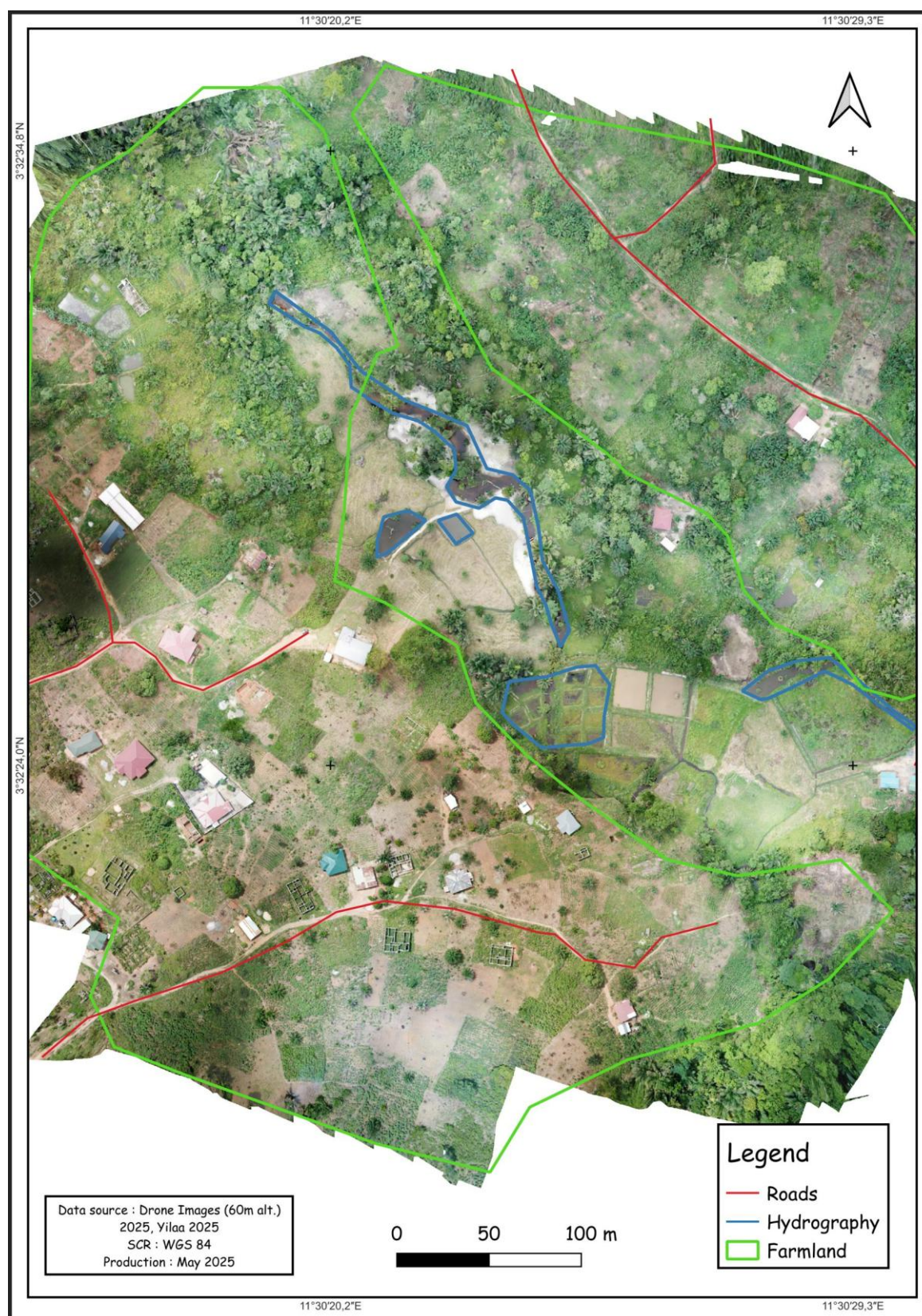


Figure 23: The aerial drone map of the agrarian and fish pond landscape in Mbockulou

D. Distance matrix tables and proximity-based patterns showing the ground distances between the Landmarks in NGALAT and MBOCKOULU

1. Result tables showing the ground distances from every fish pond or farm (crop farm or livestock farm) to the nearest road, hospital or house

The results in this section, shows the distances a farmer should cover from his fish pond or farm (crop farm or livestock farm) to nearest road or hospital in the event of a sudden climate disaster.

This distance was calculated in meters using euclidean distance analysis on QGIS. The results of these ground distances will determine the rapidity of any emergency or adaptation action in the event of a sudden climate induced disaster like landslides or wildfires.

i- NGALAT Landscape

Query Point	Nearest Neighbor(s) (Less distant neighbor)	Distance
1 st Fish Pond	Main road	9.28 meters
2 nd Fish Pond	Houses	73.99 meters
3 rd Fish Pond	Main road	28.03 meters
1 st Crop farm	Houses	29.28 meters
2 nd Crop farm	Houses	7.21 meters
3 rd Crop farm	Main road; Houses	14.79 meters; 19.81 meters
1 st Swine farm	Houses	12.22 meters
2 nd Swine farm	Houses	38.71 meters
3 rd Swine farm	Houses	7.57 meters

Result Table 1: Showing the closest distances from every fish pond and farm to the nearest roads, houses and hospitals in the agrarian landscape of NGALAT

The reason why these landmarks (main road & houses) are the Nearest Neighbors to the fish ponds, crop and swine farms is because there are many unpaved roads and some tarred road which leads to the houses and also leads to the main road. Also, in this agrarian landscape of NGALAT, there is a direct road network to every house which links every farm to the various houses.

Query Point	Farthest Neighbor(s) (Most distant neighbor)	Distance
1 st Fish Pond	Hospital	448.31 meters
2 nd Fish Pond	Hospital	379.11 meters
3 rd Fish Pond	Hospital	177.91 meters
1 st Crop farm	Hospital	388.25 meters
2 nd Crop farm	Hospital	184.27 meters
3 rd Crop farm	Hospital	363.56 meters
1 st Swine farm	Hospital	381.43 meters
2 nd Swine farm	Hospital	436.37 meters
3 rd Swine farm	Hospital	276.37 meters

Result Table 2: Showing the farthest distances from every fish pond and farm to the roads, houses and hospitals in the agrarian landscape of NGALAT

The reason why this landmark (hospital) is the Farthest Neighbor to the fish ponds, crop and small ruminant farms is because there is no unpaved path, nor tarred road which leads to this hospital. The second reason is that, in this agrarian landscape of Ngalat, there is no direct road network to the hospital. And finally, the third reason and the most significant is that: there is only one district hospital in this agrarian landscape of NGALAT. Meanwhile there are many main roads and many houses in the agrarian landscape of NGALAT.

ii- MBOCKULU Landscape

Query Point	Nearest Neighbor(s) (Less distant neighbor)	Distance
1 st Fish Pond	Houses	42.84 meters
2 nd Fish Pond	Houses	106.93 meters
3 rd Fish Pond	Houses	151.88 meters
1 st Crop farm	Houses	9.45 meters
2 nd Crop farm	Main road; Houses	60.05 meters; 65.43 meters
3 rd Crop farm	Houses	56.11 meters
1 st Small ruminant farm	Houses	14.25 meters
2 nd Small ruminant farm	Houses	33.92 meters
3 rd Small ruminant farm	Houses	5.67 meters

Result Table 3: Showing the closest distances from every fish pond and farm to the roads, houses and hospitals in the agrarian landscape of MBOCKULU

The reason why these landmarks (main road & houses) are the Nearest Neighbors to the fish ponds, crop and swine farms is because there are many tarred roads and houses which leads to the fish ponds, crop and swine farms. Also, in this agrarian landscape of MBOCKULU, there is a direct road network to every house which links every farm to the various houses.

Query Point	Farthest Neighbor(s) (Most distant neighbor)	Distance
1 st Fish Pond	Hospital	202.38 meters
2 nd Fish Pond	Hospital	290.94 meters
3 rd Fish Pond	Hospital	392.70 meters
1 st Crop farm	Hospital	219.64 meters
2 nd Crop farm	Hospital	238.54 meters
3 rd Crop farm	Hospital	516.95 meters
1 st Small ruminant farm	Hospital	235.64 meters
2 nd Small ruminant farm	Hospital	253.13 meters
3 rd Small ruminant farm	Hospital	464.98 meters

Result Table 4: Showing the farthest distances from every fish pond and farm to the roads, houses and hospitals in the agrarian landscape of MBOCKULU

The reason why this landmark (hospital) is the Farthest Neighbor to the fish ponds, crop and small ruminant farms is because there is no unpaved path, nor tarred road which leads to this hospital. The second reason is that in this agrarian landscape of MBOCKULU, there is no direct road network to the hospital. And finally, the third reason and the most significant is that there is only one functional district hospital in this agrarian landscape of MBOCKULU. Meanwhile there are many main roads and many houses in the agrarian landscape of MBOCKULU.

2. Distance matrix tables showing closest distances & Nearest Neighbors between various landmarks

The second part in this results section, shows in various distance matrix tables the closest distances between each of the twelve landmarks (creeks; lakes; slopes; swamps; plains; forest; trees; grassland; houses; unpaved roads; hospitals, and hills). These twelve varieties of landmarks are the most common areas and most popular places where the inhabitants of NGALAT and MBOCKOULU carry on their daily activities. The distances between the landmarks found in the distance matrix tables below are in meters.

These results on these closest distances between each of the twelve landmarks enabled us to know which landmark is closer to the other in terms of ground distance. These information on closest distances will improve the adaptive capacities of the inhabitants in the event of a sudden climate induced disaster. These results were obtained using euclidean distance analysis.

i- In NGALAT Landscape

Location	Longitude (X)	Lattitude (Y)
Creeks	1151216	353113
Lakes	1151234	353138
Slopes	1151176	353172
Swamps	1151333	353151
Plains	1151330	353322

Forest	1151471	353287
Grassland	1151380	353031
Houses	1151194	353231
Roads	1151318	353225
Hospital	1151415	353378
Hill	1151124	353296
Farms	1151274	353187

Table 22: Table showing the coordinate systems (longitude and latitude) of the selected twelve landmarks in the agrarian landscape of NGALAT.

	Creeks	Lake	Slopes	Swamps	Plains	Forest	Grassland	Houses	M. Road	Hospital	Hill	Farms
Creeks	0	67,23	158,40	171,03	145,28	271,69	273,12	120,03	151,49	331,40	204,82	94,02
Lake	67,23	0	171,03	145,28	271,69	279,95	124,15	120,93	300,60	192,52	63,25	63,25
Slopes	158,40	171,03	0	271,69	273,12	124,15	181,16	61,68	151,57	315,53	134,46	99,14
Swamps	171,03	145,28	271,69	0	124,15	181,16	128,88	160,38	75,50	241,36	254,37	69,12
Plains	145,28	271,69	273,12	124,15	0	302,33	185,42	163,64	97,74	101,79	207,63	146,15
Forests	271,69	279,95	124,15	181,16	302,33	0	271,69	282,60	165,08	106,85	347,12	220,93

Grasslands	273,12	124,15	181,16	128,88	185,42	271,69	0	273,12	203,67	348,76	368,46	188,61
Houses	120,03	101,24	61,68	160,38	163,64	282,60	273,12	0	124,15	265,42	95,52	91,30
M. Road	151,49	120,93	151,57	75,50	97,74	165,08	203,67	124,15	0	181,16	206,58	58,14
Hospital	331,40	300,60	315,53	241,36	101,79	106,85	348,76	265,42	181,16	0	302,33	237,41
Hill	204,82	192,52	134,46	254,37	207,63	347,12	368,46	95,52	206,58	302,33	0	185,42
Farms	94,02	63,25	99,14	69,12	146,15	220,93	188,61	91,30	58,14	237,41	185,42	0

1st Distance Matrix Table: showing the physical distances (in meters) amongst the selected twelve landmarks in the agrarian landscape of NGALAT.

ii- **MBOCKULU Landscape**

Landmarks	Longitude (X)	Latitude (Y)
Creeks	1150461	354288
Stream	1150601	354174
Slopes	1150552	353925
Swamps	1150721	354082
Plains	1150470	354168

Forest	1150535	354275
Grassland	1150791	354226
Houses	1150576	353945
M. Road	1150556	353925
Hospital	1150502	353978
Hill	1150640	354277
Farms	1150730	353937

Table 24: Table showing the coordinate systems (longitude and latitude) of the selected twelve landmarks in the agrarian landscape of MBOCKULU.

	Creeks	Stream	Slopes	Swamps	Plains	Forest	Grassland	Houses	M. Road	Hospital	Hill	Farms
Creeks	0	180,54	374,23	331,72	120,34	75,13	335,77	361,77	375,23	312,70	179,34	442,22
Stream	180,54	0	253,78	151,21	131,14	120,65	196,99	230,36	253,03	219,58	110,14	269,83
Slopes	374,23	253,78	0	230,67	256,46	350,41	384,35	31,24	4	72,86	362,83	178,40
Swamps	331,72	151,21	230,67	0	265,32	268,04	160,11	199,48	227,76	242,44	211,15	145,28
Plains	120,34	131,14	256,46	265,32	0	125,20	326,20	246,91	257,77	192,68	201,94	347,79
Forest	75,13	120,65	350,41	268,04	125,20	0	260,65	332,54	350,63	298,83	105,02	390,22

Grassland	335,77	196,99	384,35	160,11	326,20	260,65	0	353,82	381,87	380,82	159,38	295,37
Houses	361,77	230,36	31,24	199,48	246,91	332,54	353,82	0	28,28	81,02	338,11	154,21
M. Road	375,23	253,03	4	227,76	257,77	350,63	381,87	28,28	0	75,66	361,88	174,41
Hopsital	312,70	219,58	72,86	242,44	192,68	298,83	380,82	81,02	75,66	0	329,31	231,66
Hill	179,34	110,14	362,83	211,15	201,94	105,02	159,38	338,11	361,88	329,31	0	351,71
Farms	442,22	269,83	178,40	145,28	347,79	390,22	295,37	154,21	174,41	231,66	351,71	0

2nd Distance Matrix Table: showing the physical distances (in meters) amongst the selected twelve landmarks in the agrarian landscape of MBOCKULU.

E. Georeferenced images with coordinate systems of the landmarks identified on the above drone maps of the agrarian landscapes of NGALAT and MBOCKULU

There are twelve landmarks which were identified in the above drone maps, and each of these landmarks were captured in georeferenced images with their respective coordinate systems (longitude and latitudes).

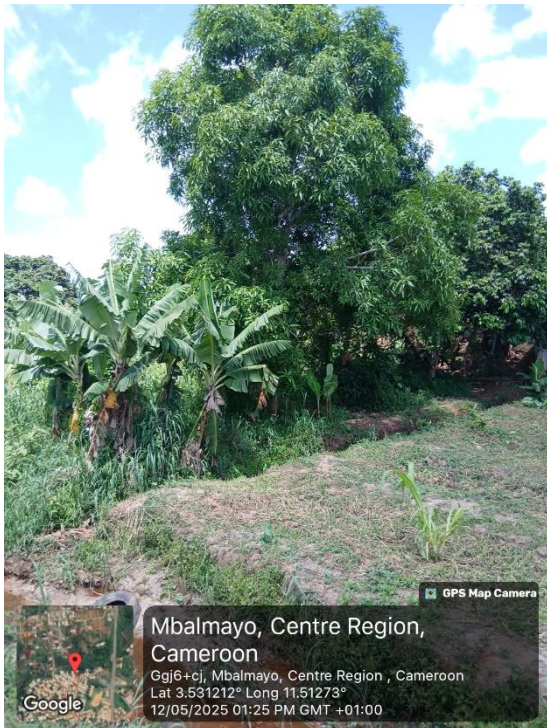


Image 1: Georeferenced image of Trees

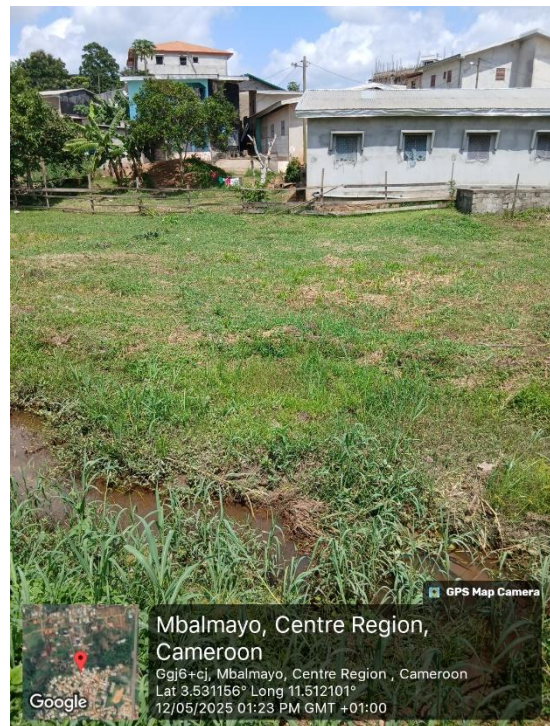


Image 2: Georeferenced image of Swamps

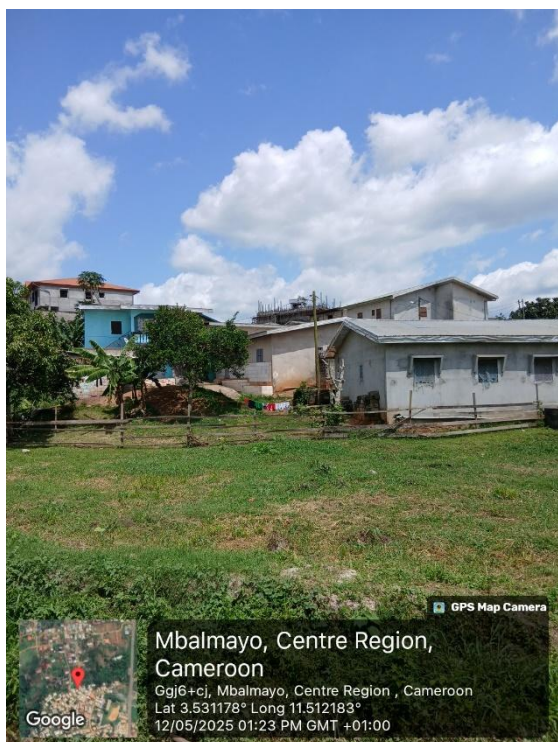


Image 3: Georeferenced image of Houses

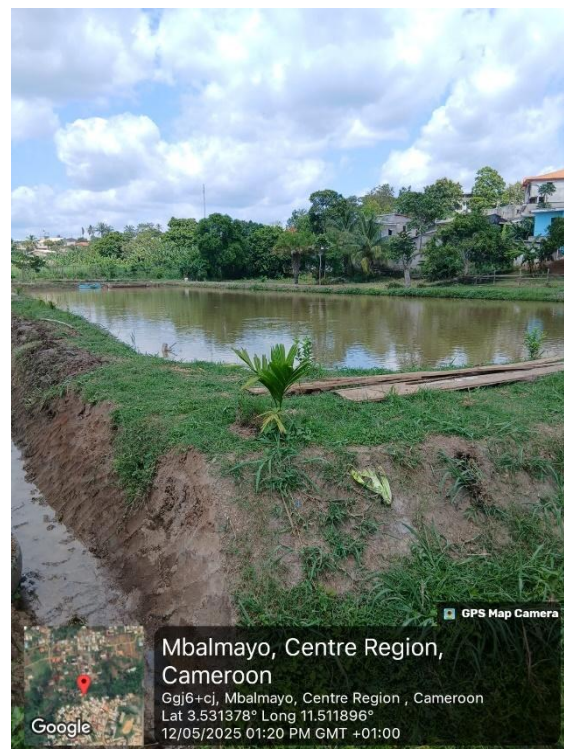


Image 4: Georeferenced image of the Lake



Image 5: Georeferenced image of the Creek field



Image 6: Georeferenced image - Agricultural

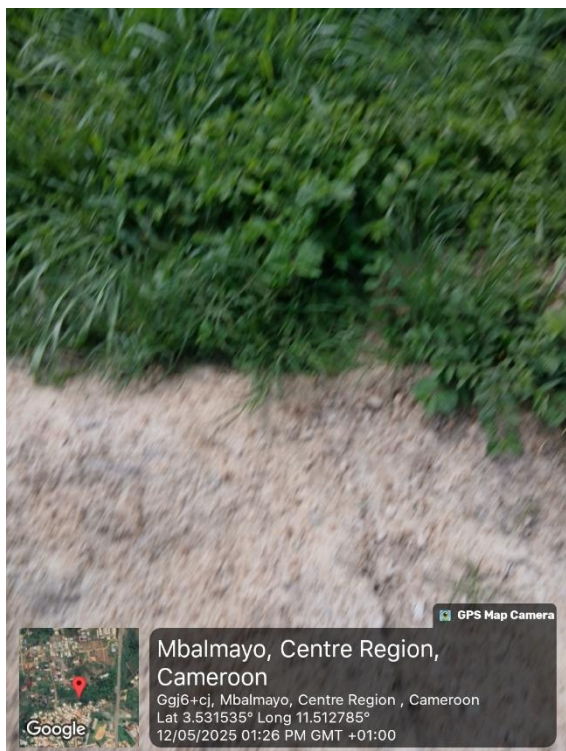


Image 7: Georeferenced image of **Grasses**



Image 8: Georeferenced image of **Plains**

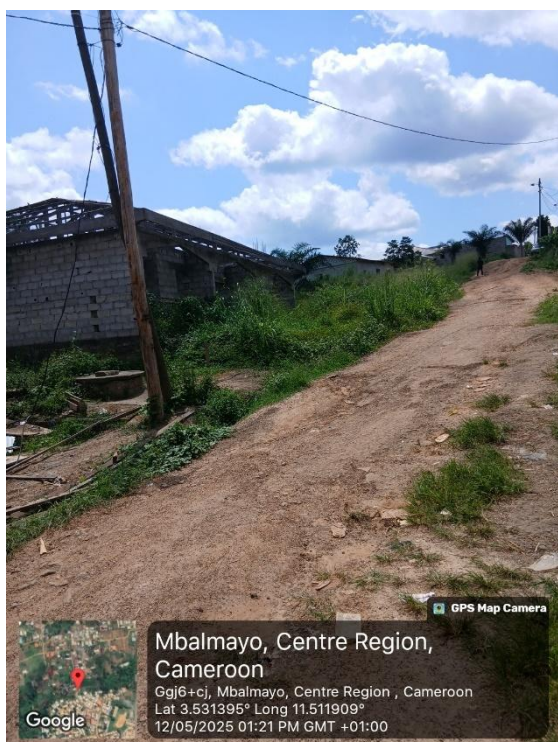


Image 9: Georeferenced image of the **Slope**

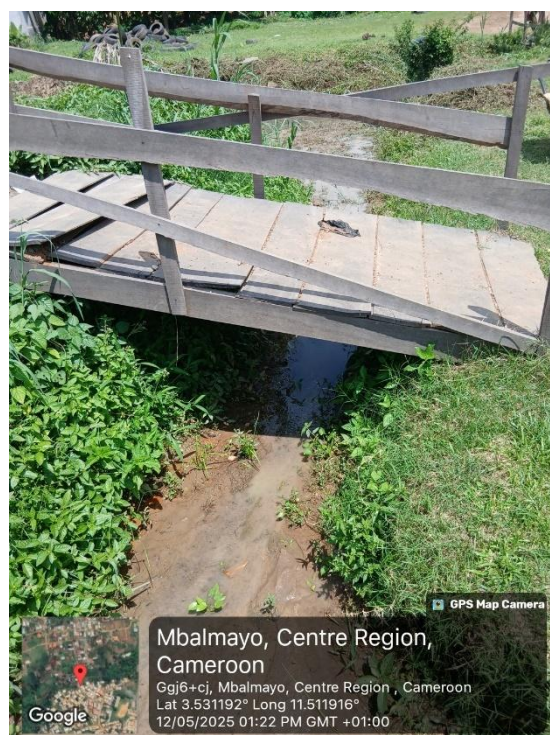


Image 10: Georeferenced image of the **Bridge**



Image 11: Georeferenced image – Un-paved road farm

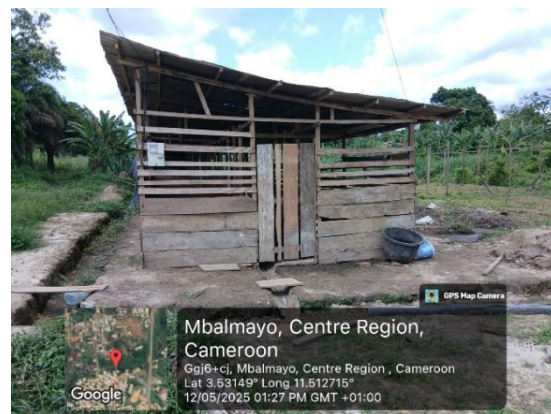


Image 12: Georeferenced image livestock



Image 13: Georeferenced interior of the livestock

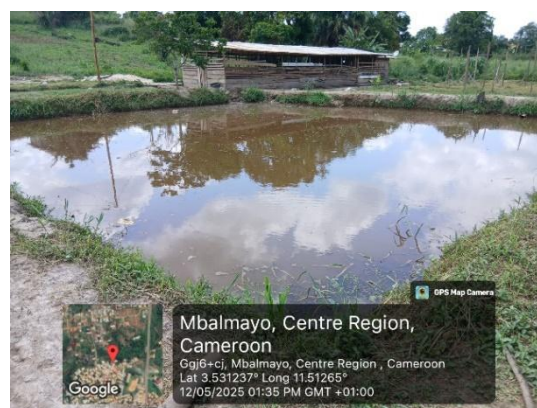


Image 14: Georeferenced image showing the proximity between the livestock farm and fish pond

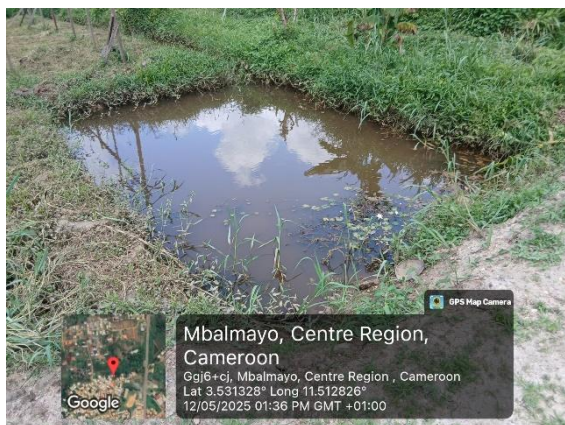


Image 15: Georeferenced image of **smallest fish pond**



Image 16: Georeferenced image of **biggest fish pond in the landscape**

IV. DISCUSSION

In this section, we will discuss and describe the various strategies and actions which can help to build adaptive capacities in an agrarian landscape in the midst of flood zones and sudden climate disasters by relying on nearest neighbors (NN), spatial proximities, landmarks disparities and distributions.

A. Handling flood risk zones when building adaptive capacities in agrarian landscapes

To identify these flood risk zones in the agrarian landscapes of NGALAT and MBOCKULU, we created a buffer zone around the following landmarks: wetlands, floodplains, swamps, rivers and fish ponds. Flood risk can be assumed to depend on flood hazard, flood exposure, and flood vulnerability, which, in turn, are driven by a complex interplay of climate system, terrestrial and hydrological system, and socio-economic system. Kundzewicz et al. (2014) indicated that increasing exposure of population and assets has been primarily responsible for the recent increase in flood losses. Efforts on flood risk reduction are embedded in the general global framework, including major documents, such as the Hyogo Framework for Action and Sendai Framework for Disaster Risk Reduction (Kundzewicz, et al., 2019).

Building adaptive capacity in flood-risk areas entails assisting communities, systems, and institutions in anticipating, absorbing, recovering from, and adapting to floods, rather than

simply responding to it. This necessitates integrating infrastructure, governance, environmental, and social resilience strategies. For example, a research study on urban homes (R., Paul, Jessica, Matthew, & Paola, 2021) discovered that better social capital (neighborhood trust, cohesion, and networks) was strongly associated with more proactive flood mitigation behavior, even after controlling for social vulnerability. This suggests that in flood-prone areas, increasing adaptive capacity entails investing in social infrastructure, supporting community networks, creating shared knowledge, and improving local risk perception, in order to activate adaptive behaviors when flood events occur (R., Paul, Jessica, Matthew, & Paola, 2021).

Scholars like John Fazey, Joern Fischer, Nathan Engle, and Liverman have noted that a system's resilience depends critically on its adaptive capacity (Fazey, et al., 2007). For example, Engle (Engle, 2011) notes that systems with greater adaptive capacity are more likely to be resilient to shocks (e.g., floods), through their improved abilities to maintain essential system functions and transform these elements into a more desirable state for managing future shocks. The relationship between resilience and adaptive capacity can also be explained through vulnerability, i.e., the varying potential of different places or social groups to be adversely affected by a hazard (Liverman, 2001). Strengthening adaptive capacity can decrease vulnerability (Engle, 2011), increase resilience and reduce the level of risk.

Other scholars emphasized the significance of diversifying flood risk management measures in flood-prone areas, rather than relying just on traditional dykes and walls. In one pilot-project analysis across Europe, authors used the "Adaptive Capacity Wheel" framework (Margo, Sander, Catrien, & Joyeeta, 2014) to demonstrate that improving capacities such as information-sharing, multi-stakeholder collaboration, visionary leadership, spatial planning, and financial resources aided in the transition from a singular flood-protection mindset to a more adaptive governance of flood risk (Flavia, Jean-Marie, Marloes, & Teun, 2019). In practice, this means that when managing flood-prone areas, practitioners should integrate actions like mitigation (e.g., zoning), preparedness (evacuation planning and early warning), and recovery capacities, to avoid lock-in by maintaining flexibility in land use and infrastructure pathways.

B. Transportation obstacles hindering adaptation actions in the event of sudden climate induced disasters

Sudden, climate-induced disasters such as: flash floods, cyclones, wildfires, and extreme heat events, necessitate quick and coordinated transportation responses for evacuation, emergency relief, and infrastructure repair. In the agrarian landscapes of NGALAT and MBOCKULU, various transportation barriers frequently impede effective adaptation and response. These transportation obstacles (barriers) hindering effective adaptation and response in NGALAT and MBOCKULU are:

- **Poor road infrastructure:** such as dirt or gravel roads that become muddy during the rainy seasons. Also, there aren't enough bridges across rivers or streams.
- **Rugged or uneven terrain:** like hills, valleys, and mountainous places that make road construction and vehicle movement problematic.
- **Seasonal weather conditions:** such as flooding during the rainy season or dust and erosion during the dry season, can impede roadways.
- **Natural vegetation barriers:** like extensive forests, wetlands, or bushlands that separate farming areas from major transportation networks.

This transportation obstacles were identified using buffer creation. With this buffer creation, we were able to identify all the transportation obstacles which are found within 500 meters of a hospital or the main road.

One of the research-supported strategy elaborated to address the above transportation obstacles in the context of climate adaptation is the strategy that was developed by Morelli & Cunha (2020). This strategy consists in “Measuring urban road network resilience to extreme events”. Designing and maintaining resilient transportation systems rely on identifying potential vulnerabilities and inefficiencies before crises occur. However, given the complexity of transportation networks, as well as the diversity of ways in which systems can fail, the problem of assessing the impacts of exceptional phenomena still lacks tools and metrics for analysis (Morelli & Cunha, 2020). Morelli & Cunha (2020) in their research found out that pedestrian movements are significantly less impacted than motorized vehicles by floods in the city, which may be due to the car-oriented nature of the avenues closest to rivers, and the shortest average length of pedestrian trips. Their findings and metrics set a framework for

further research involving other cities and natural phenomena to enrich the understanding of resilience in urban transportation networks (Morelli & Cunha, 2020).

Road construction adaptation measures aim to enhance resilience to climate-related risks, including flooding, excessive rainfall, and heat. Structural adaptations, such as raising embankment heights, using hardstone pitching or geosynthetic stabilization of slopes, and designing denser surfaces, can limit moisture ingress, reduce saturation of sub-base layers, and maintain load-bearing capacity during inundation (Mehvesh, Marco, & Shirsendu, 2024).

C. Relying on Nearest Neighbors to develop acute adaptation actions and strategies in the event of sudden climate induced disasters

In this context, "Nearest Neighbors (NN)" refers to determining the most spatially closest places or locations based on ground distances. Here adaptation actions can use nearest neighbors to identify places that might inform each other's preparedness, response, and recovery methods. For example, in the event of a flood or wildfire, emergency adaptation actions can utilize Nearest Neighbors (NN) algorithms to locate the closest operational hospitals, dwellings, or shelters. The adaptation action in this example is referred to as "Rapid Resource Allocation and Logistics".

Furthermore, by mapping the nearest safe zones (for example, higher elevation areas during floods), NN computations can help guide evacuation plans and population migration in real time. In this case, the adaptation action is called "Identification of Safe Roads for Evacuation". Shuang et al. (2023) in their study applied NN for flood inundation risk mapping. In their study, they used environmental indices (precipitation, soil, elevation etc.) and GIS + NN to infer a probability distribution of flood inundation risk for a coastal tourism region in China (Shuang, Nengzhi, & Rui, 2023).

Researchers using nearest-neighbor (NN) spatial techniques show how proximity relationships between landmarks can be used to advise immediate adaptation efforts in the event of climate-induced disasters. For example, in a study of flood-inundation risk in the coastal tourism zones of Zhejiang Province in China, researchers developed a Weighted kNN (WkNN) spatial framework combining GIS inputs (precipitation, elevation, soil, drainage) and distance-based weighting of neighbors to predict risk categories into "high", "medium", "low", and

"very low" (Shuang, Nengzhi, & Rui, 2023). The advantage of this NN-based approach is that, it enables the quick geographic mapping of high-risk zones, allowing local authorities to prioritize emergency and adaptation actions in nearest-neighbor clusters with elevated risks.

Furthermore, NN approaches aid in calibrating simulations of multi-site weather or hazard patterns, which is crucial in when sudden climate extreme events occur. In a study on multisite precipitation occurrence, Taesam Lee and Vijay Singh (2019) used a discrete k-nearest-neighbor resampling (DKNNR) method to preserve spatial and temporal cross-correlations among sites, resulting in more robust synthetic weather scenarios for climate change adaptation (Taesam & Vijay, 2019). In practice, identifying "nearest neighbors (NN)" on drone maps enables planners to predict how one place will react under extreme conditions by detecting how the nearest neighbors reacted. This contributes to the development of adaption methods such as drainage enhancements, emergency shelters, and land-use zoning (Taesam & Vijay, 2019).

Finally, nearest-neighbor spatial evaluations serve as the foundation for logistical and operational adaptation activities in immediate catastrophe response. For example, in drought monitoring and humanitarian relief in Eswatini, a nearest-neighbor GIS tool was used to locate the nearest warehouse to vulnerable settlements, enabling speedy supply deliveries (Munyaka, Chenal, Mabaso, Tfwala, & Mandal, 2024). By mapping each village's nearest relief node, adaptation strategies moves from generic planning to targeted proximity-based action, ensuring that response units are sited or pre-positioned in spatial relation to vulnerable locations (i.e., their "nearest neighbors"), so that when a sudden climate-induced disaster occurs (flood, drought, cyclone), actionable adaptation mechanisms (like relief mobilization, evacuation routing, or supply chains) are optimized with respect to closest or farthest distances (Munyaka, Chenal, Mabaso, Tfwala, & Mandal, 2024).

D. Bringing healthcare services closer to farmlands and fish ponds to effectively manage new climate-related diseases

The climate-related diseases which we are referring to are: Schmallerberg virus infection which is found in cattle and sheeps; Rift Valley Fever (RVF) which affects sheep, goats, cattle, camels; etc. Rising temperatures and shifting precipitation patterns, according to research,

are transforming the disease environment for livestock such as sheep, goats, cattle, and camels. For example, the International Livestock Research Institute discovered that climate change can increase the frequency and severity of livestock diseases: increased heat and humidity, extreme weather events, and shifting vector habitats all contribute to increased infections, particularly in cattle (Tezira, 2015). Climate change can lead to the spread or intensification of vector-borne and parasitic diseases. Bluetongue (BTV), a viral illness transmitted by vectors, has a high seroprevalence in cattle (about 49.7%) and goats (approximately 47%) in Africa, as well as camels (40.8%) and sheep (36.3%) (Medrouh, et al., 2024).

Many pastoral dryland zones have limited, remote, irregular, or absent veterinary and livestock health services. In south-central Tanzania, rural pastoral areas have limited access to livestock health care and laboratory diagnostic equipment (Gustafson, et al., 2015).

In the Nyong-et-So'o department in Cameroun, many remote rural communities experience inadequate healthcare access as a result of climate stress. Some of these remote rural communities are found in the agrarian landscape of MBOCKULU. This is also the same case with some Kenyan Agrarian Communities. In their research study conducted in the Kenyan Agrarian Communities of KILIFI, GANZE and MAGARINI Counties, Allen et al. (2025), found out that Climate change disproportionately affects vulnerable agrarian communities, exacerbating food insecurity and health risks. Their analysis revealed that climate change adversely affects health through key social determinants, including economic instability, environmental degradation, limited healthcare access, food insecurity, and disrupted education (Allen, et al., 2025).

To improve the healthcare services delivery in agrarian and fish ponds landscapes, these healthcare services need to anticipate the delivery of their services, before the occurrence of rising temperatures and shifting precipitation patterns (Gale, Drew, Phipps, David, & Wooldridge, 2009). The implementation of these anticipatory actions (such as health delivery services to cattle and goats) will reduce the occurrence and prevalence of livestock diseases in the agrarian landscape of MBOCKULU.

E. Building adaptive capacities through the spatial proximities (nearest distances) between farms, fish ponds, main roads and hospitals

Based on the spatial proximities (nearest distances) which exist between farms, fish ponds, main roads and hospitals in the agrarian landscapes of NGALAT and MBOCKULU, the farmers and pastoralist living in these landscapes can adopt the following four main adaptive capacities. These four main adaptive capacities are: Food security (i); Economic resilience (ii); Health resilience (iii); and Community cooperation (iv).

i- *Food security: farms near fish ponds can diversify production (agriculture + aquaculture).*

Food security as an adaptive capability refers to the belief that providing secure and sufficient access to food not only meets immediate requirements but also improves a community's ability to adapt to change and recover from every shock caused by climate change. Food security has four main dimensions: availability, access, usage, and stability. Each of these four main dimensions contributes to adaptive capacities in unique ways. Food security as adaptive capacity indicates that people's resilience is strengthened by secure and consistent access to adequate food, allowing them to better predict, absorb, and recover from environmental, social, or economic shocks.

ii- *Economic resilience: shorter distances to roads enable faster market access and input delivery.*

Economic resilience, as an adaptive capacity, refers to an economy's ability to absorb, recover from, and adapt to shocks or disruptions, such as financial crises, natural catastrophes, pandemics, or technological developments, while preserving long-term growth and stability (Capoani, Fantinelli, & Giordano, 2025). Economic resilience can be seen of as an adaptive capacity because it represents an economy's ability to alter and evolve in response to changing conditions rather than just absorb shocks. Adaptive capacity refers to a system's ability to adjust to possible damage, capitalize on opportunities, or deal with repercussions (Scharte, 2025).

Furthermore, adaptive capacity is an important component of resilience frameworks that distinguish between three degrees of capacity: **absorptive** (merely withstanding a shock), **adaptive** (making modifications to continue functioning), and **transformative** (fundamentally

changing structure) (Gallopín, 2006). In this perspective, economic resilience as adaptive capacity indicates that, in the event of a climate-related calamity, an agrarian landscape's economy can recover by enhancing performance and reducing vulnerabilities (Chavas, 2024). For example, wide human, financial, and technological resources, as well as social networks and governance frameworks that allow for learning and reconfiguration, could promote economic resilience. Defining economic resilience as adaptive capability emphasizes proactive, dynamic, and adjustment-oriented capacities, rather than just robustness or passive stability.

iii- *Health resilience: shorter travel times to hospitals improve response to diseases and injuries.*

Health resilience is defined as an adaptive capacity that allows individuals, communities, or systems to adapt, recover, and thrive in the face of health-related stresses, challenges, or disruptions induced by climate change. It is a dynamic concept that emphasizes not only "bouncing back" from diseases or disasters, but also learning, restructuring, and transforming in order to preserve or improve health outcomes in the aftermath of climatic disasters (Witter, et al., 2023).

Health resilience, whether at the person, societal, or system level, can be conceptualized as an expression of adaptive capacity: as the ability to modify, restructure, learn, and respond in the face of shocks and pressures in order to sustain essential health functions and well-being (Asfoor, et al., 2024). A health system that shifts from in-person to telemedicine delivery during a pandemic, reallocates staffing, or repurposes supply chains is an example of adaptive capacity. In this sense, resilience entails not only "bouncing back" but also "adjusting and evolving" in order to cope with changing surroundings (Asfoor, et al., 2024).

To summarize, health resilience can be understood as the product of adaptive capacity (including absorptive and transformative capacities) that enable continued functioning and enhanced readiness under evolving health and climate hazards (Ziglio, Azzopardi-Muscat, & Briguglio, 2017).

iv- *Community cooperation: closer farms can share irrigation, equipment, or knowledge.*

Community collaboration is essential for building adaptive capacity because it improves a community's ability to anticipate, learn from, respond to, and adjust in the face of climate change. According to resilience theory, adaptive capacity refers to a system's ability to adapt to climate change, mitigate harm, capitalize on opportunities, and cope with repercussions (Konstantin, Niesters, & Braun, 2025). When members of a community work together to share information, coordinate responses, and pool resources and capacities, they create social capital, collective knowledge, and flexible networks that help to strengthen their capacities. For example, one study discovered that collaborative activities within communities promotes social learning and raises common understanding of environmental dangers, thus increasing resilience (Olivia & Corinne, 2020).

Community cooperation as an adaptive capability refers to how a community's ability to collaborate improves its ability to adapt to change, stress, or shocks such as caused by climate change (Chapagain, et al., 2025). Finally, collaborative community activities enable gradual changes that go beyond simple coping and shock absorption: they allow communities to adapt by reorganizing behaviors, institutions, and relationships in preparation of future change. A community that works together to build early warning systems, reform land-use patterns, or negotiate with external partners demonstrates adaptive capacities by being proactive rather than reactive (Choko, et al., 2019).

V. CONCLUSION

Building adaptive capacities in flood-prone agricultural landscapes necessitates a multifaceted approach that combines spatial intelligence, economic diversification, and community health resilience. Nearest Neighbors and geographical proximity modeling help farmers, planners, and policymakers locate and duplicate resilient practices from adjacent to ecologically comparable places. Communities can determine which adaptive measures are most effective in similar flood-prone locations by studying geographical data such as: landmark disparities and distribution, topography, water flow patterns, and land-use histories. This geospatial perspective encourages regionally tailored interventions, ensuring that adaptive measures are

not generic but rather rooted in the experienced environmental conditions of each agrarian landscape.

Spatial proximities can serve as the foundation for cooperative networks, allowing nearby farms and settlements to share knowledge and resources. By grouping agricultural communities based on proximity and risk exposure, it is possible to create collective flood management measures such as shared drainage canals, coordinated planting dates, and buffer zones. These spatially coherent networks enable real-time communication and mutual aid during climate disasters, transforming fragmented responses into coordinated resilience plans. Furthermore, proximity-based planning promotes regional policy coherence by coordinating disaster management procedures and land-use planning across jurisdictional boundaries, which frequently fragment response capacities.

The inclusion of landmark disparities and distributions enriches this method by emphasizing how differences in topography, land-use, vegetation density, and infrastructural access cause uneven exposure to climate threats. Mapping these discrepancies allows for a more tailored strategy: where high-ground farms can serve as evacuation or seed-saving sites, while low-lying farms can be modified for flood-tolerant agricultural systems or aquaculture. Recognizing the variability of the agricultural landscapes in Mbalmayo–Cameroon ensures that adaptive methods are both geographically equitable and ecologically cohesive. This recognition will shift adaptation from uniform policy interventions to **spatially sensitive frameworks** that take into account both environmental changes and socioeconomic situations.

Finally, the combination of spatial analysis, local knowledge, and adaptive capacities, transforms the agricultural landscapes of Mbalmayo–Cameroon into a resilient network. When Nearest Neighbors algorithms and proximity-based models are combined with participatory mapping and continuous monitoring, they create an interactive and constructive environment in which communities can learn and adapt progressively (step by step). This interaction will not only enable survival in the face of floods and climate shocks, but will also enable long-term recovery of agricultural productivity and ecological stability. **In this way, adaptive capacity becomes a living spatial process, rooted in data, shaped by geography, and sustained by collective (participatory) action.**

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VIII. AUTHOR CONTRIBUTIONS

Individual authorship

IX. REFERENCES

- Allen, E. M., Munala, L., Frederick, A. J., Quito, C., Enayat, A., & Ngunjiri, A. S. (2025). Climate Change and Health: Impacts Across Social Determinants in Kenyan Agrarian Communities. *MDPI, Climate, Volume 13, Issue 8*.
- Asfoor, A. D., C., T., M., A.-Z., A., M., S., S., & S., R. (2024). Concept analysis of health system resilience. *Health Resilience Systems, Volume 22, Issue 1*.
- Barnett, J. (2001). Adapting to climate change in Pacific Island countries: The problem of uncertainty. *World Development, Volume 29, Issue 6* , 977–993.
- Burton, I. (1997). Vulnerability and adaptive response in the context of climate and climate change. *Climatic Change, Volume 36, Issues 1-2* , 185-196.
- Capoani, L., Fantinelli, M., & Giordano, L. (2025). The concept of resilience in economics: a comprehensive analysis and systematic review of economic literature. *Continuity & Resilience Review, Vomume 7, Issue 2* , 121–145.
- Chapagain, P. S., Banskota, T. R., Shrestha, S., Khanal, N. R., Yili, Z., Jianzhong, Y., . . . Poudel, K. R. (2025). Studies on adaptive capacity to climate change: a synthesis of changing concepts, dimensions, and indicators. *Humanities and Social Sciences Communications, Volume 12, 331*.
- Chavas, J.-P. (2024). Economic resilience: Measurement and assessment across time and space. *Research in Economics, Volume 78, Issue 2*.
- Choko, O. P., Olabisi, L. S., Onyeneke, R. U., Chiemela, S. N., Liverpool-Tasie, L. S., & Rivers, I. L. (2019). A Resilience Approach to Community-Scale Climate Adaptation. *Sustainability, Volume 11, Issue 11*.
- Engle, N. L. (2011). Adaptive capacity and its assessment. *Global Environmental Change, Volume 21, Issue 2*, 647-656.
- Eraydin, A., & Taşan-Kok, T. (2013). *Resilience Thinking in Urban Planning*. Springer Dordrecht.

-
- Fazey, I., J.A., F., J., F., K., S., J., W., R.F., N., & S.R., D. (2007). Adaptive capacity and learning to learn as leverage for social-ecological resilience. *Frontiers in Ecology and the Environment*, Volume 5, Issue 7, 375-380.
- Flavia, S. C., Jean-Marie, B., Marloes, B., & Teun, T. (2019). Adaptive Capacities for Diversified Flood Risk Management Strategies: Learning from Pilot Projects. *MDPI, Water*, Volume 11, Issue 12.
- Folke, ., Carpenter, ., Elmqvist, ., Gunderson, ., Holling, ., & Walker, . (2002). Resilience and sustainable development: Building adaptive capacity in a world of transformations. *Ambio*, Volume 31, Issue 5 , 437-440.
- Gale, P., Drew, T., Phipps, L. P., David, G., & Wooldridge, M. (2009). The effect of climate change on the occurrence and prevalence of livestock diseases in Great Britain: a review. *J Appl Microbiol*, Volume 106, Issue 5.
- Gallopin, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*, Volume 16, Issue 3, 293-303.
- Gustafson, C. R., VanWormer, E., Kazwala, R., Makweta, A., Goodluck, P., Smith, W., & Mazet, J. A. (2015). Educating pastoralists and extension officers on diverse livestock diseases in a changing environment in Tanzania. *Pastoralism*, Volume 5, Issue 1.
- Konstantin, G., Niesters, L.-M., & Braun, B. (2025). The role of community leadership in building community adaptive capacity to coastal hazards – Insights from neighborhood networks in Semarang, Indonesia. *Environmental Science & Policy*, Volume 163.
- Kundzewicz, Z. W., Su, B., Wang, Y., Wang, G., Wang, G., & Huang, J. (2019). Flood risk in a range of spatial perspectives – from global to local scales. *Natural Hazards Earth System Sciences*, Volume 19 , 1319–1328.
- Liverman, D. (2001). Environmental Risk and Hazards. *International Encyclopedia of the Social & Behavioral Sciences*, 4655-4659.

-
- Margo, v. d., Sander, M., Catrien, T., & Joyeeta, G. (2014). Climate-proof planning for flood-prone areas: assessing the adaptive capacity of planning institutions in the Netherlands. *Reg Environ Change, Volume 14*, 981–995.
- Medrouh, B., Abdelli, A., Belkessa, S., Quinten, Y., Brahimi, M., Hakem, A., . . . Pasolli, E. (2024). Seroprevalence and risk factors of bluetongue virus in domestic cattle, sheep, goats and camels in Africa: a systematic review and meta-analysis. *Vet Q. Volume 44, Issue 1*, 1-12.
- Mehvesh, M., Marco, C., & Shirsendu, S. (2024). Climate Adaptation of Roads to Flooding Hazards—A Review. *MDPI, Construction Materials, Volume 4, Issue 4*, 748-776.
- Morelli, A. B., & Cunha, A. L. (2020). Measuring urban road network resilience to extreme events: an application for urban floods. *Physics and Society*.
- Munyaka, B. J.-C., Chenal, J., Mabaso, S., Tfwala, S. S., & Mandal, K. A. (2024). Geospatial Tools and Remote Sensing Strategies for Timely Humanitarian Response: A Case Study on Drought Monitoring in Eswatini. *MDPI, Sustainability, Volume 16, Issue 1*.
- Olivia, J., & Corinne, O. (2020). Collaborative Action for Community Resilience to Climate Risks: Opportunities and Barriers. *Sustainability, Volume 12, Issue 8*.
- Palmer, . A., & Filoso, . (2009). Restoration of ecosystem services for environmental markets. *Science, Volume 325(5940)*, 575–576.
- R., P. B., Paul, S., Jessica, J., Matthew, P., & Paola, P. (2021). Unpacking Adaptive Capacity to Flooding in Urban Environments: Social Capital, Social Vulnerability, and Risk Perception. *Front. Water, Volume 3*.
- Scharte, B. (2025). The need for general adaptive capacity—Discussing resilience with complex adaptive systems theory. *International Journal of Risk Analysis, Volume 45, Issue 6*, 1443-1452.
- Shuang, L., Nengzhi, T., & Rui, L. (2023). A Weighted k-Nearest-Neighbors-Based Spatial Framework of Flood Inundation Risk for Coastal Tourism—A Case Study in Zhejiang, China. *ISPRS International Journal of Geo-Information, Volume 12, issue 11*.

-
- Smit, ., & Wandel, . (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change, Volume 16, Issue 3*, 282-292.
- Taesam, L., & Vijay, P. S. (2019). Discrete k-nearest neighbor resampling for simulating multisite precipitation occurrence and model adaption to climate change. *GMD Articles, Volume 12, Issue 3*, 1189–1207.
- Tezira, L. (2015). *Livestock scientists say climate change can increase risk of animal pests and diseases*. International Livestock Research Institute.
- Tiwari, P. C. (2024). Development of Climate Resilient Integrated Farming System in Himalaya: An Illustration of Women Centric Adaptive Headwater Management Approach. *Quest A Journal of the Social Sciences, Volume 18, Issue 1*, 1-24.
- Witter, S., Thomas, S., Topp, S. M., Barasa, E., Chopra, M., & Cobos, D. (2023). Health system resilience: a critical review and reconceptualisation. *Viewpoint, Volume 11, Issue 9*, 1454-1458.
- Wohl, C., Villamayor, J., Galí, M., Mahajan, A., Fernández, R., Cuevas, C., . . . Saiz Lopez, A. (2024). Marine emissions of methanethiol increase aerosol cooling in the Southern Ocean. *Science Advances, Volume 10, Issue 48* , 1-9.
- Ziglio, E., Azzopardi-Muscat, N., & Briguglio, L. (2017). Resilience and 21st century public health. *European Journal of Public Health, Volume 27, Issue 5*, 789–790.

Chapter 6: GENERAL CONCLUSION

This chapter draws some conclusions and recommendations from our PhD research by bringing out the main findings, designed recommendations, novelty, and the way forward that will enable the improvement of the agrarian landscape's adaptive capacities. This general conclusion emphasizes the contribution of landmarks in providing major dynamics that helped enhance the adaptive capacities of agrarian landscapes in Cameroon. These dynamics appear to be one of the best tools that agrarian landscapes have for their resilience against sudden climate hazards. In this light and based on the dynamics we observed in Cameroon, some valuable recommendations are being addressed to academia, to government, and to NGOs for an effective consideration of landmarks and landscape dynamics in the fight against climate change in all the regions of Cameroon.

I. MAJOR FINDINGS THAT CAN HELP ADVANCE THE SCIENCE OF LANDSCAPE SUSTAINABILITY AND RESILIENCE STUDIES (LSRS)

The main findings of this PhD research highlight the function of landmarks in redynamizing and reviving agrarian landscapes by preparing them to meet unforeseen climate hazards. The functions (roles) these landmarks performed made the agrarian landscapes in Mbalmayo become resilient to any climate disaster. These main findings highlighted various landmarks, which are rivers, creeks, ponds, swamps, floodplains, wells, farmland, slopes, plains, trees, bridges, grasses, unpaved farm roads, houses, hills, mountains, roads, and hospitals.

A. Major findings concerning the spatial relationships between landmarks

Our first major finding talks about the spatial relationships between landmarks. The identification and understanding of the spatial relationships between these ten landmarks enabled us to detect some key functions deployed by two or more landmarks who have the same spatial relationships. We named we gave to these key functions performed by two or more landmarks is "joint function". The ten landmarks we are referring to are rivers, creeks,

ponds, swamps, floodplains, wells, arable land, grazing land, orchard land, and mixed farming land.

The first case of joint function is provided by the spatial relationships between rivers, creeks, ponds, swamps, and floodplains. The description of their spatial relationship is adjacency (meaning the landmarks share a common boundary). The function provided here is the "regulation of water flow and availability." This joint function helps agrarian landscapes to adapt to climate hazards because it slows runoff, increases infiltration, and recharges groundwater, thereby reducing flood risk and sustaining dry-season irrigation. These five landmarks (rivers, creeks, ponds, swamps, and floodplains) found in OYACK and NGALAT play the most direct and reliable role in regulating water flow and availability. This role-play reduces flood damage and improves water security during droughts.

The second case of joint function is provided by the spatial relationships between grazing land, creeks, ponds, and swamps. The nature of their spatial relationship is adjacency (meaning the landmarks share a common boundary). The function provided here is "Microclimate Modification." This joint function means that when water bodies are found near croplands, it increases humidity and reduces temperature fluctuations.

The third case of joint function is provided by the spatial relationships between grazing lands and floodplains. Their spatial relationship is adjacency. The joint function provided here is "Soil Protection and Fertility Maintenance." In the agrarian landscapes of Oyack, Ngalat, and Mbockulu, grazing lands (reeds, grasses, and trees) slow water movement during floods, and this prevents soil erosion.

The fourth case of joint function is provided by the spatial relationships between rivers and creeks. The nature of their spatial relationship is adjacency. The joint function provided here is "Biodiversity and Ecosystem Service Connectivity." In Mbalmayo, both rivers and creeks have flowing freshwater, similar oxygen levels, and comparable temperature patterns. Because of these shared boundaries between rivers and creeks, in Mbalmayo many organisms, such as certain fish, aquatic insects, algae, and amphibians, can live in both.

The fifth case of joint function is provided by the spatial relationships between floodplains and orchard lands. The nature of their spatial relationship is disjoint (meaning that these two

landmarks do not share space). The function provided here is "spatial separation of vulnerable and critical assets" (e.g., seeds planted and stored far from flood zones).

The sixth case of joint function is provided by the spatial relationships between mixed farming, grading, and orchard lands. The description of their spatial relationship is intersection and connectivity (meaning that these landmarks are connected at a node or point). The joint function provided here is "Adaptive Capacity through Traditional Knowledge."

The last (seventh) case of joint function is provided by the spatial relationships between Grazing Land, Creeks, and Swamps. The nature of their spatial relationship is adjacency. The joint function provided here is "Integration of Social and Ecological Functions."

B. Major findings on landmarks distribution and disparities, as well as their relationship with climate disasters and agriculture: A comparison between the agrarian landscapes of OYACK and MBOCKULU

Here, our research looked at the relationship that these agrarian landmarks have with crop cultivation, livestock farming, natural regeneration, and climate disasters. On the other hand, the climate disasters that occurred in Oyack and Mbockulu had some impacts on (negative relationship) landmarks, crop cultivation, and livestock farming. These relationships on both sides give an overview of the disparities and distributions of landmarks and their impacts on crop cultivation, livestock farming, natural regeneration, and climate disasters. These disparities and distributions of landmarks vary in each of the two landscapes below (OYACK and MBOCKULU), and these variations are based on five main adaptive elements, which are crop cultivation, livestock farming, natural regeneration, exposure, and sensitivity to climate disasters. Each of these adaptive elements determines the adaptive capacities that exist in the agrarian landscapes of OYACK and MBOCKULU.

1. Comparing the landmarks that nourish the most crop cultivation and livestock farming in the agrarian landscapes of Oyack and Mbockulu

Landmark's impact	In OYACK	In MBOCKULU
The landmark that sustains the most crop cultivation	Rivers & Trees	Swamps
The landmark that sustains the most livestock farming	Rivers	Swamps
The Landmark which is likely to regenerate naturally the most without human intervention	Trees	Trees

2. Comparing the climate disasters to which landmarks are more exposed and sensitive to, and the various nature-based adaptive measures implemented.

Climate Disasters and nature-based adaptive measures	In OYACK	In MBOCKULU
The climate disaster to which landmarks are more expose	Droughts	Droughts
The climate disaster to which landmarks are more sensitive	Droughts	Droughts
The most implemented Nature-based adaptive measures in crop cultivation	Agroforestry	Wetland restorations
The most implemented nature-based adaptive measures in livestock farming	Agroforestry	Wetland restorations

3. A comparison of the crop cultivated, livestock farming, and landmarks, which are more exposed to climate disasters in Oyack and Mbockulu

Exposure to climate disasters	In OYACK	In MBOCKULU
The most exposed landmark	Trees	Swamps
The most exposed food crop	Cassava	Maize
The most exposed livestock farming	Poultry farming	Aquaculture

4. A comparison of the crop cultivated, livestock farming, and landmarks, which are more sensitive to climate disasters in Oyack and Mbockulu

Sensitivity to climate disasters	In OYACK	In MBOCKULU
The most sensitive landmark	Trees	Trees
The most sensitive food crop	Maize	Maize
The most sensitive livestock farming	Poultry farming	Aquaculture

C. Major findings on the proximity-based patterns showing the nearest and farthest landmarks in NGALAT and MBOCKOULU with regards to five types of land use: a comparative analysis

Straight-line distance (also called closest distance) is the shortest possible distance between two points, measured along a straight line connecting them (shortest possible distance through space) (Li & Wang, 2008). This straight-line distance helps to identify the Nearest and Farthest Neighbors between several points (landmarks) found on a map. Here we want to present to you the four categories of land used whose landmarks are the closest and farthest in terms of Straight-line distances. These five types of land use are "aquaculture," "agriculture," "transportation," "healthcare," and "residential" land use.

We consider this a major finding in our research because the above five types of land use are the main land uses that are practiced in the agrarian landscapes of NGALAT and MBOCKOULU. That is, 99% of the populations in NGALAT and MBOCKOULU are involved in at least one of these lands used types. In our research study, the landmarks that represent the land use of aquaculture are fish ponds. The landmarks that represent the land use of agriculture are farms (crop farms or livestock farms). The landmark that represents the land use of transportation is roads. The landmarks that represent the land use of healthcare are hospitals. And the landmarks that represent the residential land use are houses.

1. Nearest Neighbors (NN) and closest distances in the agrarian landscape of NGALAT and MBOCKOULU

The table below compares the landmarks (with their land use types) that have the closest straight-line distances in the agrarian landscape of NGALAT and MBOCKOULU.

Agrarian landscapes	The closest landmarks (from one landmark to the other)	The type of land uses	Minimum Straight-line Distance (meters)
In NGALAT	Crop farms & Houses	Agricultural vs. Residential	7.21 m
In MBOCKOULU	Small ruminant farms & Houses	Agricultural vs. Residential	5.67 m

The above table shows us that the landmarks that have the closest distances in NGALAT are crop farms and houses, with a minimal distance of 7.21 meters. And the landmarks that have the closest distances in MBOCKOULU are small ruminant farms and houses, with a minimal distance of 5.67 meters. This means that in NGALAT, the nearest neighbors (NN) are crop farms and houses, and in MBOCKOULU, the nearest neighbors (NN) are small ruminant farms and houses.

2. Farthest Neighbors (FN) and farthest distances in the agrarian landscape of NGALAT and MBOCKOULU

The table below compares the landmarks (with their land use types) that have the farthest straight-line distances in the agrarian landscape of NGALAT and MBOCKOULU.

Agrarian landscapes	The farthest landmarks (from one landmark to the other)	The type of land uses	Maximum Straight-line Distance (meters)
In NGALAT	Fish pond & Hospitals	Aquaculture vs. Healthcare	448.31 m
In MBOCKOULU	Crop farms & Hospitals	Agricultural vs. Healthcare	516.95 m

The above table shows us that the landmarks that have the farthest distances in NGALAT are fish ponds and hospitals, with a maximal distance of 448.31 meters. And the landmarks that have the farthest distances in MBOCKOULU are crop farms and hospitals, with a maximal distance of 516.95 meters. This means that in NGALAT, the farthest neighbors (FN) are fish ponds and hospitals, and in MBOCKOULU, the farthest neighbors (FN) are crop farms and hospitals. These major findings on farthest neighbors and farthest distances clearly show that the landmarks that are separated and far from every other landmark are hospitals. How do the farthest distances from hospitals affect the adaptive capacities and resilience to climate disasters of the people living in NGALAT and MBOCKOULU?

II. RECOMMENDATIONS AND WAY FORWARD

A. Translating research findings into practical action steps

The findings of our research cover a wide range of practical challenges which are been faced everyday by the people living in the agrarian landscapes of Oyack, Ngalat and Mbockulu. Amongst these challenges, we have interrelated environmental, climatic, and socio-ecological challenges, especially those arising from climate variability, land degradation, and human–ecosystem interactions.

With regard to the environmental, climatic, and socio-ecological challenges, our research finds out that the joint functions developed by the spatial relationships between hydrographies and

farmlands provide seven solutions, which we will convert below into five practical actions. If correctly applied, these seven practical actions will solve the above-mentioned challenges

Action 1: To address the challenges of flooding, waterlogging, and water scarcity in these three agrarian landscapes, the first practical action will be to regulate water flow and availability. This action is inspired by the joint function provided by the spatial relationship between rivers, creeks, ponds, swamps, and floodplains. Because rivers, creeks, ponds, swamps, and floodplains share common boundaries, it is important to implement a combination of landscape, farm-level, and governance activities. These activities include:

- Community leaders should conserve and restore wetlands, riparian buffers, and floodplains in Oyack to slow runoff and enhance groundwater recharge. This is because the landscapes in Oyack A & B have so many riverine corridors.
- Farmers should adopt soil and water conservation practices such as contour farming, cover crops, and reduced tillage in the landscape of Mbockulu, which will help improve infiltration and soil moisture retention.
- Community leaders, together with farmers should construct small-scale water harvesting and storage infrastructures like farm ponds in the landscape of Ngalat (where we have five fish ponds), and check dams in the agrarian landscape of Oyack (where we have the Nyong river) to help reduce flooding, waterlogging, and water scarcity.
- Community leaders should efficiently manage the watersheds in the agrarian landscapes of Oyack A & B through coordinated land-use planning and reforestation of upper catchments to help reduce the occurrence of flooding and waterlogging.

Action 2: To solve the issues of extreme temperatures (heat stress), crop failure, and reduced agricultural productivity due to climatic stress. This action is motivated by the collaborative function offered by the spatial relationship between grazing land with creeks, ponds, and swamps. Because grazing land with creeks, ponds, and swamps share boundaries, it is important to implement a combination of vegetation and management practices that influence temperature, humidity, and wind at the field scale. These practices include:

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- Community leaders together with farmers should establish shelterbelts and windbreaks in the agrarian landscapes of Oyack, Ngalat, and Mbockulu to protect the farms and fish ponds against wind speed and evapotranspiration.
 - Community leaders should encourage farmers to practice agroforestry and intercropping as their major form of farming technique in the agrarian landscapes of Oyack and Mbockulu to provide shade, moderate temperature extremes, and enhance humidity.
 - Farmers should set up soil covers with cover crops and crop residues to regulate the soil temperature and moisture in the agrarian landscapes of Oyack, Ngalat, and Mbockulu.
 - Community leaders together with farmers should shape and design all the farms as terraces, contour farms, and bunds to influence cold air drainage and water retention in the landscapes of Oyack, Ngalat, and Mbockulu.

Action 3: To address the difficulties of soil nutrient depletion, declining soil fertility, land degradation, and desertification, the third practical action will be to boost soil protection and fertility maintenance. This action is prompted by the collaborative function provided by the spatial relationship between grazing lands and floodplains. Because grazing lands share boundaries with floodplains, it is critical to incorporate a combination of complementary practices, which includes minimizing soil disturbance with no-tillage and maintaining continuous soil cover using cover crops. Other complementary practices also include the following:

- Providing in the landscape of Mbockulu crop residues to prevent erosion and moisture loss and diversifying crop rotations to improve soil structure, break pest cycles, and enhance nutrient availability. This is mostly important in the landscapes of Ngalat and Mbockulu, which have the highest number of fish ponds.
- Farmers should implement in all their farms additional measures such as contour farming, terracing, buffer strips, and agroforestry to also help reduce erosion and runoff.

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- Finally, in Ngalat and Mbockulu, pastoralists have to control the grazing of land and proper irrigation practices to protect soil structure and prevent compaction, salinization, and nutrient leaching.

Action 4: To handle the challenges of habitat fragmentation, biodiversity loss, and ecosystem instability in agrarian landscapes, the fourth action will be to maintain a strong connectivity between biodiversity and ecosystem services. This action is inspired by the joint function provided by the spatial relationships between rivers and creeks. Because rivers and creeks share common boundaries, to maintain a strong connectivity between biodiversity and ecosystem services in an agrarian landscape, it is important to integrate ecological principles into farming and land-use practices. Therefore, to integrate these ecological principles, the following activities must be implemented:

- Farmers, conservation organizations, and local authorities have to conserve and restore habitat networks (hedgerows, riparian buffers, field margins, and woodlots) that will allow species movement and ecological flows in the agrarian landscapes of Oyack, A & B, Ngalat, and Mbockulu.
- In Oyack and Mbockulu, farmers need to promote diversified farming systems (crop rotations, intercropping, agroforestry, and mixed crop–livestock systems) that will support functional biodiversity.
- Local authorities have to safeguard water resources by preserving and maintaining the existing wetlands and vegetated waterways in the agrarian landscapes of Oyack and Mbockulu;
- Especially in Mbockulu, the local authorities have to support all these ecological actions with incentives and participatory governance to align farmers' livelihoods with long-term ecosystem service provision.

Action 5: To address the difficulties of loss of genetic resources, food insecurity, and risk concentration caused by climatic extreme events (floods, forest fires, or landslides), a fifth action has to be implemented. This action will focus on separating vulnerable and critical assets from areas where climate disasters constantly occur. This action is inspired by the joint

function that results from the spatial relationships between floodplains and orchard lands. To carry out this action effectively, it is important for floodplains and farmlands not to share the same space nor boundaries. In the agrarian landscapes of Oyack, Ngalat, and Mbockulu, the spatial separation of vulnerable and critical assets can be achieved through the following practices:

- The implementation of appropriate land-use planning and strategic zoning to ensure that essential infrastructures, such as water sources, storage facilities, livestock pens, and residential areas, are physically distanced from high-risk zones like floodplains or erosion-prone fields.
- The establishment of protective buffers in Mbockulu, such as hedgerows, tree belts, or uncultivated strips, to reduce the spread of hazards in such vulnerable zones, where routes and service corridors are designed to minimize cross-exposure between floodplains and farmlands.
- Additionally, the integration of natural barriers, such as wetlands or contour-based field layouts, in high climate hazard-prone areas, will limit potential losses, thereby creating a resilient spatial configuration that separates agricultural activities from high-risk climatic zones.

Action 6: To solve the issues of poor adaptation, reduced community resilience to climate variability, and weak governance that hinders every adaptation effort in Oyack, Ngalat, and Mbockulu, a sixth action is recommended. This action will focus on building strong adaptive capacities by integrating traditional knowledge and ecological functions. This action results from analyzing the joint function, which is derived from the spatial relationships between mixed farming, grazing, and orchard lands. Therefore, to build these strong adaptive capacities, communities can integrate traditional knowledge with ecological functions by doing the following activities:

- Community leaders should promote diversified cropping systems, such as intercropping and agroforestry, which enhance soil fertility, water retention, and pest resilience.

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- Community leaders should encourage farmers and pastoralists to preserve and revive indigenous seed varieties, seasonal calendars, and local weather prediction practices to strengthen their resilience to climatic variability.
 - Farmers and pastoralists should implement soil and water conservation techniques like contour farming, terracing, and natural wetlands restoration that will maintain ecosystem services while reducing vulnerability to erosion and floods.
 - Community leaders should conduct effective community-based resource management, knowledge sharing, and participatory decision-making, thereby ensuring that their local ecological wisdom and traditional knowledge will guide sustainable land use, with traditional practices such as rotational grazing.

If correctly implemented, all these six actions and their sub-activities will collectively enhance the landscape's adaptive capacity, resulting in biodiversity conservation, nutrient cycling, and long-term agricultural productivity.

B. The extension of current theories and proposition of new conceptual, analytical, and empirical frameworks

When we started this PhD research three years ago, the objective of our thesis was to address three main research gaps that have been existing in the science of landscape resilience. These three gaps which existed till date where: the lack of a conceptual framework that describes the spatial relationships between farmlands and hydrographies, the lack of an analytical framework that investigates the role of landmarks in enhancing the adaptive capacities, and the lack of an empirical framework showing the landmarks that can be used to improve adaptive capacity in an agrarian landscape. This objective has been achieved with regards to the analysis and results obtained in chapters 3, 4, and 5 of this PhD thesis. Our PhD research therefore adds three new research frameworks to the science of landscape resilience.

Each of these frameworks can be cited and used by future researchers who are interested in understanding the dynamics of agrarian landscapes and determining what the factors are that should be considered when building the adaptive capacities of any agrarian landscapes in the world.

The conceptual framework we developed in our research is a theoretical map (word map) that shows the key concepts or variables of our study (the twelve landmarks) and illustrates how these concepts are related in spatial sciences, based on the theory of spatial relationships. The theory of spatial relationships explains how the location, distance, and arrangement of things in space influence how they relate to one another (Christaller, 1966). It studies patterns in space and how those patterns affect movement, communication, behavior, and social or physical outcomes. In this theory, the relationships between things are shaped by how they are positioned in space. This theory is commonly known as the "*Central Place Theory—spatial relationships between settlements*" and was developed by Walter Christaller (1933) in his book titled *Central Places in Southern Germany* (1933).

The conceptual framework that we developed in this thesis clarified the various landmarks that we studied, explained why we studied these landmarks, explained how these landmarks are connected, and guided our research questions and hypothesis. The landmarks we studied are rivers, creeks, ponds, swamps, floodplains, wells, farmland, slopes, plains, trees, bridges, grasses, farm un-paved roads, houses, hills, mountains, roads, and hospitals. We studied the above eighteen varieties of landmarks because we wanted to determine the role played by these landmarks in building the adaptive capacities of agrarian landscapes, with the goal of making these landscapes resilient to climate disasters. These landmarks are connected through seven types of spatial relationships, which are adjacency, containment, connectivity, intersection, disjoint, overlapping, and same-space relationships. The conceptual framework we developed helped us to inform, shape, and frame our hypothesis and research questions.

The analytical framework that we developed through our research translated our conceptual framework into a systemic research plan, in which we detailed step by step the various analyses that we did to examine the relationships between the landmarks and determine the role played by these landmarks in building the adaptive capacities of agrarian landscapes. The analytical framework we developed guided the type of data collected and informed us on the analysis to do to analyze these data. Our analytical framework also enabled us to identify our dependent and independent variables. And finally, in our analytical framework, we included all the equations (formulas) we used, and we detailed all our analytical steps.

The type of data collected through this analytical framework was both quantitative and qualitative data. These data are the positioning in space, geolocation and perceptions on

landmarks, georeferenced data, drone map data, spatial data, land use data, perceptions, land ownership data, sketch map data, geometry, and straight-line distance data. To analyze this data, we conducted the following analysis: topological analysis, cross-tabulation analysis, analysis of landmark perceptions, spatial analysis, Euclidean distance analysis, symbol recognition analysis, buffering, and proximity analysis. Our independent variables are the spatial relationships and straight-line distances between the various landmarks. And our dependent variables are people's perceptions about landmarks and the impact that landmarks have on adaptive capacity. This perception and impact are classified in seven levels from -2, -1, 0, 1, 2, +1, and +2, each of these levels has a perceptive value attached to it. Our dependent is conceptual or latent, meaning it cannot be measured directly. This dependent variable represents the outcome or effect of the role played by these landmarks in building the adaptive capacities. According to the analytical framework we developed, these dependent variables can change if the independent variables are manipulated differently. And finally, the formula we used in our analytical framework was the Euclidean distance formula (Lay, 2015). This formula is written as follows:

$$\textit{Distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (\text{Lay, 2015})$$

where (x1, y1) and (x2, y2) are the coordinates of the two landmarks (locations):

- X_1 and Y_1 are the coordinates of the first landmark.
- X_2 and Y_2 are the coordinates of the second landmark.
- D is the distance between the two landmarks.

Finally, the empirical framework that we developed in this thesis shows the extent to which our research is based on observable data and earlier empirical discoveries. This empirical framework shows that our PhD research focused more on evidence (data and results) rather than theories. Through this evidence, we demonstrated how our variables (dependent and independent) were measured. The empirical framework we developed based on our data enabled us to link our study with existing empirical research such as the research conducted by Priya Chetri et al. (2021) on the "role of information and ICTs as determinants of farmer's adaptive capacity to climate risk: an empirical study from Haryana, in India." (Chetri, Sharma, & Ilavarasan, 2021). In this study published in 2021, Chetri attempted to understand the

constituents of a farmer's adaptive capacity at a local level and how it can be enhanced (Chetri, Sharma, & Ilavarasan, 2021). Unlike our PhD research, which attempts to enhance the adaptive capacities of farmers and pastoralists, we both (Chetri's research and I) concluded that information and the understanding of landmarks are a direct and significant contributor to enhancing farmers' adaptive capacity (Chetri, Sharma, & Ilavarasan, 2021). Our empirical framework is strong and very useful because it is based on good quantitative data that were thoroughly measured.

**C. The identification of future research directions to resolve the outstanding
(unanswered) questions of our thesis: way forward**

In conducting this PhD research, our intention was to fill the research gap caused by the unanswered questions we identified in our literature review. While answering these questions to fill the research gap, two directions erupted, opening the possibilities for future research. These two directions are two open questions that could be explored and investigated in the nearest future by any scientist. These open questions are research directions that can lead to postdoctoral studies. Our PhD research revealed the edge cases, or new directions for future research that weren't visible before. These open questions are the limits and boundaries we design when conducting our research. The two opened questions are

Opened Question 1: What impact do long distances between farmlands and hospitals have on the adaptive capacities and resilience of NGALAT and MBOCKOULU, and what could be the best way for farmers to combat climate-related diseases?

Opened Question 2: Can the perception of landmarks by farmers and pastoralists improve because of an increase in map literacy levels in the landscapes of Oyack, Ngalat and Mbockulu ? And what is the percentage of the population in Mbalmayo who are map literate?

One of the famous sentences we constantly wrote in our PhD research is that "Adaptation starts with knowing where risks actually exist." So, if asked, we will say that map literacy is very useful in building adaptive capacities, because this map literacy will be used to anticipate threats, identify safe zones (even for evacuation), and make informed decisions before, during, and after disasters.

Due to data constraints and theoretical boundaries, we could not in this PhD research explore or investigate on these two open questions. Therefore, based on these open questions, future researchers should employ more mapping assistants, community facilitators, and interpreters. And deploy more large printed base maps, more drones, more metadata templates, more mapping guides & training materials, more voice recorders for capturing narratives, more GPS devices for geolocating features, and more printed maps for validation sessions. All these are efficient tools to conduct good and accurate participatory mapping sessions. These open questions represent two promising research studies, and if handled correctly, they could form the bases for strong and well-defined theoretical and methodological frameworks.

Finally, these opened questions are a vital component of our PhD thesis because they demonstrate our deep understanding of the research field and its boundaries, showing not only what has been discovered but also what remains unknown. This is possible only because we explicitly identified open limitations and avenues for future work, enabling our thesis to position its contributions within the broader science of landscape sustainability and resilience studies. These questions also highlight the dynamic and evolving nature of our research, thereby inviting further investigations from the wider academic community. These two open questions reinforce the idea that our PhD is not about providing final answers but about advancing knowledge and setting the stage for continued research.

D. Recommendations for the use and reuse of our PhD research data: the who, why, how and when

The data we collected throughout this PhD thesis is especially valuable to actors (researchers or practitioners) who work at the intersection of space, people, and decision-making. To determine the **who**, **why**, **how**, and **when** to use or reuse our PhD data, we divided or categorized the data we collected into four categories, which are: spatial + cognitive representations of landmarks, geospatial data, land use and land ownership data, and mental map data.

1. Spatial and cognitive representations of landmarks

These data concern all the information we collected on the positioning in space, geolocation, and perceptions of landmarks. Here we also have in our PhD thesis spatial cognition data on how people perceive the distance and the spatial relationships between the various landmarks. We also have Landmark data, which consists of the prominent features people use to save and secure themselves in the event of a climate disaster. And finally, here we have topological data, which are the connections between places (routes, nodes, paths) rather than exact distances

The first category of researchers who can use the data and results obtained from the spatial and cognitive representations of landmarks are researchers studying memory, perception, attention, and mental representation (the who). These researchers can do so by examining how people encode landmarks in memory (visual, semantic, and emotional cues) and by studying cognitive maps—how landmarks anchor spatial memory and navigation (the how). The use of our data and results by other researchers is very important because it can guide various experiments that seek to determine how people remember routes better than before by using landmarks and map digital tools. Researchers studying memory can use the results once the data are validated and analyzed, meaning that the study is completed, because the data in this study have been cleaned and statistically analyzed, and the findings are interpreted and, ideally, peer-reviewed.

The second category of researchers who can use the data and results obtained from the spatial and cognitive representations of landmarks are human geographers, GIS specialists, and spatial analysts. They can use our data to model how people conceptualize cities and environments, not just their physical layout, and incorporate these cognitive landmarks into wayfinding systems and maps. This process is very important because it will enable the design of maps that highlight and display the landmarks people utilize on a daily basis for a variety of survival needs (such as surviving climate disasters). Because the data in our PhD study have been cleaned and statistically analyzed, and the results are interpreted and, ideally, peer-reviewed, human geographers, GIS specialists, and spatial analysts can use the results once the study is validated and assessed.

2. Geospatial data and Straight-line distance data

These data concern all the information we collected when flying the drone over each area where the landmarks are found. These data can also be referred to as georeferenced and drone map data. Here we also have the data on the distance along a straight line between two landmarks. In our PhD research, this data was calculated using the Euclidean distance formula, which is a geometric or coordinate formula.

Firstly, the data and results obtained from geospatial data and straight-line distance data can be used by Geographers & GIS specialists. These researchers can use this data in four different ways, which are: to map physical and human features (cities, rivers, land use) ; measure distances between locations ; analyze spatial patterns (clustering, dispersion) ; and model accessibility to various locations, such as distance to schools and hospitals. The usage of our data and results by geographers & GIS specialists is critical because it will enable them to study spatial patterns (urban growth, land use, and climate impacts) and map relationships between places. Straight-line distance data helps to compare locations without road or network constraints. These geographers & GIS specialists will be able to use the data of our PhD research once the data has been validated, evaluated, and published by a peer review.

Secondly, the other group of people who can use the data we provided in this PhD thesis are disaster management & emergency researchers. The best way for them to use our data will be by modeling disaster impact zones, estimating response coverage, and planning evacuation strategies. These three actions are very important because they convert uncertainty (climate variabilities) into practical decisions that save lives. Predicting where and how severe a climate disaster will occur allows authorities to prioritize resources, position responders and shelters where they will be most effective, and identify populations at most risk before a crisis occurs.

The third group of researchers to whom our data will fit are urban planners & transportation researchers. These third groups of researchers can use our data to study urban sprawl and land-use patterns, estimate proximity to services (parks, transit, jobs), and compare straight-line distance vs. travel distance/time. It is important for these researchers to conduct such actions because it will enable them to develop quick comparisons and theoretical planning models by using straight-line distance data.

3. Land use and land ownership data

These data concern all the information we collected on how the inhabitants of Mbalmayo (Ngalat, Oyack, and Mbockulu) use their land, and we also collected various information on who owns and controls the land they are using.

Urban planners & regional planners are the first group of practitioners and researchers who can apply the land-use and land-ownership data and results that are present in this PhD thesis. These practitioners can use these data in three ways to determine three related aspects. These three ways will be used to analyze how land is currently used (residential, commercial, agricultural, or industrial), to plan zoning changes, housing development, and transportation networks, and to assess rural exodus and land-use efficiency. The analysis urban planners & regional planners might conduct is very important because it will help determine if there is a need for new housing or infrastructure in the city of Mbalmayo. They will also be able to understand if zoning affects affordability or mobility.

Agricultural scientists & rural development researchers are the second group of academics who can use the data and findings of our PhD research effectively. The data and findings we obtained on land use will help these researchers and agricultural scientists to assess crop patterns, land suitability, and soil management. Meanwhile, the data on land ownership will help rural development researchers to examine land tenure systems and farming practices to identify what is needed between land consolidation and land fragmentation to improve farming activities in the agrarian landscapes of Oyack, Ngalat, and Mbockulu. These analyses on crop patterns, land suitability, land tenure systems, and farming practices are very important because they will help determine if land ownership structure affects farming efficiency and determine what land uses are most sustainable for food production.

4. Mental map data

The mental map data we are referring to here are photograph selection data (what images people choose to represent a place); discrepancy data (gaps between mental maps and objective maps); landmarks; attention data (what landmarks or features people notice first); social meaning data (places associated with identity, status, or community); and cultural narratives & symbols (how stories, media, or history shape perception of space). Therefore,

we tried to detect and examine which type of researchers or scientists will mostly desire to use the mental map data that we collected in our PhD thesis. The details on the type of researchers or scientists are found below.

The first group of researchers or scientists are cognitive psychologists, behavioral scientists, and spatial cognition researchers. This group of researchers can use the mental map data, discrepancy data, and landmark attention data we collected in our PhD thesis to compare mental maps to actual layouts to measure distortion, link mental maps to some brain activities, measure cognitive biases, determine which landmarks aid memory and wayfinding, and analyze how people orient themselves in real or virtual environments. These various research activities that this group of researchers can conduct are very important because they will show how attention shapes internal representations, illustrate how people perceive, understand, and navigate systems, and reveal what captures attention and guides people's behavior.

The second group is mostly made up of practitioners such as geographers and rural planners. This group of practitioners can use the mental map data, discrepancy data, and landmark attention data we collected in our PhD thesis to examine how residents perceive landscapes vs. official maps and identify perceived barriers, unsafe areas, or important zones. These numerous research tasks that this group of practitioners can carry out are critical because they will demonstrate how attention influences internal representations, how people see, interpret, and traverse systems, and what catches attention and leads people's behavior.

BIBLIOGRAPHY

- ActionAid, K., GROOTS, K., & LANDac, &. (2018). *Securing women's land rights: Scaling for impact in Kenya*. Nairobi: LANDac Working paper 1 on Securing women land rights in Africa.
- Adger, D. (2006). Combinatorial Variability. *Journal of Linguistics* 42(3), 503–530.
- Adger, W. N., Jouni, P., Saleemul, H., & Mace, M. J. (2006). *Fairness in Adaptation to Climate Change*. Cambridge, MA: MIT Press.
- African Union. (1986). *African Charter on Human and People's Rights [Treaty on Human Rights in Africa]*. Addis Ababa: African Union.
- African Union. (2003). *Protocol to the African Charter on Human and People's Rights on the Rights of Women in Africa [Treaty on Women and Gender Issues in Africa]*. Maputo: African Union.
- African Union. (2009). *Declaration on Land Issues and Challenges in Africa [A treaty on improving land issues in Africa]*. Sirte: African Union.
- Ait Mous, F., & Berriane, Y. (2014). Terres collectives et inégalités: le combat des soulaliyates. *Economia*, 28-31.
- Akinola, A. O. (2018). Women, Culture and Africa's Land Reform Agenda. *Journal of Frontiers in Psychology, Section Gender, Sex and Sexualities, volume 9*, 8 pp.
- Alderson, D., Li, L., Willinger, W., & Doyle, J. C. (2005). Understanding Internet Topology: Principles, Models, and Validation. *IEEE/ACM Transactions on Networking, Vol. 13, No. 6, December 2005*.
- Allen, E. M., Munala, L., Frederick, A. J., Quito, C., Enayat, A., & Ngunjiri, A. S. (2025). Climate Change and Health: Impacts Across Social Determinants in Kenyan Agrarian Communities. *MDPI, Climate, Volume 13, Issue 8*.
- Allen, V. G., Baker, M. T., Segarra, E., & Brown, C. P. (2007). Integrated Irrigated Crop–Livestock Systems in Dry Climates. *Agronomy Journal of Texas Tech University, Volume 99, Issue 2*, 346-360.
- Al-mahdy, S. (2006). The Inheritance of Women in Upper Egypt between Realities and Aspiration: Socio-anthropological study in Sohag and Qena governorates. *Scientific Journal of the College of Arts, Issue 20*, 284-335.
- Ananda, G. A., Moseti, B., & Mugehera, L. (2020). *Women's Land Rights Scorecard: The Failure of Land Policy and Legal Reforms in Securing Women's Land Rights in Africa*. Nairobi: Oxfam.

-
- Andris, C., & O'Sullivan, D. (2021). Spatial Network Analysis. *Handbook of Regional Science*, 1727–1750.
- Anugya, S., & Kamal, J. (2020). Automatic extraction of urban land information from unmanned aerial vehicle (UAV) data. *Earth Science Informatics, Volume 13*, 1225–1236.
- Any, B., Adrian, M., Maxime, A., & Sami, B. (2015). Describing Spatial Relationships between Objects in Images in English and French. *Association for Computational Linguistics*, 104-113.
- Arunima, N., & Brij, B. (2022). Wetland Ecosystems and Their Relevance to the Environment: Importance of Wetlands. *Handbook of Research on Monitoring and Evaluating the Ecological Health of Wetlands*, 16 pp.
- Asfoor, A. D., C., T., M., A.-Z., A., M., S., S., & S., R. (2024). Concept analysis of health system resilience. *Health Resilience Systems, Volume 22, Issue 1*.
- Avelino, F., & Rotmans, J. (2009). Power in Transition: An Interdisciplinary Framework to Study Power in Relation to Structural Change. . *European Journal of Social Theory*, 12(4), 543–569.
- Ayalew, H., Admasu, Y., & Chamberlin, J. (2021). Is land certification pro-poor? Evidence from Ethiopia. *Land Use Policy Journal*, 105483.
- Barnett, J. (2001). Adapting to climate change in Pacific Island countries: The problem of uncertainty. *World Development, Volume 29, Issue 6* , 977–993.
- Belaunde, S., Cortes, M., Hogstad, J., Ku, E., Nascimento, K., & Trzcinski, L. (2010). *Land, legitimacy and governance in Cameroon*. New York: Institute for Research and Debate on Governance & Columbia University School of International and Public Affairs.
- Benjeddi, M. (2017). Les terres collectives à l'épreuve des mouvements sociaux au Maroc. *Montpellier [France] : CIHEAM-IAMM*, 89 pp.
- Bera, R., & Claramunt, C. (2003). Topology-based proximities in spatial systems. *Journal of Geographical Systems, Vol. 5, Issue 4*, 353-379.
- Berge, E., Kambewa, D., Munthali, A., & Wiig, H. (2014). Lineage and land reforms in Malawi: Do matrilineal and patrilineal landholding systems represent a problem for land reforms in Malawi ? *Land Use Policy Journal, volume 41*, 61–69.
- Birkmann, J., Cardona, O. D., Carreño, M. L., Barbat, A. H., Pelling, M., Schneiderbauer, S., . . . Welle, T. (2013). Framing vulnerability, risk and societal responses: the MOVE framework. *Natural Hazards: Journal of the International Society for the Prevention and Mitigation of Natural Hazards*, 67(2), 193–211.

-
- Bohle, H. G., Downing, T. E., & Watts, M. J. (1994). Climate change and social vulnerability: Toward a sociology and geography of food insecurity. *Global Environmental Change*, 4(1), 37–48.
- Bonye, S. Z., & Kpieta, R. A. (2012). Women, Ownership and Access to Land in the Upper East Region of Ghana. *Bonye, S. Z., & Kpieta, R. A. (2012). Women , Ownership and Access to Land International Journal of Humanities and Social Sciences*, 2(9).
- Boval, M., & Dixon, R. M. (2012). The importance of grasslands for animal production and other functions: a review on management and methodological progress in the tropics. *Cambridge University Press, Animal , Volume 6 , Special Issue 5*, 748-762.
- Burch, S., & Robinson, J. (2007). A framework for explaining the links between capacity and action in response to global climate change. *Climate Policy*, 7(4), 304–316.
- Burton, I. (1997). Vulnerability and adaptive response in the context of climate and climate change. *Climatic Change*, Volume 36, Issues 1-2 , 185-196.
- Calo, A. (2020). Who Has the Power to Adapt? Frameworks for Resilient Agriculture Must Contend With the Power Dynamics of Land Tenure. *Frontiers in Sustainable Food Systems*, 4, Article 555270.
- CAMPOS, A. P., WARRING, N., BRUNELLI, C., DOSS, C., & KIERAN, C. (2015). Gender and Land Statistics Recent developments in FAO's Gender and Land Rights Database. *FAO Gender and Land Rights Database*, 35 pp.
- Campos, D. G. (2011). On the Distinction between Peirce's Abduction and Lipton's Inference to the Best Explanation. *Synthese*, 180(3), 419–442.
- Capoani, L., Fantinelli, M., & Giordano, L. (2025). The concept of resilience in economics: a comprehensive analysis and systematic review of economic literature. *Continuity & Resilience Review*, Vomume 7, Issue 2 , 121–145.
- Carlier, I., Rotar, i., Vlahova, m., & Vidican, R. (2009). Importance and Functions of Grasslands. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, volume 37, issue 1, 25-30.
- Carniel, A. C. (2024). Defining and designing spatial queries: the role of spatial relationships. *Journal of Geo-spatial Information Science*, Volume 27, issue 6, 1868-1892.
- Carr, E. R., & Thompson, M. C. (2014). Gender and climate change adaptation in agrarian settings: Current thinking, new directions, and research frontiers. *Geography Compass*, 8(3), 182–197.
- Castells, M. (1996). *The Rise of the Network Society*. Springer Nature Link.
- Chang, X., Anthony, G.-O. Y., & Anqi, Z. (2020). Analyzing spatial relationships between urban land use intensity and urban vitality at street block level: A case study of five Chinese megacities. *Landscape and Urban Planning*, Volume 193, January 2020, 103669.

-
- Chapagain, P. S., Banskota, T. R., Shrestha, S., Khanal, N. R., Yili, Z., Jianzhong, Y., . . . Poudel, K. R. (2025). Studies on adaptive capacity to climate change: a synthesis of changing concepts, dimensions, and indicators. *Humanities and Social Sciences Communications, Volume 12*, 331.
- Charu, M., Jakub, K., & Angela, S. (2024). An algorithmic approach to detect generalization in sketch maps from sketch map alignment. *PLoS One. 2024 Jun 26;19(6)*.
- Chavas, J.-P. (2024). Economic resilience: Measurement and assessment across time and space. *Research in Economics, Volume 78, Issue 2*.
- Cherry, K. (2006). Psychology research with correlational studies. *Verywell Mind*.
- Cheung, W., Houston, D., Schubert, J. E., Basolo, V., Feldman, D., Matthew, R., . . . Luke, A. (2016). Integrating resident digital sketch maps with expert knowledge to assess spatial knowledge of flood risk: A case study of participatory mapping in Newport Beach. *California. Applied Geography, 76*, , 56–64.
- Choko, O. P., Olabisi, L. S., Onyeneke, R. U., Chiemela, S. N., Liverpool-Tasie, L. S., & Rivers, I. L. (2019). A Resilience Approach to Community-Scale Climate Adaptation. *Sustainability, Volume 11, Issue 11*.
- Christaller, W. (1966). Central places in Southern Germany (C. W. Baskin, Trans.). *Englewood Cliffs, NJ: Prentice-Hall*.
- Claudia, J. C., Jill, E. K., Tsui, C., & Marilyn, S. (2001). Mapping Residents' Perceptions of Neighborhood Boundaries: A Methodological Note. *American Journal of Community Psychology, 29(2):371-383*.
- Claudia, L., Auriol, D., Gergely, V., Kaspar, K., & Angela, S. (2023). The SmartLandMaps Approach for Participatory Land Rights Mapping. *Land, MDPI, vol. 12(11)*, 1-21.
- Curtis, J. W., Shiau, E., Lowery, B., Sloane, D., Hennigan, K., & Curtis, A. (2014). The Prospects and Problems of Integrating Sketch Maps with Geographic Information Systems to Understand Environmental Perception: A Case Study of Mapping Youth Fear in Los Angeles Gang Neighborhoods. *Environment and Planning B: Planning and Design, 41(2)*, , 251-271.
- Damayanti, R., & Kossak, F. (2016). Examining spatial identity of kampungs through young adults' perception in Surabaya – Indonesia. *Journal of Architecture and Urbanism, 40(1)*, 18–28.
- Daniel, R., Zachary, D., Donna, G., & Sandra, L. (2024). Tree contributions to climate change adaptation through reduced cattle heat stress and benefits to milk and beef production. *Global Change Biology, Volume 30, Issue 5*.

-
- Daniel, V., Rolf, W., & Bruno, M. (2003). Assessing the Hydrological Significance of the World's Mountains. *Mountain Research and Development Journal*, Vol. 23, issue 1, 32-40.
- Daoudi, F. (2011). Droits fonciers des femmes au Maroc Entre complexité du système foncier et discrimination. *es Etudes et Essais du Centre Jacques Berque N° 4*, 36 pp.
- David, Ř., Tomáš, K., Josef, K., Jan, V., & Martin, P. (2017). Effect of Windbreaks on Wind Speed Reduction and Soil Protection against Wind Erosion. *Journal of Soil & Water Resilience*, 12, 2017 (2), 128–135.
- Diallo, A. (2021). The administration judge and the protection of land rights of citizens in Senegal. *African Journal on Land Policy and Geospatial Sciences*, Vol. 4 No. 2, 17 pp.
- Dorrough, J., Yen, A., Turner, V., Clark, S. G., Crosthwaite, J., & Hirth, J. R. (2004). Livestock grazing management and biodiversity conservation in Australian temperate grassy landscapes. *Australian Journal of Agricultural Research* 55(3), 279-295.
- Eakin, H. C., Lemos, M. C., & Nelson, D. R. (2015). Differentiating capacities as a means to sustainable climate change adaptation. *Global Environmental Change*, 27, 1–8.
- Eakin, H., & Luers, A. L. (2006). Assessing the vulnerability of social-environmental systems. *Annual Review of Environment and Resources*, 365-39.
- Eakin, H., & Luers, A. L. (2006). Assessing the vulnerability of social-environmental systems. *Annual Review of Environment and Resources*, 31, 365–394.
- Egenhofer, M. J., & Franzosa, R. D. (2007). Point-set topological spatial relations. *International Journal of Geographical Information*, 161-174.
- Egenhofer, M. J., Mark, D. M., & Herring, J. (1994). *The 9-Intersection: Formalism and Its Use for Natural-Language Spatial Predicates*. UC Santa Barbara: National Center for Geographic Information and Analysis.
- Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, 14(4), 532–550.
- Engle, N. L. (2011). Adaptive capacity and its assessment. *Global Environmental Change*, Volume 21, Issue 2, 647-656.
- Engle, N. L. (2011). Adaptive capacity and its assessment. *Global Environmental Change*, 21(2), 647–656.
- EPA, U. S. (2024). *What are the trends in land use and their effects on human health and the environment?* Washington, DC: epa.gov.
- Eraydin, A., & Taşan-Kok, T. (2013). *Resilience Thinking in Urban Planning*. Springer Dordrecht.
- Eraydin, A., & Taşan-Kok, T. (2013). Resilience Thinking in Urban Planning. *GeoJournal Library*, Vol. 106. Dordrecht, Netherlands: Springer.

-
- Essombo Essombo, B., Seutche, J., Goune, A., Ekani, R., & Ben-Bolie, G. (2023). Assessment of the activity of the Mbalmayo Thermal Power Plant on groundwater quality. *SN Applied Sciences*.
- Evans, J. D. (2018). A Reciprocal Triangulation Process For Identifying And Mapping Potential Land Use Conflict. *Environmental Management Journal, Volume 62*, pp. 777–791.
- Fang, M., Tang, C., Chen, Y., Li, J., Chen, Z., Wang, F., & Zhu, W. (2022). hermo-compression bonding process characteristics and shape control of Cu-pillar microbump joints by optimizing of solder melting. *Journal of Materials Science: Materials in Electronics*, 33(13), 10471–10485.
- FAO. (2012). *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security*. Rome: Food and Agriculture Organization of the United Nations.
- FAO Gender and Land Rights Database. (2016, June). *Gender and Land Rights Database*. Récupéré sur FAO Policy Support and Governance Gateway: <http://www.fao.org/gender-landrights-database/en/>
- Fazey, I., J.A., F., J., F., K., S., J., W., R.F., N., & S.R., D. (2007). Adaptive capacity and learning to learn as leverage for social-ecological resilience. *Frontiers in Ecology and the Environment, Volume 5, Issue 7*, 375-380.
- Flavia, S. C., Jean-Marie, B., Marloes, B., & Teun, T. (2019). Adaptive Capacities for Diversified Flood Risk Management Strategies: Learning from Pilot Projects. *MDPI, Water, Volume 11, Issue 12*.
- Folke, ., Carpenter, ., Elmqvist, ., Gunderson, ., Holling, ., & Walker, . (2002). Resilience and sustainable development: Building adaptive capacity in a world of transformations. *Ambio, Volume 31, Issue 5* , 437-440.
- Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology and Society*, 15(4), Article 20.
- Fonjong, L., Sama-Lang, I., & Fon, F. L. (2010). An assessment of the evolution of land tenure system in Cameroon and its effects on women’s land rights and food security. *Perspectives on Global Development and Technology (PGDT)*, 9(1), 154-469.
- Frank, E., Eakin, H., & López-Carr, D. (2011). Social identity, perception and motivation in adaptation to climate risk in the coffee sector of Chiapas. *Mexico. Global Environmental Change*, 21(1), 66–76.
- Fraser, E. D., Mabee, W., & Slaymaker, O. (2003). Mutual dependence, mutual vulnerability: The reflexive relation between society and the environment. *Global Environmental Change*, 13, 137–144.

-
- Gaesing, K., & Bliss, F. (2021, May 12). *LAND RIGHTS, GENDER AND SOIL FERTILITY IN BENIN*. Récupéré sur Food Transformation: <https://www.foodfortransformation.org/full-article/land-rights-gender-and-soil-fertility-in-benin.html>
- Gagné, M., & Keïta-Diop, M. (2022, October 24). *Land Governance Context in Guinea*. Récupéré sur Land Portal: <https://landportal.org/book/narratives/2022/guinea>
- Gale, P., Drew, T., Phipps, L. P., David, G., & Wooldridge, M. (2009). The effect of climate change on the occurrence and prevalence of livestock diseases in Great Britain: a review. *J Appl Microbiol, Volume 106, Issue 5*.
- Gallopín, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change, Volume 16, Issue 3*, 293-303.
- Gallopín, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change, 16(3)*, 293–303.
- Galton, A. (2009). Spatial and temporal knowledge representation. *Journal of Earth Science Informatics, Volume 2 Number 3*, 169-187.
- Gillard, R., Gouldson, A., Paavola, J., & Van Alstine, J. (2016). Transformational responses to climate change: Beyond a systems perspective of social change in mitigation and adaptation. *Wiley Interdisciplinary Reviews: Climate Change, 7(2)*, 251–265.
- Goldman, M., & Riosmena, F. (2013). Adaptive capacity in Tanzanian Maasailand: Changing strategies to cope with drought in fragmented landscapes. *Global Environmental Change, 23(3)*, 588–597.
- Goodchild, M. F., Luc, A., Richard, P. A., & & Barbara, H. H. (2000). Toward Spatially Integrated Social Science. *International Regional Science Review, Vol. 23(2)*, 139-159.
- Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly, 37(2)*, 337–355.
- Gregor, S., & Hevner, A. R. (2013). Positioning and Presenting Design Science Research for Maximum Impact. *Management Information Systems Research Center, University of Minnesota*, pp. 337-355.
- Grothmann, T., & Patt, A. (2005). Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Global Environmental Change-Human and Policy Dimensions, 15(3)*, 199–213.
- Gumel, D. Y. (2022). Assessing climate change vulnerability: a conceptual and theoretical review. *Journal of Sustainable Environmental Management, 1*, 22–31.
- Gustafson, C. R., VanWormer, E., Kazwala, R., Makweta, A., Goodluck, P., Smith, W., & Mazet, J. A. (2015). Educating pastoralists and extension officers on diverse livestock diseases in a changing environment in Tanzania. *Pastoralism, Volume 5, Issue 1*.

-
- Hamlin, M. (2022). Participatory Sketch Mapping for Policy: A Case Study of Reentry Housing from Chicago. *The Professional Geographer, Volume 74, Issue 1*.
- Hannan, M. T., & Freeman, J. (1977). The Population Ecology of Organizations. *American Journal of Sociology, 82(5)*, 929–964.
- Hasanbasri, A., Kilic, T., Koolwal, G., & Moylan, H. (2022). *Multidimensionality of Land Ownership among Men and Women in Sub-Saharan Africa*. Washington, DC: World Bank Group.
- Hennings, A. (2021, May 20). *Land Governance Context in Cameroon*. Récupéré sur Land Portal: <https://landportal.org/book/countries/2021/cameroon>
- Hodbod, J., & Eakin, H. (2015). Adapting a social-ecological resilience framework for food systems. *Journal of Environmental Studies and Sciences, 5(3)*, 474–484.
- Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics, 4*, 1–23.
- Israel, O. T., Sunday, O. O., & Matthew, O. I. (2023). *Comparative Analysis of GNSS-derived Ground Control points on UAV Orthomosaic Accuracies; A Case Study of The Federal Polytechnic Ado-Ekiti, Nigeria*. Akure: Remote Sensing and Geoscience information System Department, Federal University of Technology, Akure, Ondo State, Nigeria.
- Jacox, E., & Samet, H. (2007). Spatial Join Techniques. *ACM Transactions on Database Systems, Vol. 32, No. 1*.
- Joan-Cristian, P., Francisco-Javier, M., Jordi, P., & Xavier, P. (2019). Comparison of four UAV georeferencing methods for environmental monitoring purposes focusing on the combined use with airborne and satellite remote sensing platforms. *International Journal of Applied Earth Observation and Geoinformation, volume 75, March 2019*, 130-140.
- Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a Definition of Mixed Methods Research. *Journal of Mixed Methods Research, 1(2)*, 112-133.
- Jose, S., & Dollinger, J. (2019). Silvopasture: A sustainable livestock production system. *Agroforestry Systems, 93(1)*, 1–9.
- Josep G. Canadell and Michael R. Raupach. (2008). Managing Forests for Climate Change Mitigation. *Science, Vol 320, Issue 5882*, 1456-1457.
- Joseph, J. (2013). Resilience as Embedded Neoliberalism: A Governmentality Approach. *Resilience: International Policies, Practices and Discourses, 1(1)*, 38–52.
- Kabeer, N. (2009). *Women's economic empowerment: Key issues and policy options*. Stockholm : Swedish International Development Cooperation Agency. .

-
- Kesmodel, U. S. (2018). Cross-sectional studies: what are they good for? . *Acta Obstetricia et Gynecologica Scandinavica*, 97(4), 388–393.
- Khodary, Y. (2018). What Difference Can It Make? Assessing the impact of gender equality and empowerment in Egypt. *The Journal of the Middle East and Africa*, 9:2, 173-193.
- Konstantin, G., Niesters, L.-M., & Braun, B. (2025). The role of community leadership in building community adaptive capacity to coastal hazards – Insights from neighborhood networks in Semarang, Indonesia. *Environmental Science & Policy, Volume 163*.
- Kumar, S., & Ujire, D. (2024). Inductive and Deductive Approaches to Qualitative Research. *International Journal of Multidisciplinary Educational Research*, 13(1), 58–63.
- Kundzewicz, Z. W., Su, B., Wang, Y., Wang, G., Wang, G., & Huang, J. (2019). Flood risk in a range of spatial perspectives – from global to local scales. *Natural Hazards Earth System Sciences, Volume 19* , 1319–1328.
- Lakshminarasimhappa, M. (2021). Web-Based and Smart Mobile App for Data Collection: Kobo Toolbox / Kobo Collect. *Journal of Indian Library Association (JILA)*, 57(2), 72–79.
- Leach, M., Mearns, R., & Scoones, I. (1999). Environmental Entitlements: Dynamics and Institutions in Community-Based Natural Resource Management. *World Development*, 27(2), 225–247.
- Legal Agenda. (2019, March 1). *In the first application of criminalizing the deprivation of women's inheritance, an Egyptian court sentenced a person to imprisonment for depriving his sister of her inheritance*. Récupéré sur The Legal Agenda: <https://is.gd/89uYRI>
- Lemmen, C. (2010). The Social Tenure Domain Model: A Pro-Poor Land Tool. *FIG Publication No. 52*.
- Liliane, M. D., Romain, N. J., Caroline, M. S., Abigaëlle, T., & Loic, T. T. (2022). Quantifying Forest Loss in the Mbalmayo Forest Reserve (Center Region, Cameroon). *Journal of Geoscience and Environment Protection, Vol.10*, pp. 271-288.
- Liverman, D. (2001). Environmental Risk and Hazards. *International Encyclopedia of the Social & Behavioral Sciences*, 4655-4659.
- Lonsdale, K., Pringle, P., & Turner, B. (2015). Transformative adaptation: what it is, why it matters & what is needed ? *University of Oxford, Oxford, UK*.
- Lund, C., Odgaard, R., & Sjaastad, E. (2006). *Land Rights and Land Conflicts in Africa: A review of issues and experiences*. Denmark: Danish Institute for International Studies.
- Mahdi, M. (2014). Devenir du foncier agricole au Maroc. Un cas d'accaparement des terres. *Revue Méditerranéenne d'Economie Agriculture et Environnement*, 13(4), 2, 2-10.

-
- Margo, v. d., Sander, M., Catrien, T., & Joyeeta, G. (2014). Climate-proof planning for flood-prone areas: assessing the adaptive capacity of planning institutions in the Netherlands. *Reg Environ Change, Volume 14*, 981–995.
- María, P. M., Abel, S., Javier, F., Teodoro, E., & Javier, P.-A. (2015). A review of water scarcity and drought indexes in water resources planning and management. *Journal of Hydrology, Volume 527*, 482-493.
- Mariam Diallo, M. A. (2021). *Land Reforms in Guinea: Challenges and Prospects for the Recognition of Legitimate Rights*. Conakry: International Institute for Environment and Development (IIED).
- Marshall, N. A., Gordon, I. J., & Ash, A. J. (2011). The reluctance of resource-users to adopt seasonal climate forecasts to enhance resilience to climate variability on the rangelands. *Climatic Change 107*, 511–529.
- Marzi, S., Mysiak, J., & Santato, S. (2018). Comparing adaptive capacity index across scales: The case of Italy. *Journal of Environmental Management, 223*, 1023–1036.
- Masters, D. G., Dominique, B. A., Lockwood, A. L., Shane, C. ., D, M., Norman, H. C., . . . Hancock, C. (2023). Shelter and shade for grazing sheep: implications for animal welfare and production and for landscape health. *Animal Production Science, Volume 63, issue 7*, 623-644.
- McAuliffe, W. H. (2015). How Did Abduction Get Confused with Inference to the Best Explanation? *Transactions of the Charles S. Peirce Society, 51(3)*, 300–319.
- McDaniels, T., Axelrod, L. J., & Slovic, P. (1996). Perceived ecological risks of global change: A psychometric comparison of causes and consequences. *Global Environmental Change, 6(2)*, 159–171.
- Mediebou, C., & Gaspard, A. K. (2022). Decentralization and Contractualized Management of Water Works: Lessons from Mbalmayo, Centre Region — Cameroon. *International Journal of Advanced Research and Review (IJARR), 7(2)*, 20–31.
- Medrouh, B., Abdelli, A., Belkessa, S., Quinten, Y., Brahimi, M., Hakem, A., . . . Pasolli, E. (2024). Seroprevalence and risk factors of bluetongue virus in domestic cattle, sheep, goats and camels in Africa: a systematic review and meta-analysis. *Vet Q. Volume 44, Issue 1*, 1-12.
- Mehvesh, M., Marco, C., & Shirsendu, S. (2024). Climate Adaptation of Roads to Flooding Hazards—A Review. *MDPI, Construction Materials, Volume 4, Issue 4*, 748-776.
- Meinzen-Dick, R., & Mwangi, E. (2008). Cutting the web of interests: Pitfalls of formalizing property rights. *Land Use Policy, 26(1)*, 36–43.

-
- Melesse, M. B., Dabissa, A., & Bulte, E. (2017). Joint Land Certification Programmes and Women's Empowerment: Evidence from Ethiopia. *The Journal of Development Studies*, 1–19.
- Mevoa, A.-M., Tohozin, B., & Mouhamadou, T. (2015). Utilisation du SIG pour une réorganisation urbaine du centre-ville de Mbalmayo au Cameroun. *Afrique SCIENCE*, 11, 73–81.
- Mondschein, A., Blumenberg, E., & Taylor, B. D. (2010). Accessibility and Cognition: The Effect of Transport Mode on Spatial Knowledge. *Urban Studies*, 47(4), 845-866.
- Monfreda, C., Ramankutty, N., & Foley, J. A. (2008). arming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles*, Volume22, Issue1.
- Monteh, R. N. (2021). Local Government and The Politics of Decentralization in Cameroon: The Case of Elak-Oku Municipality, 2007–2017. *International Journal of Research and Innovation in Social Science*, 5(2), 320–333.
- Morelli, A. B., & Cunha, A. L. (2020). Measuring urban road network resilience to extreme events: an application for urban floods. *Physics and Society*.
- Mosley, L. M. (2015). Drought impacts on the water quality of freshwater systems; review and integration. *Earth-Science Reviews*, Volume 140, 203-214.
- Mudashiru, R. B., Sabtu, N., Ismail, A., & Waheed, B. (2021). Flood hazard mapping methods: A review. *Journal of Hydrology*, Volume 603, Part A, December 2021, 126846.
- Munyaka, B. J.-C., Chenal, J., Mabaso, S., Tfwala, S. S., & Mandal, K. A. (2024). Geospatial Tools and Remote Sensing Strategies for Timely Humanitarian Response: A Case Study on Drought Monitoring in Eswatini. *MDPI, Sustainability*, Volume 16, Issue 1.
- Mwendera, E. J., M. A. Saleem, M., & Dibabe, A. (1997). The effect of livestock grazing on surface runoff and soil erosion from sloping pasture lands in the Ethiopian highlands. *Australian Journal of Experimental Agriculture* 37(4) , 421-430.
- Nigel, W. (2017). Tobler's First Law of Geography. *Wiley Online Library*.
- Nyantakyi-Frimpong, H., & Kerr, R. B. (2017). Land grabbing, social differentiation, intensified migration and food security in northern Ghana. *The Journal of Peasant Studies*, DOI: 10.1080/03066150.2016.1228629.
- O'Brien, K. (2012). Global environmental change II: From adaptation to deliberate transformation. *Progress in Human Geography*, 36(5), 667–676.
- OECD. (2021). *OECD Agriculture Statistics*. Paris: OECD publishing.
- Olivia, J., & Corinne, O. (2020). Collaborative Action for Community Resilience to Climate Risks: Opportunities and Barriers. *Sustainability*, Volume 12, Issue 8.

-
- Olson, G. M., & Olson, J. S. (2000). Distance Matters. *HUMAN-COMPUTER INTERACTION*, 2000, Volume 15, A Journal of Theoretical, Empirical, and Methodological Issues of User Science and of Sytem Design, 139–178.
- Orchardson, E. (2015, October 2). *Women and Land Rights in Burkina Faso*. Récupéré sur The Communication Initiative: <https://www.comminit.com/la/content/women-and-land-rights-burkina-faso>
- Owona, S., Mvondo, O. J., Lothar, M., Ndzana, S. P., Tchoua, F. M., & Ekodeck, G. E. (2011). The geometry of the Archean, Paleo- and Neoproterozoic tectonics in the Southwest Cameroon. *Géoscience*, 343(4), 312–322.
- Paavola, J., & Adger, W. N. (2006). Fair adaptation to climate change. *Ecological Economics*, 56(4), 594–609.
- Palmer, . A., & Filoso, . (2009). Restoration of ecosystem services for environmental markets. *Science*, Volume 325(5940), 575–576.
- Palmer, M. A., & Filoso, S. (2009). Restoration of ecosystem services for environmental markets. *Science*, 325(5940), 575–598.
- Parry, M., Canziani, O. F., Palutikof, J., van der Linden, P., & Hanson, C. (2007). *imate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.
- Petersen-Rockney, M., Baur, P., Guzman, A., Bender, S. F., Calo, A., Castillo, F., . . . Bowles, T. (2021). Narrow and brittle or broad and nimble? Comparing adaptive capacity in simplifying and diversifying farming systems. *Frontiers in Sustainable Food Systems*, 5, Article 564900.
- Piya, A. K., Raihan, M. M., & Khan, R. A. (2019). Characterization of Natural Fibres and Their Polymer-based Composites. *Journal of Research Updates in Polymer Science*, 8, 35–51.
- R., P. B., Paul, S., Jessica, J., Matthew, P., & Paola, P. (2021). Unpacking Adaptive Capacity to Flooding in Urban Environments: Social Capital, Social Vulnerability, and Risk Perception. *Front. Water*, Volume 3.
- Reid, K. J. (2025). A Multiscale Evaluation of the Wet 2022 in Eastern Australia. *Journal of Climate*, Volume 38, Issue 4, 909-929.
- Renzhong, G. (1998). Spatial Objects and Spatial Relationships. *Geo-spatial Information Science*, Vol. 1, No. 1, 38-42.
- Rhoades, R. E., & Thompson, S. I. (1975). Adaptive strategies in Alpine environments: Beyond ecological particularism. *American Ethnologist*, 2(3), 535–551.
- Ribot, J. C., & Peluso, N. L. (2003). A theory of access. *Rural Sociology*, 68(2), 153–181.

-
- Ringo, J. (2023). Roles of village land councils in mitigation of land conflicts in Ngorongoro district, Tanzania. *Heliyon - Cell Press, Volume 9, Issue 4, E15132, APRIL 2023*, 8 pp.
- Rowley, J. (2014). Designing and using research questionnaires. *Management Research Review, 37*(3), 308–330.
- Ryan, C. (2018). Large-scale land deals in Sierra Leone at the intersection of gender and lineage. *Third World Quarterly, 39*(1), 189-206.
- Santosh, K. C., Bart, L., & Laurent, W. (2012). Symbol Recognition using Spatial Relations. *Pattern Recognition Letters, Volume 33, Issue 3*.
- Scharte, B. (2025). The need for general adaptive capacity—Discussing resilience with complex adaptive systems theory. *International Journal of Risk Analysis, Volume 45, Issue 6*, 1443-1452.
- Schneider, M., & Behr, T. (2006). Topological relationships between complex spatial objects. *ACM Transactions on Database Systems, Vol. 31, No. 1*, 39-81.
- Schneider, M., & Behr, T. (2006). Topological relationships between complex spatial objects. *ACM Transactions on Database Systems*, 39-81.
- Schramski, S., & Barnes, G. (2016). Agrarian Change and Adaptive Capacity in Rural South Africa. *Review of Agrarian Studies, 6*(2), 1–41.
- Selva Das, A. (2024). “KoboToolbox.” In Open Electronic Data Capture Tools for Medical and Biomedical Research and Medical Allied Professional. *Academic Press*, 241–329.
- Sen Amartya, K. (1981). Poverty and Famines: An Essay on Entitlement and Deprivation. *Oxford University Press*.
- Shuang, L., Nengzhi, T., & Rui, L. (2023). A Weighted k-Nearest-Neighbors-Based Spatial Framework of Flood Inundation Risk for Coastal Tourism—A Case Study in Zhejiang, China. *ISPRS International Journal of Geo-Information, Volume 12, issue 11*.
- Smit, ., & Wandel, . (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change, Volume 16, Issue 3*, 282-292.
- Smith, D. A., Ibanez, A., & Herrera, F. (2017). The Importance of Context: Assessing the Benefits and Limitations of Participatory Mapping for Empowering Indigenous Communities in the Comarca Ngäbe-Buglé, Panama. *The International Journal for Geographic Information and Geovisualization, Volume 52 Issue 1, Spring 2017*, pp. 49-62.
- Soale, J. M., & Akolgo-Azupogo, H. (2022). CHANGES IN WOMEN ACCESS TO AND OWNERSHIP OF LAND IN NORTHERN GHANA. *Journal of Environment and Sustainable Development Vol. 1 No. 2*, 10 pp.

-
- Socpa, A. (2011). New Kinds of Land Conflict in Urban Cameroon: the Case of the 'landless' Indigenous Peoples in Yaoundé. *Cambridge University Press, Africa , Volume 80 , Issue 4*, pp. 553-572.
- Southern Africa Litigation Center. (2024, April 11). *Land Rights*. Récupéré sur Southern Africa Litigation Cases: <https://www.southernafricalitigationcentre.org/socio-economic-rights/land-rights/>
- Southern African Development Community. (1992). *Protocol on Gender and Development [A treaty on gender equality and women empowerment]*. Windhoek: Southern African Development Community (SADC).
- Southern African Development Community. (1997). *Declaration on Gender Development*. Blantyre: Southern African Development Community (SADC).
- Stadel, C. (2008). Agrarian diversity, resilience and adaptation of Andean agriculture and rural communities. *Colloquium Geographicum*, 31, 73–88.
- Steiniger, S., & Weibel, R. (2007). Relations among Map Objects in Cartographic Generalisation 34(3). *Cartography and Geographic Information Science*, 175-197.
- Sulle, E., Mbaya, S., & Codispoti, B. e. (2019). Women's land rights in Africa: Does implementation match policy? *Conference on Land Policy in Africa* (p. 8 pp.). Abidjan: African Land Policy Centre (ALPC).
- Taesam, L., & Vijay, P. S. (2019). Discrete k-nearest neighbor resampling for simulating multisite precipitation occurrence and model adaption to climate change. *GMD Articles, Volume 12, Issue 3*, 1189–1207.
- Teague, R., & Barnes, M. (2017). Grazing management that regenerates ecosystem function and grazingland livelihoods. *African Journal of Range & Forage Science Volume 34, Issue 2*, 77-86.
- Tejendra, C., & Manish, N. R. (2017). Agronomic Challenges and Opportunities for Smallholder Terrace Agriculture in Developing Countries. *Front. Plant Sci., Sec. Agroecology, Volume 8 – 2017, Department of Plant Agriculture, University of Guelph, Guelph, ON, Canada*.
- Tezira, L. (2015). *Livestock scientists say climate change can increase risk of animal pests and diseases*. International Livestock Research Institute.
- THAMBIKENI, M. (2015). Analysis of ICT application in mitigating land conflicts: case study oftanzania. *nternational Journal of Computer Science and Information Security (IJCSIS), Vol. 13, No. 11*, 6 pp.
- Theobald, D. M. (2010). Topology revisited: representing spatial relations. *International Journal of Geographical Information Science*, 689-705.

-
- Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. *American Journal of Evaluation*, 27(2), 237-246.
- Thomas, R. B., Winterhalder, B., & McRae, S. D. (1979). An anthropological approach to human ecology and adaptive dynamics. *Yearbook of Physical Anthropology*, 22, 1-46.
- Thompson-Hall, M., Carr, E., & Pascual, U. (2016). Enhancing and expanding intersectional research for climate change adaptation in agrarian settings. *Ambio*, 45(Supplement 3), 373-S382.
- Tiwari, P. C. (2024). Development of Climate Resilient Integrated Farming System in Himalaya: An Illustration of Women Centric Adaptive Headwater Management Approach. *Quest A Journal of the Social Sciences*, Volume 18, Issue 1, 1-24.
- Trauger, A. (2014). Toward a political geography of food sovereignty: transforming territory, exchange and power in the liberal sovereign state. *Journal of Peasant Studies*, 41(6), 1139-1158.
- Trimble, C. G. (2021). *GIS/GNSS Data Collection with Trimble DA2 and Subscription-Based Catalyst*. Colorado: Trimble Geospatial.
- Turner, B. L., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., Eckley, N., & al., e. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, 100(14), 8074-8079.
- Ulyshen, M., Urban-Mead, K. R., Dorey, J. B., & Rivers, J. W. (2023). Forests are critically important to global pollinator diversity and enhance pollination in adjacent crops. *Biological Reviews*, Volume 98, Issue 4, 1118-1141.
- UN-Habitat. (2023, June 23). *Land, Women Empowerment And Socioeconomic Development In The Arab Region: Evidence-based Perspectives*, UN-Habita. United Nations Human Settlements Programme (UN-Habitat). Récupéré sur https://unhabitat.org/sites/default/files/2023/03/230308_gltn_3_land_women_empowerment_final_web.pdf
- Viviroli, D., & Weingartner, R. (2004). The hydrological significance of mountains: from regional to global scale. *Hydrology and Earth System Sciences*, Volume 8, issue 6, , 14 pp.
- Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, 9(2).
- Wardell, D. A., & Lund, C. (2006). Governing Access to Forests in Northern Ghana: Micro-Politics and the Rents of Non-Enforcement. *ELSEVIER World Development Journal*, Volume 34, Issue 11, pp. 1887-1906.

-
- Werner, M., Lave, R., Christophers, B., & Peck, J. (2018). Introduction: Spatializing Power: Doreen Massey on Space as Domination and Potential. *Agenda Publishing*, 205 - 210.
- Winowiecki, L. A., Läderach, P., Mwongera, C., Twyman, J., Mashisia, K., Okolo, W., . . . R. B. (2014). Increasing Food Security and Farming System Resilience in East Africa through Wide-Scale Adoption of Climate-Smart Agricultural Practices. *Harvard Dataverse*.
- Witter, S., Thomas, S., Topp, S. M., Barasa, E., Chopra, M., & Cobos, D. (2023). Health system resilience: a critical review and reconceptualisation. *Viewpoint, Volume 11, Issue 9*, 1454-1458.
- WMO, W. M. (2024). *State of the Global Climate 2023*. Geneva, Switzerland: World Meteorological Organization, WMO-No. 1347.
- Wohl, C., Villamayor, J., Galí, M., Mahajan, A., Fernández, R., Cuevas, C., . . . Saiz Lopez, A. (2024). Marine emissions of methanethiol increase aerosol cooling in the Southern Ocean. *Science Advances, Volume 10, Issue 48* , 1-9.
- World Bank Group. (2022, May 4). *World Bank Gender Data Portal on Land Ownership*. Récupéré sur World Bank Group: <https://genderdata.worldbank.org/en/indicator/sg-own-ld?ownership=Do%20not%20own>
- Yukfu, S. B. (2022, June 6). *UN Conference Identifies Land Ownership as a Major Problem for Women in Cameroon*. Récupéré sur Earth Journalism Network: <https://earthjournalism.net/stories/un-conference-identifies-land-ownership-as-a-major-problem-for-women-in-cameroon>
- Zdeněk, V., David, Ř., Jan, C., Stanislav, V., Tomáš, K., Ram, P. S., . . . Vladimír, P. (2018). Windbreak Efficiency in Agricultural Landscape of the Central Europe: Multiple Approaches to Wind Erosion Control. *Journal of Environmental Management, Volume 62*, 942–954.
- Ziglio, E., Azzopardi-Muscat, N., & Briguglio, L. (2017). Resilience and 21st century public health. *European Journal of Public Health, Volume 27, Issue 5*, 789–790.