CLIMATE-RESILIENT MULTIFUNCTIONAL LANDSCAPES IN THE KARA RIVER BASIN (TOGO, WEST AFRICA): STEPS TOWARDS PARTICIPATORY DECISION-MAKING

BY

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Dedication

I offer this thesis to God, my parents, my wife, and my lineage.

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3D	Three-dimensional space
ABM	Agent-based modelling
ANAMET	Agence Nationale de la Météorologie Togo
AR	Assessment Report
BMBF	Bundesministerium fur Bildung und Forschung (German Federal Ministry of Education and Research)
C3S	Copernicus Climate Change Service
CCAI	Climate Change Awareness Index
CCLULCCAI	Climate Change and Land Use and Land Cover Change Awareness Index
CDD	Consecutive Dry Days
CDO	Climate Data Operator
CDS	Climate Data Store
CMIP6	Coupled Model Intercomparison Project Phase 6
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWD	Consecutive Wet Days
DEM	Digital Elevation Model
DGMN	Direction Générale de la Météorologie Nationale
DGSCN	Direction Générale de la Statistique et de la Comptabilité Nationale
DPSIR	Drivers, Pressures, State, Impacts, Responses
DSID	Direction des Statistiques Agricoles de l'Information et de la Documentation
DTR	Diurnal Temperature Range
ECMWF	European Centre for Medium-Range Weather Forecasts
EDA	Exploratory Data Analysis
EEA	European Environment Agency
ES	Ecosystem Services
ETCCDI	Expert Team of Climate Change Detection and Indices

FAO	United Nations Organisation for Food and Agriculture
FCREE-Kara Basin	Farmers' Choices and its Risk on Economic and Ecological conditions of the Kara River Basin
FGDs	Focus Group Discussions
FOREO-Ups	Farmer choices and its Risk on Economic and Ecological context for Upper watersheds
GCM	Global Circulation Model
GEF	Global Environment Facility
GFDL	Geophysical Fluid Dynamics Laboratory
GIS	Geographic Information System
GRASP	Goals, Responses, Actions, System, Powers
IBM	International Business Machines Corporation
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IHACRES	Identification of unit Hydrographs and Component flows from Rainfall, Evaporation and Streamflow data
ILSWMP	Integrated Local Soil and Water Management Practices
ILWRM	Integrated Land and Water Resources Management
INSEED	Institut National de la Statistique et des Etudes Economiques et Démographiques
IPBES	Intergovernmental Platform on Biodiversity and Ecosystems Services
IPCC	Intergovernmental Panel on Climate Change
KNMI	Royal Netherlands Meteorological Institute
KRB	Kara River Basin
LULC	Land Use and Land Cover
LULCC	Land Use and Land Cover Change
LULCCAI	Land Use and Land Cover Change Awareness Index

MAEP	Ministère de l'Agriculture, de l'Elevage, et de la Pêche
MEA	Millennium Ecosystem Assessment
MME	Multi-model Ensemble Mean
MNL	Multinomial Logistic regression model
MRI	Meteorological Research Institute
MS	Microsoft
NDC	Nationally Determined Contribution
NDP	National Development Plan
NGO	Non-Governmental Organization
PA	Protected Area
PRCPTOT	Annual Total wet-day PR
PREC	Precipitation
PTA-Togo	Agrifood Transformation Project Togo (Projet de Transformation Agroalimentaire Togo)
REED	Reduction of Emissions from Deforestation and Forest Degradation
SDGs	Sustainable Development Goals
SDII	Simple Daily precipitation Intensity Index
SESAM	Scenario Evaluation for Sustainable Agroforestry Management
SPI	Standard Precipitation Index
SPSS	Statistical Package for the Social Sciences
SRTM	Shuttle Radar Topography Mission
SSP	Shared Socioeconomic Pathways
RS	Remote Sensing
TM	Mean Temperature
TN	Minimal Temperature
TX	Maximum Temperature
UA	User Accuracy

UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environmental Programme
UNESCO	United Nations Organization for Education, Science and Culture
USA	United States of America
UTG	University of The Gambia
UTM	Universal Transverse Mercator
WANULCAS	Water, Nutrient and Light Capture in Agroforestry Systems
WASCAL	West African Science Service Centre on Climate Change and Adapted Land Use
WFP	World Food Programme
WGII	Working Group II
WMO	World Meteorological Organisation
WWF	World Wildlife Fund
ZEF	Centre for Development Research

ABSTRACT

The land-water-climate nexus has not gained full attention, especially from the human-ecological perspective and questions on the relevance of land use decision-making by farmers within the multifunctional landscapes of the Kara River Basin (KRB) are unanswered in the context of climate change. To ensure climate-resilient multifunctional landscapes for the continuous provision of key ecosystem services in the basin, steps towards participatory management approach is necessary. The study examined the awareness and perception of farmers on climate, land use and land cover (LULC) changes and traditional livelihood climate-resilient strategies. Next, the study determined the spatial and temporal LULC change and the main driving factors of change in the basin, and; third, modelled farmers' decisions to climate, land use changes and water availability for agriculture in the KRB. The CCLULCAI = 0.57 showed a moderate awareness level. Traditional climate resilient strategies included leaving farm residues on the land, contour farming, keeping trees on farmlands, terrace cultivation, compost, mulching, construction of water ponds, agroforestry, among others. Climate data analysis of the study area indicated rainfall variability and increase in temperature across four locations (Kante, Guerin Kouka, Takpamba, and Niamtougou) with extreme climate events identified over the past 30 years; likely to have had implications on water availability and farming activities of the locals. Projected temperatures and precipitations by the end of the century (2100) using the five Shared Socio-economic Pathways (SSPs) scenarios indicated high increases in both temperatures and rainfalls with important anomalies in their distributions over the years and risks of droughts and floodings. Guerin Kouka, Niamtougou and Kante is projected to experience the highest increase in temperature though Takpamba is more likely to be the hottest location by end of the century. LULC changes analysis from 1987-2021 revealed significant decreases of 75%, 22%, and 25% respectively in water bodies, forest and savannah across the basin whilst increase was recorded in settlements and agricultural lands of about 43% and 24%, respectively. A combined deforestation rate (both forest and savannah) was estimated for about 47% from 1987-2021 with an annual rate of 1.1% (84.7% by 2100). The top three identified main drivers include i) agriculture development, ii) logging, and iii) population growth. FCREE-Kara Basin, a serious game was developed to model farmers' decisions to climate, land use changes and water availability for agriculture resources in the basin using scenarios (climate, influence of actors) and land use system information. The deeply rooted traditional and local ecological knowledge (embedded in culture and food security reasons) and economic returns appeared to be the reasons behind the choices of farmers to adopt a particular land use or crop systems. Economic motivations were highly influenced by actors such as commercial agro enterprises and agricultural institutes/agencies which promote the agropole concept. External pressures like water unavailability due to climate variability or dry spells did not influence very much farmers' land use systems. The study demonstrated the need for an increase of the locals about CC and LULCC issues, the promotion of water saving technologies and reforestation actions with particular attention to agroforestry practices whilst encouraging agro-commercial enterprises to promote afforestation/reforestation and climate-resilient strategies.

Key Words: Climate Change and Land Use and Land Cover Change Awareness Index (CCLULCCAI), Driving factors, Decision-Making, Land Use Systems, FCREE-Kara Basin

CHAPTER ONE

INTRODUCTION

1.1. Background to the Study

Landscapes through their multiple functions play a significant role in the livelihoods and sustenance of people living within or outside such landscapes. They help in the support of biodiversity and deliver vital ecosystem services (ES) to people around the globe (Woolway & Merchant, 2019). Landscapes are crucial to the conservation of ecosystems but also to the global, regional, national and local economies through development of agriculture, industry, human settlements, energy and power generation, livestock production, navigation, recreation, and manufacturing (Mango *et al.,* 2011; UNESCO, 2020). Due to the multiple functions they provide, they are expressly called multifunctional landscapes. O'Farrell and Anderson (2010) describe multifunctional landscapes as 'landscapes created and managed to integrate human production and landscape use into the ecological fabric of landscapes maintaining critical ecosystem function, service flows, and biodiversity retention'. Notwithstanding, there is pressure on multifunctional landscapes, especially due to increased population growth, urbanisation, conversion of forests into farmlands, encroachment of unplanned settlements in river basins and climate change, among others.

At global level, drivers of changes in multifunctional landscapes (e.g., forest fragmentation, deforestation) remain principally human-induced such as agriculture, extensive forest harvest, and other forest disturbances (Lambin *et al.,* 2003; Damnyag *et al.,* 2013; Specht *et al.,* 2015). Logging and clearance of native flora, habitat destruction, and poor management practices on cropland and pastures, especially agricultural intensification, are behind forest degradation with strong implications on food security (Foley *et al.,* 2011; Mirzabaev *et al.,* 2016; Nkonya *et al.,* 2016a). The rapid population growth increases environmental degradation such as soil erosion, water pollution, dwindling water tables, loss of firewood and deforestation, which in turn, has harmful effects on the comfort of poor people living in rural areas (Dao, 2012). Human impacts on terrestrial ecosystems are of a high degree (Ellis, 2011; Gaia, 2011) and of key environmental concerns linked to habitat fragmentation, decline of ES, damage of biodiversity, livelihood reduction and climate instability (Schleuning *et al.,* 2011; Balthazar *et al.,* 2015; ; Kim *et al.,* 2019). For example, population growth, acting as an indirect driver, pressurises landscapes for food and energy as human needs undoubtedly increase. The latest Assessment Report on Land Degradation and Restoration (IPBES, 2018) elicits that majority of forest landscapes in tropical areas experience a decrease in biodiversity owing to human interference. The recent Global Land Outlook Report indicates that up to 40% of the land is degraded, affecting half of humanity and threatening around half of global gross domestic product ($44 trillion) (United Nations Convention to Combat Desertification: UNCCD, 2022).

These land changes also have repercussions on water bodies within river basins. In reality, the effects of land use change are directly connected to changes in the hydrological components of watersheds as described in numerous works associated to hydrologic changes in terrestrial surface (Shrestha & Htut, 2016). Most river basins are subject to increasing risks due to mounting demand for water as demography increases. Land use and land cover change impacts landscape environmental services and has direct negative effects for distant water users, through contamination of downriver water aquifers and reservoirs (Kim *et al.*, 2019).

In addition to pressures over land cover and land use, climate change as a threat multiplier (IPBES, 2018) affects water availability at various temporal and spatial scales in river basins (Lorencová *et al.*, 2013; Xu *et al.*, 2013; Xu *et al.*, 2013). There is growing scientific evidence of climate change impacts on river basins in the world. In fact, the major river basins have experienced strong variability in recent periods leading to a general upsurge of water stress (Oyerinde *et al.*, 2016). Sinha and Cherkauer (2010) affirmed that change in meteorological parameters impacts water quality and quantity ; thus, pressuring water supply system, irrigation, hydropower production, ecosystem services, and livelihoods. Indeed, precipitation and temperature trends have direct impacts on the management of water resources (Nyembo *et al.*, 2020). Climate change affects the global water cycle; thus, contributing to the alteration of hydrological cycle at river basin's level.

Knowing the key role played by river basins in natural and socio-economic processes, key socio-ecological and economic functions such as agriculture, water consumption, energy generation, food security and human health, economic growth and poverty alleviation are likely to be threatened; thus, hindering the attainment of the United Nations development agenda of Sustainable Development Goals (SDGs).

The necessity for sustainable multifunctional landscapes which concurrently offer food security, livelihood prospects, conservation of species and ecological functions, and satisfy cultural, artistic recreational needs is acknowledged (O'Farrell & Anderson, 2010). Recently, multifunctional landscapes have also been associated with increased climate-resilience and mitigation (Schleuning *et al.*, 2011; Harvey *et al.*, 2014) and biodiversity conservation (Scherr & McNeely, 2008). Across the world and

Africa continent, there are cases of how landscape (mis) management reduces multifunctionality, which, has had negative societal, economic, environmental and cultural impacts (IPBES, 2018 ; Duncan *et al.*, 2020). It is evident that land degradation and climate change pose both threats to multifunctional landscapes and endanger food security and well-being of communities living around and/or within; thus, the need for building climate-resilient multifunctional landscapes. Resilience is a valuable concept for apprehending the complexity and interactions of social-ecological systems (Folke *et al.*, 2010; Cote & Nightingale, 2012).

The Millennium Ecosystem Assessment undoubtedly confirmed that most ecosystem services are being degraded and that radical action, including restoring natural capital, is essential to guarantee the long-term constant flow of these services (MEA, 2003). For landscapes to continuously provide the array of services and remain multifunctional amidst issues of land degradation and climate change, it is necessary for a shift of management by considering landscapes as spatial human ecological systems (Termorshuizen & Opdam, 2009).

In the last decade, there have been many calls for research efforts to address human-induced global landscape challenges. Worldwide, landscapes have long-time management stories with peoples that live within and/or interact with them. Such stories are made of multiple interactions, including people's decisions over their use. Within the framework of recovering from centuries of harm to forests, wetlands, and other ecosystems, doing the right things will put the planet back on a sustainable path (van Noordwijk *et al.,* 2020). Landscape multifunctionality has turned out to be noticeable in supporting policy used to manage landscapes (Sayer *et al.,* 2013). Including multifunctional landscapes has a great potential to achieve sustainable and climate-resilient landscapes. Various attempts have been made using novel approaches to manage multifunctional landscapes including transdisciplinary research – approach that crosses traditional subject boundaries. The transdisciplinary perspective of landscape management has helped to move away from looking at purposes of landscape from a unique subject standpoints (Fry, 2001). A deeper understanding of landscape processes requires the understanding of the nature of the interactions between different countryside interests (Fry, 2001) (e.g. users, stakeholders and actors involved in the management of the landscapes). One approach to reconcile different actors' interests is the participatory decision-making which can be explored as a step towards building multifunctional landscapes.

In the context of landscape management, land use decision making can be tackled from various perspectives and using different tools. Participatory methods are now becoming a tool of genuine and sustainable land management since they integrate all stakeholders involved in the use, management and planning of land (Bourgoin, 2012). The participatory management implies an integrated management which makes use of earth-based technologies (Geographic Information System: GIS and Remote Sensing: RS), hydro-ecological modelling-based technics and stakeholders' participation and negotiation. In fact, participatory planning or integrated planning is used among several approaches to address land management issues (Bhan & Arora, 2015).

Other methods and models have been deployed to simulate and understand land use decision making, the interactions between people and their resources, and the management of resources at various scales. For instance, Agent-based modelling (ABM) is employed to simulate the actions and interactions of autonomous entities targeting to evaluating their consequences on the system (Anand *et al.*, 2016). ABM has an active setting where various agents relate with each other and the choice of one agent influences the decision of other agents. ABM helps to evaluate the influence of the individual decisions and actions of farmers/agents on the observed changes in the landscape (Parker *et al.,* 2003; Bousquet & Le Page, 2004; Le *et al.,* 2008; Le *et al.,* 2010) and this can help to model agent decision-making regarding crops, land and water management practices within a watershed (Becu *et al.,* 2003; Bousquet & Le Page, 2004; Castella *et al.,* 2005; Ng, *et al.,* 2011). For example, in Vietnam, Becu *et al. (2005)* combined ABM, role-playing game and GIS for a participatory simulation of land use changes. Land use dynamics also involve the consideration of human behaviour as humans interact with the environment. Simulation models are increasingly used as decision support tools (Barreteau *et al.,* 2001) for natural resources and environment management.

In the Volta basin as most of West African river basins, population growth and the sensitive character of water availability to climate variability and change has led to water stress (Bossa *et al.,* 2014; Mbaye *et al.,* 2015; Oyerinde *et al.,* 2016; Tall *et al.,* 2017; Sylla *et al.,* 2018). The increasing population has contributed to the enlargement of areas under agriculture, including commercial production to support consumption and food production. Considering the increase demand linked to population growth and future climate change impacts as well as the increase of agricultural growth in the region (Picard *et al.,* 2017), a sustainable land and water management is necessary. Thus, the need for the implementation of participatory integrated land and water management approach at basin level to adapt to land use and climate change impacts.

Moreover, recent studies in the world have investigated land use and land cover change in river basins or watersheds (Kim *et al.,* 2008; Slonecker *et al.,* 2013; Tan *et* *al.*, 2015 ; Kim & Heung, 2016; Badjana *et al.*, 2017; Diwediga *et al.*, 2017; Kim *et al.*, 2019), but few mostly from outside Africa focused on participatory management for decision-making within multifunctional landscapes (Hoanh & Page, 2008; Ng *et al.*, 2011; Daher & Mohtar, 2015) and very little towards building climate-resilient multifunctional landscapes, including the Kara River basin in Togo.

A recent study indicates that the multifunctional landscapes within the Kara River basin – a transboundary river basin and sub-catchment of the Volta River in Togo – has had substantial land use/land cover changes, particularly due to agricultural expansion and deforestation; resulting in a significant decrease in natural vegetation (Badjana, 2015). At the same time, few studies indicated a declining tendency in the cumulative annual precipitation over the region (Badjana, 2017). As landscapes' studies are gaining interests in the context of climate change (Fry, 2001; O'Farrell & Anderson, 2010), it has become worthy to investigate ways of building climate-resilience in that particular landscape through participatory research approach which is critical but not explored yet in the Kara River basin.

1.2. Statement of Research Problem

Globally, growing population has led to the extension of natural vegetation areas under agriculture, including marketable production, and forestry productivity to support consumption and food production. This situation is found over the West Africa Region where food, water, etc., are withdrawn mostly from major river basins such as Senegal, Gambia, Niger, Volta and Chad (Sylla *et al.*, 2018). River basins of the region experience water availability challenges due to climate change effects. Collins (2011) and Riede *et al.* (2016) evidenced a strong increasing temperature and a decrease in precipitation over West Africa between 1950 and 2010. The risk of water scarcity is particularly acute in areas where agriculture and other climate-sensitive livelihood activities are of great importance for the economy (Afzal *et al.*, 2020). Considering the increase demand for multipurpose land and water resources linked to population growth and future climate change impacts in the region (Picard *et al.,* 2017), a sustainable planning and management of multifunctional landscapes is necessary. Thus, there is a need for the implementation of a participatory approach for land and water resources management at river basin level in order to adapt to climate change impacts.

In Togo, numerous studies have used technologies like Geographic Information System (GIS) and Remote Sensing (RS) to evaluate changes in land resources both at national and local levels (Folega *et al.,* 2011; Folega *et al.,* 2014a; Folega *et al.,* 2014b; Badjana *et al.,* 2014; Folega *et al.,* 2015; Badjana *et al.,* 2015, Diwediga *et al.,* 2015; Diwediga *et al.,* 2017). Human activities, including agriculture, illegal logging and incursions in protected areas and settlement enlargement in rural and semi-urban areas have been acknowledged as causes of these changes (Kokou *et al.,* 2009; Dourma *et al.,* 2009; Fontodji *et al.,* 2011; Atsri *et al.,* 2018).

On the Kara River basin, very few studies have assessed land use and land cover (LULC) and established an information system for integrated land and water resources management (Badjana *et al.,* 2015, 2017). However, the nexus between land-water-climate has not gained full attention, especially from the human-ecological perspective and questions on the relevance of land use decision-making by stakeholders within the multifunctional landscapes of the river basin are unanswered. Most importantly, locals' perspective on land use choices and decisions seems understudied and not fully captured in the literature and in resilience building interventions in the basin.

With continuous and expected changes of climate and land use in West Africa, river basins and related landscapes require particular attention for sustainability through understanding the effects of climate and LULC changes on hydrology and human decision dynamics/processes over the climate-land-water nexus - as this is critical for sustainability of restricted water resources (Dosdogru *et al.*, 2020), for example, and river basins as a whole. Therefore, constant and additional studies are pertinent to investigate participatory approach for understanding land and water resources decision-making processes to build climate-resilient multifunctional landscapes in the Kara River Basin.

1.3. Research Questions

The subsequent research questions are asked for this study:

1. What are the perception and awareness level of farmers on climate; land use and land cover changes (LULC) and farmers' climate-resilient strategies in the Kara River Basin?
2. What are the spatial and temporal land cover changes and trends in the basin?
3. What are the main driving factors of the changes in the basin?
4. How do farmers' decisions on climate, land use changes and water availability for agriculture in the Kara River basin are made and what are they?

1.4. Objectives of the Study

1.4.1. General objective

The objective of this study is to contribute to building climate-resilience of the multifunctional landscapes using participatory approach for sustainable use of water and land resources in the Kara River Basin.

1.4.2 Specific Objectives

As part of the specific objectives, the study aims to achieve the following:

1. To assess the perception and awareness of farmers on climate, LULC and farmers' climate-resilient strategies within the landscapes of the Kara River Basin.

2. To determine the spatial and temporal LULC change and the main driving factors of changes in the Kara River Basin.

3. To model farmers' decisions on climate, land use changes and water availability for agriculture in the Kara River Basin

1.5. Research Hypothesis

The study assumes the following null hypotheses (Ho) in the attempt to answer the above-mentioned research questions:

- Ho1: Farmers in the river basin have observed no environmental changes (climate and land use changes) over time and have not used traditional resilient livelihood strategies to respond to them.

- Ho2: The river basin has not experienced any change in climate, land use and land cover.

- Ho3: The land cover has not been degraded by agriculture and population growth.

- Ho4: Farmers make decisions towards change of the climate, land use changes and water availability for agriculture in the Kara River Basin and no economic reasons motivate farmers in doing so.

The alternative hypotheses H_A are defined below:

- H_A1: Farmers in the river basin have observed environmental changes (climate and land use changes) over time and used traditional livelihood strategies to respond to them.

- H_A2: The river basin has experienced change in climate, land use and land cover

- H_A3: The land cover has been noticeably degraded by agriculture and population growth.

- H_A4: Farmers make decisions towards change of the climate, land use changes and water availability for agriculture in the Kara River Basin and economic reasons motivate farmers in doing so.

1.6. Scope of the Study

The present study consists of a diagnostic study of the landscape and an understanding of the social-ecological systems prevailing in the Kara River Basin (KRB). KRB is a transboundary catchment covering the northern parts of Togo and Benin. It is a sub-catchment of the Volta River shared between four countries: Burkina Faso, Benin, Togo and Ghana. For this study, the area of the KRB in Togo will be of focus.

1.7. Justification for the Study

There exists a high dependency of the population on water and land resources for subsistence agriculture and livestock production within the KRB. Few studies showed that the Kara River basin has experienced extensive degradation in recent decades, which has led to serious loss of vegetative cover (Badjana *et al*., 2014; Diwediga *et al*., 2017). However, statistics on the lost vegetative cover in the river basin are rare. In addition, little interventions so far in the basin followed a bottom-up procedure; rendering almost impossible the attainment of climate-resilient multifunctional landscapes.

In addition, farming communities' motivations and decisions towards this river's water availability for agriculture seems not well documented. In fact, watersheds or catchments are joined human-natural systems where human choices influence the environment (e.g., water quality, stream flow), and in turn, are affected by it (e.g., resource quality, water availability) (Ng *et al.*, 2011). A recent study by Badjana (2015) studied changes in terms of climate, land use, land cover but insufficient information was gained on socio-ecological interactions within the multifunctional landscapes of the river basin. It is necessary to gain insights on farmers' decision making for agriculture development in the area to sustainably plan and manage the multifunctionality of the landscapes within the basin. Ng *et al.* (2011) attested that the modelling of such systems for planning, management and other purposes requires an approach that considers both the human and natural pieces. The participatory approach is a recognised good practice that is useful to minimize tradeoffs within landscapes and supports transfer of information; reducing conflicts and fostering co-learning of the issues and informs better policy formulation and practitioners.

Moreover, the country targets to develop the first of its ten agropoles in the Kara River Basin in the framework of the implementation of its National Development Plan (NDP). The sustainability of this agropole may depend on the understanding of locals' perspectives and reconciling top-down approach into bottom-up understanding of farmers' choices. An assessment is, therefore, needed to understand changes in land use and land cover, the climate and land use effects on the availability of water for agricultural activities; and to provide sound solutions for decision making. This approach gives a deeper and holistic understanding of the issues as it will help to gain a broader picture of socio-ecological interactions in the Kara River basin.

In the overall, the participatory approach will add to the body of knowledge in sustainable management of natural resources and the importance to incorporate local actors' views in the management of multifunctional landscapes; especially in building their resilience to climate change.

This study will contribute to the literature as it gives new insights in river basin management in Togo taking into consideration socio-ecological interactions in the context of climatic change. In so doing, the study would benefit local communities, development actors and the scientific community on effective and efficient livelihood strategies needed to build climate resilient communities and resilient multifunctional landscapes within the river basin.

This study will also enlighten decision makers, planners, agricultural experts and other relevant stakeholders intervening in the river basin. As immediate impact, the assessment of climate, land use and land cover change will provide up-to-date baseline information on climate and land use indispensable for the development of the Kara agropole.

The development of a serious gaming scenario will inform about farmers' livelihood strategies and their attitudes and actions towards water utilisation for agricultural development within the Kara River basin, which in the overall is critical in the design and implementation of the activities of the agropole.

The study will help to inform, sensitize and educate on climate friendly strategies needed for an agropole that respects sustainability and climate resilience of the river basin.

Moreover, the study will inform future land and water management projects within the basin on individual farmers' decision-making process with regards to the utilisation of river's water responses or adaptive strategies to climate and land use/land cover change.

1.8. Definition of Key Terms

Resilience stands for "the ability of a system and its component parts to anticipate, absorb, accommodate, or escape from unacceptable standards of living due to the effects of a hazardous event, in a timely and efficient manner (Douxchamps *et al.*, 2017). According to Barron *et al.* (2021), resilience designates the capacity of communities in landscape to maintain and improve their livelihoods notwithstanding stressors and shocks through the sustainable management of natural resources while maintaining key ecological functions.

Landscape refers to that 'part of Earth's surface that can be observed at one time from one place (National Geographic Society, 2022). It consists of the geographic features that mark, or are characteristic of, a particular area'. It comprises a collection of landforms such as mountains, hills, plains, and plateaus. Lakes, streams, soils (such as sand or clay), and natural vegetation are other features of natural landscapes[1].

For the Intergovernmental Platform on Biodiversity and Ecosystems Services (IPBES, 2019), it is an area in which entities, including humans, interact according to rules (physical, biological, and social) that regulate their relationships[2]. Interactive features that define a landscape are functional connections, negotiated spaces and multiple scales.

Multifunctional landscapes: Multifunctionality of landscapes implies multiple functions which are crucial in the delivery of ecosystem services and to livelihoods for humans, animals and microorganisms. The multifunctionality of the landscape supposes the existence of a supply of a varied set of services and goods; leading to a number of environmental, social and economic benefits (Hölting *et al.*, 2020). In addition, a multifunctional landscape is anticipated to be integrated and build a resilient sector complementarity that includes farming, pastoralism, environmental and socioeconomic function (Shi *et al.*, 2021).

Climate-resilient: the IPCC Sixth Assessment Report's definition defines the concept as a set of combined approaches to adapt to climate change with actions to reduce GHGs to support sustainable development for everybody. Action to implement this notion has to start now because making progress is already challenging at current global warming levels[3].

Participatory decision-making: Over the past decades, traditional top-down, agency-driven decision-making in natural resource management has usually moved to

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[1] https://education.nationalgeographic.org/resource/landscape
[2] https://ipbes.net/glossary-tag/landscape
[3] https://www.ipcc.ch/report/ar6/wg2/downloads/faqs/IPCC_AR6_WGII_Overaching_OutreachFAQ6.pdf

processes that include stakeholders (those who have an interest in or are affected by a decision) and admit the importance of public attitudes, perceptions, beliefs, and knowledge[4]. According to Mbuvi *et al.* (2015), participatory decision-making includes local communities, government agencies, civil society, private sector, donors and all stakeholders acting together to defend species, sites, habitats and ecosystems ensuring sustainable ecological goods and services, sharing benefits, and costs equitably for the sustainability of human life.

1.9. Outline of the Thesis

The thesis consists of seven chapters. Chapter 1, the introduction describes the background of the study, the statement of the research problem, the objectives of the study and the corresponding questions and study hypotheses, justification, scope of the study. Chapter 2 provides a review of concepts, theories, empirical, conceptual framework and existing gap in the literature on the subject. Chapters 3 and 4, respectively gives the methodology and reports the research outputs as well as provides discussions in respect to each specific objective. Chapter 5 summarises the research findings in line with the specific objectives, concludes, identifies encountered challenges and further areas of investigation, and concludes with appropriate recommendations.

[4] https://coast.noaa.gov/data/digitalcoast/pdf/stakeholder-participation.pdf#:~:text=Over%20the%20past%20several%20decades%2C%20traditional%20top-down%2C%20agency-driven,natural%20resource%20management%20decisions%20can%20accomplish%20the%20following%3

CHAPTER TWO

LITERATURE REVIEW

2.1 Conceptual Review

2.1.1. Overview of Natural Resources Management Approaches

Natural resources management is an approach of managing natural resources that looks at the way management influences the quality of life for current and subsequent generations. The term refers to the planning, the use and the management that considers people and landscapes interaction bringing land use and water planning, biodiversity upkeep and sustainability of activities such as agriculture, forestry, energy production and tourism. In fact, healthy natural resources play an important role on the well-being of people.

Natural resources management is complex as it involves climate, plants, animals, geography, hydrological cycles, ecological cycles, etc. which are dynamic and inter-related. The term has evolved as it has taken several approaches with new developments in science, policy and practices which are geared towards sustainability. Hence, natural resources management includes the following approaches:

- Top-down approach
- Community-based natural resource management
- Adaptive management
- Precautionary approach
- Integrated natural resource management

The best way of managing natural resources sustainably is through the implementation of these approaches synergistically. The integrated natural resource management is a systematic procedure of managing natural resources which incorporates biophysical, socio-political and economical aspects in a manner that meets production goals of producers and other direct users (e.g., food security, productivity, risk aversion) and the goals of the wider community (e.g., poverty reduction, welfare of upcoming generations, environmental maintenance). Hence, integrated natural resource management focuses more on sustainability of the systems by trying to bring in all possible stakeholders in the planning process and ultimately helping to reduce future conflicts over the natural resources.

2.1.2. Frameworks for Understanding Social-ecological Interactions and Changes for Integrated Management of River basins

An integrated management of river basin (especially lands and water resources at basin level) implies a holistic analysis which incorporates participatory gathering of data, information from all the relevant stakeholders. The implementation of this approach requires a consistent framework as the DPSIR (D = Drivers, P = Pressures, S = State, I = Impacts, R = Responses) developed by the European Environment Agency (EEA, 2005, 2008a, b). This framework is graphically represented in Figure 2.1. Application of the DPSIR concept consists of making a diagnostic of the major issues/challenges faced by the landscapes and revealing their relevance for sustainable management planning.

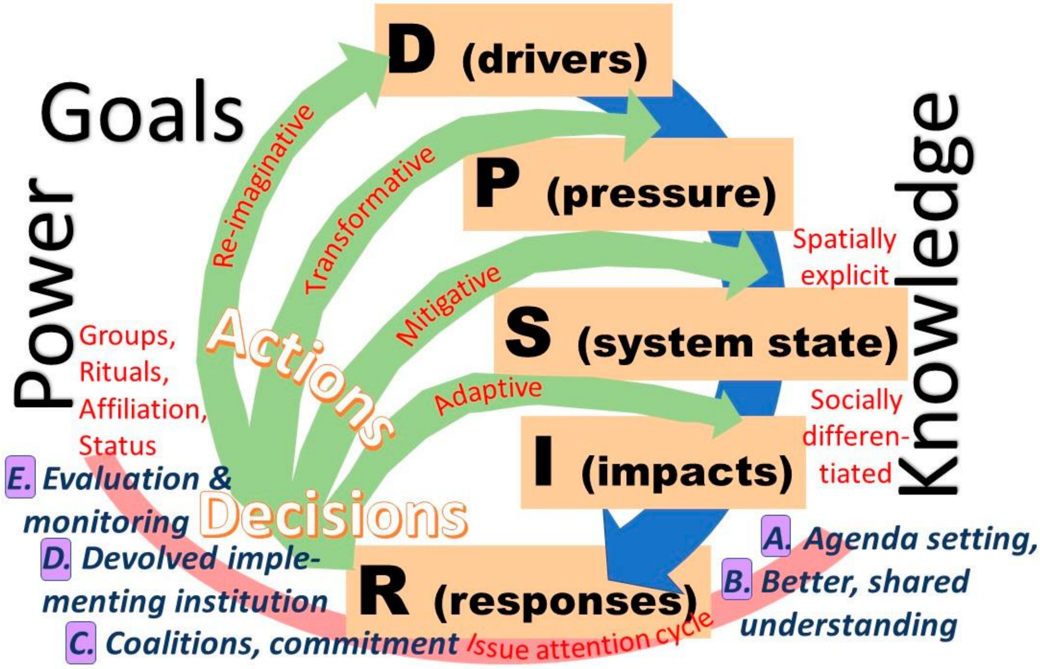


Figure 2.1. Drivers, pressures, system state, impacts and responses (also known as DPSIR) of landscape level change, with a decision cycle (A–E) closing many feedback loops interacting with knowledge, power and human sociality and its GRASP determinants. Adopted from van Noordwijk *et al.* (2020)

Note: (S) represents the 'system state' (S) of land cover/use as starting point. The underlying 'drivers' (e.g., food production, income generation, health, water and energy requirements, shield from disasters) of the 'pressures' (P) include (e.g., demographic trends, international markets, national policies). These lead to a series of effects termed as the impacts (I) on the social and ecological well-being that the 'system state' (S) tries to answer to through the 'responses' (R) that are activated. These responses can induce modification in the SI relationship, the often spatially explicit P➔S relationship, the often-generic D➔P relationships, or challenge the drivers themselves. Such choices can be called as adaptive, mitigative, transformative and re-imaginative, requiring increasingly drastic change in the existing social-ecological system. While the 'adaptive' decisions can be taken individually or in small groups, the others rely on communal action (especially the mitigative ones) and policy-level institutional change.

2.2. Empirical Review

2.2.1. Earth Based Observation Technologies for Sustainable Natural Resource Management

Novel technologies have risen to allow geographical representation and understanding of earth features at any time and spatial scale. This offers a great possibility to study changes within systems and natural resources using geographical information system and remote techniques. Recent progress in geospatial technologies have allowed distant study of the earth's surface and terrain features (Bishop *et al*., 2012; Bonham-Carter, 2014; Schumann & Bates, 2018; Lawal *et al*., 2022). Progress in computer technology, GIS, and remote sensing provides new ways of managing, editing, and producing raster and vector data, thereby easing visual interpretation methods (Mas *et al.*, 2004) to enable sustainable management of natural resources.

2.2.2. Climate Change and Land Use Analysis for Natural Resource Management

Natural resources worldwide have been faced with unfolding challenges of over exploitation and unsustainable use triggered by manmade pressures such as population growth, consumption habits, intensive economic activities, etc. Global changes induced by climate and land use changes have had implications on natural resources worldwide. Global climate change negatively affects biodiversity. Human pressures exacerbate these changes in the climate with the increase in urbanisation, over exploitation of natural resources and other extensive practices in agricultural activities. In this context of land use and land cover changes, the natural area is replaced by settlements, infrastructures and others inducing decrease in natural resources in general (Barry *et al.*, 2017).

Badjana (2015) in what is one of the first studies to assess the Kara River runoff and hydrological features using statistical methods for fitting hydrologic models (IHACRES and J2000 models), found that runoff response to rainfall is very delicate to climate and land cover changes in the basin. In fact, the basin has undergone important changes resulting from agriculture expansion and deforestation.

For proper management of these resources, it is vital to monitor these changes for sound decision making for conservation issues. Modelling climate and land use changes for natural resource management finds its place in these enormous changes which are as a result of threats from climate change and land use and land cover changes.

2.3. Theoretical Review

2.3.1. Modelling Nature-Society Interactions

As described above, society interacts very well with the nature; thus, driving changes within the climate and land use. Human actions have significant effects on the state of the nature. Thus, it is of paramount priority to look at the nature not in silo; but to understand the nature-society interactions. Social learning theory of Albert Bandura (1977, 1986) states that learning process is also a matter of observing, imitating and modelling to acquire knowledge. Knowledge generation or acquisition is important through interactions with others within a particular environment. Therefore, this study explores the social learning theory as a way to help to understand better the nature-society interactions within the framework of integrated sustainable natural resource management. For such study, the social learning theory calls for technics that are as follows:

2.3.1.1. Agent-Based Modelling

An agent-based model (ABM) is a computer-based model that simulates individuals or stakeholders' interactions and behavioural responses to analyse their influences on a particular system. Thus, ABM allows assessing the interactions between the society and the environment. This type of model primarily used in social sciences is applied to the field of natural sciences to capture and integrate the human dimension in the study of environmental sciences. For example, Monticino *et al*. (2007) as cited in Walker *et al*. (2015) employed ABM to study forest ecosystems and the infringement of built-up, commercial and industrial development. In that study, the multifaceted relations between land-use change decisions and ecosystems and how choices might influence human values and following decisions were modelled. Indeed, as management of natural resources (water, land, forest, etc.) is handled by the society, its sustainable planning, management and use should consider the mix top-down and bottom-up approach, where communities, scientists and other stakeholders are engaged for constructive negotiation.

2.3.1.2. Serious Games for Climate-resilient Landscapes

Sustainable planning for resilient landscapes that can withstand changes must integrate a diversity of knowledge for a collective better decision making. Besides, agent-based modelling, "serious games" (SG) are another mean of acquiring understanding on the connection human behaviour – ecological systems. SG are seen to be amongst the innovative participatory approaches to explore the complexity of the interactions of multiple stakeholders within landscapes. SG have gained popularity as an innovative participatory approach to learn about, discuss, and explore the complexity of global socio-environmental problems (Medema *et al.,* 2019; Speelman *et al.,* 2019; van

Noordwijk *et al.*, 2020). They can provide a perfect setting to stimulate group of actors to take choices in complex processes or change their attitudes or behaviourism (Graafland *et al.,* 2010). This type of model includes real humans in a gaming environment as a substitute of representing them inside computer model (Walker *et al.,* 2015). SG are games that have another purpose besides purely entertainment. In fact, they have been employed to encourage learning and behaviour change. Being utilised in a number of sectors, including marketing, education, healthcare, and other organisations and industries, they are promoted into understanding human and environment interactions. The strength of serious games is that they are captivating, interesting, and entertaining. Serious games combine learning strategies, knowledge and structures, and game elements to teach specific skills, knowledge and attitudes. Many scholars and enterprises leverage the challenges and rewards offered by games to solve problems in a variety of contexts while also providing fun and engagement for the user.

By understanding the landscape as a social-ecological system, the ecological pattern of 'land cover', its hydrological consequences and the social overlay of 'land use' and 'water use' can be analysed as part of multiple feedback loops (Minang *et al.,* 2015).

SG have been used for policy making in numerous fields, namely education, water management, health, etc. (Michael & Chen 2006 as cited in Walker *et al.,* 2015). According to Scharpf (1997) as cited in Walker *et al*. (2015), policies are now seen to be undertaken through policy networks that loose connection and interdependence among actors that interrelate in the policy process. This leads to a situation where powerful actors influence the outcome of this political process. Serious games have a prime goal to communicate knowledge, teaching skills or the encouragement of behavioural modification. SG are employed by companies to attain complex goals. Thus, their usage's increase in studying complex issues in the world like how people interact with their environment amidst competing values, interests and pressures. The emergence of gaming has enabled the integration of the changeable, strategic, and recurrently irrational behaviour displayed by people and organisations (Mayer, 2009). According to Mayer (2009), gaming is the technique in the policy analysis toolbox where real people – as actors or stakeholders – can be an intrinsic part of a computer model. This toolbox is more human-centred and tends to respond to the socio-political complexity. One of the main advantages in gaming as a method for analysis is its extremely flexibility and adaptability. Mayer (2009) explained further that, gaming could be united with other quantitative approaches, such as computer simulations and scenarios, unlike other methods.

Serious games are mounting as a potentially effective intervention tool (Garcios-Barrios *et al*., 2008; Villamor & van Noordwijk, 2011; Rodela *et al*., 2019). Games serve as (social) educational tools and frontier objects in multi-stakeholder situations to deliberate local voices and concerns. A game-based method can motivate participants to explore system behaviour through scenario evaluation and supports negotiations in local contexts in a low-risk environment. Shared experience and jointly acquired knowledge in scenario evaluation games may aid in the formation of coalitions in the real world. In this context, playing games has been revealed to support-informed decision-making (Speelman *et al.*, 2014; Speelman *et al.,* 2017). They are utilised for diverse purposes: education, research, and intervention (Rodela *et al.,* 2019), including raising awareness of issues (Rebolledo-Méndez *et al.,* 2009; Lameras *et al.,* 2013; Damani *et al.,* 2015), and exploring options in the socio-environmental-political domain (Orduña Alegría *et al.,* 2020; Mochizuki *et al.,* 2021).

2.3.2. Managing Multifunctional Landscapes to ensure Climate-resilient Livelihoods: Collaboration between Actors and Across Sectors

As multifunctional landscapes offer an array of services, they are typically characterized by varied land use and complex structure, thereby potentially covering many, often opposing interests of diverse stakeholder groups. Sustainable management of the landscapes are therefore required to maintain or increase the multifunctional practice of these landscapes while ensuring provision of ecological services for future generations.

Managing landscape multifunctionality involves not only conversion toward more sustainable land management, but also a collaboration between actors and across space. This is what Ekroos *et al*. (2016) coined as multiscale land-sharing and land-sparing; where land-sharing is meant for production and land-sparing connects to the need for biodiversity conservation. Most often conciliation of these two (meaning they can coexist) remains a daunting challenge with increasing demand for agricultural production (Grass *et al.,* 2021).

Nevertheless, the land-sharing and land-sparing concept or theory does not fully promote sustainable landscapes due to lack of conservation practices in agroecosystems. One way of overcoming the disconnect in the landscapes and ensuring sustainable management is bringing in elements to stop declines of farmland biodiversity under increasing agricultural demand (Grass *et al.,* 2021). To address this shortcoming, combining the "land-sharing and land-sparing theory" with ecological-friendly land-sharing practices is promising. Such integration of conflict resolution and ecological-friendly practices provides a room for building resilient landscapes. This good practice for sustainable management may pave the way to build climate resilient landscapes.

2.3.3 Biodiversity Conservation: A Way of Promoting Heterogeneity of the Multifunctional Landscapes

Proponents for sustainable landscapes advocate heterogeneity of landscapes. Landscape heterogeneity is significant to facilitate landscape connectivity, to avoid species losses in spared natural habitats and to promote spill over of organisms and ecosystem services from collective landscape essentials to agricultural land (Poggi *et al.*, 2021).

Though land use decisions are regulated by public policies, most of land management choices or decisions are made at the small scale (plot or farm level). In this outset, socio-economic, institutional, and environmental proportions interact across farm, landscape, and other scales comprising a socio-ecological system (Gallopín *et al.*, 2001).

2.3.4. Statistical Climate Analysis for Understanding and Informing Climate-Resilient Strategies

Climate analysis is the study of historical and current climate patterns and trends for the purpose to understand the behaviour of the Earth's climate system. The goal of climate analysis is to recognise and comprehend the factors that determine the climate, including temperature, precipitation, wind patterns, and other meteorological variables. There are several different approaches to climate analysis, including statistical analysis, observational data analysis, and climate modelling. In statistical analysis, large datasets of climate data are investigated using mathematical techniques to recognise tendencies and patterns. Observational data analysis involves gathering and analysing data from various sources, such as weather stations and satellites, to understand the current state of the climate. Climate modelling comprises using scientific models to simulate the Earth's climate and forecast how it will change in the future.

Climate analysis is a crucial tool for scientists, policymakers, and resource managers in their efforts to appreciate and address the impacts of climate change. By providing a better knowledge of the Earth's climate and its past, present, and future behaviour, climate analysis can help inform decision making and inform strategies for reducing the impacts of climate change.

For instance, climatological analysis of rainfall cessation and onset is an important process for understanding regional climate patterns and long-term trends in rainfall. This analysis can be carried out in several ways, but some of the common methods include:

- Study of synoptic meteorology: this requires the analysis of current and past weather systems and seasonal trends to understand the causes of rainfall cessation and onset.

- Study of long-term climate variability: this includes the analysis of long-term climate trends, such as precipitation patterns over decades or centuries, to understand the root causes of rainfall cessation and onset.

- Study of climate indicators: this comprises the analysis of climate data, such as temperature, atmospheric pressure, wind speed, and humidity, etc. to determine the relationships between these variables and the cessation and onset of rainfall.

- Numerical modelling: this contains the use of computer climate models to simulate current and predicted climatic conditions and to understand the causes of rainfall cessation and onset.

Climatological analysis of rainfall cessation and onset can help scientists, farmers and water resource managers to better understand long-term rainfall trends, plan consequently and take action to manage water resources efficiently.

2.4 Existing Gap in Literature

Few studies showed that the Kara River Basin (KRB) has witnessed extensive degradation in recent decades, which has contributed to grave loss of vegetative cover (Badjana *et al.*, 2014; Diwediga *et al.*, 2017). However, up-to-date statistics on vegetative cover in the river basin are scarce. Currently, there is insufficient knowledge on the way climate and land use change affect river water hydrological processes and water availability to sustain farming activities in the basin.

Next, farmers' choices towards land use systems and river's water availability for agriculture seems to be missing in the literature. Few studies in the landscape of KRB highlighted changes of climate and land cover with limited information on human interactions with the ecological system within the river basin (Badjana *et al*., 2017).

2.5 Theoretical Framework

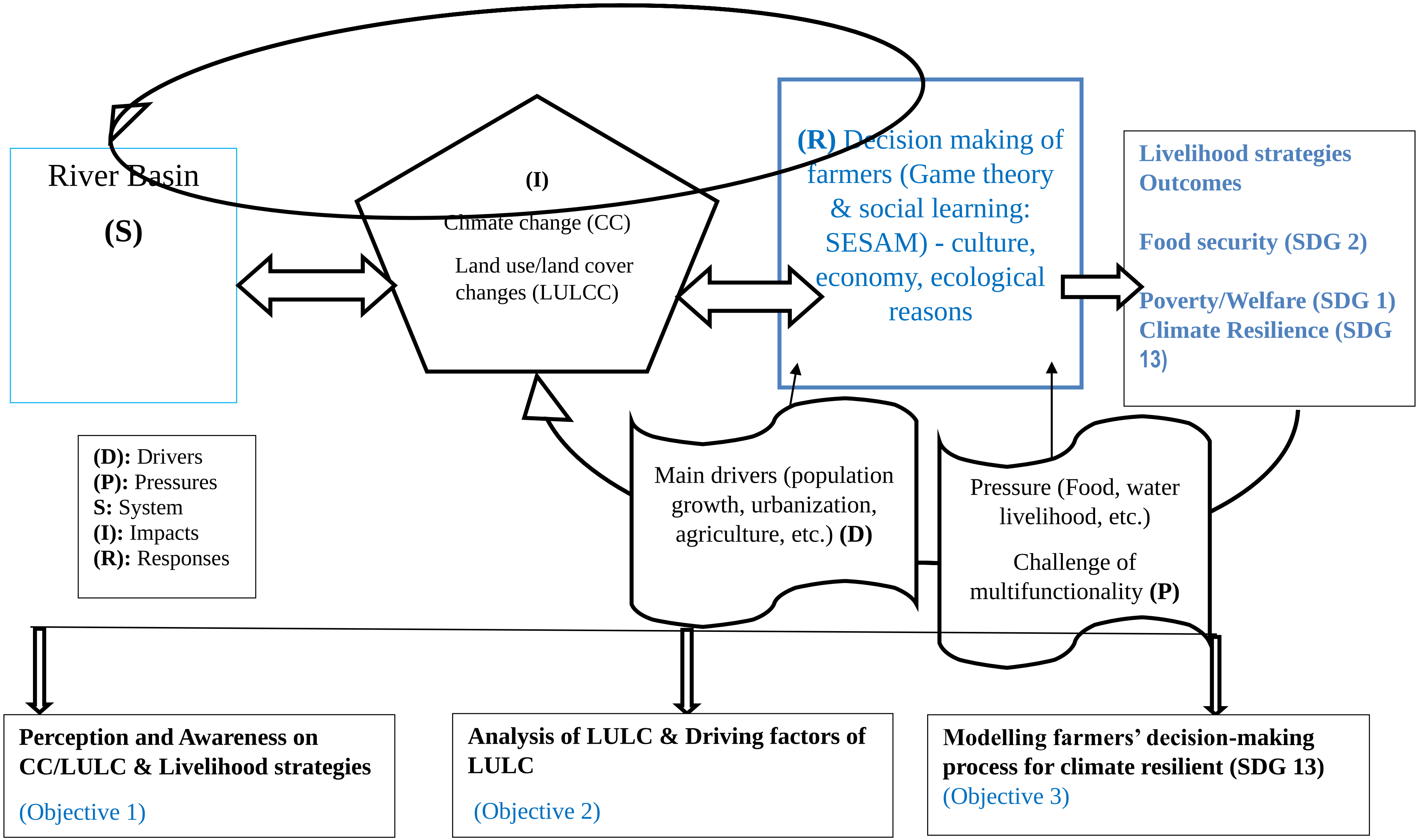


Figure 2.2: Conceptual Framework of the study: game theory + social learning + DPSIR framework (Author's own elaboration, 2021)

CHAPTER THREE

METHODOLOGY

3.1. Research Design

The research design for this study is a mixed of quantitative and qualitative approaches and methods. Thus, the research employed an in-depth literature review, collection of geospatial and climate data, a survey, and a serious game.

This design for the research will help to, first, cover the awareness and perception of farmers about environmental changes, including land use and land cover change and climate change. Second, to make an analysis of changes that have occurred within the river basin using GIS, remote sensing for the land transformation; and climate analytics to depict changes in the climate over certain time periods. Third, to utilise scenario explorations that require modelling human decisions towards land use and water for agriculture development in the Kara River basin using SESAM, a "serious game" approach. Finally, the study will unravel the SESAM concept to depict the processes behind farmers' choices, motivations and rationale for making decisions vis-à-vis land use and water management on their fields; and to establish risks or consequences for establishing climate-resilient multifunctional landscapes in the Kara River basin.

3.2. Area of Study

The multifunctional landscapes of the Kara River Basin cover a total area of 4,594 km^2 in northern Togo and part of neighbouring Benin (Badjana *et al.*, 2017b). The study area lies between longitudes 0°30' and 1°38'E and latitudes 9°15'and 10° 01'N. It is drained away from the ocean by the north-flowing Oti River, a sub-catchment of the Volta Basin in West Africa. The climate in the area is tropical sudanian with two seasons: a rainy season (April to October) with high rainfall variability, and a dry season for the remaining period of the year. The average annual rainfall was 1320 mm over the period 1960-2012, and the mean annual temperature at Kara synoptic station was 27.3°Cover the period 1977-2011. The minimum and maximum temperatures are 41°C and 15°C, respectively (Badjana, 2015). Climate variability in the region during the last decades has been characterized by a great inter-annual variability with a succession of dry and humid periods and rising temperature (Badjana *et al*., 2017a). The area is exposed to high climatic variability. The Kara River basin is predominantly located in the Kara Region (Figure 3.1). It contains the agropole of Kara which is consisted of 4 prefectures (Bassar, Keran, Doufelgou and Dankpen) (Figure 3.2). The agropole covers an area of 165,000 hectares and will be dedicated for agrobusiness and agricultural development in the basin as part of the nationwide large-scale Togo Agri-Food Transformation Project (PTA-Togo).

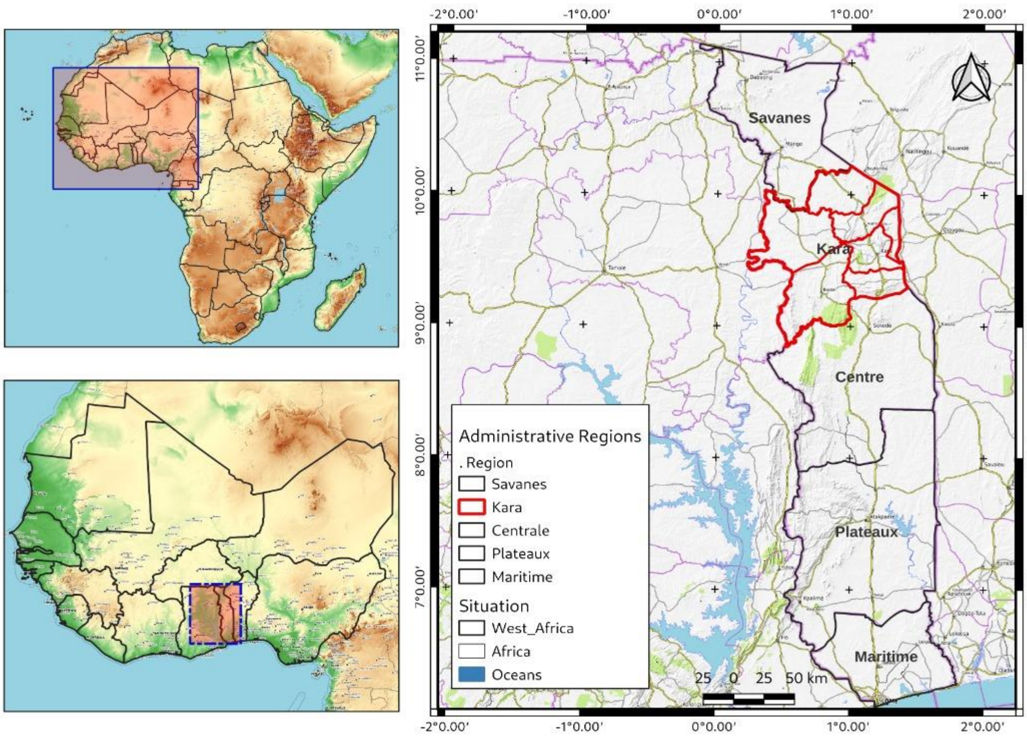


Figure 3.1. Location of the Kara Region
Source: (Author, 2022)

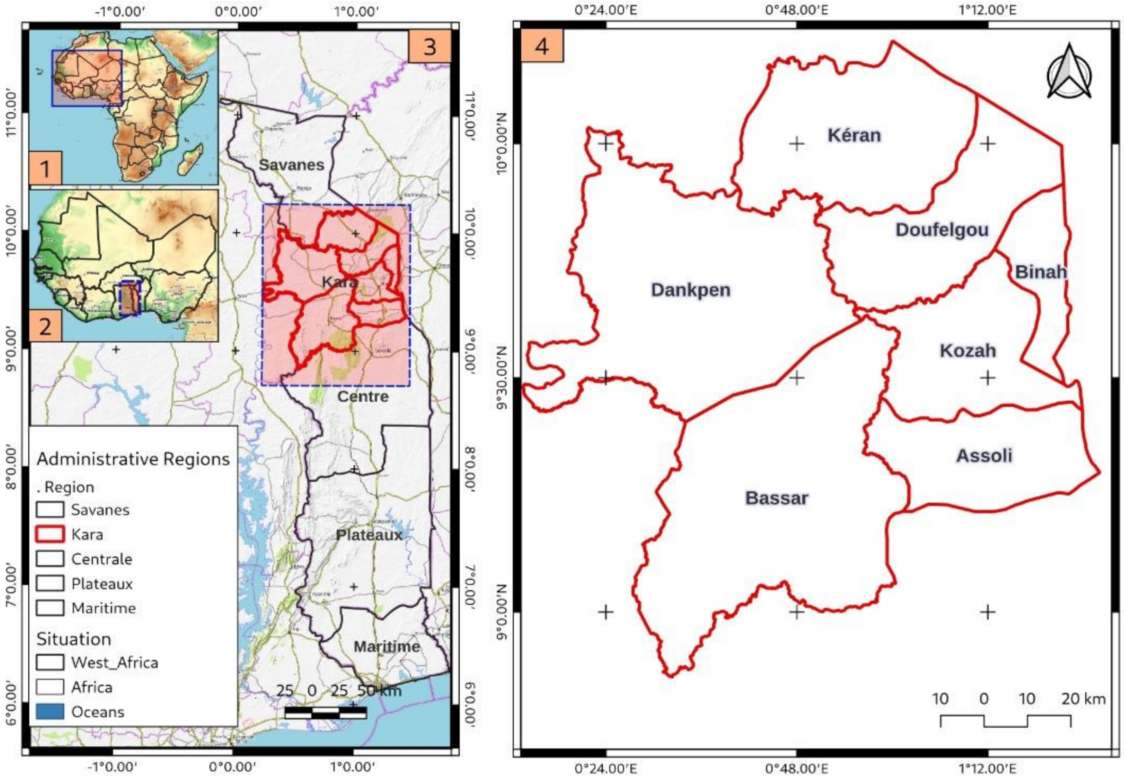


Figure 3.2. Map of prefectures within the Agropole of Kara

Source: (Author, 2021)

The similarity of these prefectures is their rural nature with the main socio-economic activity being agriculture. About 96.2% of rural households are involved in agricultural-based livelihoods with 81% headed by men and 19% by women (MAEP, 2013). Land is degraded in the watershed (Brabant *et al*., 1996) occasioning increased soil erosion and declining crop yield (UNEP-GEF, 2012).

For this study which consists, *inter alia*, of understanding the knowledge of the population in the area and choices behind their land use and management systems, a survey design was adopted. The survey targets the districts that have huge contribution to farming activities in the area. The districts are represented in Figure 3.3.

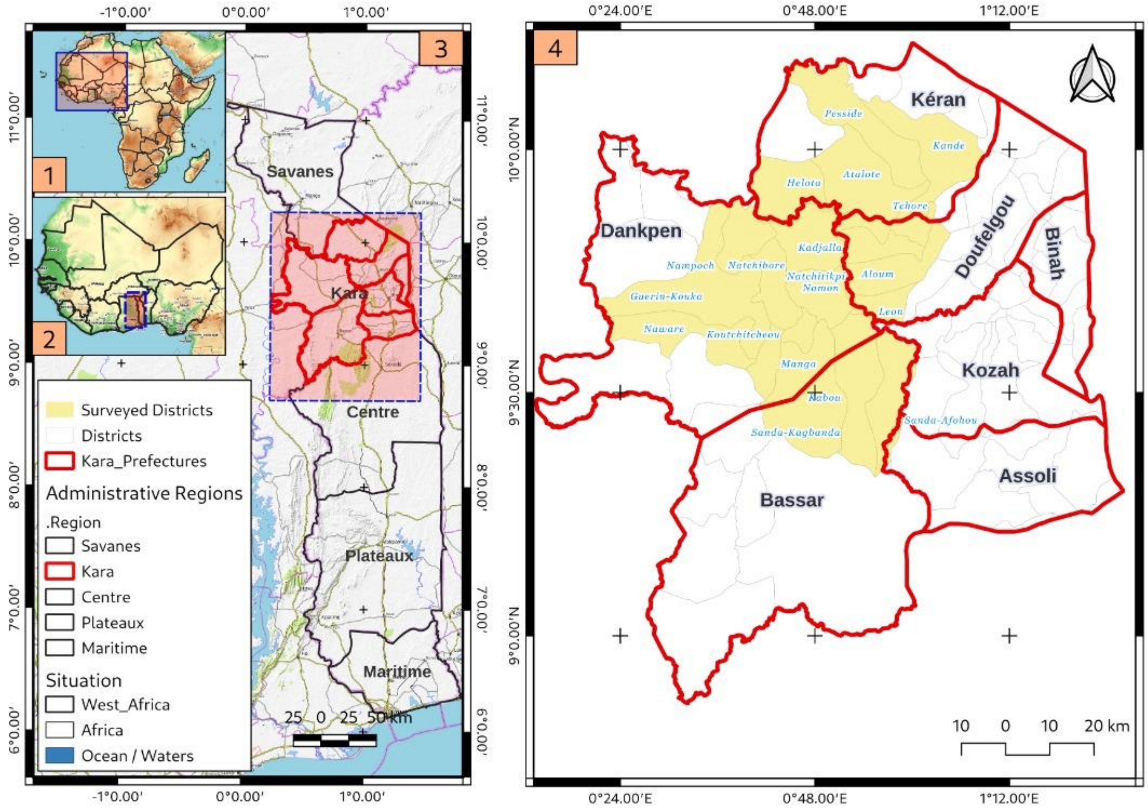


Figure 3.3. Surveyed districts
Source: (Authors' compilation, 2022)

3.2.Population of the Study

The population within the Kara River basin is about 460,000 inhabitants, largely rural and heavily dependent on natural resources (Anonymous, 2010). The main socioeconomic activity is agriculture with extensive shifting cultivation followed by livestock. Agriculture is rain-fed and mainly for subsistence and small market-oriented. The main crops that are cultivated include yams, guinea corn, corn, rice, millet and groundnuts. Although subsistence crops represent more than 70% of the production, cotton as the main cash crop is cultivated by the population in the Kara basin and the neighbouring Binah River watershed covering parts of Togo and Benin (Djagni, 2007). Livestock is composed of cattle, sheep, goats, pigs and poultry (UNEP-GEF, 2012). Agriculture is extensive and based on slash-and-burn system. Throughout the watershed, land degradation and soil erosion are widespread and mainly result from the increasing population and its pressure on land through poor agricultural practices.

Objective 1: To Assess the perception and awareness of farmers on climate, land use and land cover changes (LULC) and climate-resilient strategies within the landscapes of the Kara River Basin

The assessment of the perception and understanding of their awareness requires collection of data on the local communities. Both primary and secondary data were used.

On the other hand, changes within the climate were understood by collecting data from a mixture of hydro-climatic and geographical data sources to depict and serve to reflect on the perceptions from farmers on adaptation and devising actions for resilience to climate change.

3.2.1. Sampling Technique and Sample Size

The study used a multistage sampling approach. At the first level, all the four (4) prefectures of the Kara Agropole were selected. At the second level, all the 19 cantons of the agropole were surveyed. At the third stage, 2 villages were randomly selected per canton; making it a total of 38 villages or communities randomly selected. The sampling size calculator engine was used applying the Morgan and Krecje (1973) formulae (Equation 1) to determine the appropriate sample size for the study. A total of 436 farmers was sampled from the population of farmers in the area under study.

$S = X^2NP(1-P)/d^2\ (N-1) + X^2P(1-P)$ (Equation1)

Where: S = required sample size

X^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (3.841) that is 1.96 *1.96 = 3.841

N = the population size.

P = the population proportion (assumed to be 0.50 since this would provide the maximum Sample size)

d= the degree of accuracy expressed as a proportion (0.05)

3.2.2. Types and Sources of Data Collection

3.2.1.1. Ethical Considerations for the Study

Prior consent is understood as ‘the process of agreeing to take part in a study based on access to all relevant and easily digestible information about what participation means, in particular, in terms of harms and benefits’ (Parahoo, 2006; Hardicre, 2014). Before embarking on the investigation (especially at the beginning of the face-to-face interview), a free and prior informed consent method (Schreckenberg *et al*., 2016) was sought to ensure ethical research standards were met. Hence, the purpose of the study was disclosed to the interviewees, mainly the farm household heads or their representatives. This was helpful in getting participants’ consent before administrating the questionnaire. This is critical to avoid any misinterpretation and violation of individual rights to participate or not in the survey. Also, the disclosure of study objectives permitted to facilitate the community entrance and guarantee a proper communication with community members.

3.2.1.2. Data Acquisition

The participatory approach in this research underscores the worth of local knowledge and the importance of participant’s perspectives. Such data gathering techniques seem more suitable to gathering information from multiple viewpoints, at different scales, and mixing socio-economic, biophysical, and climate information (Mwongera *et al*., 2017). Hence, this thesis draws upon participatory fieldwork as in Duncan *et al*. (2020) to generate thorough information on how people interrelate with the landscape. This study predominantly used primary data collected from a field survey using face-to-face interviews. The tool is a semi-structured questionnaire containing the following aspects: local conditions, issues of land use and land cover change, soil fertility decline and local strategies for agricultural adaptation to changing climatic conditions and building resilience.

From April 2021 to June 2021, 436 smallholder farmers from 38 communities were interviewed in the agropole of Kara, followed by 19 focus group discussions (FGDs) on average of 8-12 peoples, and key informants' interviews techniques with 4 agricultural institutes. Triangulation techniques helped to revisit the interviews and verify the results.

3.2.3. Definition and Measurement of Variables

The study combined the climate change awareness index model developed by Kutir *et al.* (2015) on farmers and Rahman *et al*. (2014) on high school students and adapted it to the broader concept of climate change and land use/land cover.

Based on Kutir *et al.* (2015), awareness on climate change is conceptualized as a composite index of three indicators: i) conceptual awareness; ii) experiential awareness; and iii) engagement.

Conceptual awareness is about the person's knowledge on the causes of climate; land use and land cover change and their impacts.

Experiential awareness entails experiencing and knowing long term changes in climate, land use and land cover and their impacts whiles *Engagement* refers to frequency with which a person talks or hears about climate change (Gbetibouo & Mills, 2012 as cited in Kutir *et al.,* 2015), and land use and land cover change. For this study, awareness was conceptualize to be action oriented; thus, Rahman *et al.* (2014) methodological approach was relevant in assessing the awareness. Therefore, awareness encompasses climate and land cover/land use action and not just hearing or understanding the manifestation of these changes. As such, questions related to Rahman *et al.* (2014) has helped to frame questions that covered the three indicators defined in Kutir *et al.* (2015). The awareness index is estimated to range from zero to one and can be categorized into low awareness if the index is 0-0.49, moderate if the index is 0.5-0.74 and high if the index is greater than 0.74.

Computation of the Awareness Indexes: Climate Change Awareness Index, and Land Use and Land Cover Change Awareness Index

On a scale of -5 to 5, responses to questions related to awareness were rated accordingly to the answers' merit. Besides, each question has been given weight on the basis of its significance to the topics. Weighting ranges from 1 to 10 and the minimum and maximum total score ranges between -500 to 500. The totality of scores from all the questions for each household head give the awareness score of the respective smallholder farming household head.

Computation of the Climate Change, and Land Use and Land Cover Change Awareness Index

The following are the three steps for computing climate change and land use and land cover awareness index:

These steps are:

1. Computing the Climate Change Awareness Index (CCAI)

2. Computing the Land Use and Land Cover Awareness Index (LULCCAI)

3. Summing up of CCAI and LULCAI (CCLULCCAI)

The formulae to compute the climate change awareness index (CCAI) for the respective farming household has been designed by stating each household's climate change awareness score as the percentage of the maximum possible total score of the questionnaire as shown in Equation 2.

$CCAI\ (\%) = \frac{\sum_{i=1}^{n} Ri \times Wi}{\sum_{i=1}^{n} Rm \times Wi} \times 100$ (Equation 2), Adapted from Rahman *et al.* (2014).

Note: CCAI (%) is the climate change awareness index for a particular respondent, n is the number of questions considered for the index building, Ri is the rank from the i-th question, Rm is the maximum rank that can be gained from the i-th question and Wi is the weight of i-th question.

The same formulae and procedure were used to compute the LULCCAI by adapting the questions to land use and land cover change topic. The LULCCAI for each household has been expressed using land use and land cover change awareness score as the ratio of the maximum possible total score for the questionnaire as presented in Equation 3.

$LULCCAI\ (\%) = \frac{\sum_{i=1}^{n} Ri \times Wi}{\sum_{i=1}^{n} Rm \times Wi} \times 100$ (Equation 3) from Rahman *et al.* (2014).

CCLULCCAI is obtained from summing up both CCAI and LULCCAI.

3.2.4. Validity and Reliability of Research Instruments

The questionnaire was pre-tested through a pilot survey in the study area; then reviewed for validation. The review took into account feedbacks from the participants during the piloting to further refine the questionnaire to suit to local context and the research question. Validity was sought from how well the respondents during the pre-test understood and were able to efficiently give answers to the questions raised.

Later, field observations to collect factual information were conducted through transect-walk across the landscapes of the study area. This was useful in observing facts of real physical soil degradation (e.g., soil erosion, lateritic crusting, etc. and other landscape features relevant to better apprehend land degradation issues in the area). Field activities engaged in this research have been employed in other rural landscapes to apprehend how people utilize ecosystem services (Malmborg, *et al*., 2018; Sinare, *et al*., 2016).

3.2.5. Method of Data Analysis

The collected data were inputted and subjected to a clear and rigorous process of data cleaning and quality control. Next, the cleaned data were analyzed using descriptive statistics through IBM SPSS 25 and Microsoft EXCEL 2016.

The study also drew on previous studies (Rahman *et al*., 2014; Kutir *et al*., 2015) that used quantitative methods for awareness assessment. For this study, climate change, on one hand, and land use and land cover change, on the other hand are taken together not in a separate way. Global environmental change issues being interconnected, it is worthy to assess how individuals or group of people are aware on these issues.

Climate Data Collection

Building climate-resilient multifunctional landscapes requires knowledge about current and future climate that is or likely to prevail in the area. Climate change research recognises patterns and approaches to reduce the impact of climate risks. Therefore, integrative methods that combine natural and human systems are relevant for an increase understanding of the drivers and impacts that enlighten decision-making (Marajh & He, 2022). Thus, an understanding of the climatic conditions and how variability and change in the climate happen help to have evidence-based assessments of likely impacts within the landscapes to inform participatory approaches needed.

a) Observed and Satellite-based Data

Daily rainfall, temperature and evapotranspiration were collected from the database available from online repository from ERA5 (temperature, precipitation) to counter the limitations (such as gaps in data) of observed data which were taken from the national meteorological agency (ANAMET) of Togo (formerly known as “Direction Générale de la Météorologie Nationale (DGMN)”) for the period 1981-2014.

b) Geographical data

Digital Elevation Model (DEM) from Shuttle Radar Topography Mission was downloaded at a resolution of 30 arc seconds (SRTM30). In fact, Badjana (2015) has already used the same data when conducting land use analysis in the river basin (Figure 3.4).

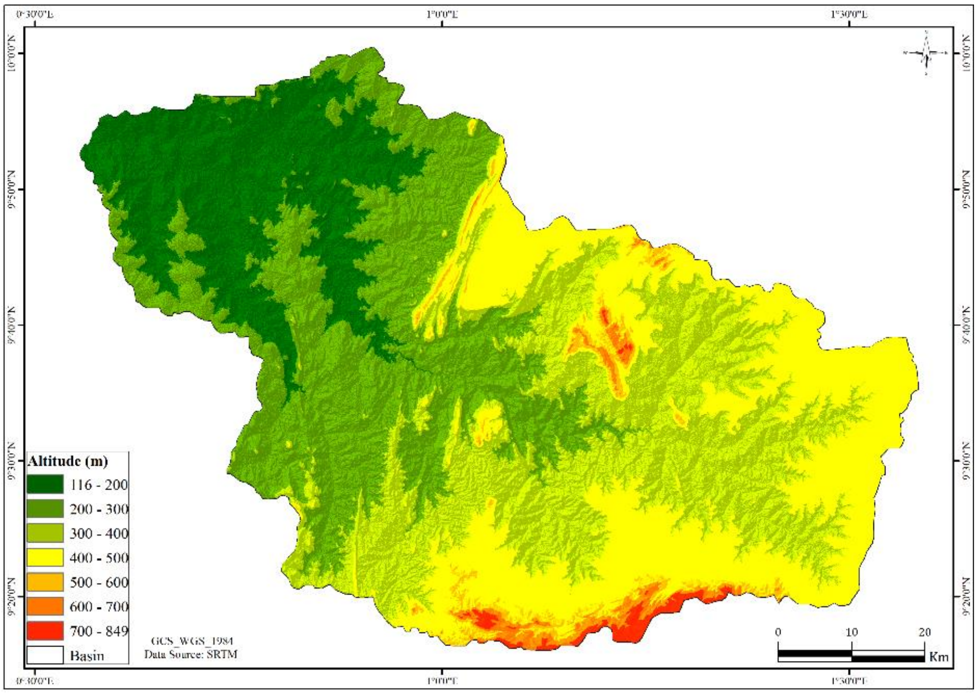


Figure 3.4. Topographical Map of the study area

Source: (Author, 2021)

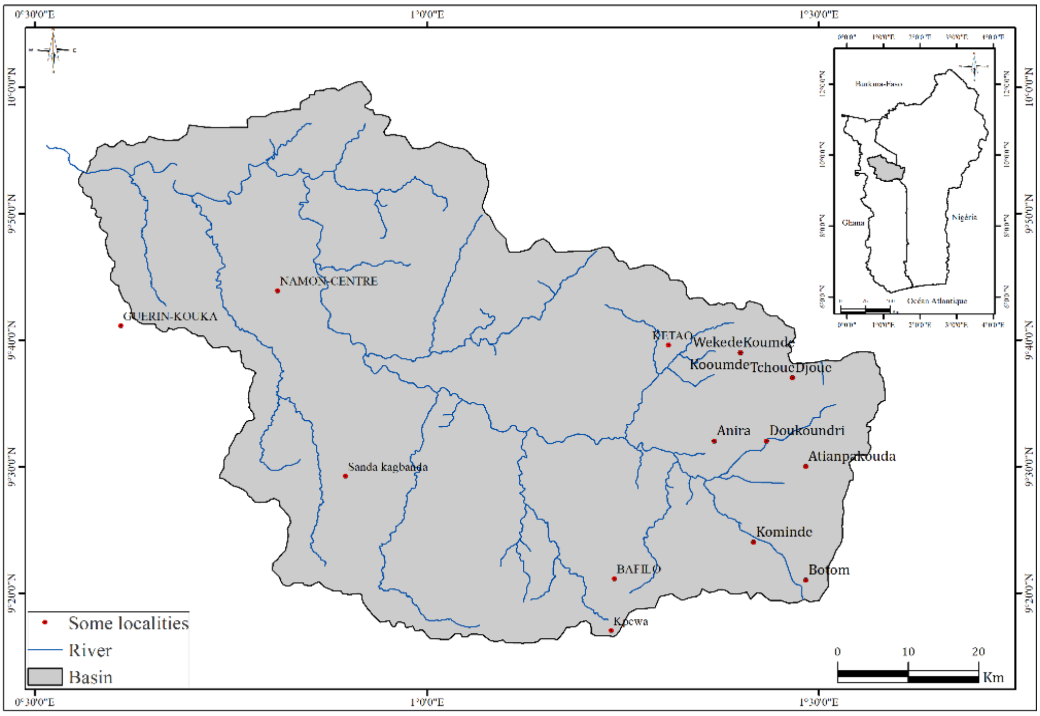


Figure 3.5: Hydrography in Kara River basin

Source: (Author, 2021)

Historical Climate Data

To palliate the inadequate number of weather stations points in the basin, ECMWF atmospheric reanalysis ERA5 datasets were taken as a substitute, particularly for climate impact studies (Foli *et al.*, 2021). Data from ERA5 are satellite based and present improved time-series close to real observed data for the analysis of the climatology. ERA5 is the fifth generation of the re-analysis dataset established by the European Centre for Medium-Range Weather Forecasts (ECMWF) and is cleaned and free from biases (C3S, 2017). At present, ERA5 data is available from 1950 with a 0.25° × 0.25° resolution (Hersbach *et al.*, 2020). To guarantee data quality, ERA5 data collected were checked for validity against ground-based precipitation and temperature data. The results show a close similarity with observed data. The ERA5 temperature data was retrieved from AWS Open Data (2022).

Data from five stations were analysed, namely Guerin Kouka, Takpamba, Kara, Niamtougou, and Kante. These data are gridded and cover the majority of the basin.

Analysis was done using Climpact[5]. Climpact is a useful software package for quick analysis of climate extremes. It has been applied to calculate climate indices in the sectors like health, agriculture and water.

Analysis conducted were trend analysis and climate indices calculation, anomaly detection and precipitation index.

Trend Analysis

Mann Kendall test is a statistical test extensively used for the study of trend in climatology (Bera, 2017; Barry *et al.*, 2017; Mavromatis & Stathis, 2011; Bhutiyani *et al.*, 2010; Burn *et al*., 2004; Hirsch *et al.*, 1984). It offers two-fold benefits: 1) It is a non-parametric test and does not necessitate the data to be normally distributed; 2) It

[5] https://climpact-sci.org/indices/

has low sensitivity to sudden breaks due to homogeneous time series (Tabari *et al.*, 2011); thus, any data reported as non-detects are included by giving them a common value that is lesser than the smallest measured value in the dataset.

The Mann-Kendall test is suitable in instances when the data values xi of a time series can be presumed to follow the model stated in Equation 4.

$Xi=fti+ \varepsilon i$ (Equation 4)

where fti is a constant monotonic increasing or decreasing function of time and the residuals εi can supposed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time.

The Mann-Kendall S Statistic is calculated as follows in Equation 5.

$$S = \sum_{i=1}^{n-1} \times \sum_{j=i+1}^{n} sign\ (Tj - Ti) \qquad \text{Equation 5}$$

$Sign\ (Tj - Ti)$={$1\ if\ Tj - Ti > 0\ 0\ if\ Tj -$

$Ti = 0\ -1\ if\ Tj - Ti < 0$

where Tj and Ti are the annual values in years j and i, j>i, respectively (Motiee & McBean, 2009).

If n < 10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall. The two-tailed test is performed. At some probability level H_0 is rejected in favor of H_1 if the absolute value of S equals or exceeds a stated value $S_{\alpha/2}$, where $S_{\alpha/2}$is the smallest S which has the probability less than α/2 to appear in case of no trend. A positive (negative) value of S designates an upward (downward) trend (Drapela & Drapelova, 2011). For n ≥ 10, the statistic S is nearly normally distributed with the mean and variance as follows:

E(S)=0

The variance (σ^2) for the S-statistic is defined by:

$(\sigma^2)= [n(n-1)(2n+5) - \sum ti(i)\,(i-1)(2i+5)] \times \frac{1}{18}$ (Equation 6)

In which ti represents the number of ties to extent i. The standard test statistic Z_s is considered as per the following Equation 7.

$Zs\{\frac{s-1}{\sigma}\ for\ S > 0\ 0\ for\ S = 0\ \frac{S+1}{\sigma}\ for\ S < 0$ (Equation 7)

The test statistic Z_s is employed to quantity the significance of trends. In fact, this test statistic is utilised to test the null hypothesis, H_0. If | Z_s| is greater than $Z_{\alpha/2}$, where α signifies the chosen significance level (e.g.: 5% with $Z_{0.025}$ = 1.96) then the null hypothesis is invalid inferring that the trend is significant (Motiee & McBean, 2009).

Climate Indices Calculation

Much works has established synthetic climate indices which are widely used to determine trends in climate conditions, concentrating on precipitation and temperature (Domínguez-Castro *et al.*, 2020) to assess the climate effects on different natural systems and socio-economic activities (Easterling *et al.*, 2003; Scott *et al.*, 2008; Yu *et al.*, 2009; Peña-Gallardo *et al.*, 2018) and provide also a comprehensive valuation of climate variability and change (Zhou *et al.*, 2014; Dosio, 2016; Campozano *et al.*, 2017).

To quantify the precipitation deficit for multiple timescales, SPI is the most used index. These timescales indicate the impacts of drought on different water resources needed by various decision-makers. SPI developed by McKee *et al.* (1993, 1995) is a powerful and flexible index easy to calculate. This index helps to analyse dry periods or cycles and wet periods/cycles for at least 20 years of monthly values (Guttman, 1994). Used by many drought planners, researchers, universities, and National Meteorological and Hydrological Services across the world, it is appreciated for its versality. SPI suits drought monitoring and early warning efforts. The strengths of this index exist in its ability to be computed in different time scales and the use of precipitation as the only input parameter unlike other indexes.

For this study, indices established through the collaborative work of the Expert Team of Climate Change Detection and Indices (ETCCDI), the World Meteorological Organization (WMO), and the Climate change and predictability (CLIVAR) (Alexander *et al.,* 2006; Klein *et al.,* 2009; Zhang *et al.,* 2011), are calculated from daily rainfall. They are labelled as per the following:

- The consecutive dry days (CDD), mentioned to as the maximum length of a dry spell (i.e., with precipitation < 1mm) which can show regions vulnerable to droughts.

- The maximum number of consecutive wet days per time period (CWD) (i.e., with precipitation > 1mm), where a rise of this index with time signifies that the chance of flood conditions will upsurge.

- The very heavy precipitation days index (R20mm) amounts the number of days with more than 20 mm of precipitation (frequency). It is stated to as the number of heavy precipitation events of a year. It is a quantity of heavy precipitation, with high values equivalent to a high probability of flooding.

- The very wet days (R95p) index points to the annual total precipitation amount (in mm) collected on days when daily precipitation exceeds the 95th percentile threshold of the wet-day precipitation (PR > 1mm). The R95P index symbolizes the upper tail of the precipitation distribution.

- Seasonal PRCPTOT designates the total seasonal amount of precipitation on wet days, defined as days with more than 1mm of precipitation; and
- SDII is the daily precipitation amount averaged over all wet days in a year. The simple daily intensity index (SDII) is demarcated as the ratio of annual or seasonal total rainfall to the number of days during the year or season when rainfall occurred (daily rain > = 1mm). Therefore, the SDII displays the average daily rainfall for a period.

The sets of equations that elaborate more on the listed indices are presented in Table 3.1.

The Climate Data Operator (CDO) is used to compute those indices on a seasonal scale over the area.

Table 3.1. Definitions and units of precipitation indices employed in this study

ID	Category	Name	Definitions	Units
PRCPTOT	Annual precipitation total	Wet-day precipitation amounts	Total precipitation in wet days (RR ≥ 1mm), demarcated as PPij representative of daily precipitation amount on day I in a period j. If the I denote the number of days in j, then; PRCPTOTj=∑ii=1PPij	mm
R95p	Percentile-based index	Extremely wet days	Total precipitation when PP > 95th percentile. Here, PPcd be daily precipitation amount on a wet day c (PP ≥ 1.0 mm) in a period i and let PPcd95. where 95th percentile of precipitation on wet days in the baseline/projected period. If d represents the number of wet days in the period, then R95Pj=∑cc=1PPcd, where PPcd>PPcd9	mm
SDII	Intensity-based index	Wet-day intensity	Average precipitation from wet days. This can be defined as PPwj be the daily precipitation amount on wet days, w (PP ≥ 1mm) in period j. If w represents number of wet days in j, then SDIIj=∑ww=1PPwjW	mm/day
R20mm	Threshold-based index	Heavy precipitation days	Number of very heavy precipitation days (RR ≥ 20 mm). That is; let PPij be the daily precipitation amount where PPij≥20mm	days
CDD	Duration-based Index	Consecutive dry days	Maximum number of consecutive dry days (RR ≤ 1mm). Let PPij be the daily precipitation amount on day I in period j. Count the largest consecutive days where PPij≤1mm	days

Source : ETCCDI developed by Zhang *et al.* (2004); Zhang *et al.* (2011); Zhang and Yang (2017)

Projections of Precipitation and Temperature

Projections were done using data taken from the multi-model ensemble mean (MME) of eleven global climate model datasets within the Coupled Model Intercomparison Project Phase 6 (CMIP6). Akinsanola *et al.* (2021) indicate that the MME universally affords a better picture of observed precipitation and related extremes unlike individual models through an assessment of CMIP6 models in defining the statistics of precipitation extreme events over Eastern Africa; thus, the choice of the MME for this study. The 2021 IPCC sixth assessment report (AR6) structures new state-of-the-art CMIP6 models (Sahabi-Abed *et al.,* 2023). CMIP6 embodies the novel generation models that have been advanced in numerous features such as developments in specifications for concentration, emission, and land-use scenarios, better representation of synoptic processes, sophisticated spatial resolution, additional earth system processes and components such as ice sheets and biogeochemical cycles (O'Neill *et al.,* 2017; Malte *et al.,* 2020). A crucial element of CMIP6 lies in the simulation of climate change detected during the so-called historical period from 1850 to 2014 (Miller *et al.,* 2021), whereas the reproduction period ranges from 2015 to 2100. In this study, the patterns of extreme precipitation and temperatures were analysed for the long-term scenario 2100 relative to the reference period (1985–2014), under five different Shared Socio-economic Pathways (SSP). The "Shared Socio-economic Pathways" (SSPs) are new "pathways" that study how global society, demographics and economics might change over the next century (Sahabi-Abed *et al.,* 2023). This method was used for instance by Sahabi-Abed *et al.* (2023) and Avila-Diaz *et al.* (2022) and have proven valid results for climate extremes detection. Extreme temperature and precipitation events are the primary causes of hazards, such as heat waves, droughts, floods, and landslides, with local impacts. Thus, it is important to study these extremes to inform local and national climate adaptation planning and decision-making (Sillmann *et al.,* 2017).

SSP1 is sustainability-focused growth and equality. The SSP2-4.5 represents the "middle of the road" socio-economic family scenario with a radiative forcing reaching 4.5 W/m^2 by the end of the century and categorised by low challenges to mitigation and high challenges to adaptation. The SSP2-4.5 puts together intermediate societal vulnerability with an intermediate forcing level. Nevertheless, it is measured a more probable result (Fricko *et al.,* 2017; Van Vuuren *et al.,* 2017; Gidden *et al.,* 2019; Malte *et al.*, 2020). A fragmented world of "resurgent nationalism" corresponds to (SSP3). SSP4 is a world of ever-increasing inequality. The SSP5-8.5 marks the robust driving of the SSP scenario spectrum characterized by a high fossil-fuelled development and a world of rapid and unconstrained growth in economic output and energy use throughout the twenty-first century (O'Neill *et al.,* 2017; Riahi *et al.,* 2017; Gidden *et al.*, 2019; Malte *et al.,* 2020).

The study made use of GCMs datasets from 11 CMIP6 model simulations with the comprehensive first realization (r1i1p1f1). All the models elected are nearly high-resolution models and taken from the Royal Netherlands Meteorological Institute (KNMI) Climate Explorer website (https://climexp.knmi.nl/ accessed on 23rd December, 2022). A remapping method was performed to analyse and describe the CMIP6 multi-model ensemble mean (CMIP6-MMET) where the datasets were re-gridded to 1.25° × 1° based. The names and descriptions of the CMIP6 products used along with their institutions (acronyms), sources and spatial resolution are described in Table 3.2.

Table 3.2. Information of the elven CMIP6 climate models used

N	Models	Institution	Horizontal resolution (lat × lon)
1	CMCC-ESM2	Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy	1.0° × 1.25°
2	BCC-CSM2-MR	Beijing Climate Center (BCC) and China Meteorological Administration (CMA)	1.125° × 1.125°
3	MRI-ESM2-0	Meteorological Research Institute (MRI) Japan	1.125° × 1.125°
4	GFDL-ESM4	Geophysical Fluid Dynamics Laboratory (GFDL) USA	1.25° × 1.0°
5	FGOALS-g3	Chinese Academy of Sciences, Beijing China	2.0° × 2.25°
6	ACCESS-CM2	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), ARCCSS (Australian Research Council Centre of Excellence for Climate System Science)	1.875° × 1.25°
7	NorESM2-MM	NorESM Climate modeling Consortium Norway	1.25° × 0.9375°
8	NESM3	Nanjing University of Information Science and Technology, China	1.875° × 1.875°
9	MPI-ESM1-2-LR	Max Planck Institute for Meteorology	1.875° × 1.875°
10	INM-CM5-0	Institute for Numerical Mathematics, Russian Academy of Science, Russia	2.0° × 1.5°
11	KACE-1-0-G	National Institute of Meteorological Sciences/Korea Meteorological Administration	1.875° × 1.25°

Source: (NASA, 2022), Retrieved from https://data.nasa.gov/

All Analyses were performed using Python programming languages and graphs and plots are generated in Python Software version 3.11.2.

Objective 2: To determine the spatial and temporal LULC change and the main driving factors of changes in the Kara River Basin

3.2.1. Study area

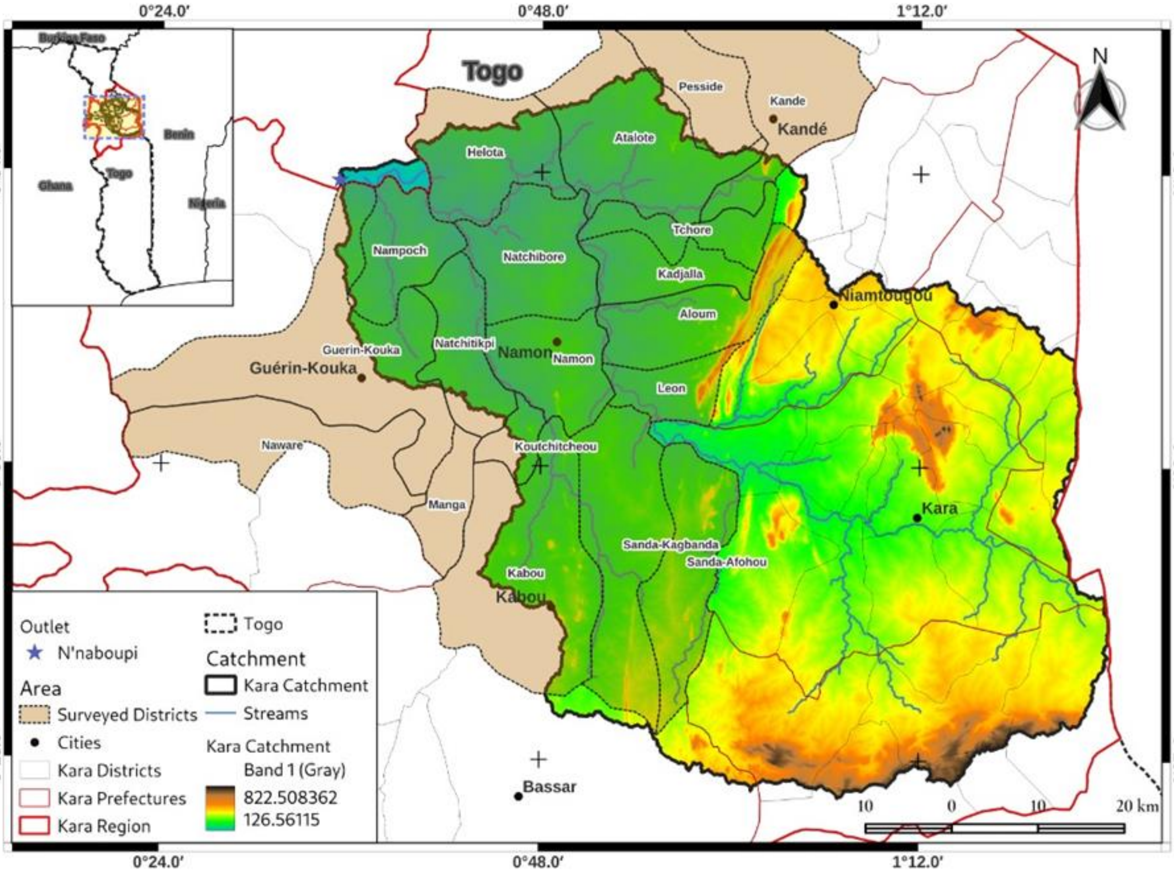


Figure 3.6. Map of the Kara River basin

Source: (Author, 2022)

3.2.2. Data Sources and Acquisition Methods

To examine the changes in land use and land cover (LULC), multi-temporal Landsat images were obtained for four dates at 30 m resolution (Mas *et al.,* 2019; Xu *et al.,* 2020) depending on the temporal and spatial availability of the scenes to cover the study area (Table 3.3). The selected periods were 1987, 2000, 2014, and 2021. Scenes were retrieved from the United States Geological Survey website (https://earthexplorer.usgs.gov/). The quality of such imagery data is enhanced if downloaded between end of rainy season and starting of the dry season to avoid clouds and cater for the exact areas under farming/cultivation (Ruelland *et al.,* 2010; Traore *et* *al.*, 2014). Therefore, the driest and cloudless months (December 2021 to February 2022) datasets were acquired to ensure the best quality. Multi-temporal satellite images concerned were Landsat TM (4) for 1987, Landsat ETM+ (7) for 2000, Landsat OLI (8) for 2014 and 2021. All images taken were previously geometrically corrected and georeferenced to the Universal Transverse Mercator (UTM) projection WGS84 zone 30 north. Table 3.3 presents the different Landsat datasets used.

Table 3.3. Satellite Imagery for LULC

S/No.	Satellite Name	Sensor Type	LULC Name	UTM Zone	Spatial Resolution
1	Landsat 4	TM	1987 LULC	30 N	30 × 30
2	Landsat 7	ETM+	2000 LULC	30 N	30 × 30
3	Landsat 8	OLI	2014 LULC	30 N	30 × 30
4	Landsat 8	OLI	2021 LULC	30N	30 × 30

Source: (USGS, 2021), Retrieved from https://earthexplorer.usgs.gov/)

3.2.3. Data Analysis and Images Processing

One of the advantages of the remote sensing techniques resides in the cost and labor saving coupled with swift reflection of large-scale forest changes over the long term. The combination of remote sensing and traditional method to supply validation data has been widely used in forest inventory. Nevertheless, the classification accuracy connected with using remote sensing is affected by many factors, such as the classification techniques, training samples, and the signal reflected from objects. LULC images were treated using pixel-based classification and post-classification comparison methods. Thirty random points were collected for each land use type to train and confirm the classification. Image calibration of the four-time steps was done using ground truth (survey data), archived geo-referenced points (30 in total) of each land use type of the following years from available statistics (DSID, 2017) and Google Earth historical records. Supervised classification was completed using Maximum

Likelihood Classifier and a post-classification technique was introduced to originate the extended cross-tabulation matrix for land use change and intensity analysis (Wang, 1990; Sisodia *et al.,* 2014) using ENVI software version 5.6. This technic was extensively used in the geospatial literature and previous publications as it helps to provide valid results.

3.2.4. Accuracy Assessment

Geometric errors, misclassifications, and undefined classes can disturb land classification and produce errors. To statistically account for these errors, a random selection of pixels of the classified maps was made to build a confusion matrix (Obahoundje *et al.,* 2017). The confusion (error) matrix technique entails a series of numbers displayed in rows and columns representing the number of pixels or polygons for a given land cover class compared to the actual class on the ground (Congalton, 1991; Kohavi, 1998). It is used to obtain descriptive and analytical statistics in the assessment of classification accuracy (Congalton, 1991; Smits *et al.,* 1999; Foody, 2002; Jensen, 2005).

In order to validate the land cover classification, an accuracy assessment in the form of an error matrix was performed as suggested by previous studies (Foody, 2002; Alrababah & Alhamad, 2006; Manandhar *et al.,* 2009; Koc *et al.,* 2012) and the kappa coefficient was used as the statistical parameter. The kappa coefficient (K) determination given by Equation 4, is utilised in accuracy valuation of thematic maps. It is an effective method to derive information from an image via the confusion matrix.

The kappa coefficient is given by the Equation 8:

$$K = \frac{N\sum_{i=1}^{r} x_{ij} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}$$

(Equation 8)

where r is the number of rows in the matrix, *ij x* is the number of observations in row i and column i, *i x* + and *i x*+ are the marginal totals of row i and column i, respectively, and N is the total number of observations.

If K > 0.80 represents strong agreement and good accuracy; K between 0.40 and 0.80 indicates a moderate accuracy, and K < 0.40 signifies a poor accuracy (Kpoti *et al.*, 2016).

Producer and user accuracies are computed as suggested in Fung and LeDrew (1988) to obtain the average accuracy. Producer accuracy is the probability of correctly classifying a reference pixel, while user accuracy is the probability of classifying a pixel on each map representative of the actual soil class or actual location (Congalton, 1991, Jensen, 2005, Campbell, 2007). The overall accuracy and producer's accuracy constructed on the generated confusion matrix were computed using Equation 9. Spectral signature analysis of satellite images has recognised five main classes of land use.

$$\text{Overall accuracy} = \frac{\text{Number of corrected pixel}}{\text{Total number of elected pixel}} \times 100 \quad \text{(Equation 9)}$$

3.2.4.1. Main Driving Factors of LULC Change

Mixed-methods serve to make a diagnostic in land change studies. Through social valuation using focus group discussions, land change drivers could be judged using qualitative data. Besides LULC change detection through remote sensing technics, it is vital to identify the set of drivers (either direct or indirect) that cause changes observed within the landscapes over times. Cheong *et al.* (2011) and Sarfo *et al.* (2022) applied these mixed methods to appreciate the drivers of land cover and land use in their various areas of research. The mixed method was used to categorise the driving factors of LULC change in the Kara River Basin. Previous attempts relied mostly on secondary data, and this current approach will make use, in addition to secondary data and satellite imageries, of primary data derived from focus group discussions organised with local communities. Figure 3.7 illustrates the procedure and workflow for the analysis of the driving factors of LULC change used for this study.

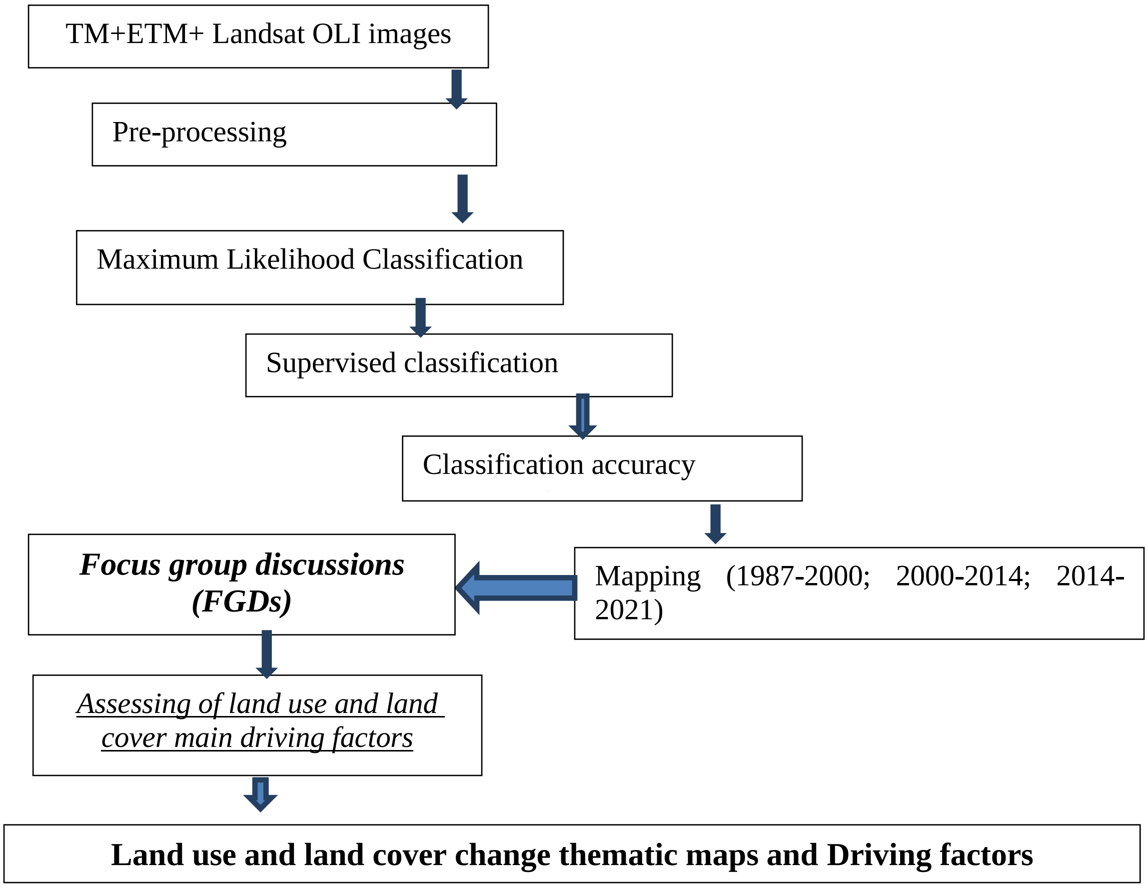


Figure 3.7. Methodological Flowchart of the analysis of the driving factors of LULC change

After having produced the thematic maps to derive the spatial and temporal LULC change, 38 focus group discussions (FGDs) were held with the selected communities to evaluate the potential driving factors for the changes detected on the land use maps over time (1987-2000; 2000-2014, and 2014 to 2021). Participants (above 50 years) form the FGDs to ensure that relevant and accurate information on LULC are provided from community elders. LULC maps and graphs were exhibited in the sessions in the form of posters to the participants. The land cover changes observed on the posters over time were clearly described to the groups for discussion on the potential drivers of LULC change in the landscape.

Participants were asked to score the potential driver on an interval score from 0 to 5 for each direct or indirect driving factor. The following scores were used: 0 = no effect, 1 = low effect, 2 = medium effect, 3 = relevant effect, 4 = high effect, and 5 = very high effect. The mean value for each factor was calculated using EXCEL software and the comparative frequency of each factor was drawn using bare 2D. The score of each indicator was presented as the mean score given by all the groups, helping to determine the level of the effect on LULC changes. The higher the score, the more likely it is ranked as a main driving factor. Population data for years 1987, 2000, 2014 and 2021 were collected from the 2010 national census (INSEED, 2010) obtained from the National Institute of Statistics, Demography and Economics Studies (https://inseed.tg/statistiques-demographiques/) and population growth computed using the following Equation 10:

$$Pn = Po * (1 + r)^{n} \text{ (Equation 10)}$$

where Pn is the population projection for year x, Po is the population at the beginning, r is the growth rate, and n is the number of years (Dansoko, 2015).

Pearson correlation analysis was calculated between population growth data and land use/cover classes in the last 30 years (1992 to 2021). The postulation for the Pearson statistic is that the association to be tested is a linear one. Correlation was calculated among LULC classes to distinguish probable specific changes. The outcome was easy to derive as per Equation 11.

$$r = \frac{C(xy)-C(x)C(y)}{\sqrt{CxxCyy}} = A \mid A \mid \ = \ \pm 1 \text{ (Equation 11)}$$

If y and x are exactly linearly related, r = ±1, dependent on whether the slope is positive or negative (correlation or anti-correlation). With real data of any kind, there will be a spread in the values of x and y, in which case the correlation will be less than maximal, i.e., [r] < 1 (Sedgwick, 2012).

Objective 3: To model farmers' decisions to on climate, land use changes and water availability for agriculture in the Kara River Basin

3.2.5. Stakeholder Analysis

A participatory tool called Net-Map could be useful to conduct a stakeholder mapping. Adopted from Schiffer (2007), it is a consultation technique to produce a map of stakeholders based on their influences and power relationships. This helps to visualize, understand and allows discussions of the processes that include many actors whose interaction influence outcomes. The researcher plays the role of facilitator to enable participants/stakeholders to examine official and informal interactions among stakeholders; helping to foster comprehension of the group's approach, strategies, and activities.

The tool consists of gathering information primarily from the actors. Information was then assembled through group consensus, interviewee similarities and differences. Respondents also explained why they thought an actor should be included after nominating one. The actors' relationship and power flows were then depicted. The influence scores were then assigned to each actor card, with 0 indicating no influence and 5 indicating the greatest degree of influence. Finally, each actor was ranked based on their active care for a sustainable use of land and water resources in the basin.

3.2.6. Description of SESAM: A Social Learning Integrative Model Approach

According to Kim (2016), farmers' decision-making for agricultural land uses and crop choices affect regional land systems and their choices have nascent features, which lead to diverse responses to policy guidelines dependent on policy types. Therefore, a thorough understanding of farmers' decision-making processes is necessary for formulating management plans for sustainable and climate-resilient ecosystems. In the process of getting information on awareness of farmers on LULC, inputs to model households' decisions to climate, land use changes and water availability for agriculture in the Kara River basin were accessed through the survey questionnaire and serve for simulation later with farmers during scenario evaluation using SESAM concept, a serious game.

To end, we need to describe farmers' behaviour in order to simulate how "complex emerging rules often raise from simple individual behaviours and interactions" (Ferber, 1994). Therefore, serious games are foreseen to model the decisions of farmers. One of the serious games being employed recently is called SESAM (Scenario Evaluation for sustainable agroforestry management) for sustainable agroforestry landscape management (van Noordwijk *et al.*, 2020).

For this particular study, the SESAM model is used to understand the choices made by farmers on their plots and what the consequences of these choices are on the ecology and economy within the realm of the landscape. The choices may be based on the values, customs, beliefs and knowledge (local ecological knowledge, local cultural knowledge, local social knowledge, scientific ecological knowledge) of farmers about water and land use and land cover change and climate change and the effects of some external factors. The term "serious gaming" is increasingly used in local stakeholder-based participatory projects. In the SESAM, participatory approaches are highly sought. A multitude of example of games are developed in the SESAM programme. One of the gamed scenario evaluations for sustainable agroforestry management called FOREO-Ups (Farmer choices and its risk on economic and ecological context for upper watersheds) was adapted from Sari *et al.* (2023) in Indonesia for use in this study. The model applies to the conditions in the middle and upper watershed.

For this study, the FOREO-Ups will be called FCREE-Kara Basin (Farmers' choices and its risk on economic and ecological conditions of the Kara Basin), a plot scale board game adapted for middle and lowlands within the Kara River basin (as in Table 3.4).

This plot-scale board game aims to: (1) investigate farmers' choices regarding land management and test their adaptability to external pressures; and (2) accommodate the self-learning process regarding how their choices affect the economic and ecological context of their farms and in-fine the landscape. The selection of plant species is an illustration of the kind of land management, and the results are what matter. For farmers in the lower to middle watershed, the game was made for one farmer to play on their own. The costs of production and labour, income, as well as water balance (water infiltration and runoff) and erosion, will all be clearly recognisable as a result of farmer decisions regarding land management. Depending on the type of land management and the climate representing the real-life situation, tokens representing litter, water, and soil show the effects on the environment.

The game includes some of the external pressures, and it tests how they deal with (1) natural disasters caused by a prolonged drought, (2) social conflict with a neighbouring farmer over a lack of water, (3) a drop in price, and (4) social influence through farmer group agreement. Economic as well as ecological benefits are impacted by external pressures. During the game's land management selection, the facilitator (the researcher) observed and inquired about reasons for decision-making, including farmers' level of satisfaction with their decision.

Table 3.2. Information about the FCREE-Kara Basin's game

Form	3D board game
Player	individual farmer
Time	50-60 minutes
Rounds	15 rounds (one round represents one year)
Goal	To play the whole game session that consists of 15 rounds by maintaining the default plot setting (2 soil tokens and one water token) and earning at least three water tokens infiltrate to the soil at the end of the game

Source: Adapted from Sari *et al.* (2023)

3.2.6.1. Game Components

The eco-hydrological dynamic model of the watershed is simplified in a 3D game environment, carrying the player into real-world situations and providing a better representation of the real world. Tokens, SESAMoney, a deck of cards, and three-dimensional boards make up the game's components. The game board comprises 24 connected hexagons, each 3 m x 3 m, that can be filled with a specific plant species (tree or annual crop) to create mixed or monoculture land management strategies. The game depicts a piece of land or field in the upper or middle watershed, where the ditch or river flows from the top to the bottom of the board (Fig. 3.8a). The board uses the default streamflow, which puts the river outside the plot. Tokens came in four varieties:1) the plants shown in Fig. 3.8b, the litter, the water, and the soil shown in

Fig. 3.8d. The plant species can be tailored based on their dominance in the area. There were two different sets of cards:1) dynamic cards (Fig. 3.8c) and labour cards (Fig. 3.8e). There are 15 labour cards in the set. These cards tell players how many laborers are available each round so that they can fulfil the requirement for labour. The 15 cards in the dynamic set depict the weather variations that emerge in each round, whether there is additional pressure or not (Figure 3.8).

Figure 3.8. Component of the game: a-3D board game, b-plants tokens, c-dynamic cards, d-tokens: water, litter, soil, e - labour cards, f-SESAMoney (Sari *et al.*, 2023)

3.2.6.2. Procedure to Set up the Game

1. Tokens (Figure 3.8b, d, e)

Plant tokens are divided into several categories: a) trees categories: fruits, timber, legume; b) annual crops: horticulture c) fodder crops. In the game, the fruits category can be mentioned as the species name directly, such as mango, etc. depend on the specific local context. The number of tokens that need to be prepared is 24 tokens for each plant category. Tree tokens can be prepared for less than 24 since it was typically chosen for a shade. These disparities can be adjusted based on the local context.

2. Labour cards (Fig 3.8e)

The number of available labours in this session was determined into two variations: one and two labourers. Prepare eight cards of one labour and seven cards of two labours, arrange it sequentially from one to two labourers. The difference number of labour can be adjusted based on the local context.

3. Dynamic cards (Fig 3.8c)

The dynamic card represents the climate variation that emerged in each round, either wet or dry year. The arrangement of dynamic cards can be seen in Figure 3.9 and Appendix II. Additionally, external pressure will be introduced every four rounds. The structure of climate and external pressures can be modified and adjusted based on the objective and local context.

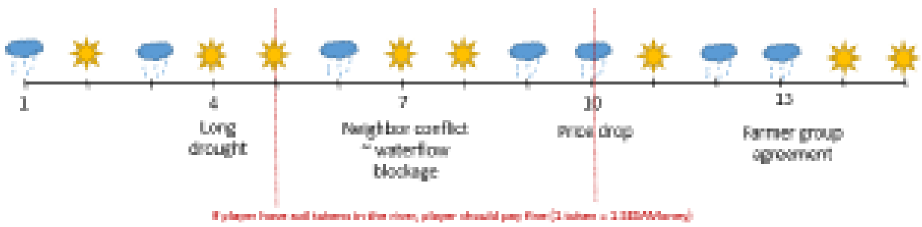


Figure 3.9. The sequential order of dynamic cards represents climate and external pressure that may emerge during 15 game rounds
Source: (Sari *et al.*, 2023)

4. Set up the 3D board (Fig 3.8a)

Set up the board game as in Appendix II. The default setting of 3D board at the beginning of game session contains 2 soil tokens and 1 water token. This condition should be met before the player can harvest and obtain income in each round.

Game points and external pressures

There were six types of land management options available that can be chosen by the farmer (Table 3.5). Each land management type has its consequences on production cost, labour, and income, including water balance and erosion, determined by climate variation. Table 3.6 was presented to the farmer at the beginning of the game session to select the type of land management they prefer. While Table 3.6 is a lookup table for the facilitator to operate the ecological consequences. In this context, Table 3.5 was scaled from the farmer interview on the cost and benefit of various farming systems.

The costs and revenues reflect the financial calculation of each land management in real-life. Production cost includes fertilizers, pesticides/herbicides, and irrigation. Table 3.6 was produced based on the simplification of simulation results of various combinations of plant composition adapting to Togo’s context. Tables 3.5 and 3.6 can be modified based on land management domination in the local context.

Table 3.3. Production cost and income obtained based on different land-use systems and land management

Land use system	Type of land management	Production cost	Labor	Income	
				Normal	Dry
Mixed	Shade trees + understorey species	2	2	8	6
	Shade trees + understorey species + crops	3	3	9	6
	Tree + crops	3	3	9	6
Monoculture	Tree	5	3	15	9
	Napier grass	3	2	9	5
	Annual crops	8	4	25	13

Source: (Sari *et al.*, 2023)

Note: When the farmer pays these costs, the default setting of the plot will be restored (2 soil tokens and 1 water).

Table 3.5: Litter, water, and soil tokens that represent local ecological consequences of various land-use system choices

Land use system	Type of land management	Number of tokens (Wet-2-tokens)			Number of tokens (Dry-1-token)		
		Litter	Water infiltration	Runoff water	Litter	Water infiltration	Runoff water
Mixed	Shade trees + understorey species	2	2		2	1	
	Shade trees + understorey species + crops	1	1	1	2	1	
	Tree + crops	1	1	1	1	1	
Monoculture	Tree	1	1	1	1	1	
	Napier grass		1	1		1	
	Annual crops			2			1

Source: Adapted from Sari *et al.* (2023)

Note: The number of soil tokens that wash away to the river equal to the runoff water tokens

The appearance of external pressures affects the economic and/or ecological benefits. The explanation of each external pressure is represented in Table 3.6, while its effect on game points is described in Table 3.7.

Table 3.6. External pressures definition and its effect on income and ecological risk

Round-External pressure	Definition in the game	Income consequences	Ecological risk
Round 4-Long drought	A prolonged drought, affecting yield and environment condition	Crops failure or yield reduction	Two water tokens will be subtracted from the field or pay more irrigation cost for 2 SESAMoney
Round 7-Neighbour conflict on water blockage	Neighbour farmers blockage the ditch and use the water to irrigate their plot	Pay more irrigation cost to bring back 1 water token in the plot to meet the default setting	Crop failure or yield reduction due to lack of irrigation or no effect when paying additional irrigation cost
Round 10-Price drop	The market price of a dominant commodity significantly decreases	Reduced 50-75% depending on management type and plant diversity	No effect
Round 13-Farmer group agreement	Offer to change to particular land management as what agreed in farmer group	Increase of income	Based on the management type

Source: Adapted from Sari *et al.* (2023)

Table 3.7. The consequences of external pressures on the game points

Round	Conditions	Availability	Income reduction				Ecological conse-quences	Additional cost
			Mixed	Tree mono	Grass	Crops		
4	Water token?	Yes	50%	50%			-2 water tokens*	
		No			100%	100%		
7	Water token?	Yes						+1 SESAMoney
		No						
10	Monoculture?	Yes		75%	75%	75%	Based on the type of land management	
		No with < 3 species	60%					
		No with > 3 species	50%					
13	Follow the offer to change?	Yes	Current incentive + 10%				Based on the type of land management	

Source: Adapted from Sari *et al.* (2023)

Note: *If the player doesn't have a water token, they should pay with SESAMoney (1 token = 1 SESAMoney)

3.2.6.3. Game Rules

1. If a farmer decides to change:

a. The type of land management from monoculture crops or grass to tree-based land management (tree monoculture or mixed system), or

b. The composition of tree species A to B in the whole board of mixed system,

The farmer needs to wait for one more round to harvest and receive income. In this case, the farmer will receive the same ecological consequences as previous land management choices since trees need longer to grow and provide both production and environmental function.

2. If farmers only change a few plant species without changing the type of land management, it can be ignored and don't change the consequences because the kind of land management is the same.

3.2.6.4. Game Play

The gameplay is a sequential 15 rounds defined by climate dynamics and four external pressures. The dynamics cards represent yearly weather variations that determine the climate in each round, including when the external pressure will appear. Each round in the game session consists of the following five phases: (1) Choosing the type of land management by selecting plant species on the board; (2) Paying the production cost and labour requirement to make sure that the default plot requirement is met; (3) Opening dynamic cards to determine either wet or dry year; (4) Receiving income and ecological consequences on water balance and erosion; (5) Evaluating the benefit obtained and satisfaction level of their decision. In this stage, farmers will consider whether they will maintain the current system or change to another type of land management (Fig 3.10).

At the start of the game, the farmer has a 3D board that is filled with annual crops, initial capital (15 SESAMoney), labour (cards), and default condition of board (1 water and 2 soil tokens, see Appendix II).

In the first round, the crops field is simulated with the intention of trial and giving the experience of how monoculture crops provide economic and ecological consequences at the plot scale. After experiencing these, farmers are allowed to choose another type of land management freely in subsequent rounds.

How does the game work in each round? (Fig 3.10)

When farmers fill the board with chosen plant species, it will form a particular type of land management. After the dynamic card is opened to determine the climate that appears, farmers will receive income. The ecological benefit will be obtained by adding litter, water, and soil tokens to the 3D board. When farmers choose a mixed system, litter tokens will be added to the board on top of soil tokens (Fig 3.10 (4)). It will visualize that litter protect soil from erosion when the rain comes. Litter token can reduce the production cost in the following round since the litter provides organic matter input, reducing fertilizer use. Only one litter token can be used to reduce production cost (1 litter token = 1 SESAMoney). Two water tokens will be added in the wet year and one for the dry year. These water tokens (all or part of it) can infiltrate the soil or become runoff depending on the current land management type (Table 3.5). Runoff water will bring the soil token in the board to the river when there is no protection from the litter. As the consequences of these, farmers need to pay a fine every five rounds if they have soil tokens accumulated in the river (Fig 3.10, a soil token = paying fine of 1 SESAMoney). At the end of each round, the default plot condition might not meet. The default plot condition will be restored when the farmer pays the production cost in the next round.

Figure 3.10. Five phases of the game session in each round, (1) selecting plant species, (2) paying production cost, (3) opening dynamic cards, (4) receiving the consequences, (5) evaluating the benefits from Sari *et al.* (2023)

- **Step by step instruction for facilitating game session (for facilitator)**

1. Give a brief introduction to the farmer about (1) the game topics and the objectives (2) game environment: board game, type of land management options, and (3) the consequences that may arise (Table 3.5), including ecological benefit on water balance and erosion in general.

2. Explain (1) the benefit of having litter, water, and soil tokens on the board (litter token ➔ can be reduced production cost for the next round, soil tokens in the river ➔ paying a fine in every five rounds); (2) game rules.

3. The farmer played with monoculture crops in the first round and filled the board with crop tokens. Make sure that to set the default setting of the board (Appendix II).

4. Give as much as 15 SESAMoney for the initial capital for paying production

cost.

5. Start the game session by explaining that they need to meet the default board setting, which contains 1 water and 2 soil tokens in each round to harvest.

6. Request farmer to pay production cost and labour needed for crops system in Table 3.5. Take one labour card to determine how much available labour is in this round. If the available labour is less than the requirement, the farmer should rent the labour by paying 1 labour for 1 SESAMoney.

7. Open the dynamic cards to determine the climate. The farmer receives the income based on the type of land management and climate appeared (Table 3.7).

8. Check ecological consequences in Table 3.8 whether there is any addition of litter token, water token that infiltrates to the soil or becomes runoff, or soil token that might wash away and accumulate to the river.

9. Assist farmers in evaluating the benefits both in terms of income and ecological consequences. Ask the farmer whether they are satisfied with the current condition or not by placing emoticon stickers in the board game (3 levels: satisfy, neutral, dissatisfy)

10. Moving to the second round, farmers can decide freely whether they want to maintain the current type of land management or change to another option. In this stage, the facilitator observes the reason behind this decision (Table 3.8).

11. When a farmer has their decision, continue steps 6 - 10 (Fig 3.10) until 15 rounds are reached. Check whether they have litter tokens or not to reduce the production cost.

12. Check every five rounds (the end of rounds 5, 10, and 15) whether farmers need to pay a fine for the cost of river cleaning due to sedimentation accumulation from soil tokens.

13. When the external pressure appears in rounds 4, 7, 10, and 13, check Table 3.7 for applying the consequences.

14. The game session ends at 15 rounds. Accumulate the total income, litter, water tokens (water infiltration) and check whether the default board setting at the beginning of the game is maintained or not.

15. Evaluate the results and check whether the player can reach the goal by accumulating a minimum of 3 water tokens and maintaining the initial board condition.

16. Start debriefing session by asking their feeling after playing the game, highlight that their decision on choosing a specific type of land management will give consequences not only for income but also for their plot condition (less soil cover increase erosion, top 'fertile' soil eroded and decrease soil fertility)

17. At the end of debriefing, assist the farmer in filling evaluation form (Appendix III).

- **Debriefing and post-interview**

The facilitator guided the conversation during the debriefing session with the intention to (1) clarify what happened in the game in terms of the consequences of farmer land management choices on the economy and ecological benefits; (2) discuss their experience during the game about the key reasons that determine farmers' decision making on changing their land management during the game, including in response to external pressures emerged; (3) The game impact based on player perspective

Follow up interview will be performed after the debriefing session to assess the impression of the farmer about their experience playing this game (playability, time spent, complexity, and the benefits – Appendix III).

3.2.6.5. Data Collection

1. The player's land management choices, including the game point, were recorded in Table 3.9.

2. The game board containing a particular land management type with one or various plant species compositions was captured in every round or when the land management type changes. The game board of round 15 was captured as well.

3. All conversations during the game session will be fully recorded, aiming that all qualitative information can be considered as data support during the game session.

Table 3.9. Observation table in each round during the game by the facilitator

Round	Plant species*		Change?		Production Cost	Income	Number of tokens				
	Mix	Mono	Y/N	Why? **			Litter	Water infiltration	Water runoff	Soil erosion	Water available for farming
1											
2											
3											

4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
Total											

Source: (Author, 2023)

*The distribution of plant choices will be captured in each round

**the reason farmers change the system whether it depends on economic benefit, ecological/cultural functions, maintenance, market, or another social aspect (neighbour or group agreement. All communication will be recorded during the plot level game.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSIONS

4.1. Socio-Demographic Characteristics of Respondents

4.1.1. Socio-Demography and Diagnostic of Climate and Land Management Issues

Table 4.1. Demographic characteristics of surveyed farm household heads

Variables	Percentage of respondents (%)	Variables	Percentage of respondents (%)
Gender		**Age**	
Female	11	<30 years	4
Male	89	30-40 years	10
Marital status		41-50 years	29
Single	2	51-60 years	40
Married	89	>60 years	17
Divorced	3	**Educational level**	
Widowed	6	Primary	34
Household size		Secondary	20
<3	9	Tertiary	5
[3-7]	70	Koranic	1
>7	21	Never attended school	40
Marriage type		**Ethnic groups**	
Monogamy	69	Kabye	61
Polygamy	31	Konkomba	16
Origin of respondents		Lamba	5
Autochthonous	92	Tem	3
Migrants to Kara basin	8	Tchokossi	5
Before 1987	0	Bassar	5
1987-1990	20	Fulhani	2
1991-2000	20	Nawda	2
2001-2010	36	Ewe	1
After 2010	24		

Source: (Field work, 2021)

Socio-demographic features of the respondents (Table 4.1) showed that the majority were male-headed household (89%); female-headed household (11%) were underrepresented in our survey relative to the 20% of female-headed household in the national agricultural surveys (MAEP, 2013). The fraction of respondents that were married (89%) also exceeds that (79.7%) in the national agriculture census of 2013 (MAEP, 2013). Almost 60% of respondents have ever attended school while 40% did not. Most respondents are from a household of a size comprised between [3-7] followed by those above 7 members. The active group is above 40 years of age. 97% of respondents own lands that are obtained from three ways: heritage (60%), clearing (27%) and gift (10%).

Table 4.2. Socio-economic profile of the respondents

Variable	%	Variable	%
Farming experience		**Belonging to a structured group**	
<10 years	6	Yes	37
10-20 years	12	No	63
21-30 years	41		
>30 years	41		
Land tenure		**Land ownership types**	
Freehold	97	Inherited	87%
Leasehold	3	Rented	13%
Farmland topography		<2ha	>2ha
Flat	81	40%	60%
Swamp	59	46%	54%
Sloping	53	44%	56%
Perceived Farm Soil fertility		**Change in soil fertility over the last 3-years**	
Low	69	Decreased	94
Moderate	28	Unchanged	5
High	3	Increased	1
Available land size *vs* land need		**Is land becoming scarce?**	
Little	3	Scarce	91
Small	58	Unchanged	7
Average	36	Abundant	2
Sufficient	3		
Farm labour type[A]		**Permanent workforce** (pers.)	
Household	90	<3	23
Hired	65	3-7	53
Mutual aid	63	>7	14
		Seasonal workforce (pers.)	
		<3	26
		3-7	40
		>7	34
Farmer properties[A]		**Sources of cooking energy**[A]	
Radio	85	Fuel wood	97
TV	42	Charcoal	45
Phone	57	Crop residues	1
		Manure	1
		Others (specify)	1
Motorcycle	34	**Time spent to collect source of energy**	
Bicycle	10	<1hour	61
Car	1	>1hour	39
Access to power supply	22	**Distance to collect a source of energy**	
Grinding/milling machine	6	0-2km	58
		3-5km	34
		>5km	18

A. Multiple answers possible

Source: (Field work, 2021)

Three types of terrain in the landscape are flat terrain, slopes, and swampy areas. Most of the farmers own more than 2 ha of land which are flat, swamp or sloping or a combination of two or three of these land types. A majority of farmers indicated low fertility of their farmlands (69%) while farm fertility was seen as decreasing in almost all farmlands of the respondents over the last 3-year period particularly. Available land for agricultural activities is seen to becoming scarce in the area by most of the locals interviewed.

Table 4.3. Other livelihoods, road network and commercialization, and accessibility to farming inputs

Variable	%	Variable	%
Other source of livelihoods, beyond crops		**Distance to the nearest main road**	
Livestock	72	<5km	50
Petty trading	21	5-10km	22
Horticulture	1	11-15km	16
Sale of petroleum products	2	>15km	12
Taxi driver	3	**Distance to the nearest secondary road**	
Others	1	<5km	66
Chemical fertilizer usage		5-10km	26
<100kg	20	11-15km	18
100-500kg	64	**Distance to the nearest water body**	
501-1000kg	11	<5km	60
>1000kg	5	5-10km	26
Fertilizer expenditure		11-15km	12
<$100	55	>15km	2
$(100-200)	25	**Distance to the nearest village market**	
$(201-400)	15	<5km	72
>$400	5	5-10km	25
		11-15km	2
		>15km	1
Did your farming revenues cover family needs during the past 5 years?		**Distance to the nearest main market**	
		<5km	57
Yes	17	5-10km	20
No	83	11-15km	13
		>15km	10

Source: (Field work, 2021)

Besides crop farming activities, livestock represents the largest livelihood strategy employed by the locals. However, farming revenues seem not to cover household needs. Distance to potable water point, road and market are relatively within the range of 5 km.

4.2. Data Presentation on Research Issues

Objective 1: Assess the perception and awareness of farmers on climate, land use and land cover changes (LULC) and traditional strategies for climate-resilient multifunctional landscapes in the Kara River Basin

4.2.1. Perception and Awareness of Farmers on Climate, Land Use and Land Cover Changes and Traditional Strategies for Climate-Resilient Multifunctional Landscapes

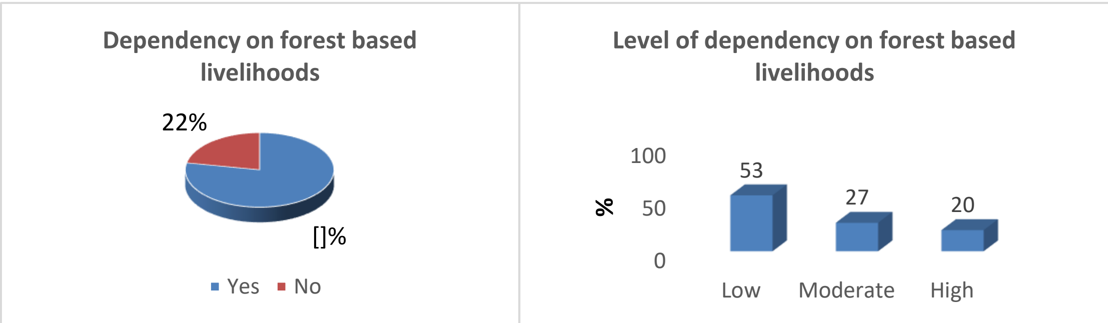


Figure 4.1. Farmers' dependence on forest products

Source: (Field work, 2021)

The majority (78%) of the farmers reported to also draw their livelihoods from forests with almost close to the half (47%) perceiving their dependency on forest related livelihoods as moderate to high (Figure 4.1).

Local knowledge about climate change in the river basin

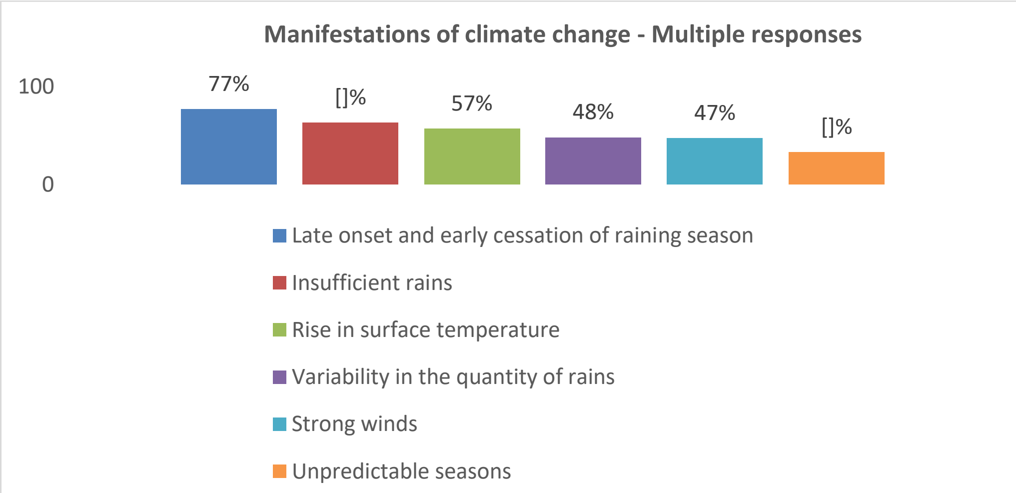


Figure 4.2. Local knowledge about climate change

Source: (Field work, 2021)

As indicated in Figure 4.2, the late arrival and early cessation of the raining period was mentioned by 77%, insufficient rains by 63%, a rise in surface temperature by 57%, variability in the quantity of rains by 48%, strong winds by 47% and unpredictable seasons by 33% as clear manifestations of climate change in the basin.

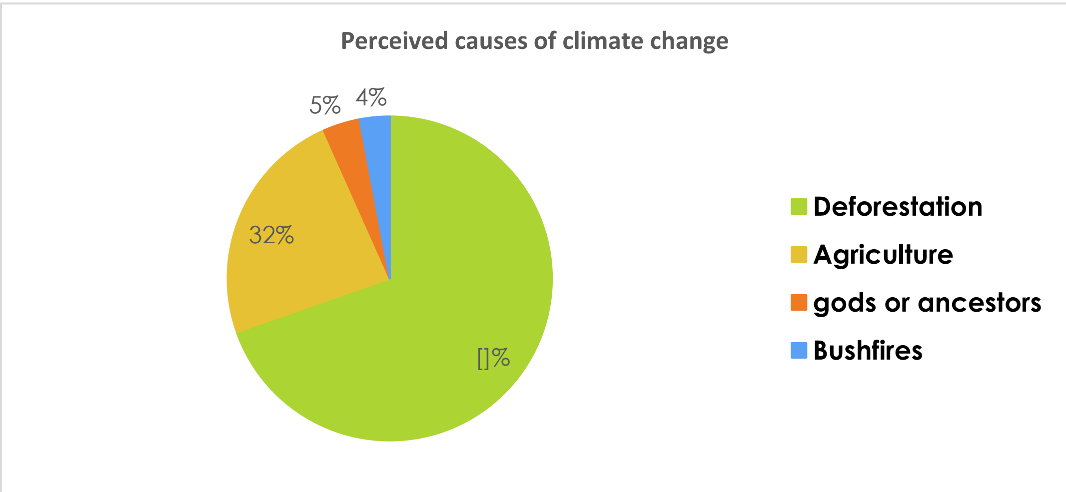


Figure 4.3. Farmers' perceived causes of climate change

Source: (Field work, 2021)

Respondents attributed climate change primarily to deforestation (94% agreed). Attribution to agriculture (32%) was the second factor, with only 5% and 4%, respectively, attributing climate change to 'gods or ancestors' and 'bushfires' (Figure 4.3).

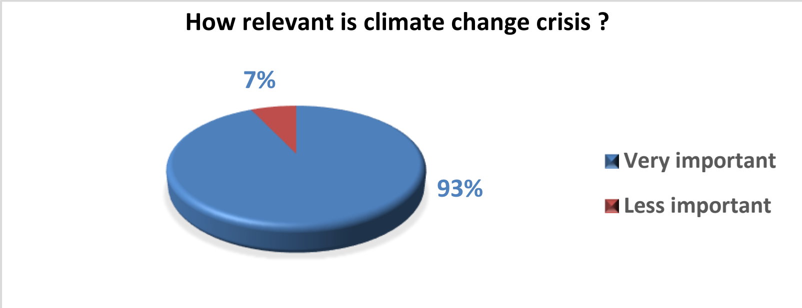


Figure 4.4. Relevance of climate change to local peoples
Source: (Field work, 2021)

The vast majority of respondents (93%) agreed that the climate change crisis is 'very important' to them, and only 7% found it to be 'less important' (Figure 4.4).

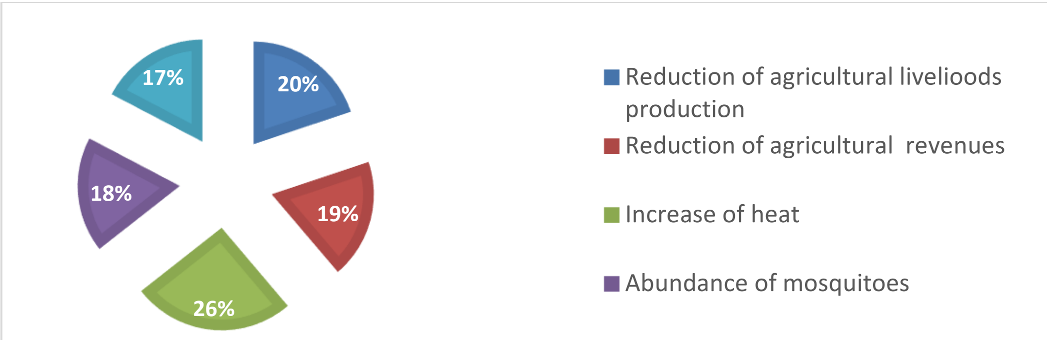


Figure 4.5. Reasons for the relevance of climate change to local peoples
Source: (Field work, 2021)

Reasons pointed out by farming households to explain the relevance of climate change issues are illustrated in Figure 4.5 as increase of heat (26%), reduction of agricultural livelihoods' production (20%), reduction of agricultural revenues (19%), abundance of mosquitoes and soil fertility decline or decrease (17%).

Land degradation issues in the river basin

- *Relation between livestock and land degradation issues*

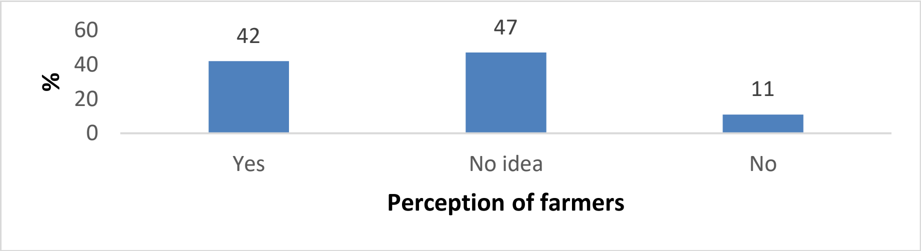


Figure 4.6. Contribution of livestock to land degradation
Source: (Field work, 2021)

The majority of respondents (47%) has no idea about any causal relationship between livestock keeping and land degradation whilst 42% see a relationship and 11% declared that there is no causal relationship between livestock keeping and land degradation in the basin (Figure 4.6).

Figure 4.7. Erosion on farmlands
Source: (Field work, 2021)

A majority (62%) of the respondents has observed erosion on their farmlands and 38% declared no observed erosion of their farmlands (Figure 4.7).

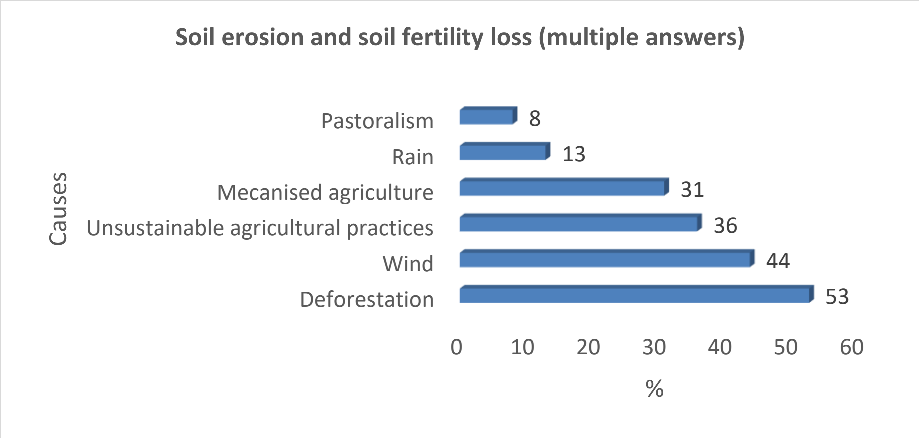


Figure 4.8. Causes of soil erosion and soil fertility loss in the Kara River Basin
Source: (Field work, 2021)

The following are considered by the respondents to be the causes associated to soil erosion and soil fertility loss in the river basin. These are in order of frequency deforestation, wind, unsustainable agricultural practices, mecanised agriculture, rain, and pastoralism (Figure 4.8).

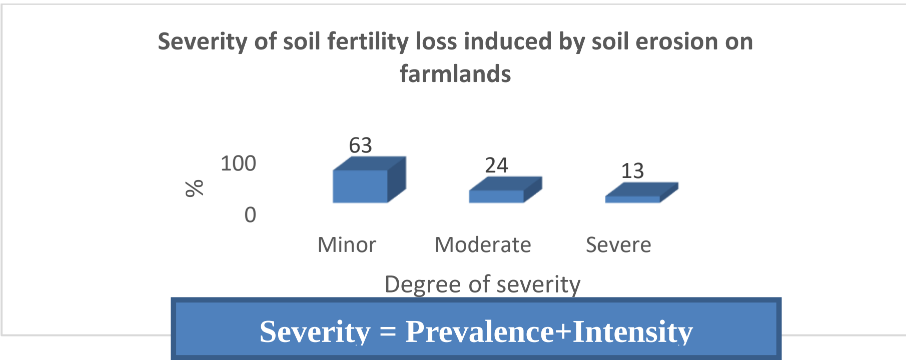


Figure 4.9. Severity of soil erosion and soil fertility on farmlands
Source: (Field work, 2021)

The severity of soil erosion and induced soil fertility loss were rated by the locals from minor to severe where 37% perceived the problem as moderate to severe (Figure 4.9). Farmlands within the multifunctional landscapes seem to be very much under pressure regarding the few available lands (91% of households declared that land is scarce, as indicated in Table 4.2).

- *Changes in the multifunctional landscapes of Kara River basin*

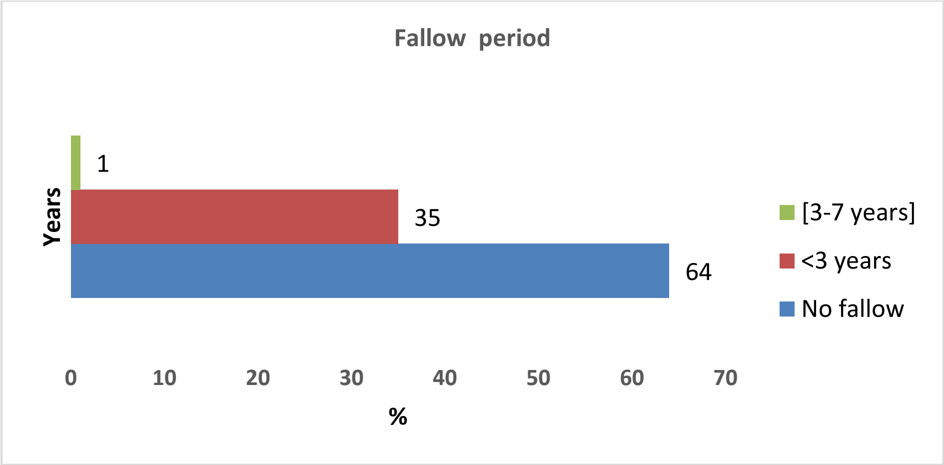


Figure 4.10. Farming fallowing in the landscapes
Source: (Fieldwork, 2021)

The majority of the respondents (64%) declared not putting their farms under fallow unlike 35% and 1% who declared to be employing less than 3 years and more than 3 years of fallowing period, respectively (Figure 4.10).

- *Changes in forest-based livelihoods product*

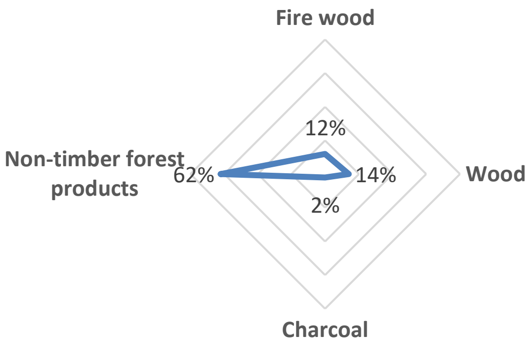


Figure 4.11. Scarcity of forest-based products
Source: (Fieldwork, 2021)

The area has seen a decrease in the availability of forest-based products that serve as livelihoods for the communities. Hence, non-timber forest products represent the scarcest products to be found in the area (62%) followed by wood (14%), firewood (12%) and charcoal (2%) (Figure 4.11).

Farmers' perspectives on the causes of land conversion

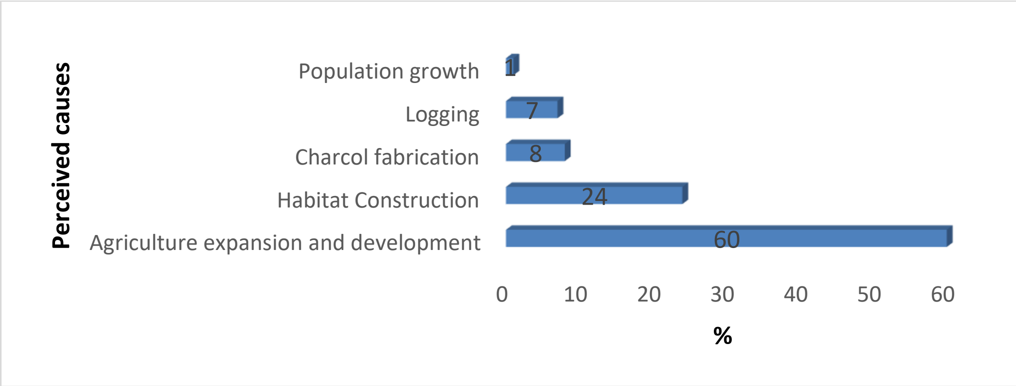


Figure 4.12. Causes of land conversion/land transition
Source: (Fieldwork, 2021)

Farmers perceived agriculture expansion and development (60%) followed by habitat construction (24%) to be among the major causes of land conversion in the area (Figure 4.12).

Land use/land cover change induced soil fertility loss implications for food security

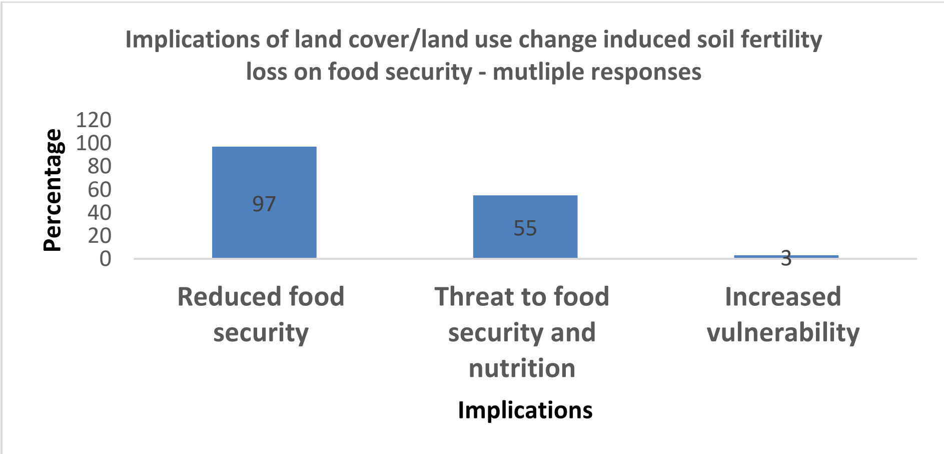


Figure 4.13. Implications of land cover/land use changes induced soil fertility loss on food security
Source: (Fieldwork, 2021)

Changes resulted from land cover and land use induced by human activities (agriculture, building, charcoal production, and logging, etc.) have many implications in terms of increasing food insecurity and ultimately, increased vulnerability. Over exploitation of resources (water, land, forest) provided by the multifunctional landscape by humans is majorly leading to reduced food security (97%), which poses a malnutrition threat (55%) and subsequently increased vulnerability for the communities (Figure 4.13).

Local farmers' perceived effects of climate, and land use and land cover change on soil fertility, rural livelihoods and revenues

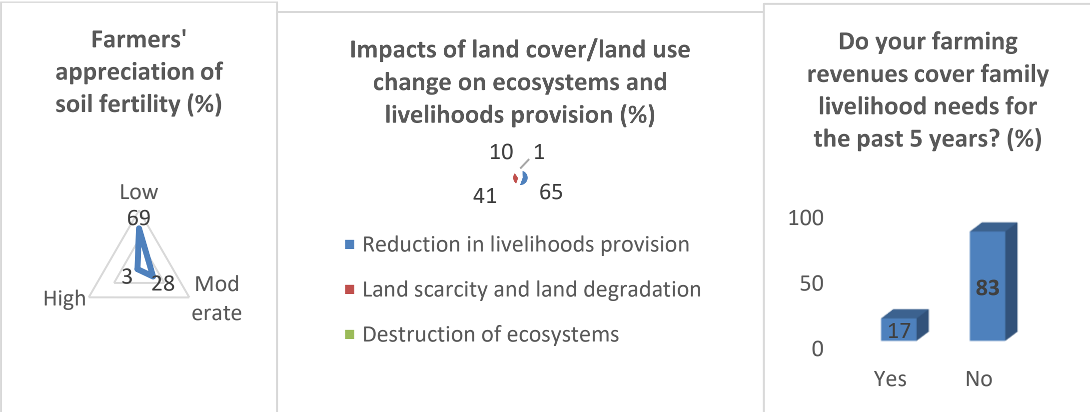


Figure 4.14. Impacts of climate, and land use and land cover change on soil fertility, livelihoods, and revenues

Source: (Fieldwork, 2021)

The majority of respondents (69%) see soil fertility to be low. At the same time, 65% preponderantly attest that land cover and land use changes have negative impacts on livelihoods provisioning of the landscape. It is said by the majority of the peoples (83%) that farming revenues seem not to cover family needs (Figure 4.14).

Local knowledge of soil erosion induced soil fertility loss biophysical indicators

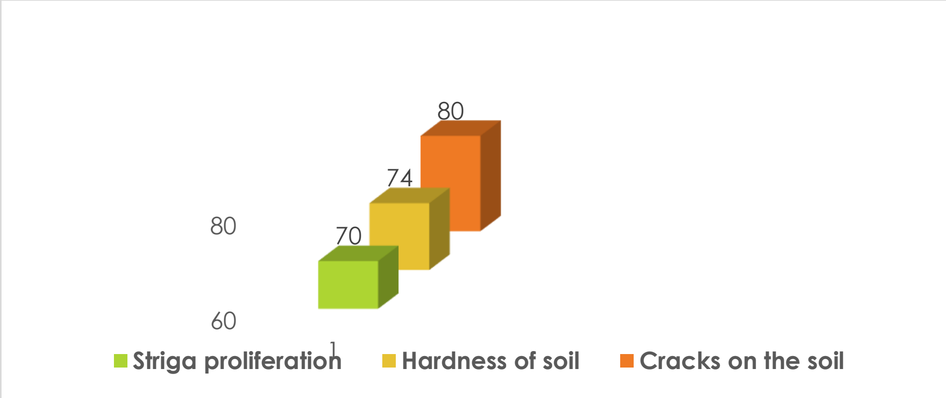


Figure 4.15. Perceived biophysical indicators of soil fertility decrease
Source: (Fieldwork, 2021)

The majority of the farmers revealed the perceived biophysical indicators of soil fertility decrease to be 1. Cracks on the soil (80% of the respondents), 2. Hardness of the soil (74%) and 3. Striga proliferation (70%) (Figure 4.15).

Local solutions: climate and land use strategies to manage soil fertility loss

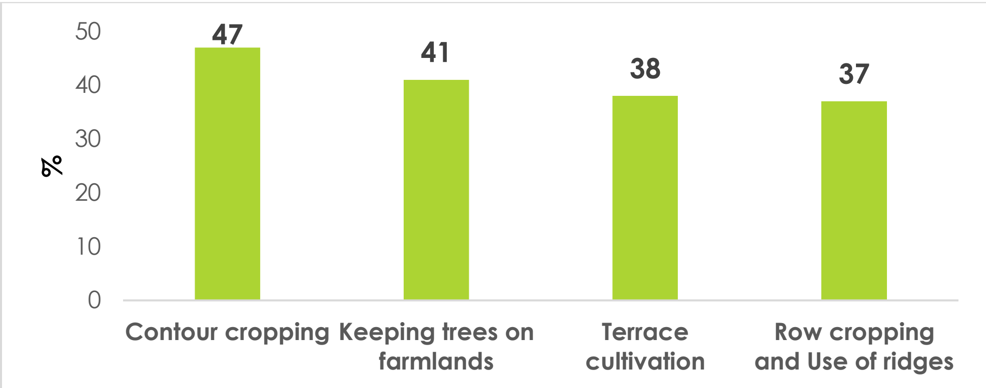


Figure 4.16. Local and traditional measures to prevent soil fertility loss
Source: (Fieldwork, 2021)

These strategies include mostly, contour cropping (47%), reducing cutting down trees on their farms (41%), terrace cultivation (38%), and row cropping with use of ridges (37%) to mitigate soil erosion effects on their farmlands (Figure 4.15).

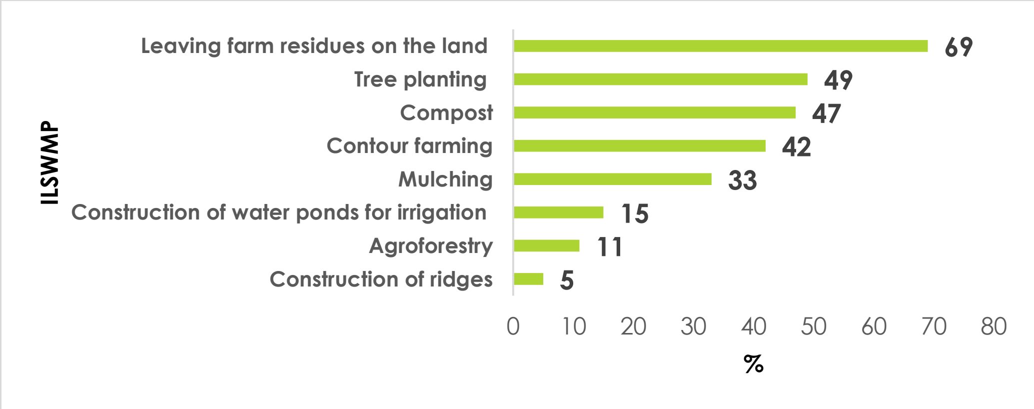


Figure 4.17. Integrated local soil and water management practices (ILSWMP)
Source: (Fieldwork, 2021)

In terms of the integrated local soil and water management practices (ILSWMP) used by farmers, leaving farm residues on the land (69%), tree planting (49%), compost (47%), contour farming (42%), mulching (33%) and others (water ponds, agroforestry, construction of ridges) were the employed techniques by the respondents (Figure 4.17).

Farmers' perceived importance of ILSWMP

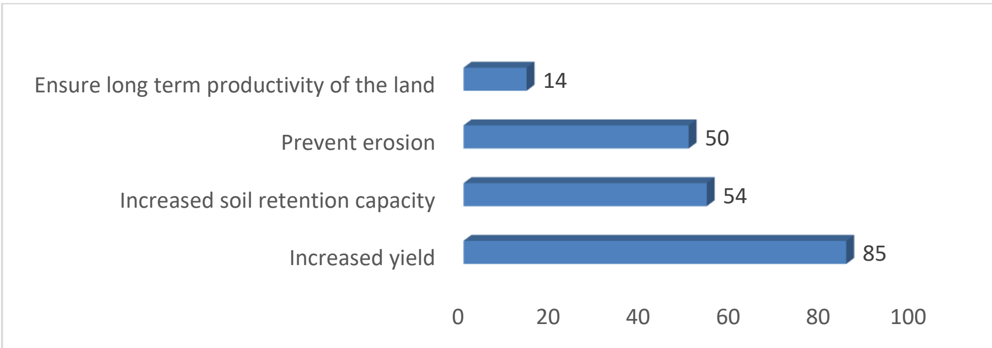


Figure 4.18. Perceived effects of ILSWMP on farming activities
Source: (Fieldwork, 2021)

In terms of importance, the ILSWMP are well perceived in the area to be beneficial in increasing yields (85%), augmenting soil retention capacity (54%), preventing soil erosion (50%) and ensuring long term productivity of the farmland (14%) (Figure 4.18).

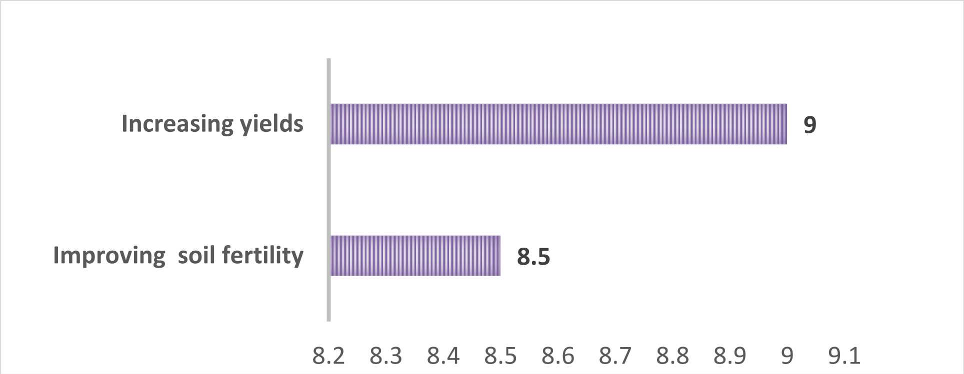


Figure 4.19. Performance of local solutions to adapt to land degradation and soil fertility decline from farmers' perspective

Source: (Fieldwork, 2021)

The utilisation of local solutions by farmers to handle climate and land use-induced land degradation was seen by the majority of farmers to perform well. The rating on a scale of 1 to 10, farmers rated 8.5 for improving soil fertility and 9 for increasing yields with respect to their performance (Figure 4.19).

4.3. Computing the Climate Change Awareness Index (CCAI)

Table 4.4. CCAI Computation

	Questions	**Weight**	**Max. score**	**Scale of score**	**Max. weight**
1	Have you heard of the term "climate change/global warming"/" Greenhouse Effect"?	10	50	Yes … 50 No … 0	500
2	How often do you talk to your friends, family, and partners about things that relates to climate change?	4	20	Everyday … 20 Sometimes … 10 Not often … 5 Never … 0	800
3	How important is climate change to you personally?	8	40	Very important … 40 Important … 30 Not really important … 10 Not important at all … 0	320
4	How would you describe your knowledge on the likely causes of climate change?	8	40	Very much … 40 Average … 20 Little … 10 None … 0	320
5	Can you name three major effects of climate change?	8	40	Yes… 40 No … 0	320
6	What do you think are the effects of climate change in your area?	8	40	More than 3 good effects … 40	320

				Three good effects … 30 Less than three good effects … 20	
7	What is the most effective way to combat climate change effects? Do you think that something can be done to solve climate change?	8	40	Yes … 40 No … 0 I do not know … 0 Maybe …. 10	320
8	Did you already involve yourself in any kind of climate change causing activity?	5	25	Yes … 25 Somehow … 15 Not really … 10 No … 0	125
9	Did you already involve yourself in any kind of climate change management related activity?	5	-25	Yes … -25 Somehow … -15 Not really … -10 No … 0	-125
10	Do you wish to involve yourself in any kind of climate change management related activity in future?	5	25	Yes … 25 Somehow … 15 Not really … 10 No … 0	125
11	Human being is responsible for climate change	10	50	Yes … 50 Maybe … 25	500

				No … 0	
12	The effects of climate change are already being felt in my area	8	40	Yes … 40 Maybe … 20 No … 0	320
13	I have a responsibility to act against climate change	4	20	Yes … 20 Maybe … 10 I don't know … 5 No … 0	320
14	The government has a responsibility to undertake steps to mitigate and adapt to climate change	6	30	Yes … 30 Maybe … 15 I don't know 7 No… 0	180
	Total 1				*4345*

Source: Adapted from Rahman *et al.* (2014)

Table 4.5. Calculation of the CCAI

Question	Weight	Option 1	Option 2	Option 3	Option 4	Answers 1	Answers 2	Answers 3	Answers 4	Calculation
1	10	50	0	0	-1	95	0	0	5	474.5
2	4	20	10	5	0	65	10	0	25	56
3	8	40	30	10	0	93	0	0	7	297.6
4	8	40	20	10	0	54	0	0	46	172.8
5	8	40	0	0	0	59	0	0	41	188.8
6	8	40	30	20	0	59	0	0	41	188.8
7	8	40	10	0	0	36	0	0	64	115.2
8	5	-25	-15	-10	0	0	90	0	10	-67.5
9	5	25	15	10	0	85	5	0	0	110
10	10	50	25	0	0	65	0	0	35	325
11	8	40	20	0	0	95	0	0	5	304
12	4	20	10	5	0	61	0	0	39	48.8
13	6	30	15	7	0	47	0	0	53	84.6
									SUM	2298.6
									CCAI	53/100

Source: (Author's computation, 2022)

The climate change awareness index (CCAI) in the study area is equivalent to ~ 0.53 meaning a moderate awareness of the respondents about climate change phenomenon in the area. Such findings could be as a result of awareness is not simply to know if climate change is real or not but here the definition of awareness goes beyond the simple response "yes" or "no" if you have heard about climate change.

4.4. Computing Land Use and Land Cover Change Awareness Index (LULCCAI)

Table 4.6. LULCCAI Computing

S.n	Questions	Weight	Max score	Scale of score	Maximum weight
1	Have you heard of the term "land transition"/" land use change"/land cover change"?	10	50	Yes … 50 No … 0	500
2	How often do you talk to your friends, family, and partners about things that relates to land cover/land use change?	4	20	Everyday … 20 Sometimes … 10 Not often … 5 Never … 0	80
3	How would you describe your knowledge on the likely causes of land cover and land use change?	8	40	Very important … 40 Important … 30 Not really important … 10 Not important at all … 0	320
4	Can you name three major effects of land use/land cover change?	8	40	Yes… 40 No … 0	320
5	What do you think are the effects of land use/land cover change?	8	40	More than 3 good effects … 40 Three good effects … 30	320

				Less than three good effects … 20	
6	What is the most effective way to combat land use/land cover change effects?	8	40	Yes … 40 No … 0 I do not know … 0 Maybe …. 10	320
7	Did you already involve yourself in any kind of land use/land cover change causal activity?	5	25	Yes … -25 Somehow … -15 Not really … -10 No … 0	-125
8	Did you already involve yourself in any kind of land use/land cover change management related activity?	5	25	Yes … 25 Somehow … 15 Not really … 10 No … 0	125
9	Do you wish to involve yourself in any kind of land cover change management related activity in future?	5	25	Yes … 25 Somehow … 15 Not really … 10 No … 0	125
10	Human being is responsible for land cover, land use change	10	50	Yes … 50 Maybe … 25 No … 0	500

11	The effects of land cover and land use change are already being felt in the area	8	40	Yes … 40 Maybe … 20 No … 0	120
12	I have a responsibility to act against land cover and land use change	4	20	Yes … 20 Maybe … 10 I don't know … 5 No … 0	80
13	The government has a responsibility to undertake steps to reduce land cover and land use change for a sustainable land use management	6	30	Yes … 30 Maybe … 15 I don't know 7 No… 0	180
	Total 2				*2685*

Source: Adapted from Rahman *et al.* (2014)

Table 4.7. Calculation of LULCCAI

Question	Weight	Option 1	Option 2	Option 3	Option 4	Answers 1	Answers 2	Answers 3	Answers 4	Calculation
1	10	50	0	0	0	0	0	0	100	0
2	4	20	10	5	0	80	10	20	0	72
3	8	40	30	10	0	30	0	0	70	96
4	8	40	0	0	0	65	0	0	35	208
5	8	40	30	20	0	65	0	0	35	208
6	8	40	10	0	0	40	0	0	60	128
7	5	-25	-15	-10	0	100	0	0	0	-125
8	5	25	15	10	0	20	0	0	80	25
9	5	25	15	10	0	90	0	0	5	112.5
10	10	50	25	0	0	83	0	0	17	415
11	8	40	20	0	0	100	0	0	0	320
12	4	20	10	5	0	87	0	0	13	69.6
13	6	30	15	7	0	47	0	0	53	84.6
									SUM	1613.7
									LULCCAI	60/100

Source: (Author's computation, 2022)

Land use and land cover change awareness index (LULCCAI) in the river basin is about 0.60 (Figure 4.7), denoting a relatively high awareness level of respondents about land use dynamics in the study area. It transpires from the respondents a high awareness of land use and land cover change as compared to climate change in the study area. These findings could signify that changes in the vegetation cover are more noticed and visualized than climatic and weather changes by the local communities.

4.5. Computing the climate change and land use and land cover change awareness index (CCLULCCAI)

The Climate Change and Land Use and Land Cover Change Awareness Index (CCLULCCAI) computed for the study is approximately 0.57 meaning respondents are fairly aware of climate change and land cover and land use change in the study are; thus, a moderate awareness level of the issues of climate change, land use and land cover change.

4.6. Climatology of the Kara River basin

Findings about the climatology in the Kara River basin revealed climate variability, seasonality of rainfall, trend analysis, climate indices, and projected climate in the future. These results are presented as follows. Analysis of precipitation data for Guerin Kouka indicates an inter-annual variability of rainfall from 1985-2014 as per Figure 4.20.

4.6.1. Rainfall/Precipitation Variability

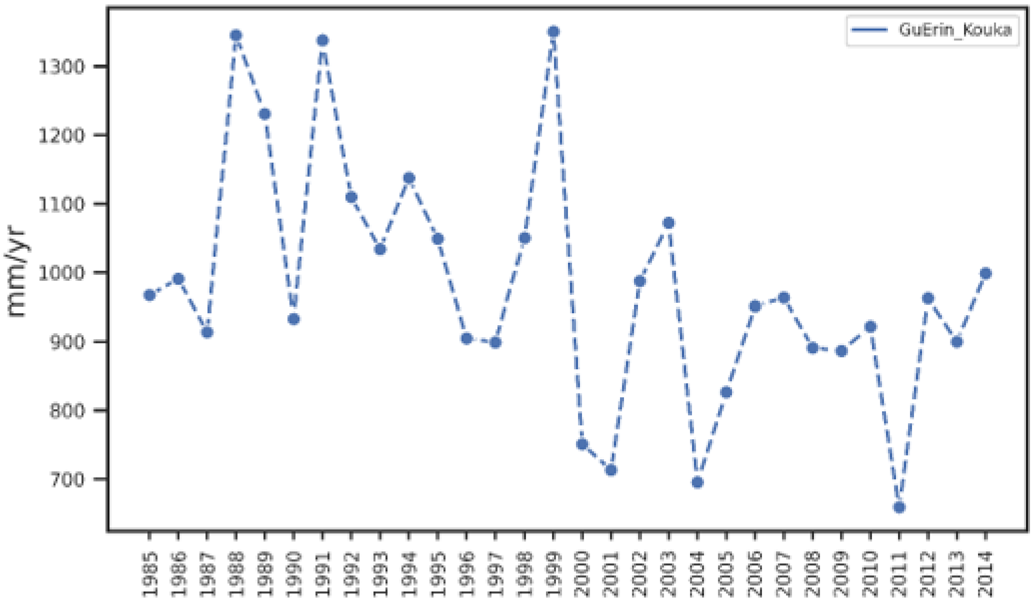


Figure 4.20. Rainfall Variability at Guerin Kouka

Source: (Author's computation, 2022)

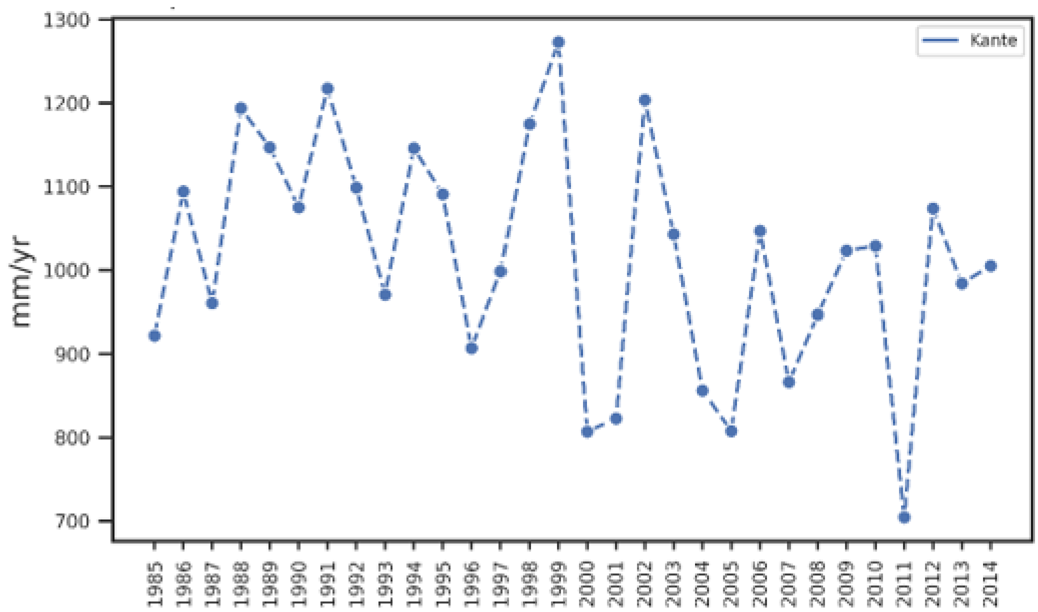


Figure 4.21. Rainfall Variability at Kante

Source: (Author's computation, 2022)

Analysis of precipitation for Kante also showed an inter-annual variability, which may have some implications of water availability for agricultural activities (Figure 4.21) as previously seen at Guerin Kouka.

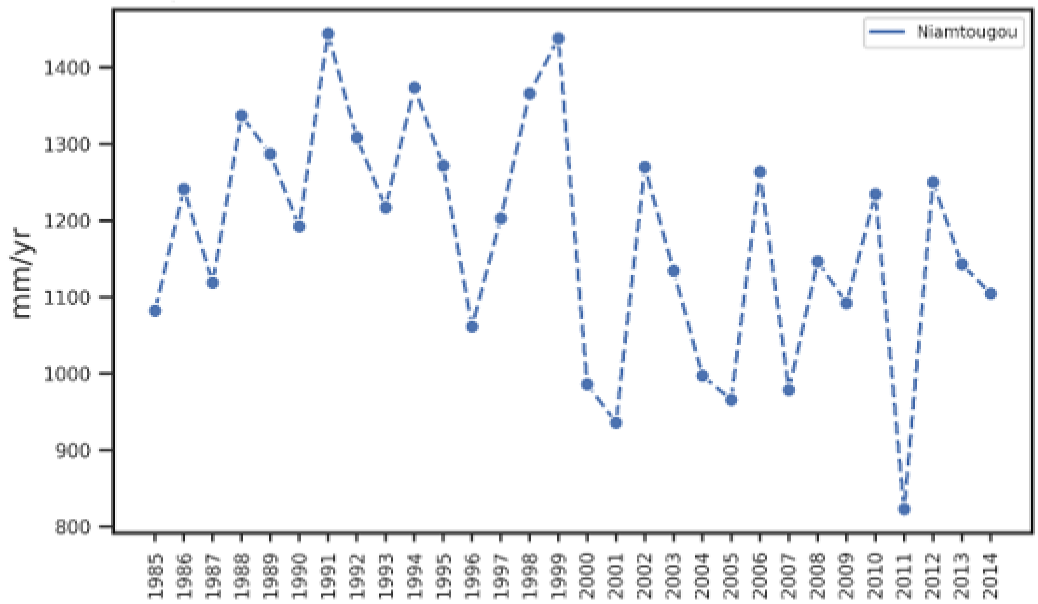


Figure 4.22. Rainfall Variability at Niamtougou

Source: (Author's computation, 2022)

Analysis of data for precipitation at Niamtougou in Figure 4.22 revealed an inter annual variability.

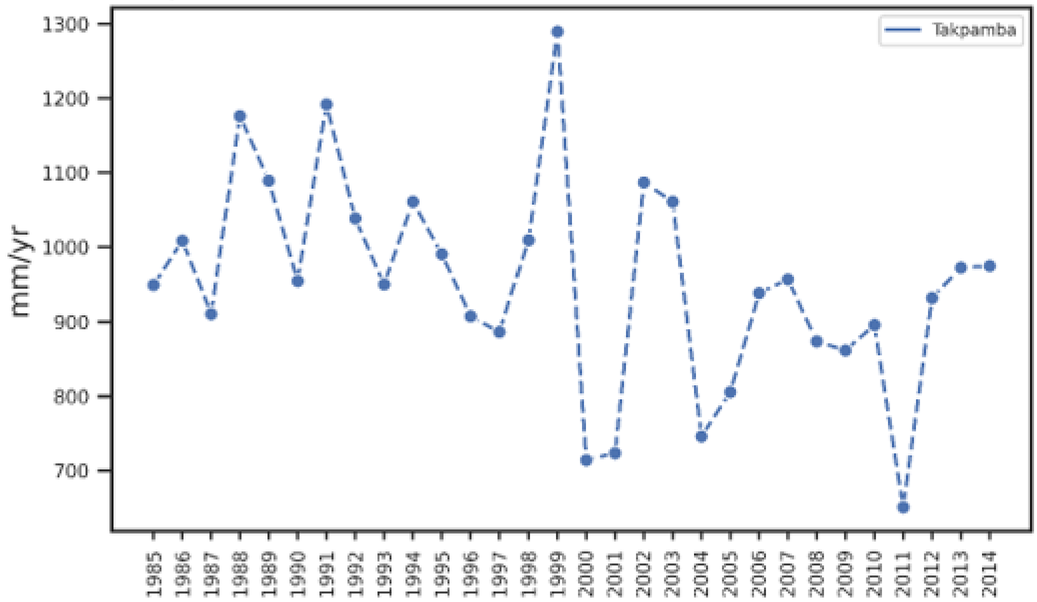


Figure 4.23. Rainfall Variability at Takpamba
Source: (Author's computation, 2022)

The analysis of data for precipitation in Takpamba revealed also an inter annual variability over 1985-2014 as in Figure 4.23.

4.6.2. Analysis of Standard Precipitation Indexes (SPI)

SPI is an index symbolising meteorological drought over some time periods. On a small timescale, the SPI relates to soil moisture, whereas at longer time periods, it speaks to groundwater and reservoir storage. SPI is a hydrological drought indicator, based on valuation of the runoff (or streamflow) of a specified basin, typically spreading over a specific period of time.

The following graphs illustrate the findings of SPI for Guerin Kouka, Kante, Niamtougou and Takpamba stations respectively.

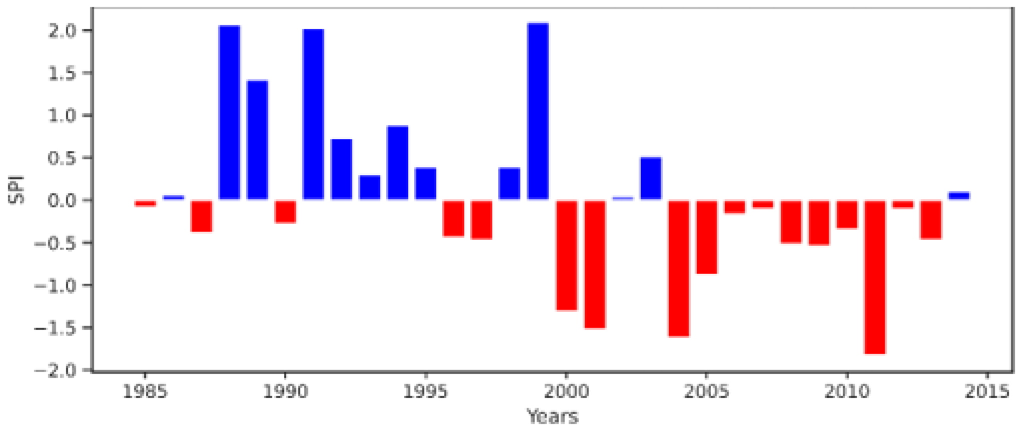


Figure 4.24. Standardized Precipitation Index (SPI) at Guerin Kouka

Source: (Author's computation, 2022)

Most years show a deficit in precipitation between 1985-2014 for Guerin Kouka (Figure 4.24). 13 years over 30 show normal to excessive precipitation while 17 years recorded low rainfall and deficit. In this particular location of the basin, the driest year is 2011 (SPI= -1.75), followed by 2004 (SPI= -1.5), 2001 (SPI= -1.4) and 2000 (SPI= -1.25). It indicates that the driest periods experienced in Guerin Kouka were in the last twenty decades (starting from 2000 to 2014).

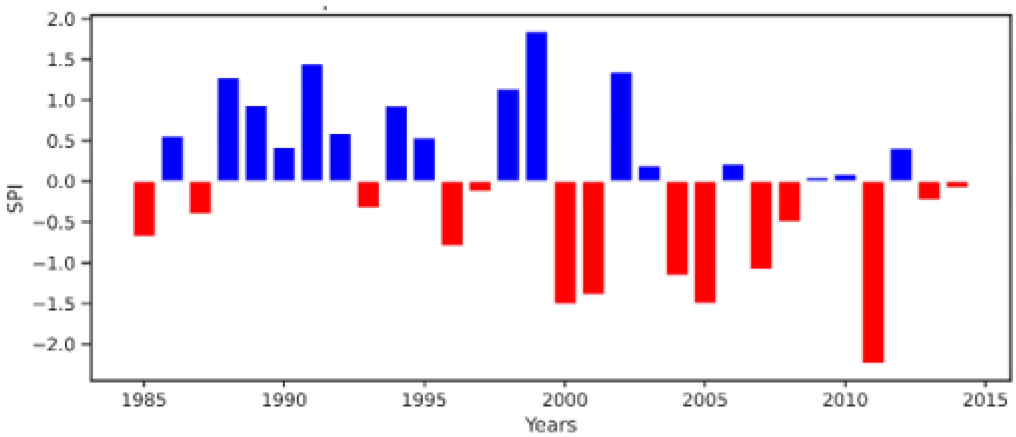


Figure 4.25. SPI at Niamtougou

Source: (Author's computation, 2022)

Kante recorded 14 dry years from the period 1985 to 2014 (as in Figure 4.25); meaning low rainfall were observed for the 14 years. In the meantime, 16 years were wet seasons globally with highest excesses recorded in 1999, 2002, 1991 with respectively 1.75, 1.25 and 1.4 of SPI.

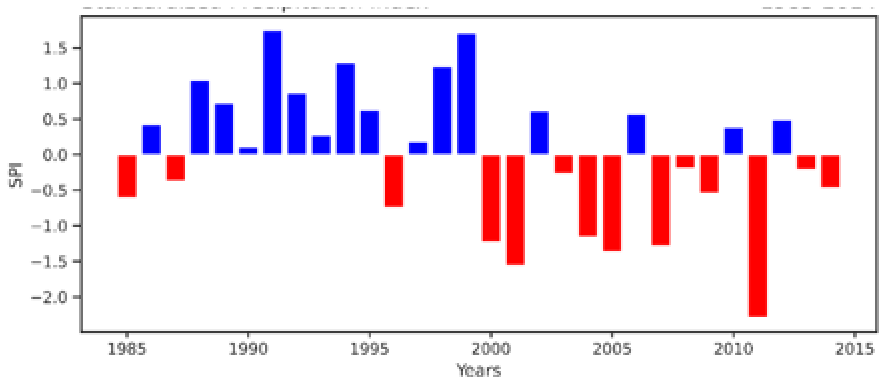


Figure 4.26. SPI at Kante
Source: (Author's computation, 2022)

The SPI here indicated more wet years in Niamtougou with a number of 16 years recording normal to high precipitations SPI above 1.5 for years 1999 and 1991 having the highest SPI (Figure 4.26). On the other hand, 14 years recorded the very low SPI such as 2011, 2007, 2005, 2000 and 2001 among others for respectively values SPI= < -2, SPI= -1.4, SPI= -1.5, SPI= -1.4. These are the driest years observed in this part of the river basin.

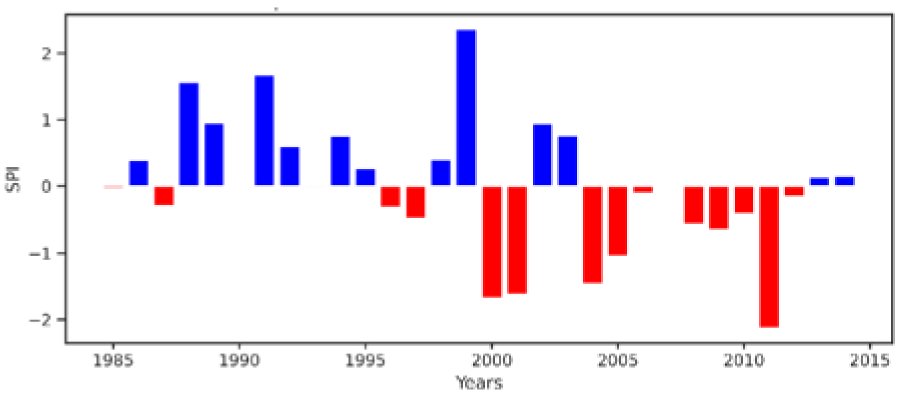
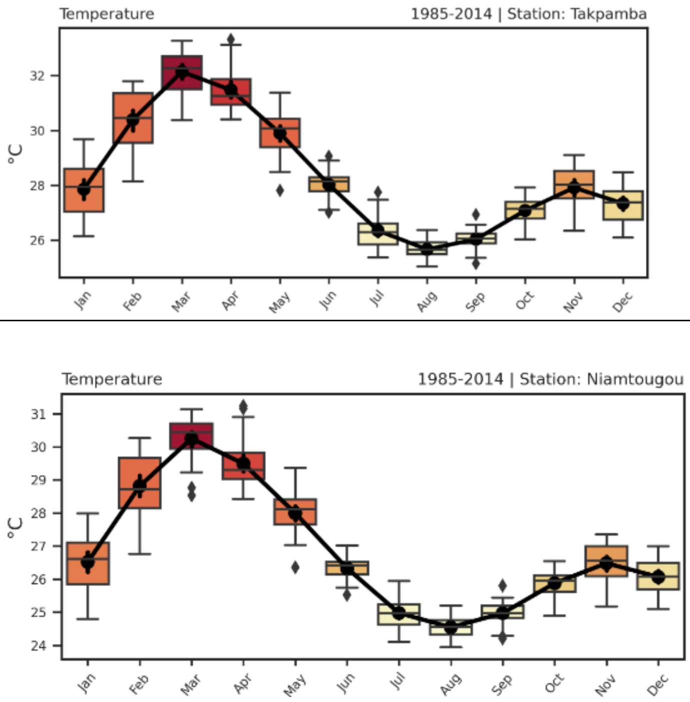


Figure 4.27. SPI at Takpamba
Source: (Author's computation, 2022)

At Takpamba, normal to high precipitations outweighed the number of dry years with a number of 16 wet years and 14 dry years (Figure 4.27). The highest excesses of precipitation were SPI= >2, SPI 1.7, and SPI= 1.5 recorded in 1999, 1991 and 1989, respectively. Here again the driest years recorded started from the period post 2000.

In summary for all the studied locations, dry periods are been observed more and more from year 2000 and onward. This translates the turning of the area into gradually a drier area if these trends continue; very likely to threatening agricultural and other rainfed livelihood activities.

Panel A



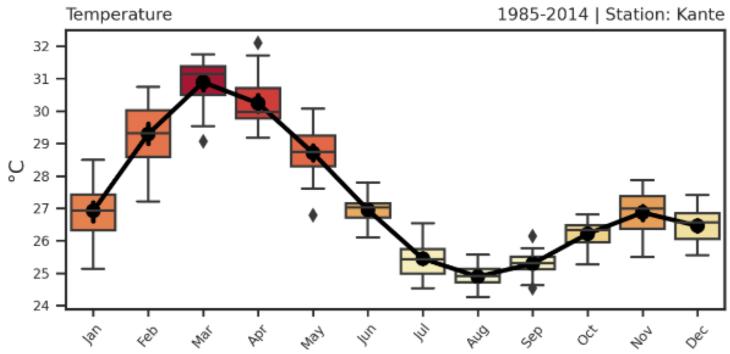
(1)

(2)

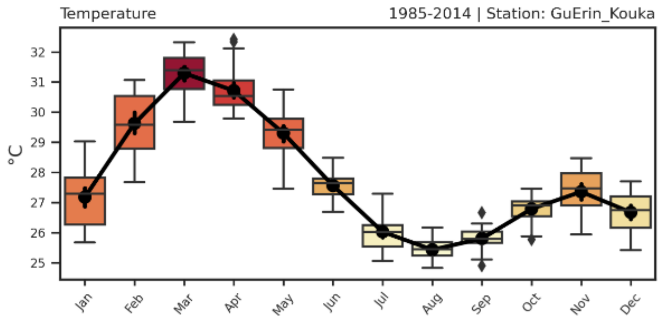
Source: (Author's computation, 2022)

Panel A (1) shows that in Takpamba temperature peaked in March and is low in August while the Panel A (2) reveals the same annual temperature regime at Niamtougou (peak in March and low value in August). The contrast lies in the values of the temperatures observed annually in the two localities. High temperatures were recorded in Takpamba as compared to Niamtougou.

Panel B



(1)



(2)

Source: (Author's computation, 2022)

Panel B (1) and (2) results indicate that temperature peaked around March and became very low in August both in Kante and Guerin Kouka as in the cases of Niamtougou and Takpamba. This shows that high temperatures were observed in Kante and Guerin Kouka in the river basin.

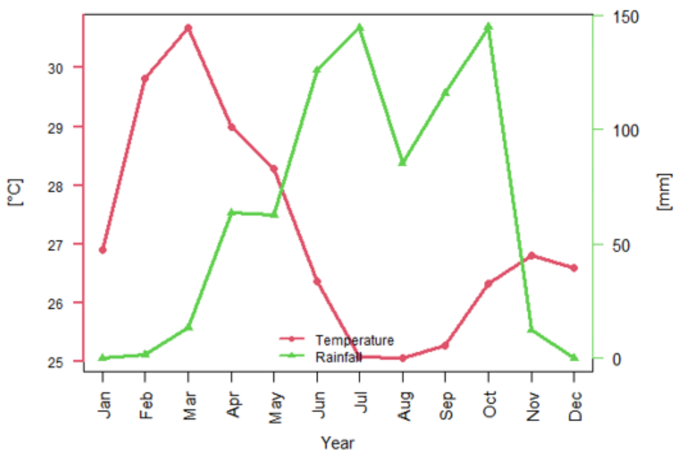


Figure 4.28. Monthly rainfall/temperature variations
Source: (Author's computation, 2022)

The monthly rainfall/temperature graphs show the climatology of the region; equivalent for two seasons, a dry season spanning from Nov-Feb and a raining season covering April to October (Figure 4.28). However, it was observed that from 1985-2014, the rainy season did not quick off early; rather there appeared some late onset and early cessation.

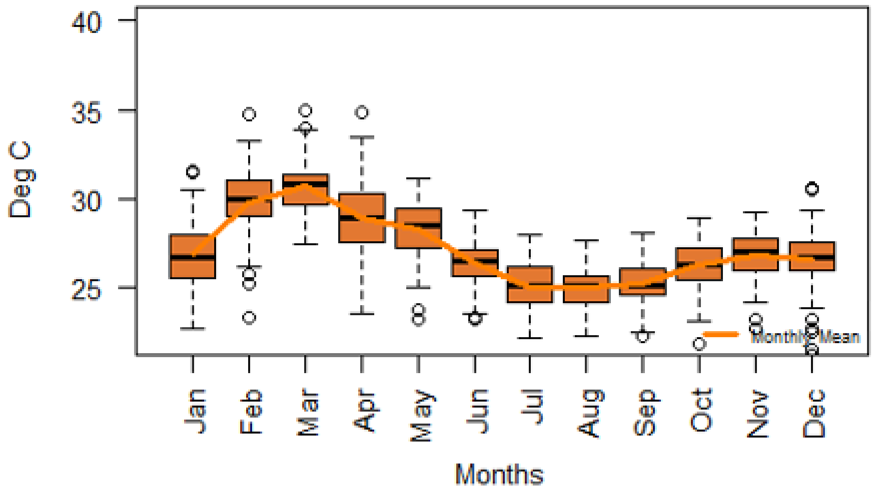


Figure 4.29. Monthly Temperature at Kara station

Source: (Author's computation, 2022)

Temperatures showed low values from March to December, with a decrease starting in March to July and a slight increase from August to December (Figure 4.29). This state of thing can be explained by the rainy period spanning from End of March to October/November and the Harmattan period characterised by low temperatures that begins from December onward, and continuing into the dry season.

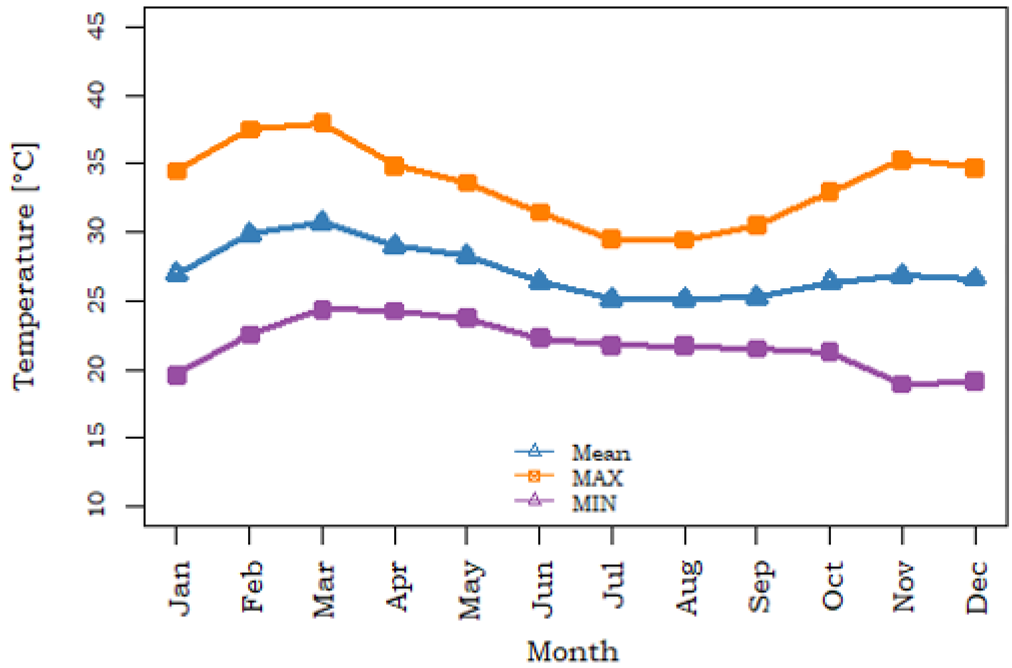


Figure 4.30. Monthly temperature variations
Source: (Author's computation, 2022)

The overall monthly temperature graph in Figure 4.30 explicitly indicates mean temperature oscillating between 25°C-30°C. The maximum temperature is within the range of 30°C-40°C; and the minimum from 20°C to 25°C in the area.

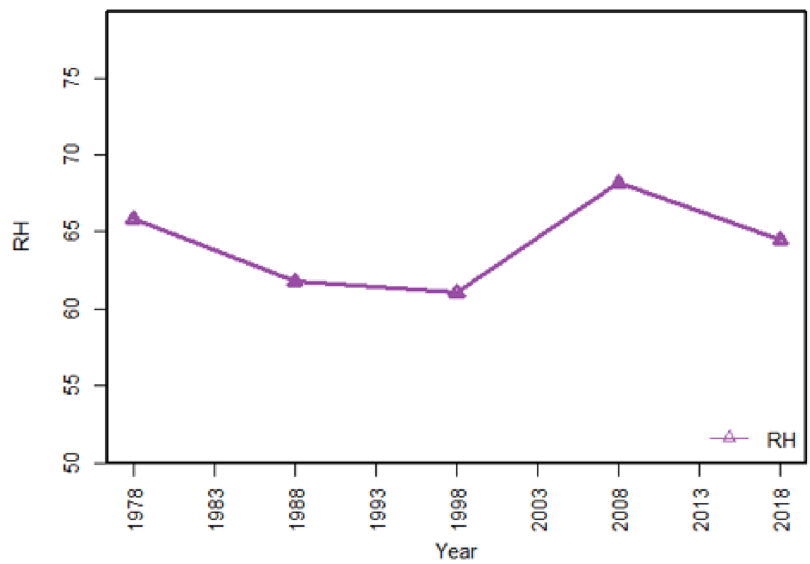


Figure 4.31. Relative Humidity from 1978-2018
Source: (Author's computation, 2022)

Relative humidity (Figure 4.31) indicated general increasing trend from 1978-2018;

with a decreasing trend between 1978 to 1998 and an increase from 1998 to 2018 characterised by decreasing values from 2008 to 2018 in the region.

4.6.3. Onset and Cessation of Rainfall (At Niamtougou Station)

The particularity of Niamtougou town is the presence of an International Airport; thus, the availability of hourly and daily recorded climate data over a relatively longer time period allowing to have data from 1981-2021.

The calculations were derived from daily temperature and rainfall data. Among the indices, the most suitable for this study were computed.

The onset and cessation over the last 41-year period (from 1981 – 2021) revealed that the starting of raining season is not consistent across the area with onset that shifted from mid-April to early May (1983, 1987, 1988, 1992, 1995, 2000, 2001, 2005, 2011, 2013, 2016, 2018, 2020) or some time to June (1984, 1989, 1999, 2014, 2015). The cessation was averagely situated in mid to end October with some early cessation in September and early October for the years 1983, 2001 and 2016, respectively. This is illustrated in the table (Table 4.8).

Table 4.8. Onset and cessation of rainy season at Niamtougou

S.n	Onset	Cessation	Duration (days)
1	18/04/1981	14/10/1981	179
2	14/04/1982	31/10/1982	200
3	01/05/1983	25/09/1983 -	147
4	12/06/1984	20/10/1984	131
5	29/04/1985	04/10/1985	158
6	21/04/1986	01/11/1986	194
7	19/05/1987	17/10/1987	151
8	10/05/1988	04/10/1988	147
9	02/06/1989	10/10/1989	130
10	29/04/1990	23/09/1990	147
11	24/04/1991	31/10/1991	190
12	01/05/1992	19/10/1992	171
13	26/04/1993	30/10/1993	187
14	25/04/1994	01/11/1994	190
15	09/05/1995	26/10/1995	170
16	13/04/1996	13/10/1996	183
17	18/04/1997	30/10/1997	195
18	27/04/1998	18/10/1998	174
19	30/06/1999	16/10/1999	108
20	10/05/2000	20/10/2000	163
21	01/05/2001	02/10/2001 -	154
22	30/04/2002	19/10/2002	172
23	14/04/2003	17/10/2003	186
24	25/04/2004	07/11/2004	196
25	08/05/2005	15/10/2005	160
26	28/04/2006	26/10/2006	181
27	26/04/2007	28/09/2007	155
28	20/04/2008	20/10/2008	183
29	11/04/2009	31/10/2009	203
30	20/04/2010	29/10/2010	192
31	01/05/2011	22/10/2011	174
32	07/04/2012	31/10/2012	208

33	12/05/2013	14/10/2013	155
34	03/06/2014	31/10/2014	151
35	23/06/2015	14/10/2015	113
36	06/05/2016	07/10/2016	154
37	25/04/2017	12/10/2017	170
38	09/05/2018	01/11/2018	175
39	22/04/2019	27/10/2019	188
40	12/05/2020	20/10/2020	161
41	24/04/2021	22/10/2021	182

Source: (Author's computation, 2022)

4.6.4. Trend of Rainfall during the period 1981-2021 in Niamtougou

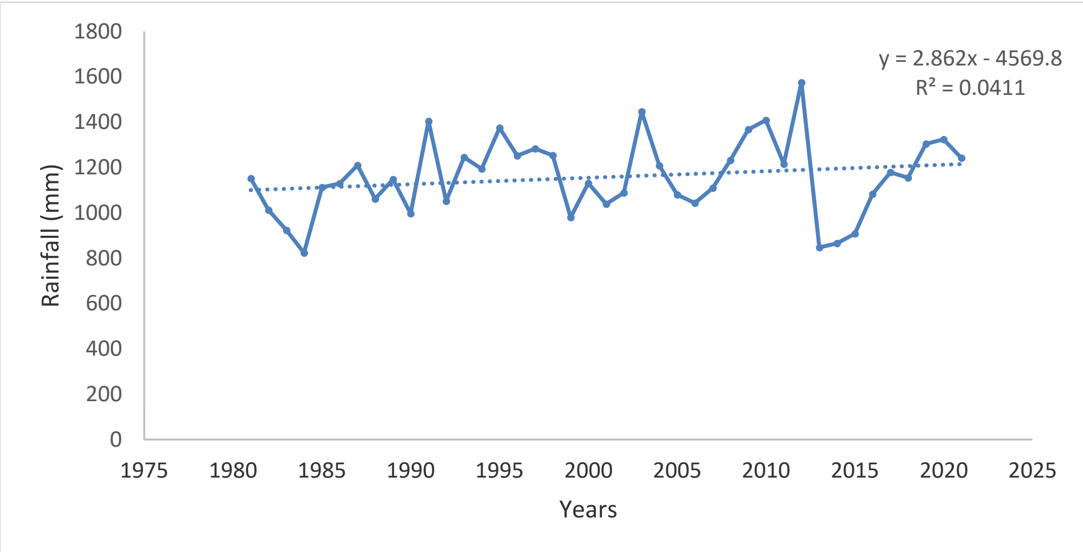


Figure 4.32. Trend of rainfall at Niamtougou station

Source: (Author's computation, 2022)

There appeared a subtle increase trend of rainfall over time with high variability noted at Niamtougou (Figure 4.32). $R^2 < 1$ that the increasing trend is not significant.

4.6.5. Trend Analysis of per Annum Rainy Days

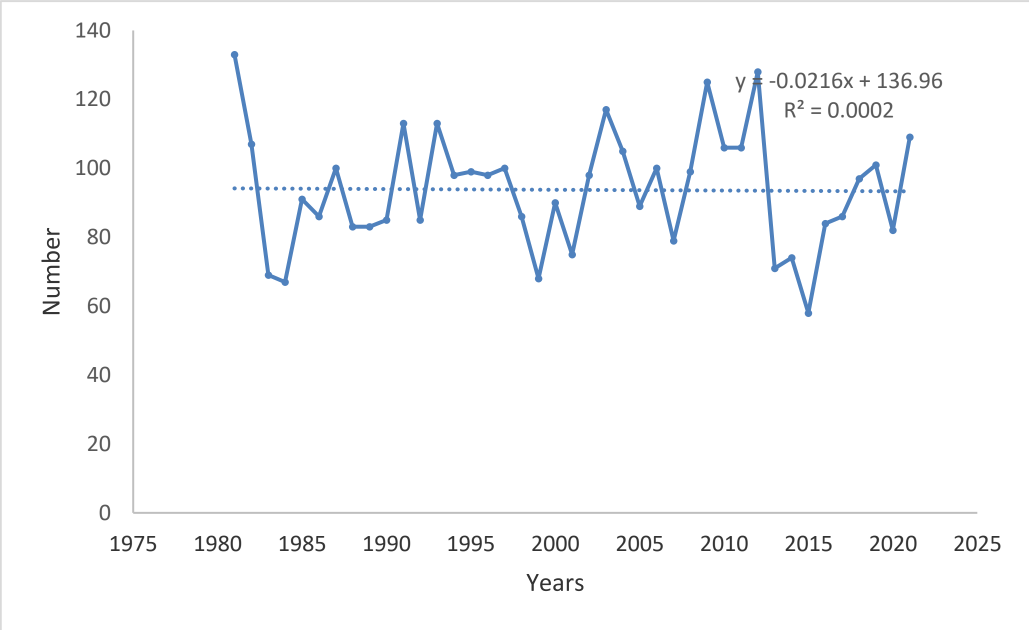


Figure 4.33. Number of rainy days
Source: (Author's computation, 2022)

The analysis showed a general decreasing trend in the number of rainy days over the period (Figure 4.33). Meaning that over time the number of rainy days has shown a decrease.

In terms of the number of rainy days, they kept on decreasing from 133 days in 1981 with some fluctuations throughout the period (1981-2021). The lowest rainy days registered were 58 days, 67 days, 69 days respectively in 2015, 1984, 1983.

In 1981, there were 70 wet days and 63 of dry days. The year of maximum consecutive dry days of the whole series occurred in 2021 and, in that year, there were 138 consecutive dry days. The year of maximum consecutive wet days of the whole series occurred in 1989 and, in that year, there were 19 consecutive wet days.

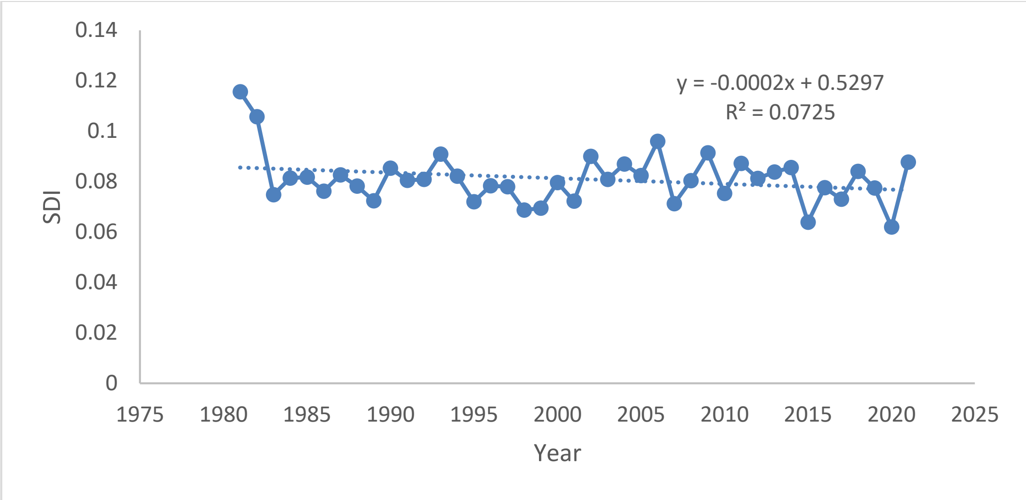


Figure 4.34. SDII
Source: (Author's computation, 2022)

Wet days have been on the decrease from 1980-2021 as indicated in Figure 4.34. This shows that average yearly rainfall in the Kara River basin has been on the decreasing trend.

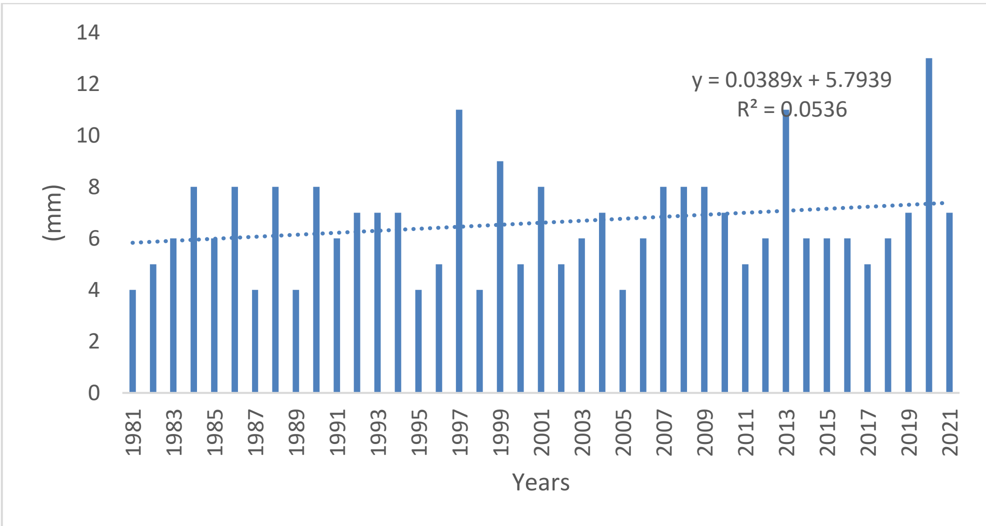


Figure 55. Consecutive dry days
Source: (Author's computation, 2022)

Consecutive dry days (CDD) and consecutive wet days (CWD) constitute two key indicators for determining extreme precipitation and seasonal drought (Klutse *et al.*, 2018). Changes in CDD and CWD may have some irregular temporal distribution of rainfall which could have a great importance for agricultural practices (Barron *et al.*, 2003; FAO *et al.*, 2015, Wiebe *et al.*, 2017) with important fluctuation observed over time. CDD computation indicated an increasing trend of the consecutive number of dry days in the past 41 years (1981-2021) (Figure 4.35).

4.6.6. Detection of Climate Extremes [Anomalies (Outliers)]

Anomalies also called outliers are important to assess climate extremes in climate analysis studies.

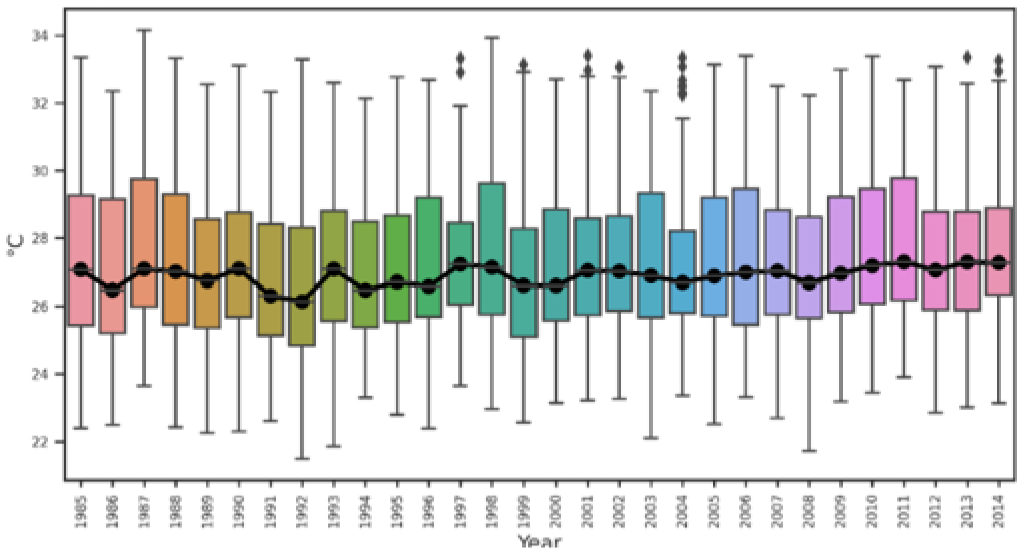


Figure 4.36. Outliers at Kante

Source: (Author's computation, 2022)

At Kante, the distribution of data over the years (1985-2014) showed that the lowest temperature recorded (21°C) was in year 1992 and the highest (34.5°C) in year 1987 (Figure 4.36).

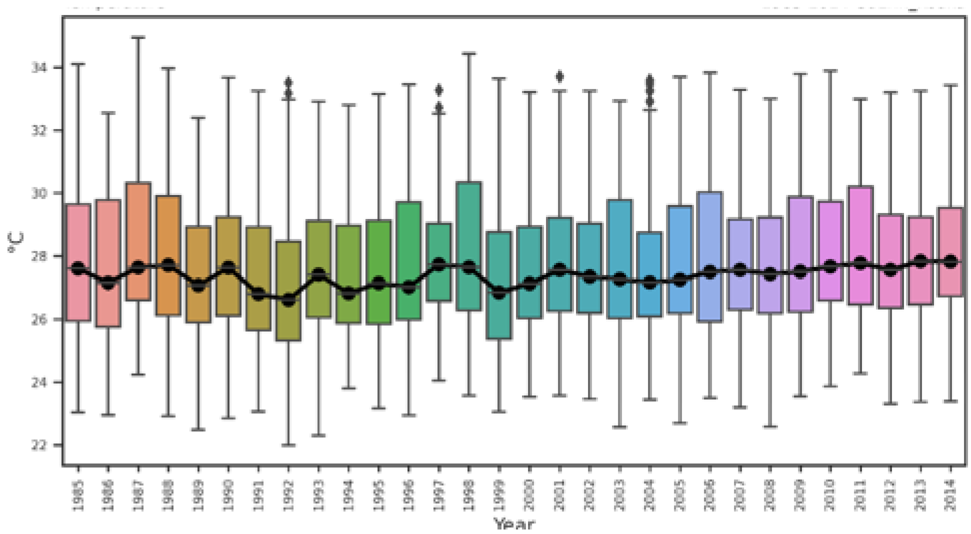


Figure 4.37 Outliers at Guerin Kouka

Source: (Author's computation, 2022)

At Guerin Kouka, the distribution of data over the years (1985-2014) indicated that the lowest temperature recorded (22°C) was in year 1992 and the highest (35.5°C) was in year 1987 (Figure 4.37).

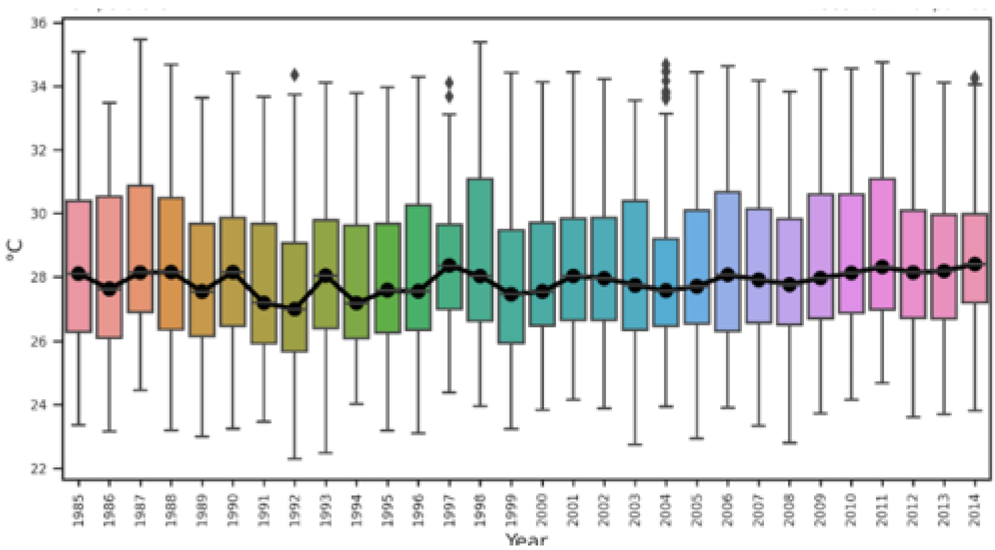


Figure 4.38. Outliers at Takpamba

Source: (Author's computation, 2022)

At Takpamba, the distribution of data over the years (1985-2014) indicated that the lowest temperature recorded (22.5°C) was in year 1992 and the highest (35.5°C) was in year 1987 (Figure 4.38).

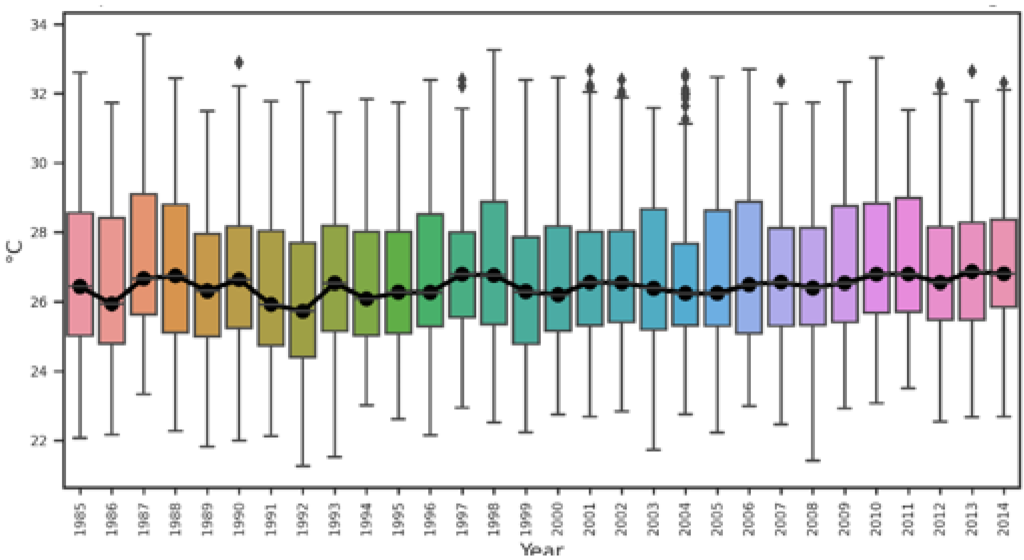


Figure 4.39. Outliers at Niamtougou
Source: (Author’s computation, 2022)

At Niamtougou, the distribution of data over the years (1985-2014) showed that the lowest temperature recorded (21°C) was in year 1992 and the highest (33.5°C) was in year 1987 (Figure 4.39).

From the analysis of the distribution of temperature in the study area, the lowest temperature recorded was at Niamtougou and the highest at Takpamba and Guerin Kouka. 1987 was particularly a hot year in all the studied locations over the Kara River basin.

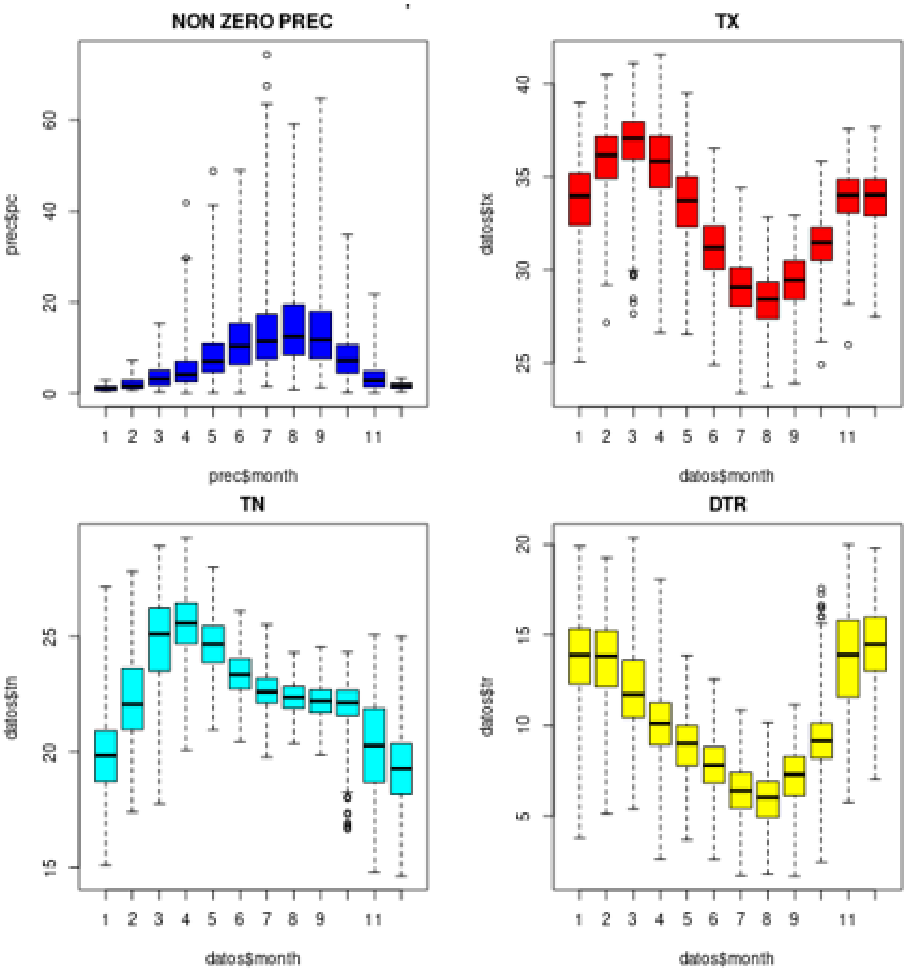


Figure 4.40. Monthly anomalies

Source: (Author's computation, 2022)

The Exploratory Data Analysis (EDA) performed outlines the computing of the monthly climatology of the studied area. This was plotted as indicated in Figure 4.40. The outliers obtained indicate the extremes values which signify the occurrence of extreme weather events. The extreme values of precipitation (NON-ZERO PREC) recorded over the river basin were in April, May and July. Such findings may translate into the existence of flooding events during these months in the river basin.

As for minimal monthly temperature (TN), October is the month to be prone to low temperatures with values (16-17^{o}C), indicating an occurrence of extreme cold days in that particular month of the year. The maximum temperature analysis (TX) indicates that the extreme high temperatures were recorded in February, March, October and

November over the years. This puts to evidence that these months are prone to heatwaves.

The Diurnal Temperature Range (DTR) confirms the nature of the days and the years (either cold or hot). When DTR is high i.e., maximum temperature was very high and min temperature was very low with implications for heatwaves and cold waves, respectively.

DTR is high for January, February, November and December meaning these months recorded the hottest days than any other. DTR is low for July and August meaning these months recorded the coldest nights in the last years.

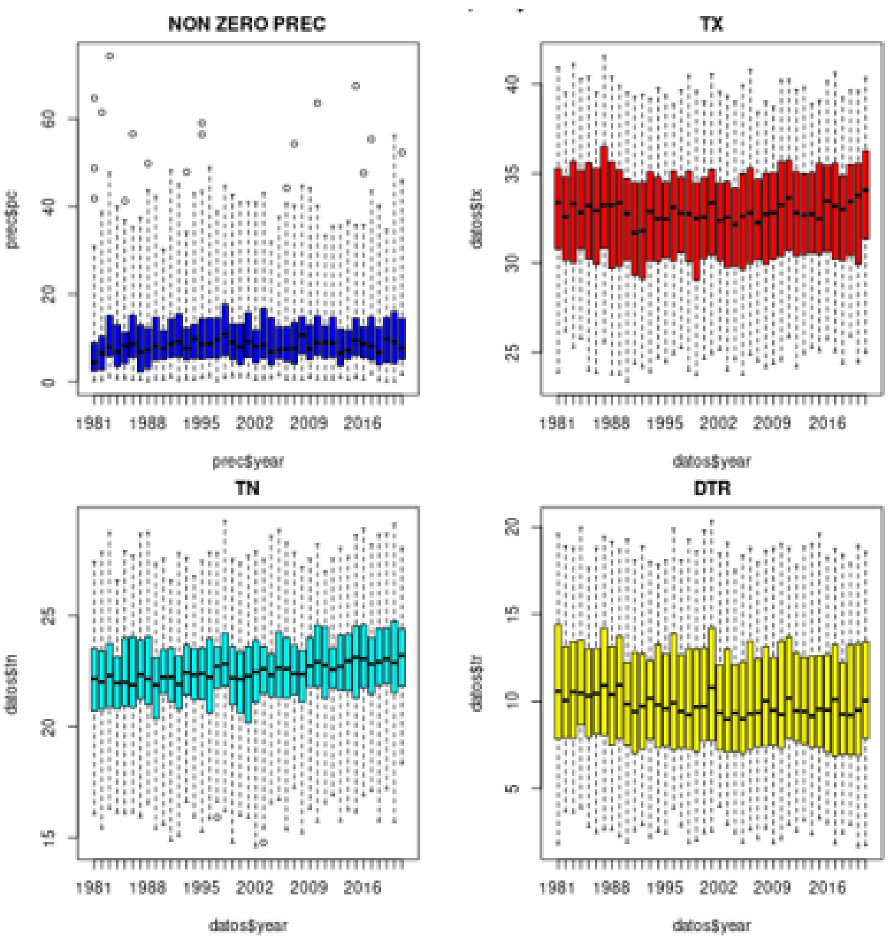


Figure 4.41. Yearly anomalies
Source: (Author's computation, 2022)

The study of extreme events is important to building community resilience. Extreme events, such as heat waves, prevalent flooding, or strong storms, are of interest for scientists because of their ability to generate wide-ranging damage and impacts on people, infrastructure, and nature. Thus, building climate resilience of multifunctional landscapes requires also understanding not only the trends of temperature and precipitation as well as climate indices, but also a knowledge about the occurrence of the extremes are very relevant. Thus, for this study, climate extremes were looked at to provide a clear meaning of what has been the occurrence of extremes in the Kara River basin.

As indicated earlier on, DTR shows the nature of the days and the years (either cold or hot), indicating the occurrence of the extreme events. The yearly plot above in Figure 4.41 indicates low DTR in 1990s, 2004, 2006 while high DTR are observed in years 1985, 2002, and 2013. Hot years were then 1985, 2002, and 2013 whereas in the same period of time, 1990s, 2004 and 2006 are recorded the coldest years. Heatwaves were recorded in years such as the 1990s, 2004 and 2006 whilst the coldest nights were observed in the years 1985, 2002 and 2013.

One of the effects of understanding DTR, is the effects on life due to heatwaves and cold waves which are without no consequences for lives and ecosystems. Heatwaves and cold waves impact human bodies and animals; thus, distrub their existence. The appearance of such heatwaves and cold nights in the area may suggest some implications on the peoples living, the entire multifunctional landscapes and livelihood acivities that are being done.

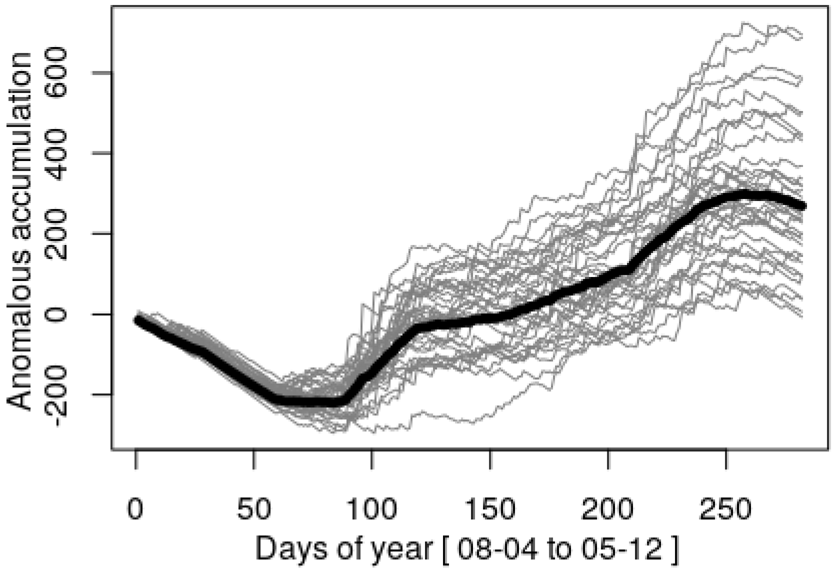


Figure 4.42. Anomalous accumulation of Rainfall in the river basin
Source: (Author's computation, 2022)

Figure 4.42 showed the anomalous accumulation of rainfall. Findings suggest that every year, precipitation has increased from day 100 (which falls under month of April) and has got to its peak to 250 days (which is around August/September). Precipitation accumulation tends to be abnormal from days [0-100] – negative accumulation and [200-250] positive accumulation of precipitation.

The negative accumulation during days [0-100] implies the risk of dryness while the positive accumulation indicates the risk of occurrence of high flooding during days [200-250].

4.7. Projected future climate scenarios in the Kara River Basin

4.7.1. Projected Rainfalls by 2100

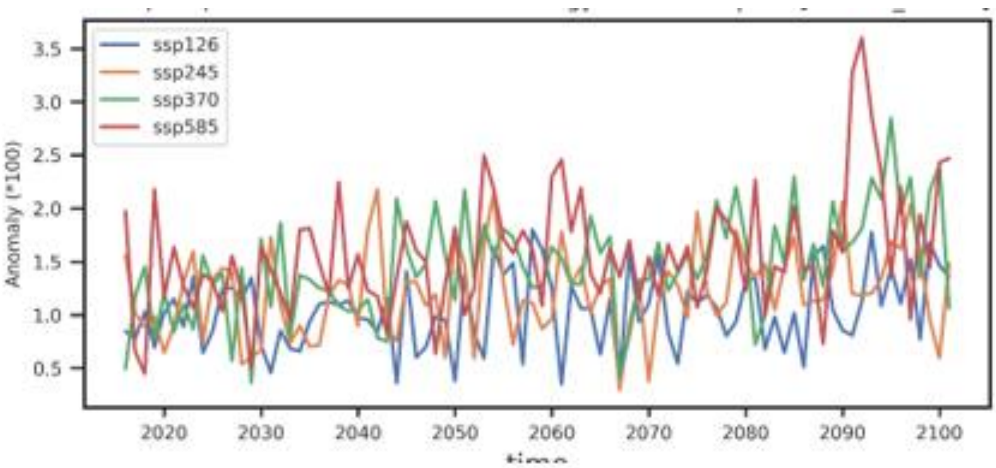


Figure 4.43. Projected rainfalls at Guerin Kouka by 2100
Source: (Author's computation, 2022)

Tendency for increase of annual precipitations of 250 mm by the end of the century in SSP5-8.5 was found. A slight increase in annual precipitation of 125mm in SSP3-7.0, of 115mm in both SSP2-4.5 and SSP1-2.6 for Guerin Kouka are projected (Figure 4.43). All these scenarios showed an increase of annual rainfall by 2100. A very high increase of precipitation is projected with the SSP5.8.5 in 2095.

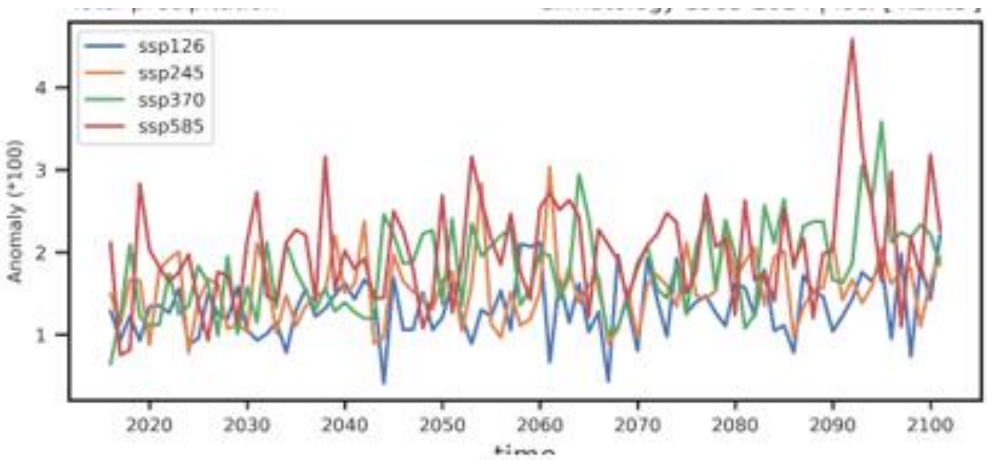


Figure 4.44. Projected rainfalls at Kante by 2100
Source: (Author's computation, 2022)

Same results of increase in annual precipitation as the above for all the SSPs. An increase of 200mm for SSP5-8.5 and SSP3-7.0. The increase is of 150mm for SSP1-2.6 and 170mm for SSP2-4.5 (Figure 4.44). All the scenarios at Kante by 2100 are showing high precipitations in the future. Highest increases are observed for SSP5-8.5 and SSP3-7.0 for close to 500mm and 350mm for years 2090 and 2095 respectively. Heavy floods are likely to happen in the future at Kante with all the 5 pathways.

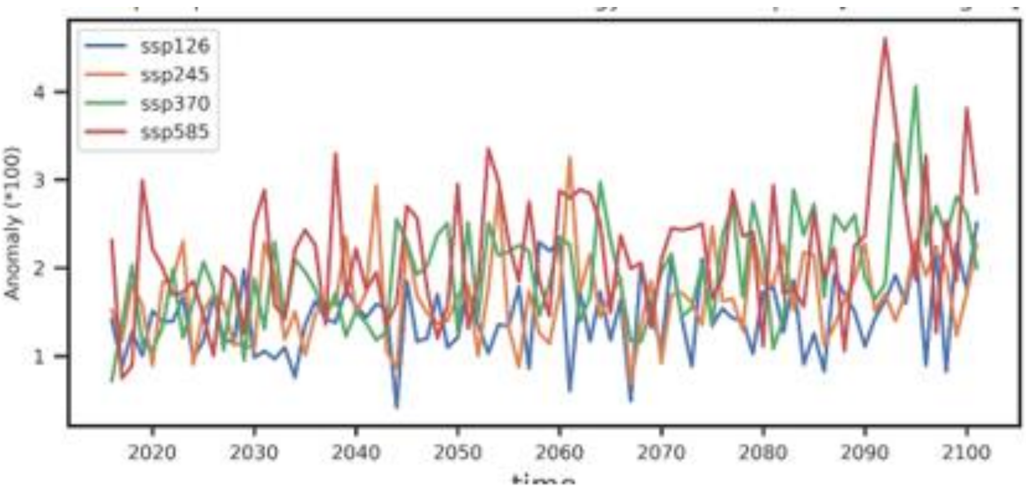


Figure 4.45. Projected rainfall at Niamtougou by 2100
Source: (Author's computation, 2022)

By the end of this century, it is projected rainfall increase as in Figure 4.45. High increases were noticed for SSP5-8.5 and SSP3-7.0 of 270mm and 170mm, respectively. Less increases were observed for SSP2-4.5 and SSP1-2.6 by the end of the century.

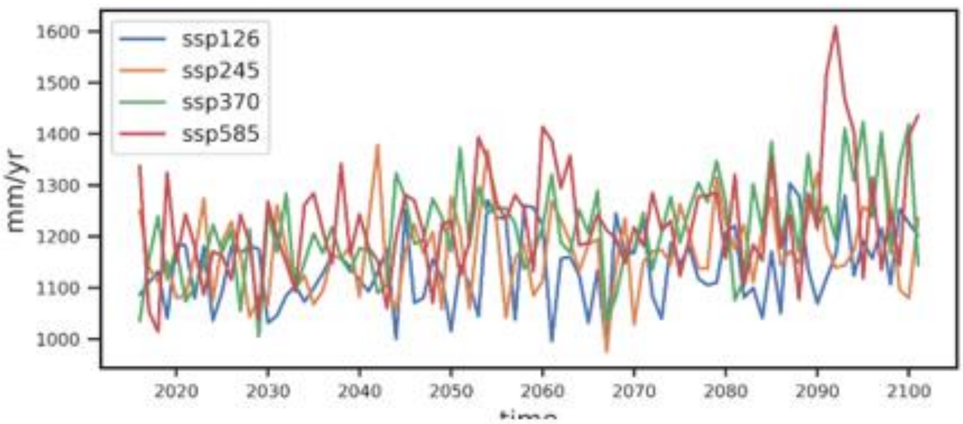


Figure 4.46. Projected rainfall at Takpamba by 2100
Source: (Author's computation, 2022)

Figure 4.46 puts to evidence high increases of rainfall for SSP5-8.5 and SSP3-7.0 while relative low increases were observed for SSP2-4.5 and SSP1-2.6. The risk of heavy floods is expected with SSP5-8.5 and SSP3-7.0 scenarios by the end of century in Takpamba.

4.7.2. Projected Temperatures

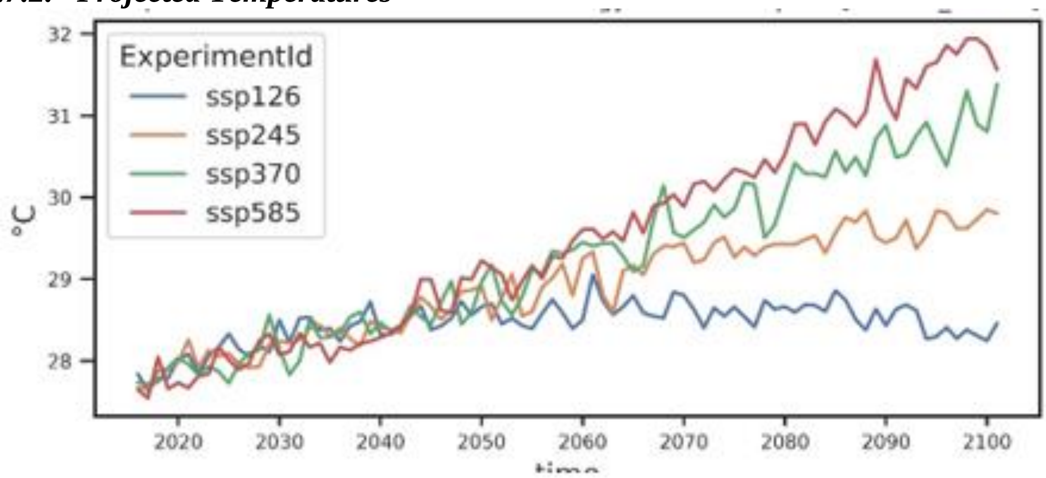


Figure 4.47. Projected temperature at Guerin Kouka by 2100
Source: (Author's computation, 2022)

All the 5 scenarios indicated in Figure 4.47, an increase of temperature at Guerin Kouka by 2100 with annual temperature peaking 28.5°C for SSP1-2.6, 29.5°C for SSP2-4.5, 31.5°C for SSP3-7.0 and 31.7°C for SSP5-8.5.

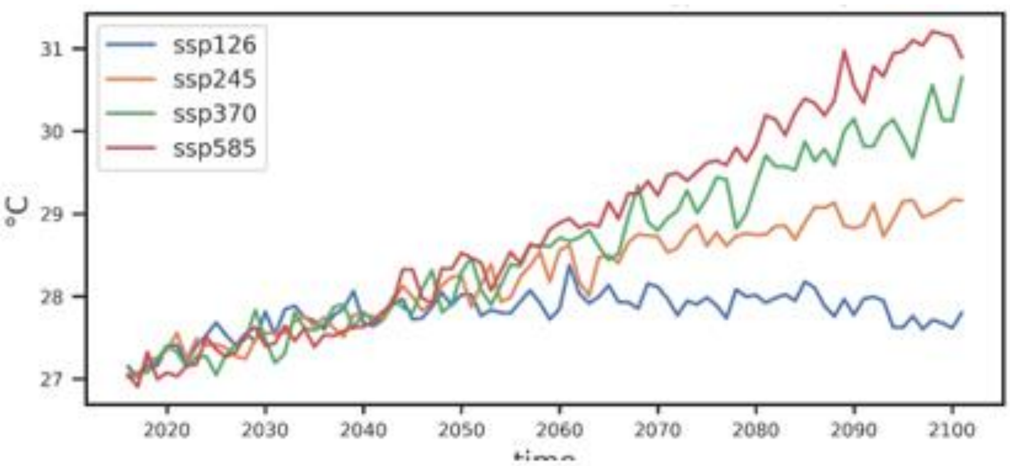


Figure 4.48. Projected temperature at Kante by 2100
Source: (Author's computation, 2022)

All the 5 scenarios indicated in Figure 4.48, an increase of temperature at Kante by 2100 with annual temperature peaking 27.5^{o}C for SSP1-2.6, 28.5^{o}C for SSP2-4.5, 30.5^{o}C for SSP3-7.0, and 30.7^{o}C for SSP5-8.5.

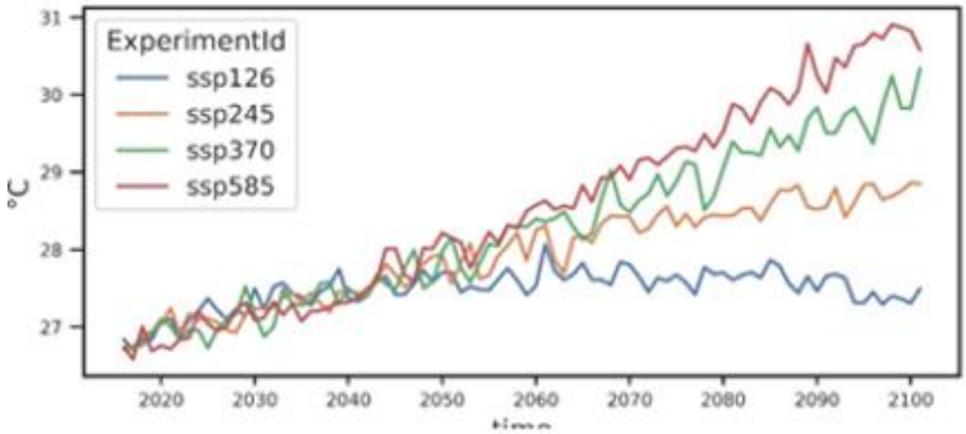


Figure 4.49. Projected temperature at Niamtougou by 2100
Source: (Author's computation, 2022)

All the 5 scenarios indicated in Figure 4.49, an increase of temperature at Niamtougou by 2100 with annual temperature peaking 27.5^{o}C for SSP1-2.6, 28.5^{o}C for SSP2-4.5, 30^{o}C for SSP3-7.0, and 30.5^{o}C for SSP5-8.5.

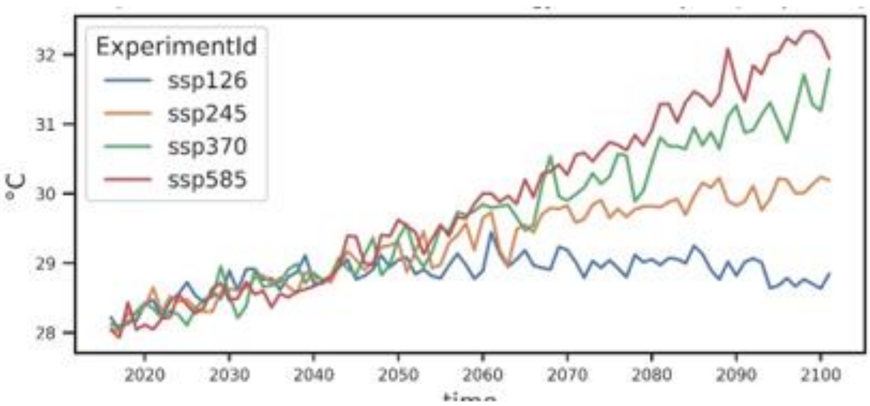


Figure 4.50. Projected temperature at Takpamba by 2100
Source: (Author's computation, 2022)

All the five scenarios indicated in Figure 4.50, an increase of temperature at Takpamba by 2100 with annual temperature peaking 28.5^{o}C for SSP1-2.6, 30^{o}C for SSP2-4.5, 31.7^{o}C for SSP3-7.0, and 32^{o}C for SSP5-8.5.

4.8. Projected temperature anomalies

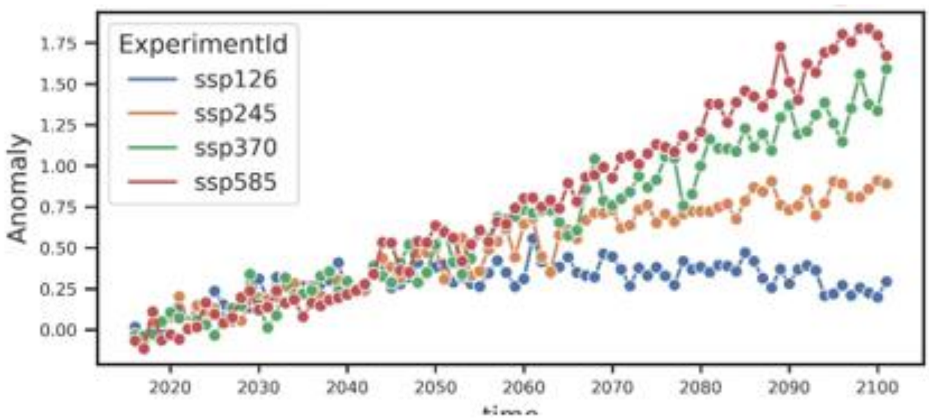


Figure 4.51. Projected temperature anomalies at Guerin Kouka by 2100
Source: (Author's computation, 2022)

Projections showed a high increase in temperature of 1.75^{o}C and 1.5^{o}C for SSP5-8.5, SSP3-7.0, respectively in the future while 1^{o}C increase and 0.25^{o}C increase for SSP2-4.5 and SSP1-2.6, respectively at Guerin Kouka (Figure 4.51).

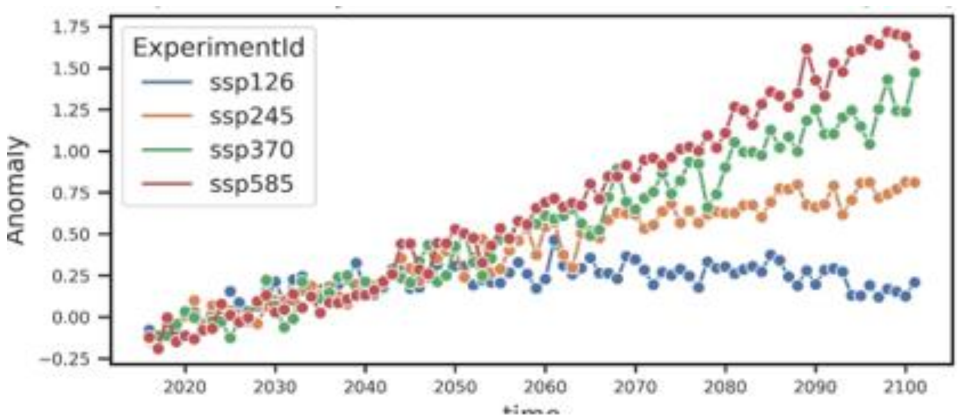


Figure 4.52. Projected temperature anomalies at Kante by 2100
Source: (Author's computation, 2022)

Same patterns were observed in Kante with increase of temperature of 1.75^{o}C for SSP5-8.5, 1.5^{o}C for SSP3-7.0, 0.75^{o}C for SSP2-4.5 and 0.25^{o}C for SSP1-2.6 (Figure 4.52).

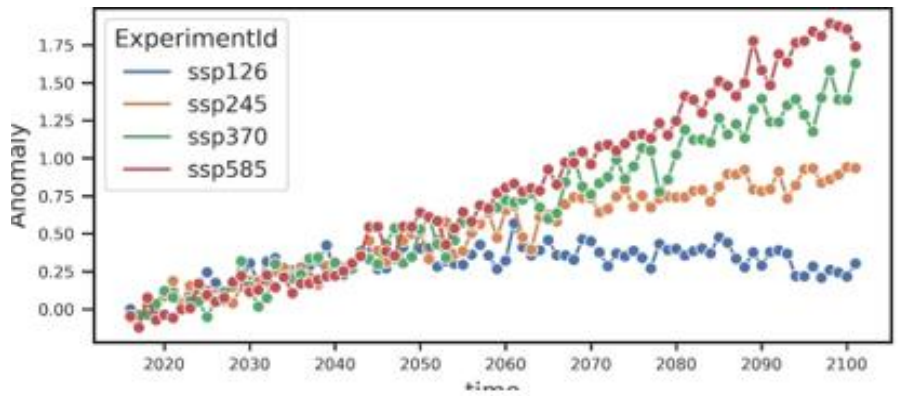


Figure 4.53. Projected temperature anomalies at Niamtougou by 2100
Source: (Author's computation, 2022)

Projections showed a high increase in temperature of 1.75^{o}C and 1.5^{o} C for SSP5-8.5 and SSP-3.70, respectively in the future; while 1^{o}C increase and less than 0.25^{o}C increase in the SSP-2.45 and SSP-1.26, respectively at Niamtougou (Figure 4.53). In overall over the years, there is more likely to have fluctuations within the temperature increase.

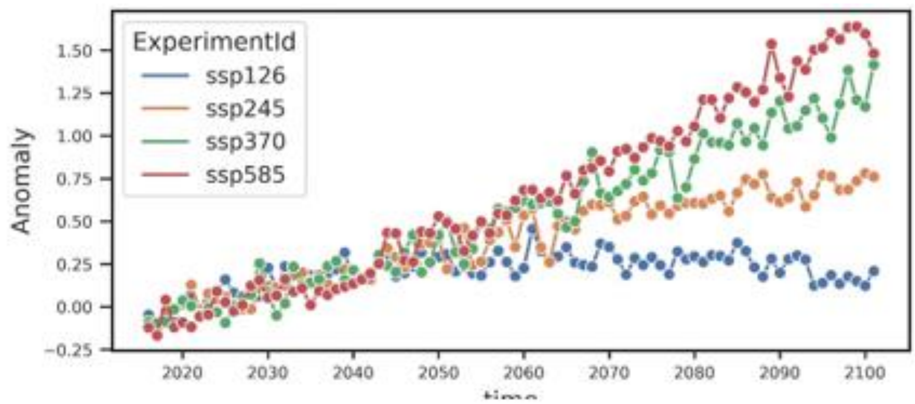


Figure 4.54. Projected temperature anomalies at Takpamba by 2100
Source: (Author's computation, 2022)

Projections showed a high increase in temperature of 1.5^{o}C and 1.25^{o}C for SSP5-8.5, SSP-3.70, respectively in the future; while 0.75^{o}C increase and less than 0.25^{o}C increase in the SSP-2.45 and SSP-1.26, respectively at Takpamba (Figure 4.54). In overall over the years, there is more likely to have fluctuations within the temperature increase.

Guerin Kouka, Niamtougou and Kante are projected to experience the highest temperature increase as shown above though Takpamba is more likely to be the hottest area by end of the century. In all, the Kara River basin is highly susceptible to high temperature and heavy precipitations by the end of this century which may have huge implications on socio-economic activities of the local communities and their resilience. With such scenarios, risks of heatwaves and flooding are more likely to be experienced by the locals.

Objective 2: Determine the spatial and temporal LULC change and the main driving factors of changes in the Kara River Basin

5.1. Spatial and temporal LULC change in the Kara River basin

The analysis of the spatial and temporal LULC change in the Kara River basin was performed using contemporary satellite imagery and processing technics. It provided a spatial view of the diverse vegetation types through a period. Figure 4.55 shows the modifications observed over 1987-2021. An accuracy assessment was led by means of the confusion matrix to compare the classification of 2021 with ground truth data from the field. As indicated in Table 4.9, the Kappa coefficient (92%) is above 50%; showing accurate results.

Table 4.9. Percentage user's (UA) and producer's accuracies (PA) for each LULC class for the year 2021 based on the pixel count matrix

Land cover class	2021	
	PA (%)	UA (%)
Settlements	96	98
Farm/agricultural lands	87	85
Water	89	86
Forest	84	86
Savannah	91	86
Overall accuracy	92	

Source: (Author's computation, 2022)

5.1.1. Land use and land cover change mapping results (1987-2021)

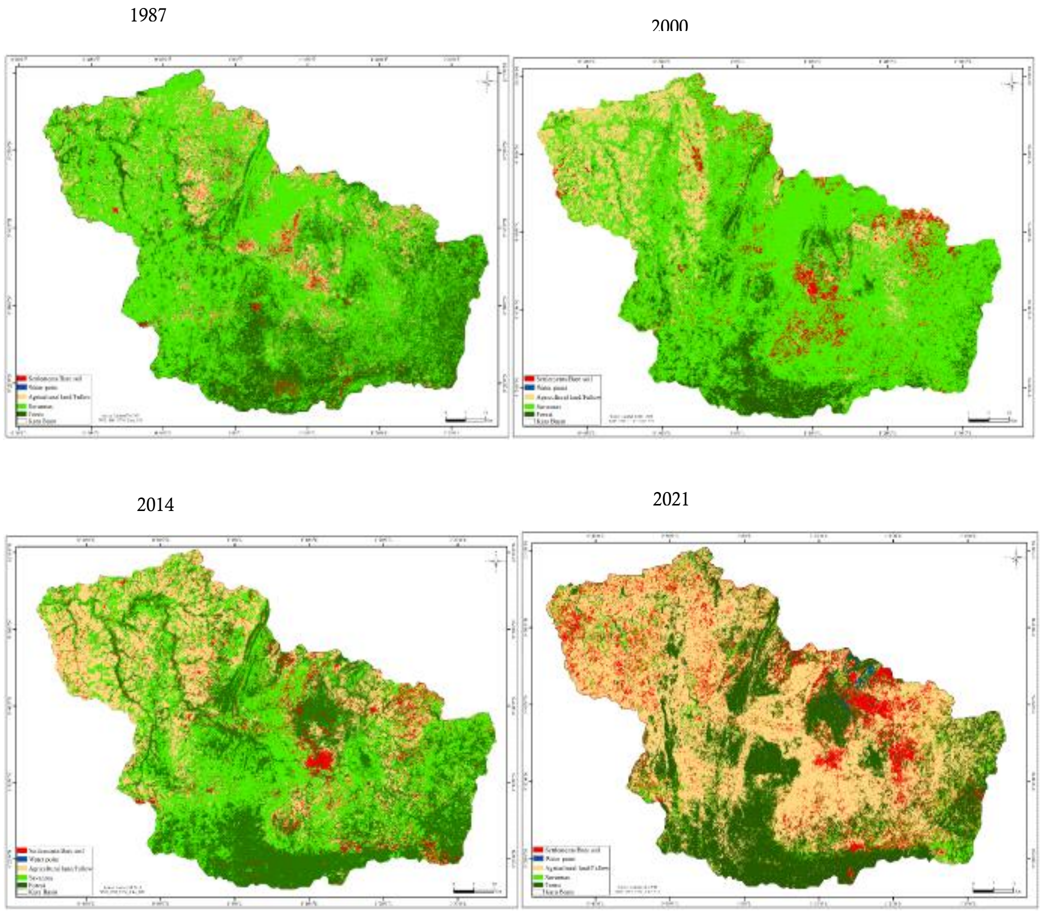
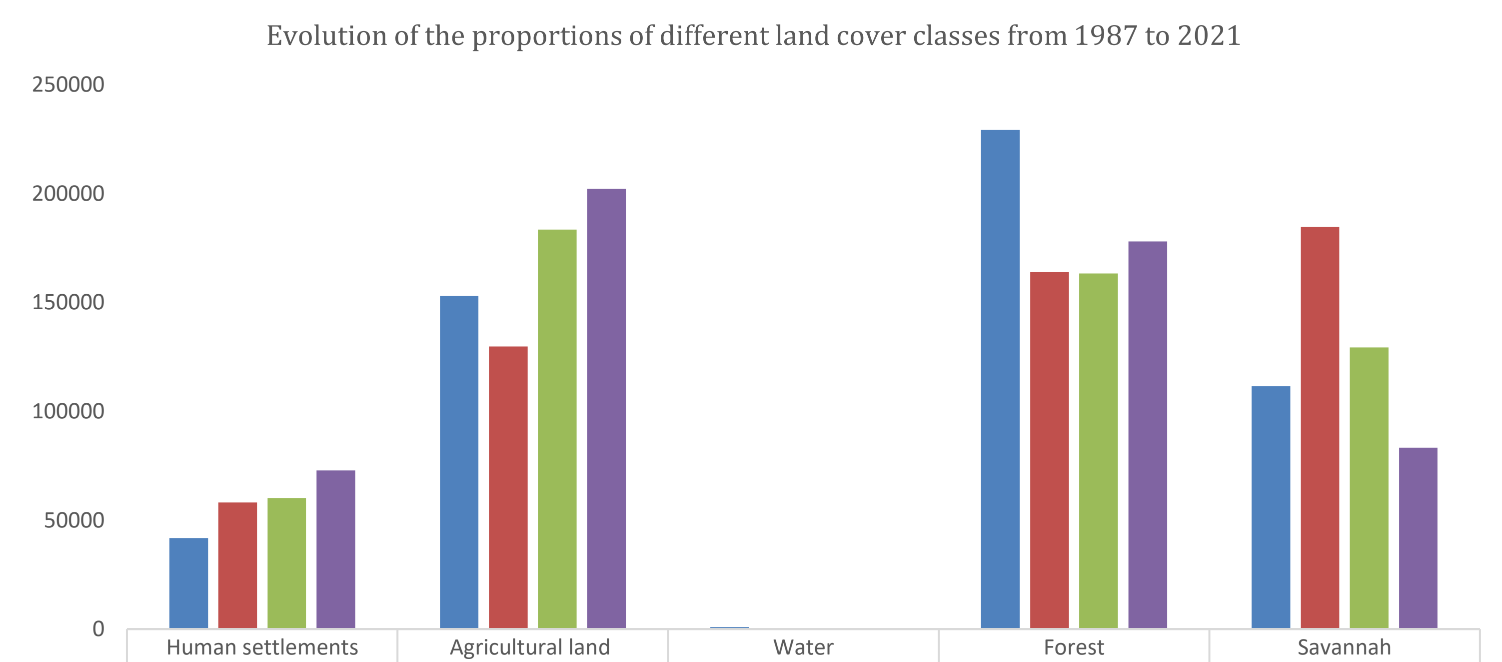


Figure 4.55. Land cover change maps between 1987 and 2021 in the Kara River basin, Togo
Source: (Landsat, 2022)

5.1.2. Quantitative analysis and statistics on land cover changes in the Kara River basin

The quantitative results presented in Figure 4.56 shows the statistics of the five LULC classes identified in the river basin and the change dynamics during the three-time nodes (1987-2000, 2000-2014, 2014-2021) of analysis.



	Human settlements	Agricultural land	Water	Forest	Savannah
1987	41802.17	153034.28	910.86	229248.56	111550.7
2000	58195.33	129753.7	36.91	163912.01	184649.07
2014	60201.42	183573.39	20.66	163429.9	129322.1
2021	72933.49	202251.39	23.04	178022.87	83314.89

1987 2000 2014 2021

Figure 4.56. Land cover dynamics between during the periods 1987 and 2021 in hectares (ha)

Source: (Author's computation, 2022)

The results showed that all land cover classes have noted spatial and temporal changes. Nevertheless, these changes are not even from a class to the other nor to a period to the other. Vegetation types (forest and savannah) and water bodies have recorded the most significant decrease of land cover. On the other hand, agricultural lands and settlements have experienced the highest increase in land surface coverage. These changes may represent the precursor signs of land degradation and poor land management strategies that are most likely to accelerate biodiversity loss and climate change while threatening sustainable food and livelihood systems for locals earning a living in the basin in a near future.

The area of forest was 229,248.56 ha in 1987 and 178,022.87 ha in 2021 corresponding respectively to 43% and to 33% of the total basin area while savannah which covered 111,550.7 ha in 1987 changed to 83,314.89 ha in 2021, representing 21% and 16% of the basin, respectively (Figure 4.56). A total decrease in forest and savannah is observed (10% for forest area and 5 % for savannah). On the other hand, agricultural lands of initial area coverage in 1987 of 153,034.28 ha (26%) were transformed to 202,251.39 ha (38%) in 2021; corresponding to an increase of farmland about 12%. Human settlements turned from 41,802.17 ha (7.8%) to 72,933.49 (13.6%) ha; making an increase of 5.8% over the last three decades. On the other hand, water area from 910.86 ha (0.17%) in 1987 has become an area of 23.04 ha (0.004%) in 2021; showing a drastic decrease of 75% of water area.

With regards to each timesteps considered in the land use and land cover analysis, the change is not uniform across the land use classes and the years. From 1987 to 2000, settlement turned from 7.8% to 10.8% corresponding to increase of 3%. From 2000 to 2014, settlements turned from 10.8% to 11.2% corresponding to an increase of 0.4%. From 2014 to 2021, settlements turned from 11.2% to 13.6% corresponding to an increase of 2.4%. This indicates that settlements have been on the rise throughout with great increases registered in these two periods from 1987-2000 (3%) and 2014 to 2021 (2.4%).

From 1987 to 2000, agricultural lands turned from 28.5% to 24.2% corresponding to a decrease of 4.3%. From 2000 to 2014, agricultural lands shifted from 24.2% to 34.2% equivalent to an increase of 10%. From 2014 to 2021, agricultural lands turned from 34.2% to 37.7% corresponding to an increase of 3.5%. Increases in agricultural lands occurred highly in the period 2000-2014 (10%) while 2014-2021 period's analysis indicates an increase of 3.5% and a shrinking in early 1987 to 2000.

From 1987 to 2000, forest turned from 42.73% to 30.55% corresponding to a decrease of 12.18%. Further, from 2000 to 2014, forest lands turned from 30.55% to 30.50% conforming to a decrease of 0.05% while there was an increase of 2.68% from 30.50 % to 33.18% between 2014-202. A great decrease (12.18%) was observed in 1987-2000 for forests while a very minimal decrease (0.05%) was seen during the transitioning period 2000-2014 which led to a beginning of an increase, even though still minimal of 2.68% in the last 8 years. The total of forest loss could be estimated in the area by roughly 10%.

From 1987 to 2000, savannah area increases from 20.8% to 34.41% matching with a percentage increase of 13.61%. An increase in savannah was seen during this period 1987 to 2000 showing a decrease in the encroachment of savannah as a result of less farming activities and unsustainable land use practices. For example, due to socio-political instability peoples flew out of the country to neighboring countries. From 2000 to 2014, savannah turned from 34.41% to 24.10% corresponding to a decrease of 10.31%. From 2014 to 2021, savannah turned from 24.10% to 15.52% equivalent to a decrease of 8.58%. Most of the decrease in savannah happened in years 2000 to 2021 with high portion of decrease during 2000-2014 followed by the year period 2014-2021. By contrast, an increase of 13.61% in savannah was seen in the period 1987-2000.

From 1987 to 2000, analysis of water area coverage indicates a sharp decrease from 0.17% to 0.007% corresponding to a decrease of more than 75% during this time-period. From 2000 to 2014, water turned from 0.007% to 0.0038% corresponding to a decrease of 50%. From 2014 to 2021, water turned from 0.0038% to 0.0043% corresponding to an increase of 0.0005%. The highest and absolute change in water coverage happened in 1987-2000 and 2000-2014, respectively.

The most important change between 1987 and 2000 consisted in the shrinking of water bodies occurred and decreased in forest. Important increase in savannah during the same period was observed. In other time steps, an important loss in savannah were observed respectively between 2000-2014 and 2014-2021. Forest losses occurred from 1987 to 2014 whilst a gain in forest was observed in the last 8 years (2014-2021). In similar with these forestland losses between 2001 and 2014, reforestation was valued at 14,379 ha, which equals to only 28% of the total loss registered in forestland during 1987-2021. Thus, as in many other ecologically sensible areas in West Africa, the region experienced a rather dramatic loss of forestlands, which was not offset by the reforestation activities.

From 1987 to 2000, the area experienced an increase of human settlements from 7.79% to 10.8% (3% of increase) and from 11.2% in 2014 to 13.6% (2.4%) in 2021, respectively. Interestingly, there was a reduction of agricultural land from 28.5% in 1987 to 24.2% in 2000 while an increase to 34.2% in 2014 and 38% in 2021 was noticed. The same year 2000 has witnessed a decrease in water bodies from 0.7% to

0.06%. This continues with the same decreasing trend to 0.03% and 0.04% in 2014 and 2021, respectively. Forest cover has decreased from 43% in 1987 to 31% in 2000 and to 30% in 2014 with a slight increase observed between 2014 and 2021. In terms of savannah, there is an increase in savannah from 21% in 1987 to 34% in 2000 and an important decrease to 24% in 2014 and to 15% in 2021.

In the overall, for the period 1987-2021, the landscape of the Kara Basin has experienced a total increase of 43% and 24% in settlements and agricultural lands, respectively with a significant decrease of 75%, 22%, and 25% in water bodies, forest and savannah, respectively. A combined deforestation of forest and savannah during 1987-2021 gives a decrease rate of 47% with an annual rate of 1.1% of deforestation. In a business-as-usual scenarios, where nothing is done to reverse this situation, by the end of this century (2100), the river basin is highly at risk of losing virtually 84.7% of its vegetation cover. This may imply a lot of changes in the landscapes that may compromise its resilience to climate change which is very likely to be exacerbated (as climate analysis shown in Objective 1 of the study).

5.2. Local Communities’ Perception of the Main driving factors of LULC change in the Kara River basin

5.2.1. Local Communities’ Perception about LULC changes

Based on the local knowledge of the peoples living in the river basin, the changes and the main driving factors of LULC change are multiple and diverse. Results listed in the graphs below tend to explain these changes within the landscape.

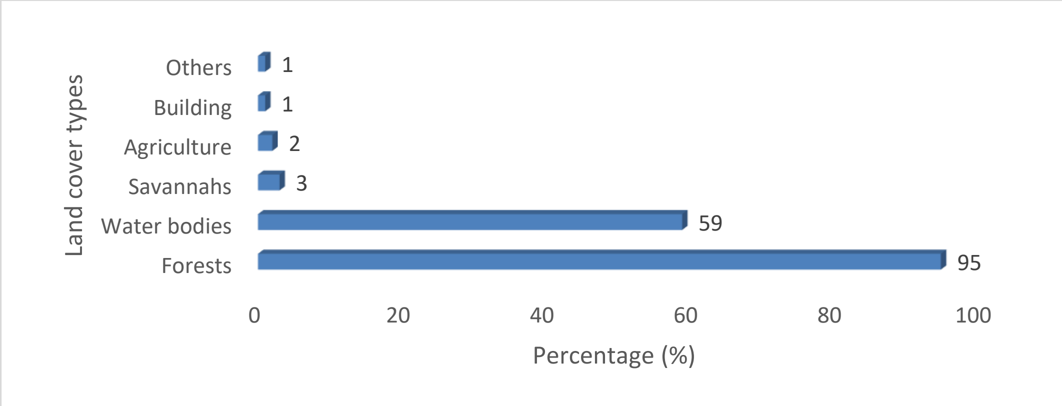


Figure 4.57. Perception of local communities of coverage of land cover types (1987-2000) -multiple responses

Source: (FGDs' computation, 2022)

Peoples indicated that LULC types coverage was essentially marked by forests (95%) and water bodies (59%) whereas savannahs (3%), agriculture (2%) and buildings (1%) constitute the remaining of land occupation (Figure 4.57). Results from 1987-2000 about Savannahs' coverage from the participants during the FGDs seem not to match with the nature of the dominant prevailing vegetation type of that period in the area.

These findings are in agreement with the aerial and remote sensing analyses conducted for this period of time for forests and water bodies. Indeed, forests and water bodies were still the main vegetation types which is not the case for the savannahs; where peoples' views negated the predominance of savannahs. This is partially due to the fact that Togo as a country experienced in the years 1990-2000 an unstable political situation that had made many peoples to migrate to neighbouring countries (Benin and Ghana) (Badjana, 2015); thus peoples could not properly recall about the nature of savannahs as the majority left their areas to other places; and can't only assume that since there was no more strict control of the Government over the territory (land), and looking at the then prevailing trend of deforestation (1987-2000), "Savannahs would have disappeared", said some old peoples during the FGDs.

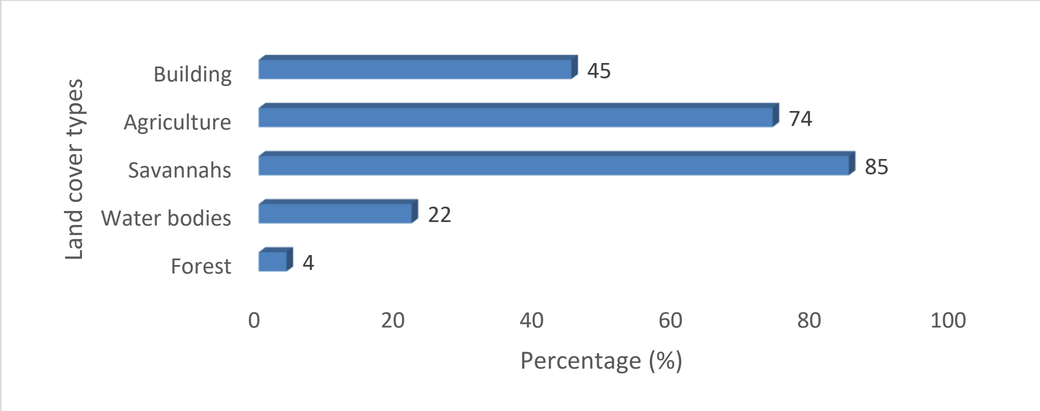


Figure 4.58. Perception of local communities of coverage of land cover types (2000-2014)
Source: (FGDs' computation, 2022)

The land cover coverage from 2000-2014 from peoples' perspective is predominantly constituted of savannahs (85%), agriculture (74%), and settlements (buildings) whilst water bodies (22%) and forest (4%) have decreased compared to the period 1987-2000 as indicated in Figure 4.58.

These results corroborate with the state of land cover analysis in the previous Section a) with Landsat imageries which also evidenced the disappearance of forests (from 95% to 4%) and water bodies (from 59% to 22%), to the detriment of savannahs, agricultural lands and settlements.

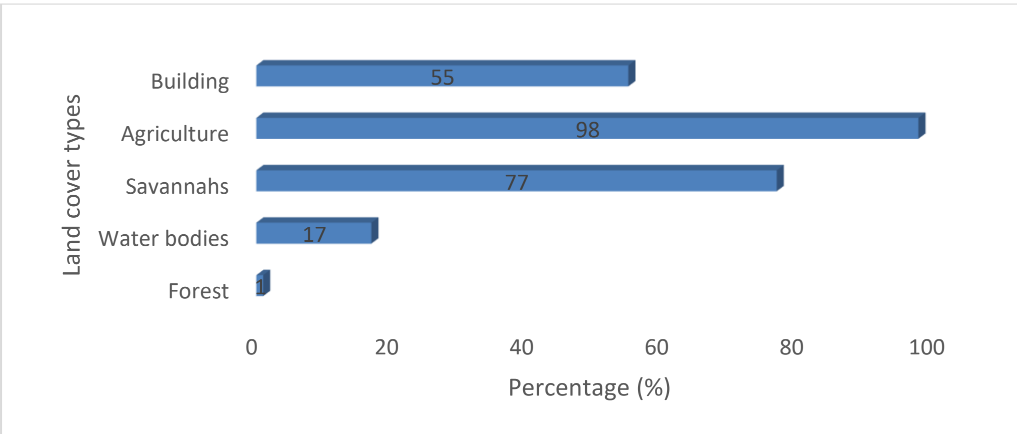


Figure 4.59. Perception of local communities of land cover types (2014-2021)
Source: (FGDs' computation, 2022)

From 2014-2021, land cover types are mostly agriculture (98%), savannahs (77%), buildings (55%) and water bodies (17%), based on the perceptions and local knowledge sourced out from the communities of the river basin (Figure 4.59). The findings show a shrinking of forest, water bodies and savannahs coupled with an increase in agricultural lands and settlements from the previous time step of analysis (2000-2014). In fact, information for 2014-2021 indicate the disappearance of forests, savannahs and water bodies, making place to agricultural lands and settlements due to demography increase in the area. While remote sensing results in Section a) indicated increase in forest areas, communities found a continuous. This might be as a result of little advances in afforestation and reforestation seen in the area lately. This will be discussed later in the below.

5.2.2. Relationship between Population Growth and Land Use and Land Cover Change in the Kara River Basin

Bivariate correlation in Table 4.10 indicates that the increase in agricultural lands significantly relates with population growth (p-value = 0.04) and decrease in Savannahs (p-value = 0.03), whereas the decrease in forests correlates with the decrease in water bodies (p-value = 0.009) and decrease in Savannahs is associated with the decrease in water bodies (p-value = 0.009). Moreover, the decrease in Savannahs connects with increase in settlements.

Table 4.10. Correlation matrix between the different land cover types and population growth from 1992-2021

Pearson's correlations		Population	Settlements	Water bodies	Savannah	Forest	Agricultural lands
Population	Pearson's r						
	P-value						
Settlements	Pearson's r	0.845					
	P-value	0.124					
Water bodies	Pearson's r	0.084	-0.402				
	P-value	0.679	0.679				
Savannah	Pearson's r	-0,876	-0.879**	-0.894**			
	P-value	0.145	0.004	0.009			
Forest	Pearson's r	0.567	0.896	-0,857**	0.678		
	P-value	0.340	0.107	0,005	0.456		
Agricultural lands	Pearson's r	0.986*	0.06	-0.167	-0.695	-	
	P-value	0.04	0.945	0.833	0.03*	0.987	
						0.167	

Note: Level of significance 95% and 99% for * P-value <0.05, ** P-value <0.01, respectively

Source: (FGDs' computation, 2022)

5.2.3. Main Driving Factors of Land Use and Land Cover Changes Identified for Kara River Basin

From the interactions had during the FGDs, several drivers come up as behind the conversion of land classes to the other. In fact, peoples have pointed out the following to be the driving factors of LULC change in their landscapes as found in Figure 4.60.

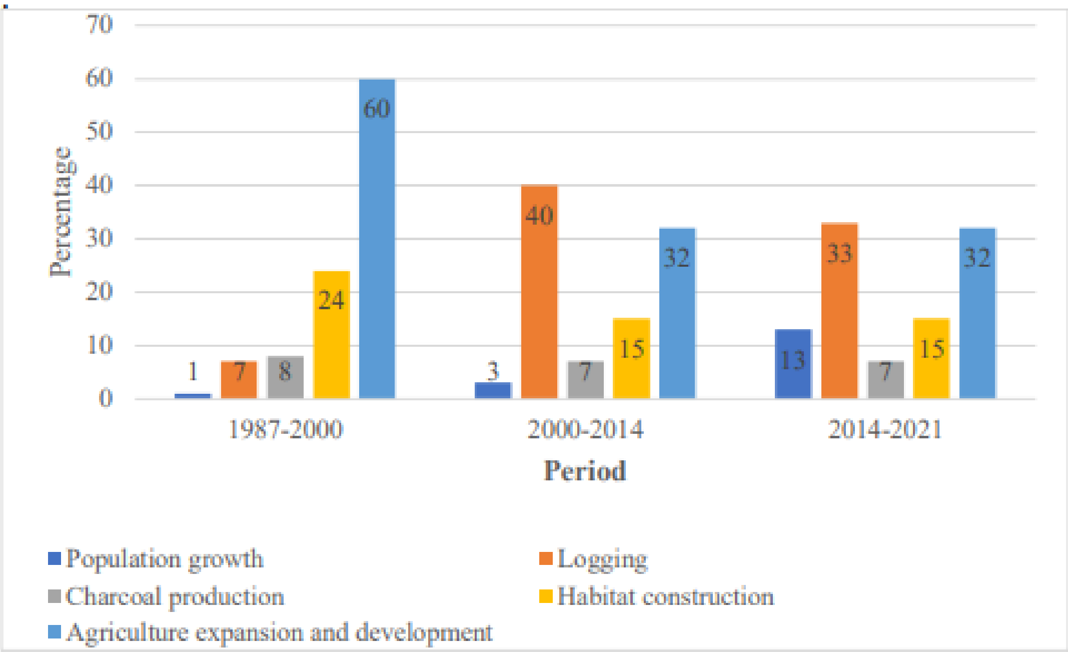


Figure 4.60. Driving factors in the river basin
Source: (FGDs' computation, 2022)

Local communities see in the order of relevance, agriculture expansion and development (60%), habitat construction (24%) and charcoal production (8%) and logging (7%) to have been the driving factors of land use and land cover changes from 1987-2000 in the area.

For the period 2000-2014, logging (40%) has taken the lead as a major driver of land use and land cover change in the river basin; followed by agriculture expansion and development (32%), habitat construction (15%) and charcoal production (7%).

For the period 2014-2021, logging (33%), agriculture expansion (32%), habitat construction (15%) and population growth (13%) were highlighted by the local communities to have been the main driving factors of the changes in LULC in the area.

The results on the scoring by communities about the main driving factors indicated earlier on for each are presented in Figure 4.61.

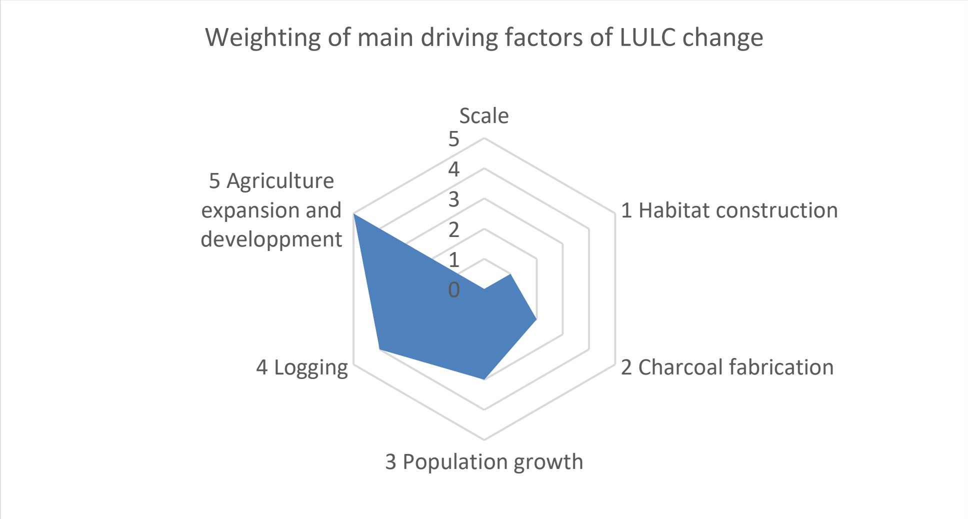


Figure 4.61. Weighting of main driving factors of LULC change
Source: (FGDs' computation, 2022)

Based on the weight (5 very high and 1 low) and the frequency of choices made by farmers during the FGDs, it came up the following ranking in the order as described in Table 4.11.

Table 4.11. Ranking the main driving factors of LULC change in the Kara River basin

Main driving factors of LULC change	Ranking
Agriculture expansion and development	1st
Logging	2nd
Population growth	3rd
Charcoal fabrication	4th
Habitat construction	5th

Source: (FGDs' computation, 2022)

Based on the findings, agriculture expansion and development is ranked first, followed by logging second, population growth, third and charcoal fabrication and habitat construction, respectively fourth and fifth.

Objective 3: Model farmers' decisions to climate, land use changes and water resources in the Kara River Basin

6.1. Stakeholder Analysis

The analysis portrayed the dynamic between the stakeholders participating in utilising the landscape and its natural resources using the Net-Map tool. First, the different stakeholders were identified, validated during the focus group discussions, and charts were drafted based on the flow of interactions (relation and power flows) and their influence in utilizing/managing land and water resources using scoring method (0 to 5).

Figure 4.62 indicates the visual illustration of the interactions among the stakeholders. Stakeholders identified to be involved in utilizing/managing land and water resources were validated by consensus from the FGDs. They are as follows:

1. Government agency and ministries of agriculture and environment through extension officers: These stakeholders offer support and advice to farmers on agricultural practices, connect them to agro-chemical service providers and organize sensitization and training on how to maintain, increase soil fertility and increase agricultural production and productivity. They are in charge of coordinating the implementation of agricultural policies, strategies, plans and projects within the area of influence. They represent the ministry in the area and are responsible for organizing farmer cooperatives, train and support them in their formalization. In addition, they are in charge of implementing the agropole of Kara's directives within the area.
2. Farmer cooperatives: They are formed by farmers usually those who cultivate crops that are highly needed for commercialization such as cotton, soybean, etc.
3. Commercial agro-enterprises: Located in the headquarters of

cantons/prefectures, they act as retailers they are at the initiative of nationals and intervene to purchase farmers' production for the purpose to commercialize them to other big agrobusinesses either in the country or abroad.

4. Individual farmer: Most food crops are produced by subsistence farmers working on family farms of less than three hectares.

5. NGOs: They have been keying on sensitization of the local communities on the need to do early bushfires to enable rapid regeneration of leaves to bring rainfall. They have been supportive in the training of peoples on how to do forestry, making nursery beds, etc.

6. Local community chiefs: they are the traditional custodians of the lands and work collaboratively with all the stakeholders to maintain peace, stability and progress in areas of agriculture. They grant access to lands to peoples and represent the central authority in the community.

7. Village Development Committees (VDCs): They are constituted entities that work to organize and coordinate actions for development of their communities such as advocating for water, sanitation, agricultural inputs (fertilizers, seeds, etc.) and maintaining the progress in their respective villages.

8. Forestry department or prefectorial directorate: they are in charge of sensitizing locals on the protection of forests. They are responsible of making sure that reserves, parks and national protected areas in general are free from human interactions. Their role encompasses the safeguard of natural resources, especially forests.

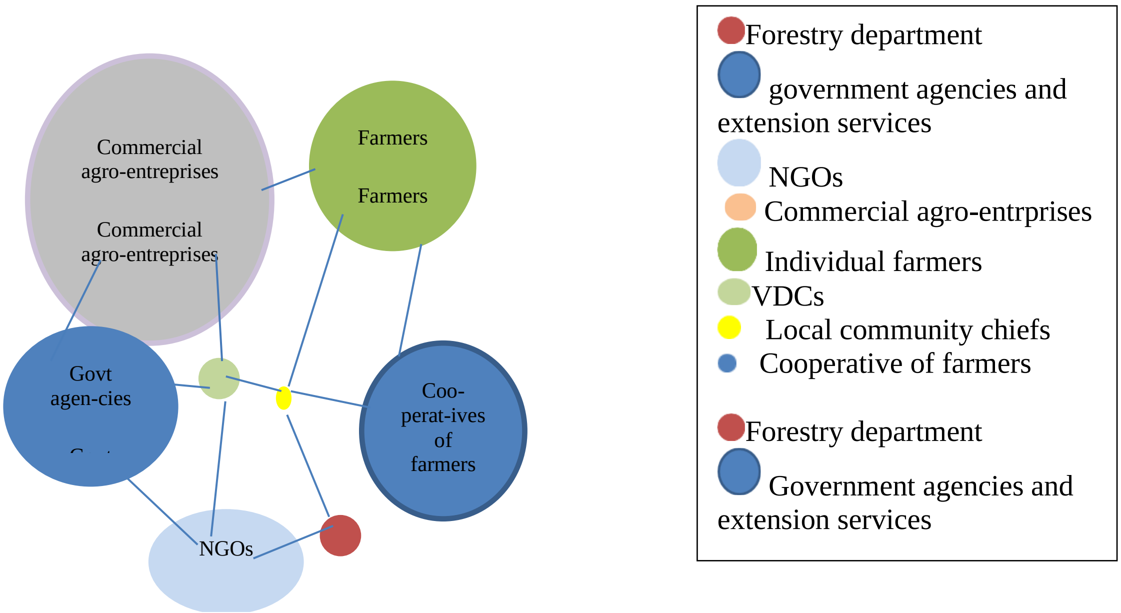


Figure 4.62. Multiplex Net-Map including relation linkages and power linkages.

Source: (FGDs' computation, 2022)

Note: Each coloured circle represents a stakeholder
The size of the circle corresponds to the degree of influence in deciding how to use/manage water and land resources within the landscape and the size of the linkage is equivalent to the degree of support.

NGOs have some influence on cooperative of farmers on how to use lands and water parsimoniously. In fact, NGOs intervening in the area work with local farmers to support them in training on sustainable natural resources management, protection of the environment, training on climate smart practices, agroecology, etc. From these interventions, farmers seem to learn and apply these knowledge and practices in the use and management of their lands and water bodies.

While Commercial agro enterprises have a very high influence on individual and cooperative of farmers to expand their production; putting pressure on land use practices. Commercial agro enterprises possess a very high influence on the locals due to a certain number of factors. First, they have a powerful relationship with the farmers due to the financial resources and other inputs (improved seeds or varieties, and market opportunities) they may offer to the locals. Second, they provide a form of guarantee to the farmers in regards to returns on farmers' investments and profits farmers would get after harvest. Third, they also have a kind of control on how much a product will be sold or purchased in the market. On the other hand, due to the guaranteed conditions that these commercial agro enterprises offer, local farmers are willing to expand farmlands and cultivate more with intensive use of agrochemical fertilizers and unsustainable land and water management practices (shifting cultivation, no or less fallowing, intensive agriculture, use of heavy equipment, deforestation, etc.).

Cooperative have a high influence on individual farmers to have more lands under cultivation or development for agricultural production. Cooperative are usually very well organized and are the direct contacts of the departments of agriculture, forestry, and commercial agro enterprises. Due to that, they interact very easily with these actors (ministries, departments, agro commercial enterprises). Thus, such interactions pushed them to use more lands and water resources for their agricultural activities.

Ministries or departments (agriculture, environment, forestry) have a high influence on the local community chiefs on how land and water resources for agriculture have to be used, and also on cooperative of farmers. These institutions direct and govern, and oversee not only the coordination and implementation of policies and actions in the sectors of concern, they also give directions and orientations in these sectors. In that sense, with the emphasis put in agriculture recently by the government and ministry of Agric through industrialisation of agriculture and development of agribusiness and manufacturing industries through the Agriculture Transformation Project in Togo (PTA-Togo) and the agropole development, cooperatives are being formed to boost agricultural development. In doing so, cooperatives are mostly influenced and tend to drive on ground these new policies.

Local chiefs have medium influence of the individual farmers to use and manage lands and water resources. Custodians and guardians of the tradition, local chiefs are the representants of the central authority in the villages or communities. They work to fulfill the directives and orientations made by the central and local government in their respective area of influence. Therefore, they act accordingly to ministries and other departments' orientations. Moreover, as lands in the communities are owned by the peoples, individual farmers can give away their lands to the state for development purposes through the intervention of local chiefs. On the other hand, they are also important in conflict resolution about land issues

VDCs have some influence on cooperative of farmers and individuals on the way land and water have to be used. Individual farmers have very low influence on cooperative of farmers. However, farmers have a high influence on the utilization of water and land resources.

6.2. Results of the FCREE-Kara Basin

Table 4.12 illustrates the choices about land use systems of most of the farmers that participated in the gaming scenarios. The game scenario FCREE-Kara Basin indicates a great proportion of farming households that practices mixed cropping land use systems (Table 4.12). Most importantly, these mixed cropping systems are food crops. Such choices are in line with the traditional land use systems to cater for family needs and ensure food security for households. Mixed food crop systems comprised of cultural and diets of the communities and include the following: maize, early millet, sorghum, yam, groundnut, sesame, rice. In the case of rice cultivation, two varieties are cultivated (4-month variety, and 6-month variety). In few cases, these crops are associated with tree species such as *Parkia biglobosa (*"néré"*) Vitellaria paradoxa ("karité"), Moringa oleifera* (moringa), *Fagara zanthoxyloides* ("fagarier"), *Milicia* *excelsa* (“iroko”), *Elaeis guineensis* (palm trees), *Mangifera indica* (mango tree).

Table 4.12. Choices of land use systems and reasons for adoption

Land use system	**Type of land management**	**Percentage (%)**	**Reasons for adoption**
Mixed	Maize + Yam	76	Culture & Tradition
	Maize + beans	69	Culture & Tradition
	Maize + Groundnut	72	Culture & Tradition
	Sorghum + beans	70	Culture & Tradition
	Sorghum + beans	61	Culture & Tradition
	Agroforestry with tree species such as palm trees, karité, néré, moringa, fagarier, fruit trees	21	Ecological
Monoculture	Teak	32	Economic
	Anacardium (Cashew)	30	Economic
	Annual crops (cotton, soybean)	67	Economic

Source: FCREE-Kara Basin, 2023

The monoculture planting includes mostly cash crops that can be sold out for revenues. As a land use strategy to cope with low production, the farming households are interested in high economic value cash crops like soybean, cotton, and trees like teak for commercialization. Another particularity for such choices of crops is their adaptation to the local climatic conditions and easy to market in the country due to the facilities offered by agro commercial enterprises which fund most of the cash crop farming related activities as explained in Section 6.1. On the other hand, these crops are also part of the priority crops identified in the PTA project which entails the development of agropole for increased production, transformation and commercialization of agrocommodities.

Further, it has been found that in the year of good production as a result of good rainfall, farmers tend to augment their production and land under cultivation the following (next) year as they believe that same conditions will be observed. This goes and so on until an extreme weather condition is observed and disrupts the status quo. When an extreme event (heavy rainfall, low or erratic rainfall, high temperature) occurs, farming households lose a lot as they have made huge investments on a large farmland size. This status of things informs farmers to reduce area under cultivation in the following year to avoid enormous losses. Next, farming households adopt short varieties of crops to minimize and reduce loss while making sure to have at least harvests for food consumption first and trade eventually.

7. Test of Research Hypotheses

This study investigates some assumptions which were defined at the beginning of the research as research hypotheses (Section 1.5). The test results of these hypotheses are presented in Table 4.13.

Table 4.13: Test of Research hypotheses

S.n	Research Hypotheses	Expected sign	Actual sign	Decision
Ho1	Farmers in the river basin have observed no environmental changes (climate and land use changes) over time and have not used traditional livelihood strategies to respond to them	-	-	Not verified, alternative hypothesis accepted
Ho2	The river basin does not experience any change in climate, land use and land cover	-	-	Not verified, alternative hypothesis accepted
Ho3	The land cover has not been degraded by agriculture and population growth	-	-	Not verified, alternative hypothesis accepted
Ho4	Farmers make decisions towards change of the climate, land use changes and water availability for agriculture in the Kara River Basin and no economic reasons motivate farmers in doing so	-	-	Not verified, alternative hypothesis accepted

Source: (Author, 2023)

8. Discussion

Objective 1: Assess the perception and awareness of farmers on climate, land use and land cover changes (LULC) and traditional strategies for climate-resilient multifunctional landscapes in the Kara River Basin

8.1. Perception of local communities on climate change, land use and land cover change, and traditional livelihoods and resilience strategies in the Kara River basin

Socio-demographic characteristics of the respondents showed that the majority were male-headed household and that female-headed household were underrepresented in the survey relative to the 20% of female-headed household in the national agricultural surveys (MAEP, 2013). The fraction of respondents that were married (89%) also exceeds that of (79.7%) in the national agriculture census of 2013 (DSID, 2013). Almost 60% of respondents have ever attended school while 40% did not. Such result matches with MAEP (2013) census data that found a decrease in the proportion of illiterate household heads from 62% to 46% thanks to efforts of the State and its partners in the education reflected in sectoral and national plans for education from 2010-2020 (Republique Togolaise, 2010). These efforts include free of charge schooling and the establishment of a school feeding programme for primary schools since 2008. In fact, this has helped to keep children in school for a long period. 70% and more are above 40 years of age meaning that agriculture activity lies in the hand of the active group even though little is handled by the youths. The majority tends to be in a monogamous marriage with most of the ethnic groups dominated by Kabye and Konkomba as they are known for being the autochthons of the region. In 2011, statistics from the World Bank indicated that land ownership was 78% (World Bank, 2023)[6]; showing an increase in land ownership over time. A situation that may result from the increase of size lands for agriculture expansion associated with a growing population in the area.

The low fertility of local farmers' lands may be due to land becoming scarce in the

[6] https://knoema.com/atlas/Togo/Kara/Proportion-of-households-Owning-Land

area driven by intense agricultural activities. Also, chemical fertilizers are widely used by most farmers as land is becoming scarce. This situation might be due to population increase in the basin; a result that is in agreement with the national census (DGSCN, 2010).

Fuel wood and charcoal remain the primary source of energy by farmers in the area; denotating the dependence vis-à-vis forest resources (or at least trees) in the landscapes. In general, water and energy source are relatively far from the respondents (with the average affirming that such facilities are less than 5 km of distance and less than 1 hour of reach; showing water scarcity and supply issues.

Besides agriculture (crop-based farming and livestock), alternative livelihood activities seem to be lingering on forest exploitation activities; denoting their dependency on forest related livelihoods. The Kara River basin landscape is multifunctional; thus, provides multiple purposes to its inhabitants. The dependency on forest-based livelihoods in the area originates in the high interest farmers place on non-timber products for their subsistence, rather than timber or wood. Wood products are mostly used by wood exploiters for commercialization; and very few by local farmers.

In terms of the local knowledge of the study area, climate change is understood and characterized as late onset and early cessation of rains, insufficient rains, increase in temperature, variability in rainfall patterns, strong winds and unpredictable seasons. These findings tend to be in agreement with observed data from meteorological stations in the study area (Section 8.2) and other previous studies in the basin (Badjana *et al.,* 2017a), which indicated a decrease of rainfall and great interannual variability of rainfall and in average annual rainfall in the basin. Also, there was a consensus among respondents vis-à-vis certain changes in weather patterns and frequency of extreme events. It is worthy to indicate the beliefs farming households have towards climate change as a punishment of god(s) or ancestors for absence of negligence in the protection of their sacred woods/forests which sometimes are intruded or cleared of as land is becoming scarce in the area.

The majority of farmers acknowledged climate change as very important as it poses threats to their means of survival (e.g., agriculture, livestock even forest-based products). Reasons pointed out by farming households to explain the seriousness of climate change issues are in agreement with previous studies which found that climate change affects rural livelihood activities the most.). Such information corroborates with climatic change profile in the Kara river basin which predicted increase in surface temperature (Republique Togolaise, 2015; Badjana, 2015) and in the overall Oti Basin (Badjana *et al.,* 2011). Such scenario undoubtedly may have led to burdens seen in climate sensitive livelihoods activities (reduction of agricultural livelihoods' production and revenues). Further, the rise in temperature coupled with increase in rainfall duration (Badjana *et al.,* 2017a) tends to increase number of mosquitoes. One factor that has been extensively discussed is the possible influence of regional warming due to climate change on the development of malaria mosquitoes (Hay *et al.,* 2002; Randolph, 2009). A study by Paaijmans *et al.* (2010) showed that increased water temperature could affect mosquito development cycle. This finding corroborates with a study by Yao *et al*. (2018) which revealed an increase in malaria cases during the rainy season in farming communities in Bole District in the northern region of Ghana, a sub-Saharan neighbouring country of Togo.

Soil erosion on farmland is evidenced in the area. Then, it will be reasonable to expect more willingness from farmers to adopt farming practices to counter land scarcity induced by land cover and land use changes.

The scarcity of forestry products, especially non-timber products could be explained by the prevailing land cover and land use change influenced by extensive agriculture, deforestation, and some sort of urban sprawl. This may have had influence on the delivery of the most essential ecosystem goods and services upon which farmers rely on such as non-timber forest products and in a little proportion wood and firewood. With the subsistence nature of farming practiced by the farmers, little imprints are made on wood-based products by the locals. However, there is an increase interest in charcoal production to gain other means of survival as land is becoming scarce and agricultural production has decreased over time, especially in leaning periods.

In the multifunctionality of landscapes, land plays a central role as it represents the substratum upon which the system lies. Therefore, farmers' perceptions on the land dynamics show that land transition has taken place as a result of anthropogenic activities. These activities found their root causes in the following factors in the order of importance, agriculture expansion and development, building, charcoal production, timber logging; and accessorily population growth acting as an indirect cause. These perceived causes of farmers explain empirically well the interrelated nature of land-forest-food web with land and forest being the core sectors in this nexus. Population growth lags behind and seems to act as an indirect cause of land conversion in this study. However, it constitutes a pressure for land conversion in many other studies (Maja & Ayano, 2021; Jiang & Hardee, 2011; Molotoks *et al.*, 2018). As a matter of fact, based on the DPSIR (driver, pressure, system, impact, responses) analysis, population dynamics increased pressure on natural resources (land, forest, water, etc.). Migration and population dynamics that prevailed in the last decades: from 1987-2010 and 2010 to date may have influenced land use and land cover changes in the basin. Such a scenario has been found in many studies to be correlated with pressures on natural resources at the expense of natural forests, causing loss of habitat and biological diversity (Zegeye, 2017; Molotoks *et al.*, 2018).

Land cover changes exert an influence on forests and land resources in general. Within the Kara River basin, changes in land cover and land use induced by human activities (agriculture, building, logging, to name a few) affect the solar net radiation on the ground and increase surface heat as well as soil erosion. Less vegetation cover is susceptible to an important risk of wind and water erosion coupled with increased pollution. This has been indicated by the local population who perceived land use and land cover change as a threat to soil fertility, reduction in livelihood provision, land degradation and scarcity, water pollutions and ecosystems destruction. An eroded soil losses nutrient (through physical degradation); thus, reducing soil fertility. Further, locals revealed an increased risk of soil fertility decline with continuous climate variability, changes and windstorms as the area faces environmental change. In the overall, this explains their farming revenues in the past 5 years not able to cover their livelihood needs. Thus, the need to go in for other alternative livelihoods (logging, etc.).

Farmers possess knowledge on soil erosion which induces loss of soil fertility. In fact, soil erosion causes top soil to be removed; thus, loss of soil nutrients content. However, locals are knowledgeable about the indicators of soil erosion as it has been recorded in the study area.

A wide range of local, almost traditional measures are being implemented by farmers to prevent their farm soils from erosion and maintain their fertility. Besides strategies to prevent soil fertility loss, other blended measures are put in place by these farmers that integrate both soil and water management; as the area experiences monthly rainfall variability and rise in temperature (Badjana, 2015).

Integrating soil and water management by locals have been identified as part of the local solutions inspired by nature that farmers mentioned to be of great reliability to improve soil fertility on their farms. In reality, the integration of soil and water management practices add more to the conservation efforts of soil fertility decline as water and soil are intrinsically connected and may not be handled separately as per sustainable agriculture and climate-smart agriculture require. In reality, this discovery agrees with Adji *et al.* (2021) study which stated that compost making from vegetable or animal waste through traditional techniques is a common practice in the country and is useful in many districts, particularly in the dry northern part of the country. On the other hand, agroforestry systems (still in small proportion) introduced by farmers are gradually gaining popularity among women and men in the northern part of the country.

These local solutions used to cope and/or adapt to land degradation and soil fertility have the desired impacts. These findings may suppose that farmers willingly accept to adopt such ILSWMP which performance are widely recognised in the scientific literature. In all, this paper provides empirical evidence that land degradation and climate change interact and pose enormous threats to local livelihoods in the Kara River basin. Farmers face soil erosion, consequence of land use and land cover changes exacerbated by climate change. Local farmers perceived the existing connection between land cover changes and climate change and its effects on agricultural outputs. To handle the decline in soil fertility generated by land use, land cover change and climate change, farming households in the Kara River Basin have managed to adapt by employing locally proven solutions that they own and seem to work out well to augment food production and limit food insecurity in the area. Such local solutions present huge potential to combat soil fertility loss aggravated by climate change, and land use and land cover change increase in the basin; which should be prioritized in other communities in the basin or other parts in Africa. These solutions may help to address the well documented barriers or constraints to adaptation in developing countries in scientific literature which chiefly derive from prevalent poverty, inequitable land distribution, over dependency on rain-fed agriculture, limited access to capital, market and technology, poor long-term weather forecasts and derisory research and extension, and inadequate public infrastructure (e.g., such as roads).

8.2. Awareness of local communities in climate change, land use and land cover change in the Kara River basin

The climate change awareness index (CCAI) in the study area is equivalent to ~ 0.53 meaning a moderate awareness level of the respondents about climate change phenomenon in the area. Such findings could be as a result of awareness is not simply to know if climate change is real or not but here our definition of awareness goes beyond the simple response "yes" or "no" if you have heard about climate change. This finding contradicts other studies (i.e., Ali (2021)) that argued otherwise. The moderate proportion of climate change awareness in this study is not consistent with other studies that claimed that most of Africa's citizens are aware of change in climate patterns (Taderera, 2010; Amos *et al.*,2015; Agwu *et al.,* 2018; Bah *et al.,* 2018; Utete *et al.*, 2019). Such divergence could be explained by the fact that most of these studies did not consider all the three indicators of awareness used in this study: conceptual, experiential and engagement as in Kutir *et al.* (2015)'s conceptualization of awareness, especially the engagement component. In this study, the engagement of farmers (refers as climate action in the broader climate literature) counted in the awareness computation. Similar studies on awareness of countries like Ghana, Beinin, The Gambia in West Africa zone that shares similar climatic conditions yielded contradictory results as well where the awareness using the same index was relatively fair (Kutir *et al.,* 2015); corroboting with the findings from this study.

For the land use and land cover change awareness index (LULCCAI), the results show a relatively high level of awareness of respondents. Based on spaceborne technology and earth observation systems, previous studies (e.g., Badjana, *et al.*, 2017) indicated some changes resulted in the overall decrease of forest and savanna areas into agricultural lands during the period 2000-2013 in the sub-catchment of the Kara River basin. The vegetation cover in the area has then decreased over the last decades due to many drivers including unsustainable agricultural practices (slash and burn technics and shifting cultivation practice in the area), charcoal production and fuel wood collection linked to increase in population growth (MAEP, 2013). Next, land degradation is widespread in the region (Brabant *et al.,* 1996) resultant in soil erosion speeding up and falling crop yield (UNEP-GEF, 2012).

The awareness computation for this study investigates new approaches to measure combined climate change and land use and land cover change awareness at community level, which is so far missing in the literature. The average CCLCLUAI computed for the surveyed population of the Kara River basin is moderate or fair (0.57). Meaning awareness about climate and land use changes in the area is above average. As climate change and land degradation and deforestation are intertwined, this finding supports the need for more awareness creation about such issues in the Kara River basin.

8.3. Climatology in the Kara River basin

Rainfall variability was noticed from 1985-2014 period over the basin with increased rainfall observed from 1985-1999 all across the four stations (Takpamba, Guerin Kouka, Kante, and Niamtougou). A decrease tendency is shown from 1999-2014 with the highest decrease at Takpamba. This tendency to decrease could be an impediment to agriculture and other rainfed activities over time.

The Standardized Precipitation Index (SPI) illustrates the dryness of the area over time, especially from year 2000 and onward at all the locations across the basin. This has serious implications for farming households and endanger food security. Such findings are in agreement with a previous study of Badjana *et al.* (2017) which also pinpointed the changes in rainfall amount and distribution over the basin.

Monthly temperatures have becoming warmer with Tmax of 40^{o}C and increase in the relative humidity due to rise in temperatures. The onset and cessation of rainfalls at Niamtougou (the international airport station) revealed that the starting of raining season is not consistent across the area with onset that shifted from mid-April to early May and early cessation are observed in September and early October.

The number of rain days has shown some decrease leading to havocs on production of crops over the years. This may be as a result of dryness and loss of soil moisture at the time plants needed the most as reported in many studies over West African Region. Wiebe *et al.* (2017) indicated that extreme precipitation and seasonal drought have consequences for agricultural practices.

Climate extremes observed were dry spells and floodings. Extreme values of temperatures and rainfalls confirms such findings with maximum temperatures leading to heatwaves; which have some health implications for the vulnerable groups (elders, children and women). The diurnal temperature range is proven to be high compromising resilience of the ecosystems in place at basin level. The anomalous accumulation of rainfalls indicates that dry seasons were becoming very dry while wet seasons have become very wet; implying some risks related to heatwaves and floodings in dry seasons and rainy seasons, respectively. Health issues like malaria are likely to be more pronounced with dangerous consequences on the most vulnerable.

Projected future climate scenarios indicate that annual rainfall will increase from now till the end of this century for all the five SSPs scenarios across all the weather stations (Takpamba, Guerin Kouka, Kante, and Niamtougou) over the Kara River Basin with risks of floodings high with SSP-3.70 and SSP-5.85. At the same time, temperatures will increase for about 1.75^{o}C and 1.5^{o}C for SSP-5.85, SSP-3.70 and 1^{o}C downward increase for SSP-1.26 and SSP-2.45, with high risks of dry spells.

Objective 2: Determine spatial-temporal land use and land cover change in the Kara River Basin and the main driving factors

8.4. Spatial and temporal analysis of land use and land cover change in the kara river basin

The land surface dynamics in the basin are not uniform over time as indicated by the findings of our study. The area underwent changes in the land use that affect the spatial and temporal distribution of all the identified classes of land use. The increase in settlements throughout the studied period shows the amounting settling down of peoples in the landscape; which may lead to encroaching of vegetation area to collect woods and other materials that are needed for housing and construction as well as energy needs. Another fact, is the sharp increase rate from 1987 to 2000 and from 2014 to 2021; denoting that human activities have been on the rise in those particular periods in the river basin. The explanation would be the limited enforcement of forest protection rules over the area associated with the increased need for settlement construction/development in those particular time periods for the communities as a result of population growth.

Generally, our study found that forest, water, and savannah have decreased while agriculture land cover and settlement have increased over the studied period in the river basin. This shows an increase in the anthropogenic activities that have been taking place in the Kara River basin in the last three decades. Findings of this study are in line with a previous study by Badjana *et al.* (2017) carried out in the same river basin; where results show a continued loss in forest and savannah loss. In addition, Koglo *et al.* (2018) revealed that forest lands are threatened due to inappropriate agriculture activities and urbanization resultant from rapid population growth, increase in food needs, and settlements. Our study's findings corroborate with Koglo *et al*. (2018) as it indicates that land use change is a continuous threatening matter within landscapes that cater for multiple resources to humans (agriculture for food needs, forest and savannah for building materials, energy needs and urbanization).

The rate of reforestation area of 14,379 ha represents a signal of the achievement of past and on-going projects in the area geared towards the reforestation, protection and rehabilitation of protected areas and community forests. Such projects not only do reforestation, but importantly focus on protecting remnant forests and woody areas by promoting sustainable land use practices and raising awareness of the populace; contributing to limit humans' pressures in the forested areas. In fact, government and non-governmental organizations (NGOs) involvements have led to increase in agroforestry and local management practices (Bagbohouna *et al.,* 2023). The crucial problem lies in enforcement of protection policies within and around the river basin as the reforestation rate (2,68%) is noticeably lower than the loss of forest and savannah that has occurred (47%). The decline in forestland is connected to population growth and its related growing demand for food and energy. The loss in savannah is linked to the increase of settlements and agricultural land through slash and burn practices (Badjana *et al.,* 2017). Other important causal factor of the deforestation experienced in the area is driven by tree cutting for firewood, charcoal and softwood lumber as cited in previous studies (Djagni, 2003; Badjana *et al.,* 2014). On an important scale, comparable fluctuations in land cover were observed within the Volta Lake Basin of Ghana with which Kara River basin are all part of the bigger Volta River basin. In the Volta Lake of Ghana, Braimoh and Vlek (2004) found in their study that the conversion of natural vegetation to farmland is the leading land cover change. Findings of this study are in line with a previous study by Badjana *et al.* (2017) carried out in the same river basin; where results show a continued loss in forest and savannah loss.

A change of 75% was found for water bodies in the area, indicating that the most significant changes were observed in the water areas which have encountered a complete decline. This situation could be as a result of important activities carried out along the riparian forests and marshlands which present some important factors of attractivity: water availability, fertile soils due to presence of alluvions, investing low capital and easy ploughing for instance as the soil is soft compared to uplands or other areas. Moreover, as acknowledged in studies in other African regions (Natta *et al.,* 2012; Pouliot *et al.,* 2012; Folega *et al.,* 2014a; Polo-Akpisso *et al.,* 2016) a significant part of the deforestation arises in riparian forests that not only demolished for firewood and softwood lumber extraction, but most importantly for offseason farming and market gardening. This may have serious implications on forest resources and water conservation, and sustainable agricultural food systems. This prompts the need for forest conservation and sustainable agriculture practices. The need for multifunctional landscapes which concurrently offer food security, secure livelihood opportunities, conservation of species and ecological functions, and satisfy cultural, aesthetic recreational needs (O'Farell & Anderson, 2010) is top of priorities in global development agenda (SDGs) and high political forums. For that reason, studying land use and land cover change is fundamental. Changes of land use and land cover affect the available energy, water availability, photosynthesis rates, nutrient levels, and land surface properties, with substantial implications for human and ecosystem development (Sterling *et al.,* 2013). The shrinking of forest resources does not favor adequate response to climate change since the carbon sequestration potential of the country reduces in the area due to decline in forest cover and savannah. It is worth noting that tropical forests with their characteristics constitute the best bet for REDD+ and the conservation and augmentation of forest carbon stocks (Taddese *et al.,* 2022).

In the view of mitigating climate change, forest conservation measures should be promoted and sustainable agriculture practices recommended and adopted by farming households in the area to avoid forest loss cover and contribute to forest conservation and climate policy efforts (UNCCD, NDCs, REED+, Paris Agreement, etc.). Moving away from unsustainable intensive agriculture to nature-positive solutions contribute to halt deforestation, preserve and restore water and forest resources and biodiversity at large. For instance, agroecological production practices such as agroforestry will limit the threat of further deforestation and wildlife species decline, while maintaining future food security (WWF, 2022).

Also, efforts are required to lessen the significant constant changes in land cover that jeopardize synergism needed on multifunctional landscapes to ensure the sustainability of land resources while catering for human needs (food, water, energy). Such efforts may comprise the intensification and upscaling of sustainable land management practices joined with the strengthening and implementation of current policies/laws/guidelines on deforestation, protected areas and the utilization of forest and water resources. To be able to do that, the maps and estimations we have come up with this study which is one of the latest in this area present ample information to guide in the identification of areas that need forest development and sound agriculture development and area with important changes in land cover for proper decision-making.

8.5. Main driving factors for land use and land cover change in the Kara River basin

The main driving factors of land use and land cover change in the Kara River basin are population growth, agriculture development and expansion, logging, etc. these factors could potentially be insistent in a business-as-usual scenario; thus threatening, the resilience of communities to climate shocks identified in Section 8.2 (droughts, floods, heatwaves, etc.).

These findings are consistent with the recent developments that are happening in the country with incremental development in the agricultural sector. Another reason, is the decline in soil fertility due to unsustainable land use practices and land degradation in the area. Recent studies (Badjana, 2015) confirm the use of unsustainable agricultural practices in the region, which result in soil fertility loss. As a coping mechanism, farmers have to increase or expand their farm sizes. This induces to have more lands and conversion of savannahs into agricultural lands.

Based on this research, it appears that a key factor contributing to the increase in the fragmentation of land is population growth which is in agreement with findings in Burkina Faso where increase of population density is one of the most important factors behind land cover change (Olumba *et al.,* 2022). The main socio-economic activity in Kara basin is agriculture which is for subsistence (Djagni, 2003). The increase of population size has noticeably led to the expansion of agricultural land over savannah which is the main vegetation type for meeting the increasing needs of population for food (Badjana, 2015).

The reduction of these vegetation types from 1987 to 2000 is as a result of deforestation for the search of wood for charcoal as domestic fuel. For instance, the landscape has been heavily destroyed for charcoal and fire wood. This could be attributed to turbulent times due the socio-political difficulties that the country experienced from 1990s, leading to the loss of government control over forest and most importantly protected areas. The strategy of biodiversity conservation in Togo indicates that the Kara region has been acknowledged among top three regions (over the 5 regions) in Togo where vegetation degradation has augmented with the growing demand of firewood and charcoal, the key sources of energy for 80% of the inhabitants (MERF, 2003).

Further to energy purposes, softwood lumber trade has also been recognized as an important cause of environmental degradation whose influence has knowingly amplified from 1975 with the introduction of a powerful tool, the chainsaw which substituted traditional tools such as machetes and axes (Badjana, 2015; MERF, 2003). A recent study by Sanogo *et al.* (2022) in Mali, a country of West Africa also evidenced as part of drivers of LULC change in Wacoro Municipality, rapid population growth, agriculture land development for crop production and high energy demand. In all, our findings support the hypothesis of socio-economic activities' contribution to land use and land cover changes.

In this study, it was observed that the last three decades have been markedly transformational for land use systems for the Kara River basin. This study reveals the most recent important spatial and temporal land use and land cover changes within the Kara River basin as a result of forest and savannah been converted into agricultural lands and increase in settlements and farming areas while water bodies decline is markedly observed throughout the studied period.

Further, it is found that while reforestation and protected areas rehabilitation projects have led to a 2.68% in increase in forested area, the 48% of forest loss and 75% of water bodies decline still is a matter of concern for the Kara River Basin. It is urgent to implement sustainable management practices, privilege participatory management of the landscape and to reinforce forest protection rules for which maps drawn in this study may serve as treasured tools for decision making.

Objective 3: Model farmers' decisions to climate, land use changes and water resources in the Kara River Basin

8.6. Land use and management systems in the area

The game scenario revealed that most farmers adopt a mix cropping system. Crops that are often cultivated are maize, yam, rice, sorghum, groundnut. In few cases, these crops are associated with tree species such as *Parkia biglobosa ("*néré"*) Vitellaria paradoxa ("karité"), Moringa Oleifera* (moringa), *Fagara zanthoxyloides* ("fagarier"), *Milicia excelsa* (iroko), *Elaeis guineensis* (palm trees), *Mangifera Indica* (mango tree). In the case of rice cultivation, two varieties are cultivated (4-month variety, and 6-

month variety). In the year of good production, farmers tend to augment their production the following (next) year. When an extreme event (heavy rainfall, low or erratic rainfall, high temperature) occurs, farming households lose a lot as they have made huge investments on a large farmland size. Due to this approach of making decisions on what and how to plant, the results are not very promising as there seems to be little knowledge and communication about prediction and early warning for farmers before the planning of farming activities. In such situations, adapting to climate variability and changes might face shortcomings and reduce the adaptive capacity of the farmers.

8.7. Game experience based on farmer perspective

The game was appreciated by participants and relatively easy to understand and simple for use. Its duration was relatively long as per participants' responses. The game was said to be educative and is a well mix of prevailing situations that may arise in farming communities. It was reported that the game helped farmers to gain insights on the consequences of their choices of land use systems on the tradeoffs between agricultural production, ecological benefits and economic gains. From these experiences, FCREE-Kara Basin seems to have helped achieve experiential learning of the participants and suggested a way to integrate innovative co-learning in a participative way with stakeholders. Such findings relate quite well with Sari *et al*. (2023); where the game has proven to be a tool to transfer information and represent a search for synergy between maintaining agricultural productivity, diversity, and ecological functions in the complex socio-ecological system context of a sustainable production system.

8.8. Gaming scenarios for FCREE-Kara Basin

Game results show that the choices of farmers' varieties of crops are from cultural, traditional, and economic point of view including food security angle. Farmers noticed the effect of their choices on the ecological and economic benefits. From this perspective, farmers are making choices based on their prior knowledge, either experienced or heard from a fellow farmer. This is as a result of the strong presence of local and traditional knowledge in the agriculture sector. Also, the need for commercialization, is a reason that motivates farmers to grow a certain type of crop. Farmers acknowledge that the commercial agro entreprises existence nowadays have increased their desire to go in for high monetized value crops such as: soyabean, cotton, etc. Commercials agro-enterprises have a power over use of land water resources in an indirect manner as they control to some extent cooperative farmers and individual farmers. In the new framework of agricultural development policies to have agricultural development pole in the Kara through the agropole of Kara, they have a huge influence and control on how farmers will decide or are deciding to manage their lands and water resources for agricultural activities. The implications from this, may be the tendency of monoculture plantations and intensive agriculture with high demand in water and lands, resulting in the lack of recognizing the effects on the ecosystem: soil fertility, water quality, etc. Economic reasons and household food security are the core and fundamental reasons why local communities make choices on the type of land use systems they practice in the area.

Weather events and external pressures do not significantly change drastically their land use systems, rather they are shifted or left for a while and used back again when climatic conditions or other external pressures come back to the normal. For instance, a change in early cessation or late onset for example of the rainy season will only dissuade the persons not to augment its land size under cultivation; rather they will just reduce it and increase it when conditions are becoming favorable as they used to.

What has been adopted as strategy for coping with changing climatic conditions, increase in seasonal variability and dry spells includes livestock and poultry or relying on fruits and nuts provided by trees like *Parkia biglobosa (“*néré”*), Vitellaria paradoxa (karité)*, *Moringa oleifera* (moringa), *Fagara zanthoxyloides* (“fagarier”), *Milicia excelsa* (iroko), *Elaeis guineensis* (palm trees), *Mangifera indica* (mango tree), etc. to go over this so-called leaning period in the area. Only few decide to embark on associating agroforestry in their farms. Those who do that are the ones that for a long time ago have still some trees on their fields. The game has also demonstrated that farmers are in a short to medium term planning of how they respond to the external pressures (climate extremes, market shocks, etc.); which may not be in the long run sustainable and contribute to building climate-resilient multifunctional landscapes in the basin. Thus, the urgency of exploring ways to enhancing and upscaling these short to medium terms responses and strategies to sustainable ones by promoting farmers’ participation.

8.9. Problems encountered in the Field

This study faces some shortcomings related to not being able to unpack all the intended scenarios of existing and potential external pressures (e.g., drop in market price, floodings) to understand the land use decision-making of the farmers due to the time constraints and limited research funding.

Besides, a number of issues arise in the attempt to conduct this research, especially on the field for data collection. These are, among others, the following problems:

- Untimely commencement of the field works due to delay in administrative and bureaucracy related works to having the green light to start data collection in the study area.
- Language barrier that was lifted by the use of translators and enumerators who were from the investigated communities.
- Weather was an important factor considering the period of the data collection. The early months of rainy season coincided with the time of the data collection; thus, some delays occurred in finishing up on time the field data collection
- Poor road networks rendered difficult the access of the researcher and his team to the study area.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

This study investigated a participatory approach for understanding issues related to building climate resilient multifunctional landscapes in the Kara River basin considering combined land use and climate studies with participatory scenario evaluation of farming communities' decision-making processes using a serious game (which simulates lived experiences of farmers' decision-making and engages relevant actors).

The study comes out with strong evidences of existing issues of land use and land cover change and climate change in the area to which farmer's awareness were relatively moderate, respectively (LULCCAI=0.60; CCAI=0.53). The composite LULCCCAI is then moderate or fair (0.57); showing a relatively good knowledge of climate change and land use and land cover change issues in the Kara River basin by the communities. Strategies to cope, adapt or mitigate these changes included traditional and effective sustainable and climate-friendly practices and strategies, though applied by a relatively small proportion of farmers.

Another important finding is linked to the statistical coverage (spatially and temporally) of land cover vegetation types within the river basin. It is indicated an important decline of water, savannah and forest to the detriment of agricultural lands and settlements, which is a serious challenge for maintaining land productivity and climate-resilient ecosystems. Factors that accelerate such degradation and deforestation in the area are found to be agricultural development and expansion, and logging primarily, and population growth, charcoal production and habitat construction, accessorily. It is evidenced that forest areas are been recovered as a result of farming communities using agroforestry technics and NGO actions towards reforestation and afforestation accompanied by the gradual regain of control of parks and reserves (protected areas) which were left on their own by the State.

Results also revealed that numerous stakeholders play a role in the landscapes of the Kara River basin; and that, their decisions greatly influence how water and land resources are managed or used. Such stakeholders among which are individual farmers, local chiefs, village development committees, departments of agriculture/environment/forestry, commercial agro entreprises, cooperative of farmers influence the utilization of the lands and use of water for agriculture and irrigation purposes. Commercial agro enterprises, ministries and cooperatives seem to be the biggest influencers about i) expanding agricultural lands for more production, ii) the selection of crop varieties to cultivate, and iii) increase use of water for agricultural production. Factors that motivate the choice of expanding are cultural, economic and not for ecological reason for most of the farmers in the scenario decision making.

5.2. Conclusion

This study has endeavored to bridge the gap of little participatory approaches employed in creating resilient multifunctional landscapes in the face of global environmental changes that include climate change and land use changes. This study, to the best of my knowledge, is the first of its kind on the continent and Togo, in particular. Most works done so far on climate-resilient multifunctional landscapes looked at European and other continents expect Africa. Additionally, this research has shed light on how climate change and land use issues are intertwined and the need to strengthen the integration of local ecological knowledge with scientific knowledge to address contemporary issues at landscape level. The Kara River basin has experienced important changes in land use and land cover that have led to dwindling of forest and savannah coverage including substantial shrinking of water bodies due to deforestation, extensive agricultural practices. These are fueled by agriculture expansion and development, logging, etc. Locals are relatively aware of such changes and have started responding to them by modifying and adjusting through the use of local knowledge and some agroforestry practices which are still minimal due to the presence of other actors that are important to consider in the multifunctional landscapes. Climate extremes have been registered in the area and projected climate variables (such as temperature and precipitation) will likely increase; creating situation of dry spells, droughts, and floodings in the next 73 years to come (by end of the century). In the other hand, heatwaves and bushfires are more likely to be recorded; threatening the existence of the peoples and undoing progresses made to reduce greenhouse gas emissions and putting more pressure on forest resources. Local communities are influenced by actors and local contexts when making decisions towards land use systems and water use for agricultural practices. In the Kara River basin, commercial agrobusinesses are powerful actors that influence choices of farmers even though government agencies/institutes are essential in regulating this relationship. Besides, local ecological knowledge is still used even though the latter is being pressurized by economic and profits considerations. Participatory decision-making processes are key for building resilient multifunctional landscapes as it reveals areas of synergies, possible tradeoffs and to reach to a balanced situation where all stakeholders in the same multifunctional landscapes interact and are aware of issues at stake and work collaboratively to reclaim, restore, mitigate and adapt effectively to threats that arise without compromising other actors' welfare, and the well-being of the ecosystems.

5.3 Recommendations

From the findings, the recommendations summarized below are to be considered for building climate-resilient multifunctional landscapes using steps towards participatory approach:

1. The results provided that although most of the farmers are aware of climate change and LULC changes, there are a reasonable group of farmers who lack awareness. Therefore, stakeholders such as **agricultural institutes and local actors** should intensify awareness creation on CC and LULCC issues and reinforce ecological knowledge.

2. The results indicated that local strategies can play an important role in building climate-resilience in the river basin, though they are practiced literally by few peoples. Therefore, the study recommends that **policymakers and NGOs** should support, upscale and promote traditional livelihoods options and strategies that are climate sensitive.

3. The findings also revealed a decreasing trend of forest, savannah and water bodies. In addition, commercial agro entreprises are powerful actors in the farmers' decision over the types of land use systems to be promoted. Therefore, the study recommends to the **government** the following:

   - To promote water saving technologies and reforestation actions with particular attention to agroforestry practices; and

- To encourage agro-commercial enterprises to provide tree seedlings for afforestation/reforestation.

5.4 Contribution to Knowledge

This study has brought in new knowledge and some insights to the field of ecology and for building climate-resilient multifunctional landscapes in the Kara River basin in the face of climate crisis by unveiling the following contributions:

- The awareness level of farmers on LULCC & CC in the Kara River basin is known; offering a baseline information to advise better on educational actions/programmes needed for building climate resilience in the area;

- Traditional livelihood options and strategies that are climate sensitive are revealed and the need for their promotion and upscaling in the river basin is essential;

- Temperature in the Kara River basin will likely rise in the future; thus, water saving technologies are relevant for the area in terms of achieving food security (SDG 2) and climate-resilience (SDG 13);

- Land use and land cover change factors such as agricultural expansion and development, logging and population growth need to be considered for building climate-resilient landscapes in the river basin;

- Actors that intervene directly in the landscapes are not really the influencers of how water and land use systems operate; rather external actors like ministries, commercial enterprises are powerful actors to be considered in the participatory decision-making of the river basin.

5.5 Suggestions for further Studies

This study which was an attempt to explore steps for participatory approach for building climate-resilience multifunctional landscapes in the Kara River basin has yielded some insightful information for the research community, development agencies and planners. Advancing this research to the next level will be key to proposing the establishment of a framework for building climate-resilient multifunctional landscapes in the Kara River basin; which can serve as a best practice for the sustainable management of socio-ecological systems in Togo, and in Africa. The following suggested studies could be further explored to do so:

- Investigating barriers and enabling factors that make local farmers consider the ecological aspect in managing their land use systems in the multifunctional landscapes of the Kara River basin.

- Modelling the forest recovery trends in the future and its consequences on the decision-making of actors in the landscapes with regards to land use and water for agriculture in the Kara River basin.

- Exploring an in-depth analysis on the game outcome for better understanding of participants' farming systems choices in response to trade-off issues in the complex social-ecological systems of the Kara River basin.

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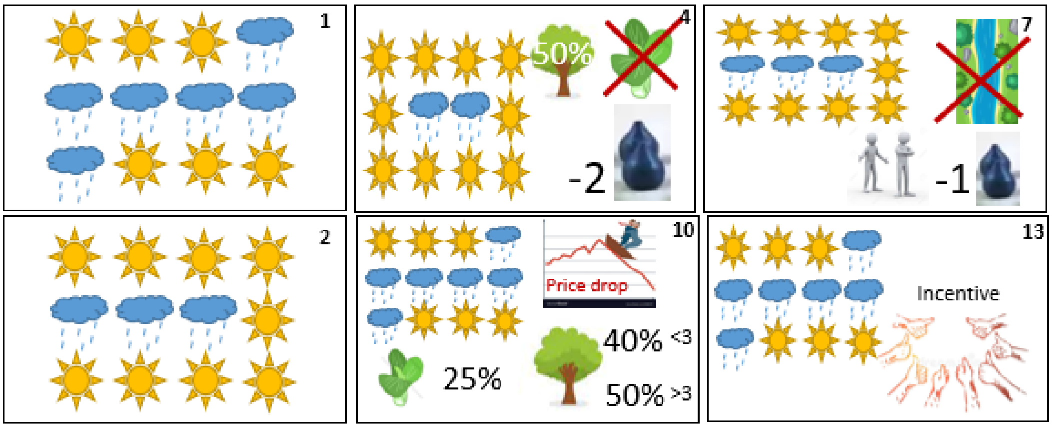
Appendices

Appendix I. The example of dynamic cards



Appendix I.1 is a card example for a wet year, while I.2 is for a dry year. Appendix I.4, 7, 10, 13 represent the occurrence of external pressures and the climate that will appear in that round

Appendix II. The default setting of the 3D board game at the beginning of the session

Appendix III. Post-game interview about the game experience based on farmer perspective

1. Is the game fun enough?

Boring Fun

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………

2. Is the game easy to understand?

Difficult/confusing Easy

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………

3. How are the complexity of the game setting and its environment?

Too simple Too complex

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………

4. Is the game duration too long?

Too fast   Too long

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………

3. Do you have specific strategy to achieve the goal?

No   Yes

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

I yes, what are they?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………

4. Does this game add new knowledge or improve your understanding?

No   Yes

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

If yes, what are they?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

………………………

Appendix IV. Pre-game interview questionnaire for a farmer (game participant)

a	***Personal information***	
1	Name	
2	Address	
3	Sex	: Male/female
4	Age	:
5	Education	:
6	Status	: Married/single
7	Number of children	:
8	Primary livelihood	:
9	Another source of income	:
10	Wealthy status	: poor/moderate/wealthy
11	Training	: From……………………, about

12	Inhabitants	…………………………………….	
		: Native/non-native, tribe………………………………	

b	***Societal position***		
1	Social position	: Yes/no	if yes, what role: …………………………………………. ex: farmer group leader, religious leader, respected local person
2	Member of farmer group	: Yes/no	if yes, name of the group: ………………………………………

c	***Farming system***		
1	Actual farming system	: Crops/tree-mono/mixed	
2	Cattle	: No/cows/goats	How many:

……………………
……………………
………………….

3	Plant species domination	:	
4	Other plants	1. 2. 3. 4. 5.	
5	Preferred farming system	: 1. 2. 3.	why……………… …………………… ………………
			4.2.6.4. . 4.2.6.5. … 4.2.6.6.
6	Preferred plant species	1. 2. 3.	why……………… …………………… …………………… … why………………

4. ……………….

5. why………………

……………………

……………………

…

why………………

……………………

……………………

…

why………………

……………………

Appendix V

Usefulness of climate indices per sector

Index	Health	Agricul-ture and food security	Water re-sources	Disaster Risk Reduction	Energy	Fisheries	Forestry/GHGs
TX		✓			✓		✓
TN		✓			✓		✓
CDD	✓	✓	✓	✓			✓
PRCPTOT		✓	✓				
SPI	✓	✓	✓	✓			
DTR							✓
SDII			✓				

Appendix VI

Focus Group Discussions

Appendix VII

FCREE-Kara Basin scenarios in the field

Appendix VIII

Publications

- **Published paper**

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Outline

ELSEVIER

Current Opinion in Environmental Sustainability

Volume 62, June 2023, 101292

Protected spring and sacred forest institutions at the instrumental – relational value interface ☆

Arief L Hakim [1 2 a], Danny D Saputra [3 4 5 b], Lisa Tanika [1 c], Irma A Kusumawati [4 d], Rika R Sari [3 4 5 e], Federico Andreotti [6 7 f], M'koumfida Bagbohouna [8 g], Ali Y Abdurrahim [9 10 h], Charles Wamucii [11 i], Elisabeth G Lagneaux [3 12 j], Margaret Githinji [13 k], Didik Suprayogo [4 5 l], Erika N Speelman [6 m], Meine van Noordwijk [3 4 14 n]

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- **Accepted for publication (Book Chapter)**

Soil fertility Recovery at the Kara River Basin (Togo, West Africa): Local Solutions at the Interface of Climate and Land Use Change - (Book Chapter of the Book "Climate Change Strategies: handling the challenges of adapting to a changing climate" (Springer)) [ePProofing (springer.com) available] - M'koumfida Bagbohouna, Meine van Noordwijk, Diwediga Badabate, Sidat Yaffa. (2023).