Doctorate Research Programme

Climate Change & Disaster Risks Management

Global Warming and Agro-climatic Risks' effects on Households Food Security in Mali

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Thesis

Submitted in partial fulfillment of the requirements for the degree of doctor at the University of Lomé, Togo

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DEDICACE

I dedicate this project to my departed father, Oumar DIARRA. I will never forget you and pray Allah Subhana wata Allah to grant you paradise, Amin.

This project is also dedicated to my honest Mother (WASSA DIABY) who taught me to trust Allah and work hard in my life, May her soul rest in peace, Amin.

ACKNOWLEDGMENTS

I would like to express my gratitude to the German Ministry of Education and Research (BMBF) for providing me with a stipend and research funds to conduct my research, as well as for enabling me to benefit from the collaboration with German and international scientists.

I am also grateful to all staff of WASCAL Lome, Togo for their very good management of this Ph.D. program on Climate Change and Disaster Risks Management.

Special thanks are going to Togo Prof. Komi AGBOKA (Director of WASCAL Lome, Togo), Dr. Prosper Begedou (Deputy Director), Dr. Idrissou Mouhamed (Scientific Coordinator), Madam Sefako A. SEGBE (Office assistant), Mr KUEVI Folly Amegnon H (Accountant) , AKPENE Koudjo (IT) for their supports and availability during this hard work periods.

I would like to sincerely thank my supervisors, Professor ABBEY Abbevi Georges at the University of Lome, Togo and Dr. TRAORE Kalifa Scientific Director at the Institute of Rural Economy (IER) in Sotuba, Bamako, Mali, who have never failed to be supportive and provide valuable advice, encouragement, motivation, and critical feedback on my research. I really appreciate your support.

I am deeply thankful to our lecturers during the course work. Indeed, I benefited useful comments while discussing my project theme.

I would like to thank the Institute of Rural Economy (IER) Sotuba, Mali for their very good accommodation to me during my research stay in Mali.

To my fellow Ph.D. students, who have tolerated me through this process, for the fun times and the support of knowing we are not alone through the ups and downs. Thank you to my parents for teaching me the value of education and hard work, which gave me the confidence to embark on this adventure.

And finally, thanks to my family, mum and dad, brothers, particularly to my lovely and passion wife “YALCOUE Aminata” who was always there with her continuous support and encouragement throughout my Ph.D., and to my lovely daughters Aichata B, Nadie, and Wassa for given me much needed distraction and entertainment.

SUMMARY

In Mali, the climate parameters are high variables. Their distributions are unevenly spread from north to south. Climate change strengthens to increase air temperature and evapotranspiration. It also increases the intense rainstorms and the risk of drought or flooding. Changes in the temperature and precipitation regime significantly impact crop production rate. Thus, these phenomena affect the population's livelihoods and all households' food security dimensions. Therefore, this study focus on two significant themes: Trends of historical climate parameters over the period from 1989 to 2019 and their influences on crops (maize and sorghum) production and households' food security status, determinants, constraints, and adaptation strategies.

To address these themes, Mann-Kendall was used for trend analysis; the CARI approach (WFP, 2014) was used to assess the households' food security status (455 household heads); and the binary probit model was applied to determine the main factors of households' security. In addition, descriptive analysis was done to determine the observed and perceived climate variability or change effects by farmers on natural resources and to identify and assess the coping strategies used by the farmers.

The Mann-Kendall test results show a positive trend (from 1989 to 2019) for all climate parameters analyzed (maximum and minimum temperature, precipitation, and evapotranspiration) in the Koutiala and San districts, respectively. However, both districts have a highly significant trend in temperature (maximum and minimum) and evapotranspiration. At the same time, there is no significant trend in precipitation in these districts.

The standardized precipitation evapotranspiration index (SPEI) has been analyzed to identify the study area's wet and dry conditions from 1989-2019. However, the results confirmed climate variability and change in the study area. Moreover, the frequency of dry spells is high in both districts. Furthermore, drought is one of the observed and perceived natural disasters by farmers and affects their livelihoods in those areas. At the same time, flooding sometimes occurs in the same areas because of the effects of climate variability and change around the country.

The standardized anomaly index (SAI) was analyzed to determine the study area's temperature variability. Mann-Kendall statistical test for the mean annual maximum and minimum temperature showed significant warming in all the districts.

The monthly average rainfall in June (-120) and August (-083) was negatively correlated with the production rate of maize in the Koutiala district. In contrast, a positive correlation was observed between maize production and precipitation in July (.319) and September (.076).

We observe a negative correlation between sorghum production and precipitation during the growing season (June: -.198; July: -.083; August: -.406*; September: -.294) in the San district. In addition, a significant negative correlation was observed between sorghum production and rainfall in August (-.406*).

The monthly average temperature positively correlates with maize production during all the growing periods of maize (June: .316; July: .449*; August: .475**; September: .369*) in the Koutiala district. In comparison, this positive correlation between temperature and sorghum production was only observed in August (.004) in the San district. The average temperature has a negative correlation between sorghum production in June (-.161), July (-.207), and September (-.254) in the San district.

Through the CARI approach, the results show that the households have an acceptable food consumption score (99.8%). (100%) of those households spent less than 50% on food. Most of the households (64.4%) used an emergency strategy for food, a crisis strategy (33.6%), a stress strategy (1.8%), and no strategy (0.2%). Concerning the households' food security index, the results reveal that most (97.8%) of households are marginally food secure, and only (2%) of them are food secure.

The results showed that the main factors that correlated with the households' food security were: the age of households' heads, their level of education, family and farm size, fishing activity, sheep and cow ownership, and working for cash. However, there was a significant correlation between cow ownership and working for cash with households' food security ($P<0.05$).

The study found that there are several constraints that households are faced for their food security in the study area. Those constraints are social, environmental, and economic. Consequently, those constraints can be seen as the increase in agricultural inputs price, the difficulty for food availability, an increase of food price, rainfall variability, increase in

temperature, income reduction, debt payback, effects of natural disasters (drought and flood), and human insecurity.

Descriptive statistic results revealed that farmers in the study observed and perceived several climatic risks. Those risks are as follows: late start and early ending of the rainy season; high frequency of dry spells; soil degradation and infertility; the increase of water erosion; vegetation degradation; earlier drying up of waterways; increase of drought and flooding frequency; decrease rainfall amount per year, and increase in temperature.

Regarding the land use/ land cover changes (LU/LCC) in the study area, there were land use and land cover changes in the study area from 1989 to 2019. However, the wood savannah decreased in the Koutiala and San districts. Nevertheless, we observed that the shrub savannah increased in the Koutiala district and decreased in the San district. The farmlands increased gradually from 1989 to 2019 in both districts. The increase in bare soil was observed in the Koutiala district but decreased in the San district. Both districts observed an increase in building levels from 1989 to 2019.

Various types of technics were used regarding the farmers' adaptation strategies to face climate variability or change. Therefore, most of the respondents used strategies such as utilizing organic and chemical fertilizers, improving crop varieties, crop rotation, assisted natural regeneration, and stone bunds. For them, these technologies are also considered the most effective. Face climate variability or change effects. The farmers develop some off-farm activities. The goal of those activities is to cope with those shocks. Therefore, those activities are as follows: trading (75.9%), vegetable growing (69%), livestock (65.7%), fishing (57.6%), and working for cash (50.8%).

Keywords: Climate parameters, agro-climatic risks, households, food security, Koutiala, San, Mali

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Abbreviations and acronyms

AEDD : Agence de l'Environnement et du Développement

AMEED: Malian Awakening Association for Sustainable Development

ANR: Assisted Natural Regeneration

AR5: Fifth Assessment Report

ARC: Regional Agrhymet Centre

CARI: Consolidated Approach for Reporting Indicators of Food Security

CCAFS: Climate Change, Agriculture and Food Security

CCCMA: Canadian Center for Climate Modelling and Analysis

CCSR/NIES: Center for Climate System Research/ National Institute for Environmental Studies

CDKN: Climate and Development Knowledge Network

CGIAR: Consultative Group for International Agricultural Research

CIAT: International Center for Tropical Agriculture

CILSS: Inter-State Committee for Drought Control in the Sahel

CIMMYT: International Maize and Wheat Improvement Center

CMDT : Compagnie Malienne pour le Développement des Textiles

CO2: Dixode of Carbone

COP: Conference of Parties

CREDD: Strategic Framework for Economic Recovery and Sustainable Development

CSA: Climate Smart Agriculture

CSIRO: Common Wealth, Scientific and Industrial Research Organisation

CSV: Climate Smart Villages

CWR: Crop Wild Relatives

DNA: National Direction of Agriculture

ECOWAS: Economic Community of West African States

ENSAN : Enquête Nationale sur la Sécurité Alimentaire et Nutritionnelle

ETP : Evapotranspiration

FEWS NET : Famine Early Warning Systems Network

FOA: Food and Agricultural Organization

FST: Faculte des Sciences et Technologies

FtF: Feed the Future

GCM: Global circulation models

GDP: Gross Domestic Product

GFDL: Geophysical Fluid Dynamic Laboratory

HADCM: Hadley Centre Coupled Climate Model CGCM: Canadian Global Couple Climate Model

HF: Harmonized Framework

HFIAS: Household Food Insecurity Access Scale

i.e: For instance

ICRAF: World Agroforestry Centre

ICRISAT: International Crops Research Institute for the Semi-Arid Tropics

IER: Institut d'Economie Rural

IFAD: International Fund for Agricultural Development

IISD: International Institute for Sustainable Development

IITA: International Institute for Tropical Agriculture

ILRI: International Livestock Research Institute

INSTAT: Institute National de la Statistique

IPC: Integrated Food Security Classification Framework

IPCC: Intergovernmental Panel for Climate Change

IRIN: Integrated Regional Information Networks

ITCZ : Intertropical Conversion Zone

LC /LU: Land Cover/Land Use

MEA: Ministère de l'Environnement et de l'Assainissement

MES: Ministère de l'Enseignement de Supérieure

MET : Ministère de l'économie et de Transport

MPIM: Max Planck Institute for Meteorology

N: Azote

NAPA : National Adaptation Program of Action

NCAR PCM: National Center for Atmospheric Research –Parallel Climate Model

NCARCSM: National Center for Atmospheric Research-Climate System Model

NCEA: National Certificates of Educational Achievement

NDM: National Direction of Meteo in Mali

NGOs: Non-Governmental Organizations

^{o}C: Degree Celsius

OECD: Economic Co-operation and Development

PCA: Principal Components Approach

PGR: Plant Genetic Resources

PGR: Plant Genetic Resources

QTL : Quality related Traits

RGPH: Recenssement General de la population

RQ : Research Quesion

SAI: Standardized Anomaly Index

SAP : System Alerte Précoce

SDGs: Sustainable Development Goals

SPEI: Standardized Precipitation Evapotranspiration Index

SSWA: West Africa Sahel-Sudan

SWAC: Sahel and West African Club

Tmax : Température maximum

Tmin : Température minimum

UNFCCC: United Nations Framework Convention on Climate Change

UNOWAS: United Nations Office for West Africa and the Sahel Search

USAID: United States Agency for International Development

WFP: World Food Program

WV: World Vision

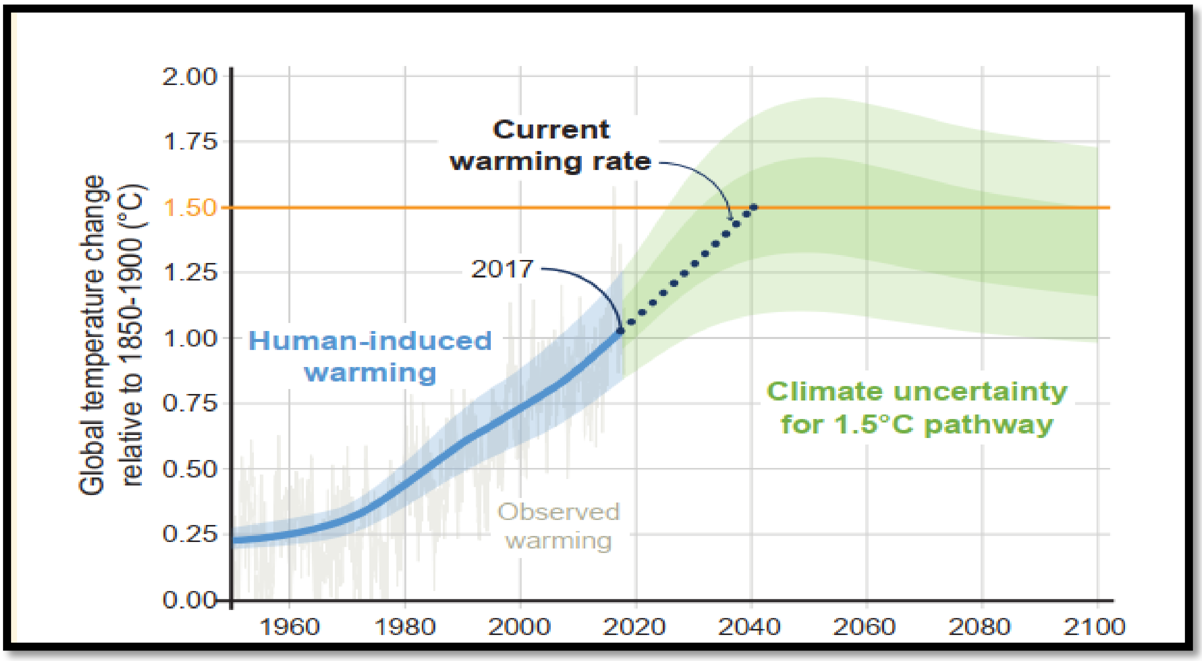
CHAPTER 1: GENERALE INTRODUCTION

In this chapter, we will present the general introduction to the thesis. It contained the research problem that describes the issues of climate variability or change at the regional, national, and local levels. Furthermore, it showed the gap between this research and its contribution to scientific research promotion among the stakeholders (searchers, students, farmers, government, and NGOs).

1.1 Research Problem

Since roughly 1850, average global temperatures have been rising, primarily due to the buildup of greenhouse gases in the atmosphere (CO2, CH4) (FAO, 2008b.). The leading causes are the growth of intensive agriculture to satisfy rising food demand, which frequently results in deforestation, and the burning of fossil fuels (coal, oil, and gas) to meet rising energy demand. These occurrences, according to FAO, highlight how climate anomalies can lead to food insecurity in semiarid sub-Saharan Africa. Furthermore, there are no signs of global warming slowing down, and it is anticipated that long-term changes in the weather will result (FAO, 2008b.)

According to the paper by Hoegh-Guldberg et al. (2018), a 1.5$^{\circ C}$ increase in global warming is expected to result in an increase in climate-related hazards to human security, food supply, health, livelihoods, and economic growth. However, the range of values defining the boundaries within which impact estimates are anticipated to fall is impacted by several different sets of parameters. These elements contribute to the lack of clarity in assessing agroclimatic risks. Models disagree over the West African Sudan-Sahel (WASS) regarding the volume and direction of precipitation trends (Paeth et al., 2011). The considerable variations in model responses to the forcing of greenhouse gases may contribute to some of this uncertainty.



Source: Hoegh-Guldberg et al. (2018)

Figure 1: Human-induced warming reached approximately 1$^{\circ C}$ above pre-industrial levels in 2017. At the present rate, global temperatures would reach 1.5$^{\circ C}$ around 2040.

To reduce the impacts of climate change, the United Nations Framework Convention on Climate Change (UNFCCC, 2015) has proposed a mitigation goal to limit global warming to 1.5$^{\circ C}$ and 2 $^{\circ C}$ above the pre-industrial levels. Most parties accepted this proposition at the 21st session of the Conference of the Parties (COP21) in 2015 in Paris, France. Consequently, several studies have discussed how achieving this target could reduce the risks and impacts of climate change on global (Rubin et al., 2018) and regional scales (Vautard et al., 2014; Riede et al., 2016; Donnelly et al., 2017). While some studies found a substantial difference in the impacts of 1.5$^{\circ C}$ and 2$^{\circ C}$ warming on regional climate variables (for instance, rainfall), others claimed that the difference is negligible when compared to the uncertainties associated with internal variability and model diversity (Karmalkar & Bradley, 2017). Nevertheless, there are no known studies on how 1.5$^{\circ C}$ and 2 $^{\circ C}$ warming may impact crop production in West Africa in the future (Naomi & Babatunde, 2018).

Moreover, further studies have documented the impacts of climate change on crop production and related variables. However, there have also been a few studies that demonstrate a strengthening relationship between observed climate variables and crop yields that indicate future expected warming will have severe impacts on crop production (Mavrommatis, 2015). Furthermore, the IPCC Special Report on global warming of 1.5$^{\circ C}$ found that climate-related risks to food security are projected to increase with global warming of 1.5$^{\circ C}$ and increase further with 2$^{\circ C}$ (IPCC, 2018).

Sahelian countries (Senegal, Mauritania, the Gambia, Guinea Bissau, Mali, Burkina Faso, Niger, Chad, Sudan, and Eritrea) depend mainly on subsistence and small-scale farming. Therefore, global warming threatens these countries' food systems (Hummel, 2015). However, with the increasing frequency of droughts and floods associated with climate change, agricultural production will decline, and food insecurity and malnutrition will increase in those countries.

The rainfall regime in the West Africa Sahel-Sudan (WASS) is unimodal, and the cropping season is confined between May and October. During the 1970s and 1980s, the area experienced a sharp decrease in rainfall (Boulain et al., 2011). According to Lebel and Ali (2009), a negative rainfall anomaly is observed from 1968 until early 1990. During the same years, the rainy season was characterized by late sowing, early cessation dates, and more frequent dry spells (Salack, 2014). According to Olwoch et al. (2008), modeling future climate change may lead to lower precipitation, implying that less water will be available for agriculture and consequently negatively affect the farm economy. The mean temperature increased by 0.13℃ from 1960 to 2003 (Shongwe, 2004) and is expected to increase by 1.2℃ in 2020, 2.4℃ in 2050, and 4.2℃ by the year 2080. At the same time, they projected a decrease in rainfall amount of about 5–10% in the next 50 years. Lobell et al. (2011) showed that the rainfall remained constant in sub-Saharan Africa by mid-century, which decreased the crop yields by about 15% due to the higher temperatures reducing the length of the crop growth cycle and increasing water stress as a result of more significant soil water evaporation losses.

Mali's climate is indeed changing, along with the whole Western Sahel, one of the world's climate change hotspots (Turco et al., 2015). In the past 50 years, Mali has experienced an increase in mean temperatures, changes in rainfall patterns, and variations in the onset and end of the growing season in many parts of the country (McSweeney C, 2010), with direct, adverse impacts on its crop yields, production, land dryness, and water availability. Furthermore, Mali's climate has also been characterized by significantly high annual variability, particularly noteworthy concerning the steep increase in drought events (Dai, 2011).

In Mali, the economy heavily depends on the primary sector: agriculture, livestock, fishing, and forestry occupy 68.0% of the working population. This sector depends on exogenous factors, mainly climatic factors such as recurrent droughts, floods, and producers' precarious technical and economic capacities (ENSAN, 2016). In Mali, the rainfall declined rapidly between 1950 and the mid-1980s, partially recovered in 1990, and declined slightly in the 2000s. From 2000 to 2009, the average remained about 12 percent lower than the 1920–1969 mean (USAID, 2018). According to Traore (2018), in most areas of the Sahel, agricultural production systems face drought problems that manifest themselves in various forms. The most recurrent and critical dry spells occur at the season's beginning and end. Mali receives most of its rain between June and September, and the annual rainfall is highly variable, ranging from less than 200 mm–1 300 mm, and its distribution is unevenly spread between north and south (Toure et al., 2017). According to Traore et al. (2014), there is evidence for increases in the frequency of heavy rains and severe droughts in many regions of the world. According to Butt et al. (2005), Mali's literature on climate change makes various predictions about the specific changes that will occur. In Mali, the impact of climate change on precipitation varies by which global and regional combination climate models are used (Toure et al., 2017). Climate change is expected to increase vulnerability in all agroecological zones of Mali through rising temperatures and more erratic rainfall, which will have drastic consequences on food security and economic growth (Butt et al., 2005). Climate change projections from the Hadley Centre Coupled Climate Model (HADCM) and Canadian Global Couple Climate (CGCM) suggest that by the year 2030, Malian average temperature may increase by 1–2.75°C and 2–4°C before 2060 (Butt et al., 2005). The impact of temperature on agriculture is of principal significance since the 1°C rise is linked to a 2.7% reduction in growth in agricultural outputs (Dell et al., 2012). Rainfall characteristics are particularly affected by these changes in rainfall: the onset and end date of the rainy season and the distribution and intensity of rainfall events (Sarr B., 2010). The impact of these changes on rainfall characteristics is 20–60% yield losses for agricultural productions by 2025 (Butt et al., 2005). Here too, the biophysical basis is relatively clear-cut: rainfall characteristics affect water balance, specifically water availability and evapotranspiration, and plant physiology directly (Dell et al., 2012).

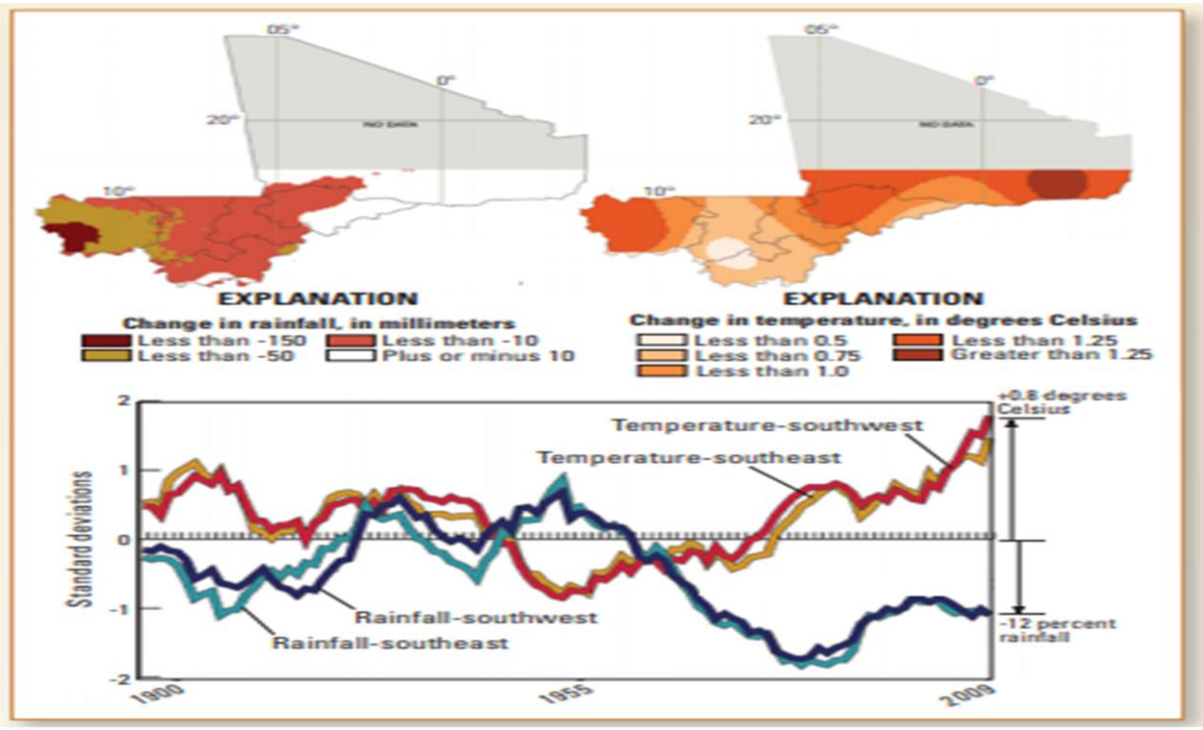


Figure 2: Observed and projected change in June–September rainfall and temperature for 1960–2039 in Mali.

Over the next few decades, some of the most profound and direct impacts of climate change will be on agricultural and food systems (Purse et al., 2008). Lobell and Field. (2007) show that increasing temperatures and declining precipitation over semiarid regions will likely reduce yields for corn, Sorghum, wheat, rice, and other primary crops in the next two decades. These situations could have a substantial impact on global food security. Since the 1990s, rising commodity prices and declining per capita cultivated area have led to decreased food production, eroding food security in many communities (FAO, 2007). In general, many regions that lack food security rely on local agricultural production to meet their food needs.

In West African sub-regions, one of the real significant concerns is the food security issue (FAO, 2015). Indeed, the Strategic Framework for Economic Recovery and Sustainable Development in Mali 2016–2018 (CREDD), formulated in 2016, aims at achieving the Sustainable Development Goals (SDGs_2) by 2030 through the promotion of intensive, diversified, and sustainable agriculture. Therefore, many countries that have failed to reach international hunger targets, natural and human-induced disasters or political instability have resulted in protracted crises with increased vulnerability and food insecurity of large parts of the population (FAO, 2015). Indeed, climate change and food security have multiple interrelated risks and uncertainties for agricultural and livestock production, societies, and ecologies. The complexity of global food security is illustrated by the United Nations' Food and Agricultural Organization (FAO) definition: (i) the availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports; (ii) access by individuals to adequate resources for acquiring appropriate foods for a nutritious diet; (iii) utilization of food through adequate diet, clean water, sanitation, and health care to reach a state of nutritional well-being where all physiological needs are met; and (iv) stability, because to be food secure, a population, household or individual must have access to adequate food at all times (FAO, 1996).

The Malian economy is still largely dependent on agriculture, measured by the contribution of agriculture to the national gross domestic product (GDP) (36.9% in 2006; (World Bank, 2015). A majority of the population engages in agriculture (66% in 2006; (World Bank, 2015) and derives the most significant fraction of income from agricultural production. This situation is about the median value of 70% of income among the rural households surveyed in this study. Mali and its neighboring countries are a minority of sub-Saharan African countries that have met or surpassed the target of 10% of government expenditures going to agricultural development set by the Africa Union's Comprehensive Africa Agriculture Development Program (W.B., 2015).

Furthermore, among the stable crops cultivated, apart from irrigated rice, agricultural production in Mali is rain-fed. Therefore, this sector is susceptible to climate (Butt et al., 2005). As a result, Malian households have been exposed to shocks and stress in the last decades, such as irregular rainfall, droughts, flash floods, strong storm and winds, pests, wildfires, and poor harvests. Indeed, cereal production has increased at the same rate as the population over the last decade, with imports contributing to only 5% of the national cereal budget, and dependence on food aid has decreased from 4 kg of cereal per person in 1990 to 0.5 kg/person in 1999 (FCPNET, 2011). These aspects all contributed to the resilience shown by Malian households to the 2008 global food price crisis (Moseley, 2011; Smale, Diakité, 2011). However, these shocks, coupled with the effects of the ongoing terrorist attacks till 2012, have increased households' vulnerability to poverty and food insecurity.

Since the 1970s, climate change in West Africa has been characterized by increased variability in annual rainfall and variability of annual rainfall and rainy season characteristics (CILSS, 2016). Nevertheless, in the Sudano-Sahelian zone of West Africa (SSWA), agricultural production remains the primary source of livelihood for rural communities. It employs more than 60 percent of the population and contributes about 30% of the gross domestic product (FAO, 2016). Moreover, smallholder agricultural production is dominated by rain-fed production of millet, Sorghum, and maize for food consumption and cotton as a crash crop. As a result, farmers experience low yields resulting in increasing uncertainty about being able to produce the food needed for their families (Breman & Sissoko, 1998; Drechsel et al., 2001). However, the significant factors contributing to such uncertainty and low productivity are climate variability and change, poor soil fertility, poor knowledge about agricultural management, and weak governmental policies.

In West Africa, soil fertility is inherently low (Bationo & Buerkert, 2001; Giller et al., 2011; Piéri, 1989; Vanlauwe et al., 2011) and represents the primary constraint for agricultural development. This situation is aggravated by the reduction of fallow lengths, cultivation of fragile lands, limited use of inorganic fertilizer due to high world market fertilizer prices, and limited access to credit (de Graaff et al., 2011). In addition, the low availability of organic fertilizers contributes more to the decline in soil fertility. Land degradation, including water and wind erosion, further impoverishes this region's soil (Cleaver & Schreiber, 1994).

Moreover, on top of low soil fertility, climate variability and future climate change constraints affect farmers' crop yields and livestock. Indeed, since the early 1990s, the Intergovernmental Panel for Climate Change (IPCC) has provided evidence of accelerated global warming and climate change. The latest IPCC's Fifth Assessment Report (AR5) presents new evidence of climate change (IPCC, 2013b). The global average temperature showed a warming of 0.78 (0.72 to 0.85) ℃ from 1850 to 2012, and current predictions for the end of the 21stcentury that the global average temperature increase will be between 1.5℃ and 2℃ (IPCC, 2013b). In Africa, global warming is likely to be even more significant than the global annual mean warming, and this is across the whole continents and all seasons (IPCC, 2013b).

The increase in global warming would be less marked in Guinean areas, and the highest increase would occur in the Western Sahelian region (*FAO*, 2009). Significant increases have been observed for rainfall in the eastern parts of North and South America, northern Europe, and northern and central Asia. In contrast, a decrease and drying have been observed in the Sahel (IPCC, 2007b) against the background of multi-substantial decadal variability in rainfall (Dai, A. and Trenberth, 2004; Le Barbé, Lebel, and Tapsoba, 2002). In the Sahel region, wet conditions in the 1960s alternated with drier conditions in the 1970s and 1980s (IPCC, 2007a). However, the evidence of changes in rainfall at global scales is complex because of significant regional differences. Also, there are gaps in spatial coverage and a lack of long-term data. Climate predictions indicate that the contrast in rainfall between wet and dry regions and between wet and dry seasons will increase (IPCC, 2013a) even though the projections of rainfall are uncertain for the West African region because of uncertainty in the quantification of potential vegetation-climate links (IPCC, 2013b).

Climate variability and change are a reality affecting rural livelihoods in West Africa today and present a growing challenge in the region, as in many other parts of the African continent and elsewhere (Jalloh et al., 2013). Climate change will have far-reaching consequences for the poor and marginalized groups, of which the majority depend on agriculture for their livelihoods and have a low capacity to adapt.

Climate extremes that occurred in 1972 and 1984 demonstrated the highly variable climate conditions and illustrated the difficulty of the majority of sub-Saharan smallholders to cope with extremes climate events (Cook, C., Reason, C.J., and Hewitson, 2004; IPCC, 2001; Segele & Lamb, 2005; Washington, R., and Harrison, 2004). Future climate projections suggest that the continent will become drier (Desanker, P. and Magadza, 2011; Hulme et al., 2001) and extremes more frequent (IPCC, 2007b). Climate change will cause more harm to vulnerable countries because their populations rely more heavily on rain-fed agriculture and natural resources, which are susceptible to destruction by floods or droughts caused by climatic changes. Thus, it is likely to affect the livelihoods of the poor and deepen poverty negatively (Hope, 2009).

For many countries worldwide, including Mali, changes in rainfall are expected to constrain agricultural production and, therefore, detrimentally impact food security. Consequently, agricultural yields in some countries are projected to fall by 50% by 2020, and overall crop revenue might decrease by 90% by 2100 (Boko et al., 2007). Because of their low adaptive capacity, small-scale farmers are likely to be the worst affected by these decreases in revenue (Boko et al., 2007). Sultan et al. (2014) predicted for eight contrasting sites in the Sudano-Sahelian zone of Burkina Faso, Senegal, Mali, and Niger using a process-based crop model a negative impact on yields of millet and Sorghum of up to -41% by the end of the century under a scenario with increased temperature and decreased rainfall. Müller. (2011) and Cired & Roudier. (2009) predicted that crop yield would decrease by up to 50% across West Africa due to increasing temperature. Furthermore, when warming exceeds 2^{oC}, negative impacts caused by this temperature rise cannot be counteracted by any potential positive change in rainfall (B Sultan et al., 2014).

According to Baum et al. (2020), adaptation options based on appropriate planting dates are essential for maximizing cereal grain yields because optimum planting dates favor establishing healthy and vigorous plants. In general, planting time in the Sudano-Sahelian zone coincides with the first substantial rains of the season to optimize grain and straw yields (Baum et al., 2020). However, due to the erratic rainfall patterns, the first rain suitable for planting is often followed by several dry days that may cause the planting to fail and oblige the farmer to replant. Another constraint related to the planting date is the availability of labor, especially at the beginning of the rainy season because of the high rate of youth migration from rural to urban areas. The lack of or insufficient labor can hinder the capacity of the farmers to prepare the soil, thereby causing a delay in the planting date (Mohino et al., 2011).

In the smallholder farming system of southern Mali, the cropping areas allocated to food crops (maize, millet, and Sorghum) and cash crop (maize and cotton) vary according to farm types (Bazile & Soumare, 2004). Therefore, the large and medium farm types are more cash crops oriented while small farm types are more food crops oriented. Long-duration varieties mostly planted early produced more because they could use the extended period for grain filling (Bello et al., 2012). On the other hand, short-duration varieties require lower temperature sums to reach flowering earlier and are generally associated with low grain yield (Akbar et al., 2008) but can be harvested early to meet food shortages during the lean period (Fok et al., 2000). However, the choice of a crop variety is as important as the planting date. Therefore, the farmer needs to make clear choices of crop varieties depending on the start of the rainy season.

Moreover, crop management practices based on crop diversification, rotation, adjusting the planting date, soil restoration (Zai, half moon, stone bund), and choice of varieties are the adaptation strategies most readily available to farmers to deal with the effects of climate variability in Mali. However, a good understanding of seasonal weather variability patterns is critical. Furthermore, to guide future adaptation, we need an understanding of past and current climates and coping strategies to understand better what is acceptable or suitable for farmers. This information, in combination with farmers' perceptions of climate change and variability, is a key to prioritizing measures to address and prepare for climate impacts.

Despite the numerous studies on the future impacts of climate change in West Africa (Tall et al., 2017), there needs to be more information on how climate parameters could affect households' food security in West Africa. Indeed, this gap needs to be added to most of the literature from Mali concerning the impacts of global warming and agro-climatic risks as it affects households' food security. The present study intends to provide more information in this area.

1.2 Theoretical framework

Resilient food systems underpin food security. They ensure that "all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (Aliaga & Chaves-Dos-Santos, 2014), despite climate shocks and stresses. However, climate variability and change can disrupt critical elements of food systems. They can also affect food availability and access. These disruptions can increase the risk of hunger, malnutrition, and poverty in a specific area.

To better understand the complex relationship among food systems, food security, and climate change, International Institute for Sustainable Development (IISD), funded by the Climate and Development Knowledge Network (CDKN), has released a conceptual framework for assessing, planning, and monitoring climate resilience and food security at the community, regional and national levels. Nowadays, most research has focused on the direct impacts of extreme events such as storms, droughts, floods, and high temperatures on food production. However, other aspects of food systems, such as the services supporting food availability or access, are also likely to be affected by climate extremes. Therefore, the impacts of uncertain future climate events on complex food systems cannot be predicted confidently. Instead, the communities and policy-makers should assess the resilience of these systems to a broad range of anticipated and potential impacts.

Both the resilience of food systems and broader concepts of climate resilience have been characterized in the literature by direct and indirect linkages. Dynamic response mechanisms and emergent features (i.e., many vital properties of both concepts emerge from system interaction rather than from the inherent character of any one element, such as social assets or agent responsiveness). Conceptual frameworks must accommodate this complexity.

The study's objective is to apply concepts and tools that can be understood and applied locally and used to support strategic decision-making at the community and national levels.

1.3 Definition of concepts

Global warming is crucial since it helps to determine future climate expectations. It is the scientific study of climates, defined as the mean weather conditions over time. This study aims to determine the relationship between climate parameters and crops (Maize and Sorghum) production and their impacts on households' food security. Therefore, the results of this study can be helpful for scientists, students, decision-makers (government, NGOs), and farmers regarding the issues of climate change around the country. The researchers and students can use the results of this study to project future studies about the weather conditions in a specific area. In addition, it can be a way to create awareness creation on climate variability and change among the farmers. Moreover, this study will provide helpful information about the food security issues in Mali. However, it will contribute to the achievement of sustainable development goals 2 (SDG2: No hunger) and 13 (SDG 13: assess the impacts of climate parameters for strengthening resilience and adaptive capacity to climate-related hazards).

In order to properly define the research problem, it is essential to clarify the concepts related to the research topic. These concepts were based on global warming, climate change, food security, droughts, flooding, household, and adaptation strategies.

1.3.1 Global warming

The hazard of global warming is continuously causing significant damage to the Earth's environment worldwide. Most people are still unaware of global warming and do not consider it a big problem in years to come. Most people do not understand that global warming is currently happening, and we are already experiencing some of its withering effects. It is and will severely affect ecosystems and disturb the ecological balance. Global warming begins when sunlight reaches the Earth. The clouds, atmospheric particles, reflective ground surfaces, and surface of oceans then send about 30 % of sunlight back into space, while oceans, air, and land absorb the remaining. This condition consequently heats the planet's surface and atmosphere, making life feasible. As the Earth warms up, this solar energy is radiated by thermal radiation and infrared rays, propagating directly out to space, thereby cooling the Earth (Umair, 2015). However, some of the outgoing radiation is re-absorbed by carbon dioxide, water vapors, ozone, methane, and other gases in the atmosphere. It is radiated back to the surface of the Earth. As a result, the planet has experienced the most significant increase in surface temperature over the last 100 years. Between 1906 and 2006, the Earth's average surface temperature augmented between 0.6 to 0.9 degrees Celsius, and 97 % of climate scientists and researchers agree that humans have dramatically changed the Earth's atmosphere over the past two centuries, resulting in global warming (Umair, 2015).

To understand global warming, it is first necessary to become familiar with the greenhouse effect. The natural greenhouse effect typically traps some portion of heat so that our planet is safe from reaching freezing temperatures. In contrast, human enhanced greenhouse effect leads to global warming. This phenomenon is due to the burning of fossil fuels which increases the number of greenhouse gases (carbon dioxide, methane, and oxides of nitrogen) present in the atmosphere (Marc, 2015)

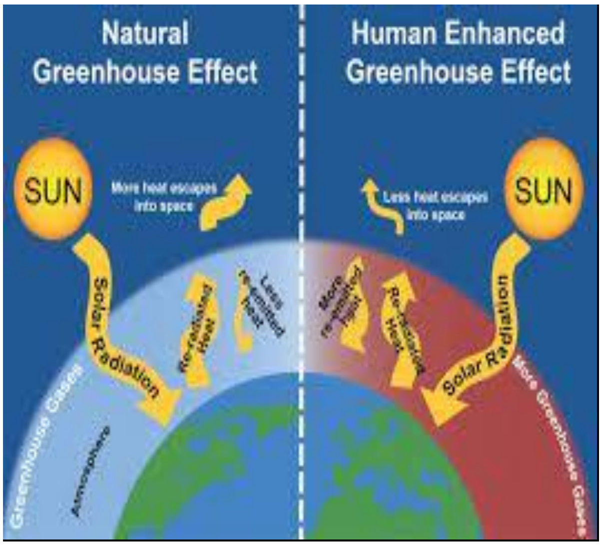


Figure 3: Types of greenhouse effects (Marc, 2015)

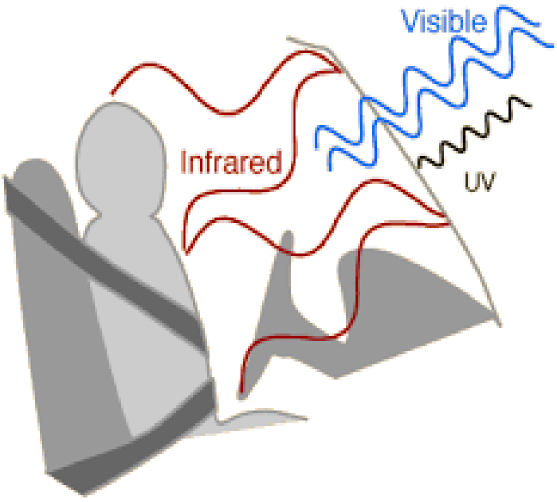


Figure 4: Greenhouse effect example (Marc, 2015)

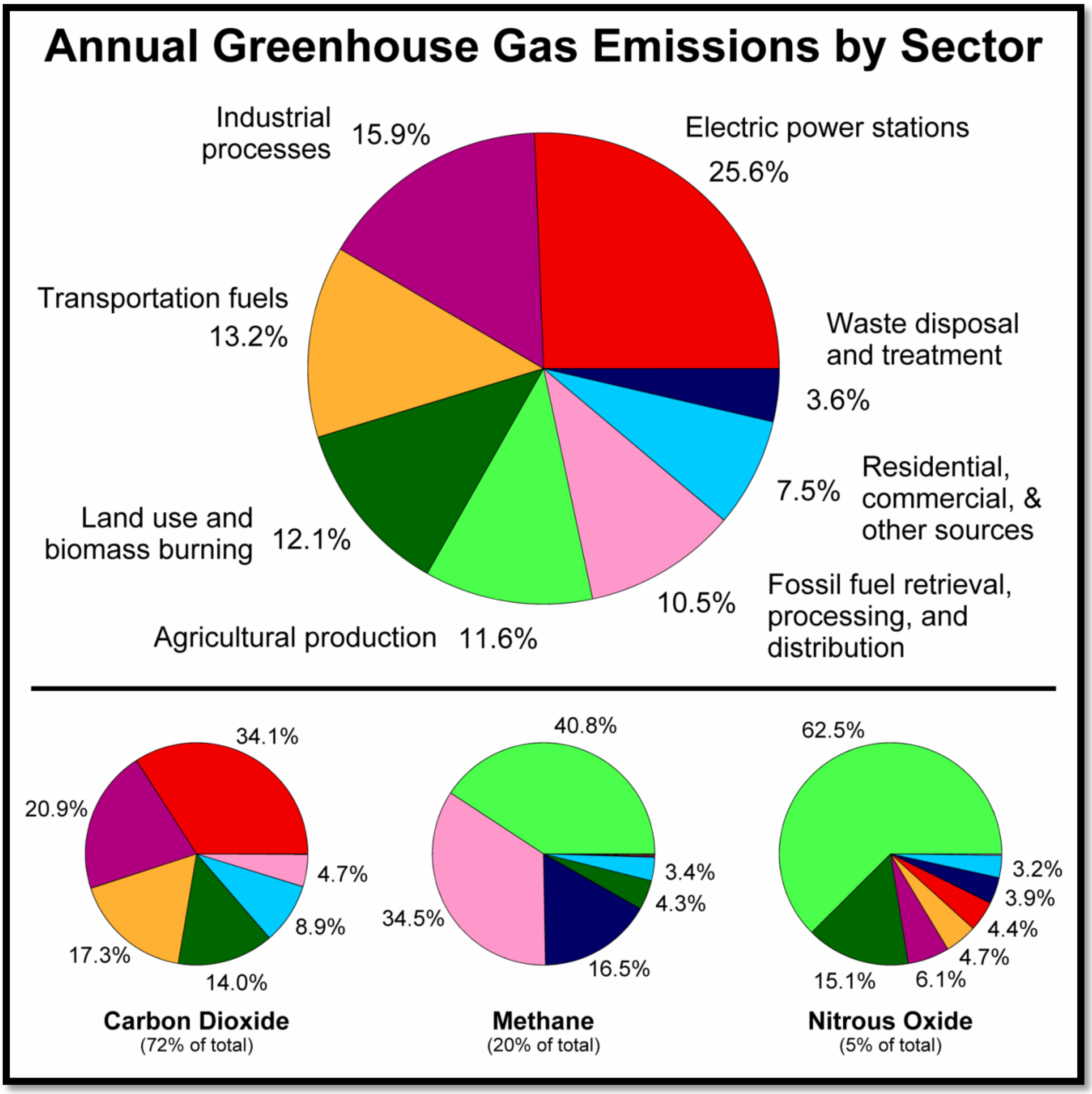


Figure 5: Distribution of greenhouse gases (Marc, 2015)

1.3.2 Climate Change

According to the IPCC, climate change refers to a statistically significant change in the mean state of the climate that may be due to natural variability or human activities. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as any change attributable directly or indirectly to human activities that affect the atmosphere's composition. It can also link directly or indirectly with human activities that affect the composition of atmospheric air and natural climate variability.

Climate change can result from natural causes of human activities. Thus, climate change is expected to bring warmer temperatures; changes to rainfall patterns; and increased frequency, and perhaps the severity, of extreme weather. Climate change is a reality with changes in CO_2, temperature, and precipitation regimes worldwide (Shyam et al., 2019). Climate change is the average weather-including temperature variances, precipitation, and wind over a select period (Shyam et al., 2019). The Earth's climate system evolves due to natural occurrences and human influences called anthropogenic. Therefore, this has led to climate change caused by increasing concentration of greenhouse gases (GHGs) in the atmosphere. GHG is a gas in an atmosphere that absorbs and emits infrared radiation or heat through fossil fuels. The Fourth Assessment Report (AR4), issued in installments by the Intergovernmental Panel on Climate Change (IPCC) from February to November 2007, noted that if greenhouse gases continue to be emitted unchecked. With this situation, the climate system will change significantly in the 21st century, and that extreme climate phenomena and increasing sea levels will adversely affect natural and human systems (IPCC, 2007).

In Mali, climate change is likely to lead to an increase in evapotranspiration and a reduction in the amount of water available for agriculture, a loss or displacement of agricultural areas, and a reduction in vegetation, affecting pasture and forage production (FEWSNET, 2010). However, there is also a strong probability that this uncertainty affects the crops and the occurrence of parasites and diseases affecting livestock.

1.3.3 Agriculture

Agriculture is all the work of conserving and transforming the natural environment to cultivate and harvest plants and animals that are valuable to man. It implies the domestication of plants and animals from simple gathering, which, combined with hunting and fishing, ensured humans' subsistence in the Paleolithic (Lemou, 2014).

In the context of the agricultural economy, agriculture is defined as the sector of activity whose function is to generate financial income from the exploitation of the land, forest, sea, lakes and rivers, domestic animals, and wild animals (Lemou, 2014). For Mind & Nyaki. (2016), he has distinguished, through his research, several types of agriculture, of which he clarified the following terminologies:

- Rain-fed agriculture, whose performance depends to a large extent on the regularity and reasonable distribution of rainfall in time and space. For this type of agriculture, all agricultural practices require rainfall;
- Flood recession agriculture is practiced in lowlands, along riverbanks, and in valleys;
- Cash crop or commercial agriculture, which provides products for trade on the markets;
- Export agriculture, whose products are sold mainly abroad;
- Subsistence agriculture based on ancestral customs and endogenous practices, which aims to satisfy family needs;
- Market agriculture uses a range of inputs from scientific research, industry, and trade.

However, this research is concerned with rain-fed and subsistence agriculture, which is primarily for food in the study area but whose surplus can also be sold. Therefore, this study focuses on two main crops: maize and Sorghum.

1.3.4 Agro-climatic risks

Climate-related hazards such as drought and flooding are expected to threaten future crop production and lead to food insecurity. In particular, more frequent and intense drought; more significant inter-annual variability in total annual rainfall; and shifts in rainfall distribution, leading to early or delayed seasonal rainfall, have the potential to limit crop productivity. The productive potential of many of the nation’s staple crops, such as millet and Sorghum, can drop significantly if annual rainfall is within a certain threshold (NCEA, 2015). Increasing temperatures in Mali may also begin to exceed crop tolerance thresholds and reduce soil moisture, reducing crop yield and available land for cultivation (USAID, 2018). More frequent and intense rainfall events also potentially exacerbate flood damage to crops. Drought is a recurrent climatic phenomenon worldwide, which varies every time it occurs in terms of its magnitude, severity, duration, and geographical coverage (Dodangeh, 2017). Drought episodes have been recurring for many years in Mali and have affected humanity in many ways, such as causing loss of life, crop failures, and food shortages. These situations, in turn, have triggered famine in many regions, resulting in malnutrition, health issues, and mass migration (Dodangeh, 2017).

Conflict and political instability, particularly in Mali's North and Central regions, have displaced people and hindered crop production by interrupting supply routes and the ability to reach agricultural land (USAID, 2018). Insecure land tenure and lack of training for agro-food jobs further hinder crop production. In addition, Mali's policies, including misaligned subsidies, adversely affect trade and weaken private sector incentives to invest in crop production and extension services (USAID, 2015).

1.3.5 Household

A 'household' is usually a group of persons who typically live together and take their meals from a common kitchen unless the exigencies of work prevent any of them from doing so.

The household consists of an individual or group of individuals, related or unrelated, living under the same roof and recognizing the authority (or not in some cases) of a person called the head of the household. A distinction is made between ordinary and collective households (INSTAT, 2009).

1.3.6 Food security

The term food security was established in the 1960s in the international development literature (Osman 2002, cited in Le Page 2004). According to the World Food Summit (1996), food security exists when all people, at all times, have access to sufficient nutritious food to meet their dietary needs and food preferences for an active and healthy life. Schmidhuber and Tubiello (2007) add to the concept of food security by arguing that it is affected by many factors, including the ability to be self-sufficient in food production through their production, accessibility to markets, and the ability to purchase food items. Anderson (1990) defines food security in terms of the ability of individuals to obtain sufficient food on a day-to-day basis.

Food Security ‘exists when all people, at all times, have physical, social, and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy lifestyle (FAO, 2001).’

Thompson, Berrange, and Ford (2010) clearly distinguish between the two by defining food availability in terms of sufficient quantities of food with appropriate quality. Similarly, the

Human Sciences Research Council (HSRC) defines food security in terms of three dimensions: availability, access, and use. The council suggests that a country must have sufficient food available consistently at both national and household levels. Food access, on the other hand, refers to the ability of the nation and its households to acquire sufficient food on a sustainable basis (Aliber, 2010). According to Ludi (2009), access to food refers to the country, communities, and individuals' ability to purchase sufficient quantities and quality food. Another concept of food security involves food utilization, which Negin et al. (2009) argue depends on how food is used, noting that although food availability and accessibility are necessary conditions for food utilization, they are insufficient to reduce malnutrition. Wlokas (2008), on the other hand, argues that the direct impact of climate change on food security is through food availability due to changes in agricultural productivity. Similarly, the Food and Agriculture Organization (FAO, 2011) reported that climate change affects the production rate and patterns of different food items.

Smith, Pointing, and Maxwell (1993) define food security within the context of national food self-reliance, suggesting that a country should be able to produce and distribute adequate food that all its citizens need. On the contrary, Reddy and Moetsane (2009) argue that food security does, however, not guarantee food security at a household level. Furthermore, the United Nations Development Programme (UNDP, 2006) indicates that the concept of food security is closely linked to poverty, noting that the two concepts are interrelated and influence one another. The report further reveals that poverty and unemployment have a strong relationship with food insecurity, indicating that it begins with the loss of employment, which, in turn, leads to a significant degradation in the living standard.

From the initial concepts, food security can briefly be defined as accessibility, availability, stability, utilization, and affordability. This situation is succinctly summarised by Ziervogel (2009), noting that food security is not just about food availability (production, distribution, and exchange) but also about access (affordability, allocation, and preference) and utilization (food safety, nutrition, and social value). In addition, the World Bank (2016) reported that climate change affects food utilization capacity through changes in production rate and the pattern of various food items, which, in turn, affects the population's nutritional requirements.

Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (de Graaff et al., 2011).

From this definition, four main dimensions of food security can be identified:

- **Availability of food:**

Food availability addresses the "supply side" of food security and is determined by food production, stock levels, and net trade.

- **Access to food:**

An adequate supply of food at the national or international level does not in itself guarantee Household level food security. Concerns about insufficient food access have resulted in a greater policy focus on incomes, expenditure, markets, and prices in achieving food security objectives.

- **Food utilization:**

Utilization is commonly understood as how the body makes the most of various nutrients in food. Sufficient energy and nutrient intake by individuals is the result of reasonable care and Feeding practices, food preparation, and diversity of the diet and intra-household distribution of food combined with good biological utilization of food consumed determine the nutritional status of individuals.

- **Stability of food:**

Even if your food intake is adequate today, you are still considered to be food insecure if you have inadequate access to food on a periodic basis, risking a deterioration of your nutritional status. In addition, adverse weather conditions, political instability, or economic factors (unemployment, rising food prices) may have an impact on the food security status.

1.3.7 Food security measurement

There are many approaches to measuring food security, ranging from a single indicator to a combination of indicators. The levels of analysis vary according to the objectives of the assessment. It can be country-wide, local, community, household, or individual. The main methods commonly used today in sub-Saharan Africa are:

1.3.7.1 Household Food Insecurity Access Scale (HFIAS)

This method, developed by the Food and Nutrition Technical Assistance Project (FANTA), is based on the idea that food insecurity (access) leads to predictable reactions and responses.

Therefore, that can be captured and quantified through a survey and then summarized on a scale (Coates, 2007). Thus, that allows households to be classified into four food security groups (food safe, low food insecure, moderately food insecure, and severely severe food insecurity).

1.3.7.2 Harmonized Framework (H.F.)

Developed by the Inter-State Committee for Drought Control in the Sahel (CILSS), the H.F. is inspired by the Integrated Food Security Classification Framework (IPC) developed by the FAO (FAO, 2012). It is a unifying tool for classifying the nature and severity of acute food insecurity during assessments of current and projected food and nutrition security situations of zones in five phases, namely: Phase 1 or minimal phase, phase 2 or under pressure, phase 3 or crisis, phase 4 or emergency and phase 5 or famine phase 5 or famine (CILSS, 2016).

1.3.7.3 Consolidated Approach for Reporting Indicators of Food Security (CARI) (WFP 2014)

It is a method that combines a set of food security indicators into a single indicator called the household food security index (WFP, 2014). This method was developed to put an end to the wide variety of methods diversity of methods previously used by WFP and is now the standard approach for assessing household food insecurity and reporting on the situation in the country. The CARI food insecurity index classifies households into four groups according to their food security indices food-secure households, borderline food-secure households, moderately food-insecure households, and severely food-insecure households.

For all food security assessment or analysis methods (HFLAS, H.F., and CARI) explored in the literature review, only the CARI method is used at the household level as in the case of our study. Although the H.F. is the tool adopted by the CILSS for analyzing food and nutritional security in member countries, its unit of analysis is different from the household and is unsuitable for our study. On the other hand, the HFLAS method, although its unit of analysis is the household, the case of our study, is a lightweight method to assess the food situation of a household better, as it is based essentially on qualitative or even subjective responses. Given the above, the CARI method was chosen to measure household food insecurity in this study.

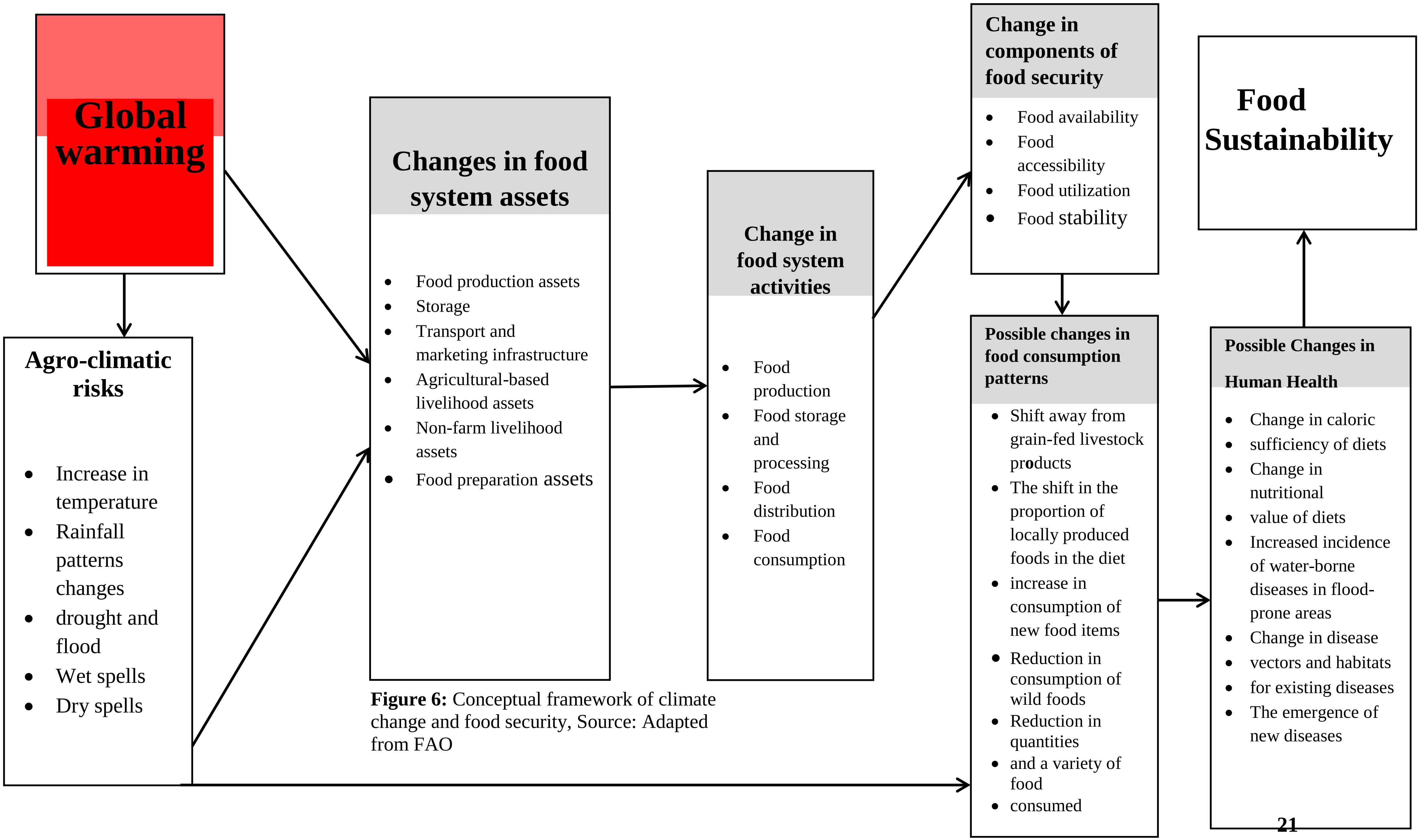


Figure 6: Conceptual framework of climate change and food security, Source: Adapted from FAO

1.3 Aim of the thesis and research questions

This research aims to contribute to providing more information on climate variability or change in relationship with food security in order to develop effective coping strategies in Mali. The overall objective can be divided into four research objectives supported by research questions (R.Q.).

Objective 1: To examine the historical trends of climate parameters and assess the influence of these climate parameters on maize and sorghum production from 1989 to 2019;

RQ1: How did the study area's climate parameters change from 1989 to 2019?

How do climate parameters influence maize and sorghum production in the study area?

Objective 2: To assess and determine the factors that affect the households' food security status

RQ2: What are the levels of households' food security?

What are the determinants and constraints of households' food security?

Objective 3: To determine farmers' perceived and observed climate risks and their impacts on land cover.

RQ3: What are the perceived climate risks' impacts on the land cover by farmers in the study area?

Objective 4: To identify and assess the adaptation strategies implemented by farmers in the study area

RQ4: Do farmers have effective coping strategies to deal with the adverse impacts of climate variability and change?

1.4 Hypotheses

1.4.1 Main hypothesis

Global warming and agro-climatic risks affect the households' food security in the study area.

1.4.2 Secondary hypotheses

1. Climate parameters are variable over the period 1989 to 2019 in the study area.
2. Climate variability has a significant influence on maize and sorghum production.
3. Socioeconomic factors affect the household's food security status.
4. The significant climatic risks farmers perceive in the study area (drought, floods, high temperature, and poor rainfall) impact water resources, croplands, and forest resources.
5. Farmers used various adaptation strategies and mainly crop rotation, the use of organic and chemical fertilizers, the use of improved crop varieties, and stone bund.

1.4.3 Literature review

A. Global warming: The effects

The three main indicators of global warming are temperature, precipitation, and sea level (Mark, 2004). The most sophisticated and powerful computer models suggest global warming will cause significant climatic changes by the end of the 21st century (Mark, 2004). These changes will potentially have wide-ranging effects on the natural environment, human societies, and our economies. Global warming will have significant adverse effects on food security, with estimates of an additional amount of between 5 and 170 million people at risk of hunger by the year 2080 (Statistical Review on World Energy 2016).

Predicting the consequences of global warming is one of the most challenging tasks faced by climate researchers. This situation is because natural processes that cause rain, snowfall, hailstorms, and rising sea levels rely on many diverse factors. Moreover, it is tough to predict the size of emissions of greenhouse gases in the future years as this is determined majorly through technological advancements and political decisions. Global warming produces many adverse effects, some of which are described here. Firstly, extra water vapor in the atmosphere falls again as rain, leading to floods in various regions of the world. Second, when the weather turns warmer, the evaporation process from both land and sea rises. This phenomenon leads to drought in regions where the increased evaporation process is not compensated by increased precipitation (Umair, 2015). In some areas of the world, this will result in crop failure and famine, particularly in areas with high temperatures. Third, the extra water vapor in the atmosphere will fall again as extra rain, causing the flood. Towns and villages dependent on the melting water from snowy mountains may suffer drought and scarcity of water supply. According to Intergovernmental Panel on Climate Change (IPCC), about one-sixth of the world's total population lives in the regions which shall be affected by a decrease in melting water. The warmer climate will likely cause more heat waves and violent rainfall and amplify the severity of hailstorms and thunderstorms. The rising sea levels are the most deadly effect of global warming; the temperature rise is causing the ice and glaciers to melt rapidly. This evidence will lead to rising water levels in oceans, rivers, and lakes that can pilot devastation in the form of floods.

As evident from Fig. 7, temperature anomalies are projected to increase in the coming years. Before the 20th century, the situation was well under control, but the situation started to worsen at the beginning of the current century. This situation was all due to an increase in global warming, majorly because new industries and powerhouses started operating and emitted harmful gases which cause the planet to heat up. This data is based on the research carried out by different climate and environmental research agencies.

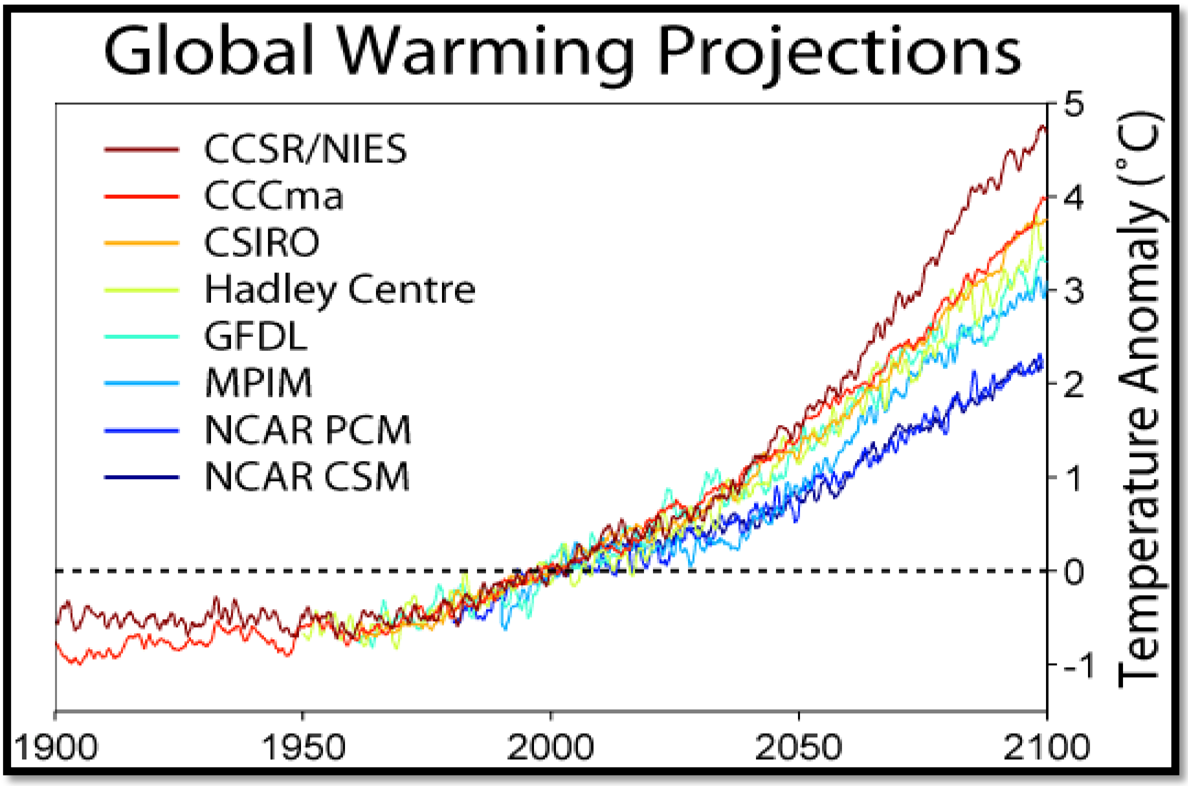
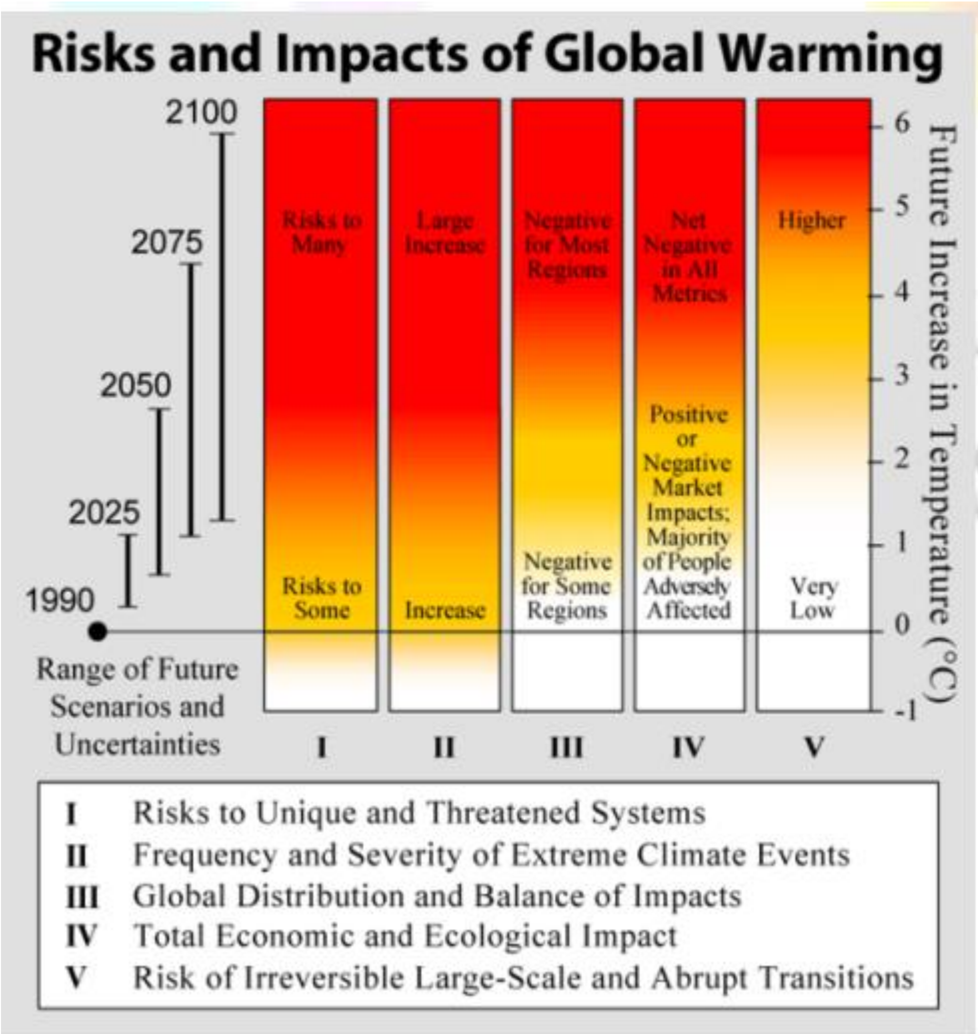


Figure 7: Global warming projections by various Science and Engineering research agencies (Global Temperatures: Global Mean Temperatures as an Indicator of Global Climate Change, n.d. in Umair, 2015)

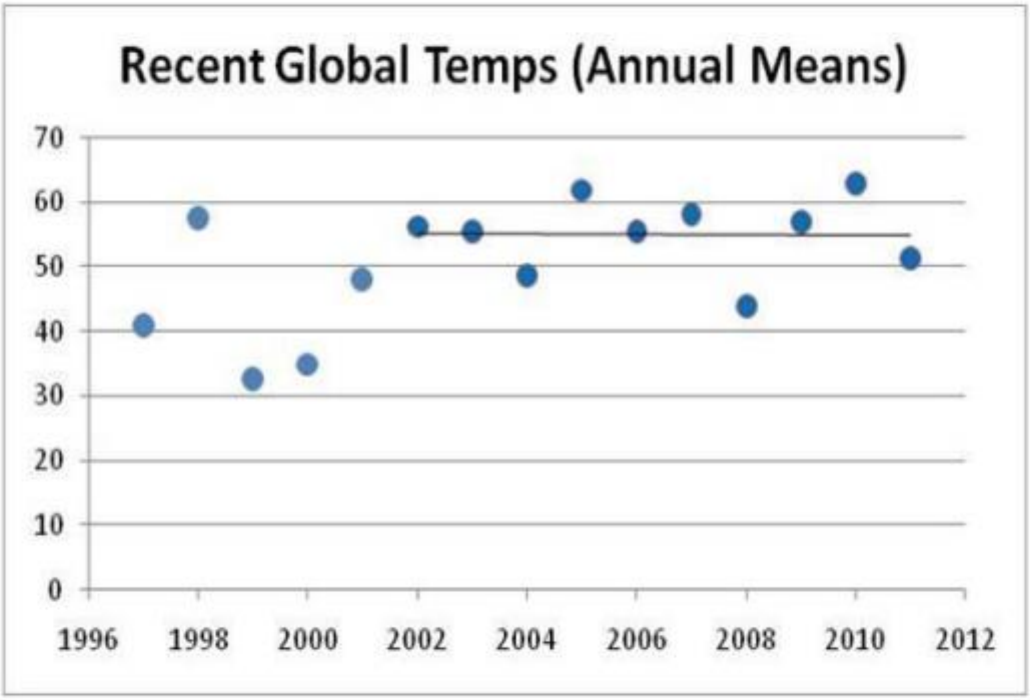
Similarly, Fig.7 elaborates on the risks and impacts of global warming in years to come. As inferred from the figure, we are currently experiencing the severity of extreme climate events in thunderstorms, floods, drought, and earthquakes. This destruction will take a sharp hike if nothing stops this menace. Fig. 8 depicts the global mean temperature in recent years, according to the National Aeronautics and Space Administration (NASA).



Source: Global warming projections by various Science and Engineering research agencies (*Global Temperatures: Global Mean Temperatures as an Indicator of Global Climate Change*, n.d. in Umair, 2015)

Figure 8: An assessment of the relative impact and risks connected with global warming.

Five categories are assessed. The bars are color-coded to show the level of impact/concern for each factor as a function of temperature increase.



Source: (Hoven, 2012)

Figure 9: Recent global mean temperatures according to NASA

Temperatures in West Africa, particularly in the Sudan-Sahel, have evolved faster than the global average since the late 1980s (Sarr, 2020). However, the increase becomes continuous and more marked for the minimum than the maximum temperature. These conditions are often associated with intense rainfall and more frequent flooding, causing extensive damage to crop production (Sarr, 2020). According to the latest estimations from the Intergovernmental Panel on Climate Change (IPCC, 2018), human activities have caused global warming of 1$^{\circ C}$ above pre-industrial levels, with a range of 0.8–1.2 $^{\circ C}$. This warming could reach 1.5$^{\circ c}$ between 2030 and 2052 if it continues to increase at the current rate (IPCC, 2018). This climate change could impact a large panel of sectors and activities by raising pressure on water resources, reducing agricultural productivity, and significantly developing vector-borne and water-borne diseases (IPCC, 2014). In addition, a continuous increase in temperatures could intensify the hydrological cycle and lead to more frequent extreme weather events (Ndiaye et al., 2021). According to Res et al. (2015), in 2011-2050 perspectives, relative to the 1981-2010 baseline, a slight increase in temperature (for instance, +0.6 to +0.8$^{\circ C}$) combined with a stationary to moderate decrease in precipitation leads to a 10 to 15% decrease in aboveground biomass production (grain yield). Then when the warming is moderate (for instance, +1.4 to 1.8°C), the decline in grain yield worsens (10 to 20%), despite a slight increase in rainfall projections (Salack et al., 2018).

In Mali, the average annual temperature has increased by 0.7°C since 1960, at a rate of 0.15°C per decade (Mc Sweeney et al., 2008). Projected temperature change is expected to increase by 1.2 to 3.6°C in 2060 and by 1.8 to 5.9°C in 2090 for the country as a whole (Tim & Joachim, 2013)

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Tableau 1: Temperature variability in Mali from 1951 to 2000

Stations	1951–1970 °C	1971–2000 °C	Différence °C
Kayes	36,3	36,5	+0,2
Bamako-Sénou	34,4	34,5	+0,1
Sikasso	33,7	33,9	+0,2
Ségou	34,8	35,3	0,5
Mopti	35,0	35,9	+0,9
GAO	37,1	37,3	+0,2
KIDAL	36,1	36,2	+0,1

Source: Tim and Joachim (2013)

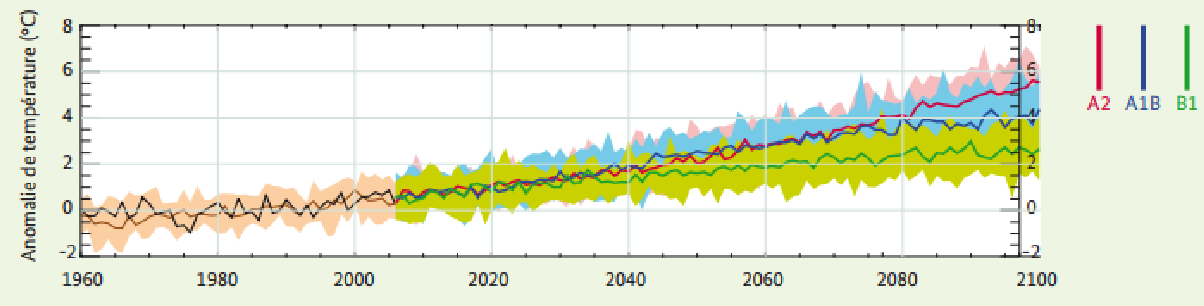


Figure 10: Projection of temperature change in Mali

A2: Maximum temperature; A1B: Minimum temperature; B1: Mean temperature

Source: Tim and Joachim (2013)

B. Effects of global warming on Living Beings

Global warming can severely affect the health of living beings. Excess heat can cause stress which may lead to blood pressure and heart disease. Crop failures and famines, which are a direct consequence of the heating up of EarthEarth, can cause a decline in human body resistance to viruses and infections. Global warming may also transfer various diseases to other regions as people shift from regions of higher temperatures to regions of comparatively lower temperatures.

Warmer oceans and other surface waters may lead to severe cholera outbreaks and harmful infections in some types of seafood (Marc, 2015).

Moreover, it is a fact that warmer temperatures lead to dehydration which is a significant cause of kidney stones. A medical team from The Children's Hospital of Philadelphia examined the health proceedings of more than 60,000 Americans alongside weather records. They discovered that individuals were most likely hospitalized with kidney stones three days after a temperature rise. Since 1994, kidney stone incidence has risen from about one in 20 people to one in 11. This trend is likely to increase as the globe gets hotter. Valley fever infections have been rising, probably because of warming climates and drought-causing dust storms. Dry soil and wind can carry spores that spread the virus. Hotter and drier climates are projected to increase the dusting carrying this disease. In addition, researchers have noticed a rise in mosquito-borne diseases like dengue fever and malaria due to warmer and longer summers (Marc, 2015).

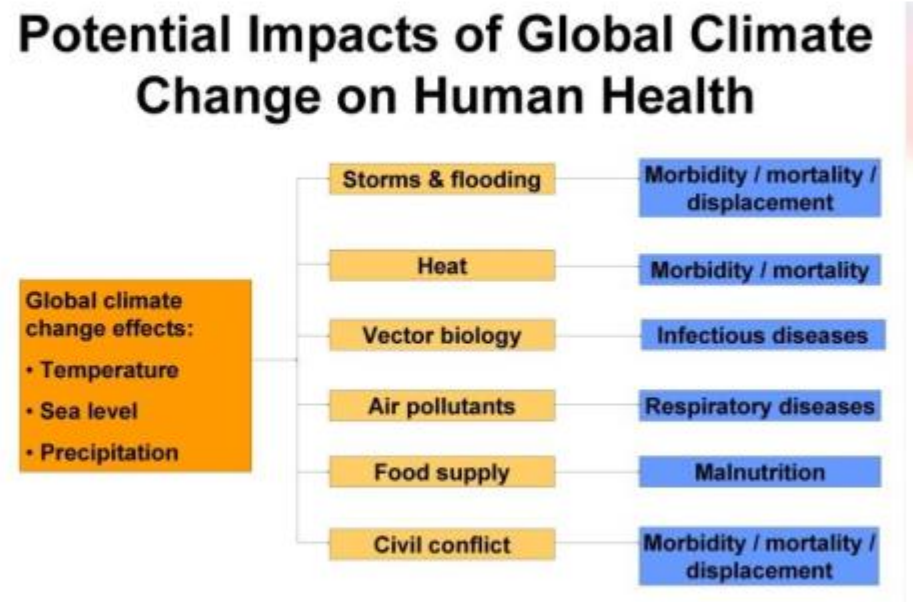


Figure 11: Potential impacts of global climate change on human health (Marc, 2015)

Global warming is also affecting animals. They need to move to more incredible places in order to survive. This process has been observed in various places around the world. With global warming continually increasing the duration and frequency of droughts, bushfires are occurring more often in these heavily logged forests, further fragmenting the orangutan's living domain. Similarly, in Africa, elephants face a series of threats, including shrinking living space, which brings them more regularly into divergence with people. With this reduced living space, elephants cannot escape any changes to their natural habitat caused by global warming, including more common and longer dry periods, placing further pressure on their survival (Marc, 2015).

C. Global warming and food security

Exposure to temperatures exceeding the optimum growth temperature or the maximum temperature for significant portions of the growing season will impact crop productivity. The increase in minimum temperatures has been shown to significantly impact the productivity of wheat, rice, and maize (Peng, 2004; TAO et al., 2008; Lobell et al., 2008; Peraudeau et al., 2015). This effect is related to the increase in respiration rates and plant senescence. Nagarajan. (2010) found that minimum temperatures had the most significant environmental impact on rice yield in India, while Peng et al. (2004) observed a 10% reduction in yield for every degree C increase above 22–24 $^{\circ C}$ (Peng et al., 2004). Climate change is estimated to have already reduced global yields of maize and wheat by 3.8% and 5.5%, respectively (Lobell et al., 2011), and several researchers predicted steep decreases in crop productivity when atmospheric temperatures exceed critical physiological thresholds of crops (Battisti & Naylor, 2009).

Agriculture is inherently sensitive to climate variability and change as a result of either natural causes or human activities. Climate change caused by emissions of greenhouse gases is expected to directly influence crop production systems for food, feed, or fodder; affect livestock health; and alter the pattern and balance of trade of food and food products. These impacts will vary with the degree of warming and associated changes in rainfall patterns, as well as from one location to another (Tim & Joachim, 2013).

The agricultural sector is most affected by climate variability and change in developing countries in West Africa. However, in these regions, rain-fed and irrigated food agriculture play a significant role in the national economies. Indeed, the populations of these countries are primarily rural and operate production systems (agriculture, livestock) whose performance is closely linked to the climate (Bazzaz et al., 2005). This structural vulnerability to climate was particularly acute in the Sahel at the end of the 20th century, following a reduction in rainfall concomitant with an increase in population (Sultan, 2012). During the 1970 and 1980, the area experienced a sharp decrease in rainfall. A clear break in the rainfall series was observed from 1968 to the early 1990s (Nicholson, 2005; Le Barbé et al., 2002). In the Sahel, the annual rainfall has suffered an average decrease of 20 to 40 % between 1931-1960 and 1968-1990 compared to 15 % in the tropical rainforest regions. These rainfall deficits have as a corollary the variability of the characteristics of the agricultural season, including the start and end dates and the occurrence of dry sequences (Bouba, 2014). However, since the mid-1990s, there has been a return to better rainfall conditions in the Sahel, with increased inter- and intra-seasonal variability, especially in the central and eastern parts (Le Barbé et al., 2002). This increased rainfall variability tends to make agricultural planning increasingly difficult. However, this apparent return of wet conditions coincides with the acceleration of global warming (IPCC, 2007a). These favorable conditions are often associated with intense and increasingly frequent rains causing flooding and extensive damage in West Africa (Sarr, 2010). The droughts of the 1970s and 1980s and the heavy recurrent rains of the 2000s that hit the area are some of the extreme events that would be amplified by climate change (IPCC, 2012). These changes are clearly impacting the agriculture and livestock sectors, respectively. For example, the decrease in cumulative rainfall can explain 35 to 45% of the decrease in crop yields in the Sahel (Sivakumar et al., 2005). Moreover, if adaptation measures are not taken, reductions in cereal crop yields are expected in sub-Saharan Africa by 2050 (CILSS, 2009). In the coming decades, the hypotheses of changes in rainfall patterns could have a significant impact on the production of millet, maize, and sorghum (Sultan, 2012), with the possibility of reaching critical thresholds of food insecurity in many parts of West Africa (Roudier et al., 2011).

Changes in rainfall patterns in the West African sub-region have long been the subject of debate (Dai, A. and Trenberth, 2004), as the methods used to assess rainfall patterns in the sub-region have yet to be fully understood. For example, when L'Hôte et al. (2002) use standardized precipitation and evapotranspiration index (SPEI), they find that the drought is still in progress in the Sahel. Whereas using the Pettitt breakpoint test, Ozer et al. (2009) indicate that the drought stopped in the early 1990s. Given these discussions, there is a strong need to define a consistent basis for analysis to reach a consensus on the direction and degree of these changes (Giannini et al., 2013). They considered that the deficits identified are of the order of climate variability and change when they are statically significant. (Camberlin & Diop, 2003) proposed an analysis of the Principal Components Approach (PCA) applied to daily rainfall data for Senegal. This method made it possible to identify the spatial and temporal variability of the season's start and end dates and note that they had become increasingly late since the early 1970s. However, these results do not target agronomic applications and do not consider the false starts and early ends of the seasons often observed in the region (Salack et al., 2013).

According to the Organization for Economic Co-operation and Development (OECD), of all human activities, agriculture is the most influenced by climate change (OCDE/FAO, 2016). As agriculture is the most climate-dependent sector of activity, the impact of climate change has become a significant issue that goes far beyond the scientific framework (Clopped, 2004).

Africa is the continent most vulnerable to climate change and variability, not only because of its dependence on climate for many of its economic activities, including agriculture (CSAO/OCDE, 2010). Today, agriculture is one of the sectors most affected by climate change through the degradation of soils and the decrease in crop productivity.

Indeed, in Africa, more than 70% of the poor live in rural areas and depend on agriculture for their food and livelihoods. As a result, they are particularly vulnerable to the hazards and expected adverse effects of climate change (Sultan, 2012). Over 95% of African agriculture is rain-fed (IPCC, 2007b).

In sub-Saharan Africa, global warming poses a serious threat to agricultural development and could accelerate the poverty of rural populations, considered the most vulnerable (Sarr et al., 2012). Sub-Saharan agriculture is rain-fed and irrigated, which implies strong constraints on production and lifestyles—the IPCC. (2012) has confirmed that agricultural production will be severely compromised by increased variability in precipitation coupled with rising temperatures and devastating extremes (IPCC, 2012). In agricultural production in sub-Saharan Africa, the impact of climate change will depend not only on extreme weather events but also on the internal dynamics of agricultural systems, i.e., their adaptive capacity (Kaere, 2009). According to Lona (2015), climate change will likely disrupt agricultural landscapes.

In addition, 2007 was one of the worst years for flooding in West Africa in over 30 years, resulting in an estimated 13,500 tonnes of agricultural production losses (S. B. et Lona, 2009). According to the (IPCC, 2007b) report, there will be a 5-8% increase in the area of arid and semi-arid lands by 2080 and divides the effect of climate change according to climatic zones: higher yields in cold regions, lower yields in hot regions; more frequent insect outbreaks and lower yields in hot regions due to heat stress. Similarly, Sarr et al. (2012) argue that warming by about 2°C would lead to a 10% reduction in total agricultural yield in sub-Saharan Africa by 2050.

In the Sahel, the shortening of the rainy seasons has led to hotter and drier conditions, adversely affecting crops (Kouassi et al., 2010). In addition, studies by Alhassane & Lona (2013) have shown that in the Sahel, the increase in temperature leads to a reduction in the crop cycle, the size of the grains formed, and the agricultural yield.Salack (2006) showed that for a variety of millet, warming of more than 1.5℃ would inevitably have adverse effects on yield. Similarly, Sultan et al. (2014) showed that in the Sahel, climate change will lead to a 12% loss in sorghum yields by 2031-2060. However, they point out that yield losses will be more significant in the western Sahel than in the central Sahel. Furthermore, the Regional Agrhymet Centre (CRA), in its 2011 report, notes that the impacts of climate variability and change on agriculture in the Sahel region are unequivocal (CRA, 2010). Rising temperatures and increased precipitation variability will lead to dysfunctional agricultural seasons, disruption of crop life cycles, and deterioration in agricultural production (CRA, 2010).

Three-quarters of Malians rely on agriculture for food and income, much of which is small-scale subsistence agriculture and pastoralism (FAO, 2019). As a result, climate shocks and stresses to agriculture can significantly impact households' livelihoods and food security.

- **Crop Production**

Many households grow much of their food and generate income by selling crops or performing agricultural labor (FEWSNET, 2010). The following stressors have posed and will continue to pose the greatest threats to crop production:

- **Drought, limited rainfall, and shortened rain seasons**

The vast majority of crops (95 percent) are rain-fed; thus, limited rainfall, drought, and increasing temperatures have significantly constrained crop production (USAID, 2018). For example, many farmers grow rice in the Inner Niger Delta and Sourou floodplain, and annual flooding helps to irrigate rice fields (Caballero, 2014). In the past, reduced wet season rainfall drove lower river levels, and floodwaters that receded too early reduced the rice harvest (FEWSNET, 2010; Morand et al., 2016). Rain-fed crops, including those in the Inner Niger Delta and Sourou floodplain, are particularly vulnerable during the dry season when they rely on shallow groundwater or ephemeral water sources. A lack of monsoon rains and a long dry season can cause crop stress and failure (USAID, 2013).

- **Extreme events, such as floods or high winds**

Strong winds blow sand over fields, covering or damaging crops. These winds have also damaged germinating seeds, reducing potential productivity and forcing households to resow their fields (FEWSNET, 2010). In the rice cultivation areas along the Niger River, floods drown rice plants. Many farmers build dikes along their rice fields to protect them from this hazard; however, heavy floods and strong winds often break the mud dikes, flooding crops and destroying harvests (FEWSNET, 2010; IFRCRCS, 2001).

- **Environmental degradation and desertification**

Desertification is a widespread issue in Mali, threatening 98 percent of the country (Holthuijzen et al., 2011; JICA, 2012). Driven by deforestation, intensive cultivation and poor soil management, overgrazing, and drought, desertification degrades the soil quality and renders it unsuitable for agriculture. In addition, rapid population growth Mali had a fertility rate of six children per woman in 2017, has been a primary driver of deforestation for agricultural expansion and reduced fallow periods, intensifying pressure on the land (USAID, 2017; WB, 2019; Jones-Casey, K., and Knox, 2019).

- **Crop pests**

The staple crops grown in Mali suffer from various crop pests and diseases, including insects, grain-eating birds, rice-eating fish, and, more recently, the fall armyworm (FEWSNET, 2010; Henry, 2018). This situation mainly affects the main grain crops, such as millet, sorghum, maize, and rice.

- **Socio-economic factors**

Conflict and political instability, particularly in Mali's North and Central regions, have displaced people and hindered crop production by interrupting supply routes and the ability to reach agricultural land (USAID, 2018). Insecure land tenure and lack of training for agro-food jobs further hinder crop production. In addition, Mali's policies, including misaligned subsidies, adversely affect trade and weaken private sector incentives to invest in crop production and extension services (USAID, 2015). Limited access to finance and insurance, limited market access, and high transport costs are significant constraints on agribusiness (FtF, 2018; WBG, 2017).

Climate-related hazards (drought and flood) are expected to threaten future crop production further. In particular, more frequent and intense drought; more significant inter-annual variability in total annual rainfall; and shifts in rainfall distribution, leading to early or delayed seasonal rainfall, have the potential to limit crop productivity. The productive potential of many of the nation’s staple crops, such as millet and sorghum, can drop significantly if annual rainfall is within a certain threshold (NCEA, 2015). Increasing temperatures in Mali may also begin to exceed crop tolerance thresholds and reduce soil moisture, reducing crop yield and available land for cultivation (USAID, 2018). More frequent and intense rainfall events also potentially exacerbate flood damage to crops. Due to projected temperature increases and precipitation decreases, crop yields are expected to change by -17 percent to +6 percent (NCEA, 2015). In addition, more frequent and intense droughts may further accelerate desertification in the Sahel and increase the risk of bushfires, destroying crops and diminishing land suitable for agriculture and pastoralism.

Furthermore, changes in rainfall may reduce water and pasture availability for livestock, which can, in turn, lead to conflict with crop farmers that reduce agricultural yields (UNOWAS, 2018). In addition, growing populations and increasing food demand may further pressure crop production (USAID, 2017). Drought may also cause increases in groundwater withdrawals and reduce the groundwater available for crops, which may become particularly problematic during the dry season when groundwater is a crucial resource (USAID, 2013).

It is essential to improve and update the agro-climatic monitoring of the Sudanian zone with agro-meteorological applications that consider not only the regional and local character of the critical parameters of the rainy season but also the levels of statistical significance of the observed changes and their impacts on agriculture.

Tableau 2: Climate sensitivities of staple crops and crops with the most outstanding gross production value

Crop	**Climate sensitivities**
Rice	• High river levels and strong winds can break the mud dikes protecting rice fields from excess flooding and destroying the harvest. • Floodwaters that recede too early result in not enough water for rice cultivation) • Overly intense floods can drown rice plants • Rice viral infections
Millet	• Bushfires (January–April) • Drought and limited rainfall, temporally and spatially
Sorghum	

Maize **Cotton**	irregular rainfall and annual rainfall totals under 400 mm for millet, 500 mm for sorghum, 600 mm for maize, and 750 mm for cotton will significantly reduce productivity. • Low water levels in rivers • Floods (July–September) • High winds that cover fields with sand or damage germinating seeds

Sources: (USAID, 2018)

Tableau 3: Crop production at climate risks

Climate Risks
Drought, flood, early or delayed rains, more significant inter-annual variability in total annual rainfall, reducing water availability and increasing unpredictability and challenges in agricultural planning, and increasing temperatures reducing soil moisture.
Accelerated desertification limiting the availability of cropland
Rising and extreme temperatures damaging crops

Sources: (USAID, 2018)

D. Climate variability and change

According to the IPCC, climate change refers to a statistically significant change in the mean state of the climate that may be due to natural variability or human activities. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as any change attributable directly or indirectly to human activities that affect the composition of the atmosphere and that directly or indirectly from human activities that affect the composition of atmospheric air in addition to natural climate variability. However, natural climate variability expresses variations in the mean state of climate variables.

The IPCC believes climate change is linked to strengthening the anthropogenic greenhouse effect in the atmosphere, the primary source of which is the burning of fossil fuels. According to Sarr. (2010), the EarthEarth has always experienced climate fluctuations marked by alternating dry and wet periods over millions of years. Thus, since 1850, CO_2 has increased by 40%, resulting in a constant increase in the planet's average temperature (Marion D., 2018).

Furthermore, at current CO_2 emissions rates, IPCC scientists expect an increase in temperature of between 1.5$^{℃}$ and 5.3$^{℃}$ by 2100, depending on the scenario.

In its latest report, the IPCC warns the international community about the trend towards more extreme warming with high variability of precipitation (IPCC, 2014b). In the same report, the IPCC underlines that global warming is more pronounced over continental areas and more significant at night than during the day. Indeed, between 1880 and 2012, the Earth'sEarth's surface temperature increased by 0.85$^{℃}$ (IPCC, 2013b). Similarly, in its 2018 report, the IPCC pointed out that between 2006 and 2015, 20-40% of the EarthEarth experienced a warming of 1.5$^{℃}$ in at least one season, with more significant warming in the Arctic than in Antarctica (IPCC, 2018).

Africa is the most vulnerable continent to climate change (IPCC, 2007b). Global warming is more significant there than at the global level. For example, according to the Regional Agrhymet Centre (IPCC, 2018), the African continent has experienced a temperature increase of 0.6 to 0.7 $^{℃.}$

At the regional level, West Africa has experienced temperature increases ranging from 0.2$^{℃}$ to 0.8$^{℃}$ (IPCC, 2018). However, the observed increase is more remarkable for minimum temperatures (up to +1$^{℃}$) than for maximum temperatures (up to +0.5$^{℃}$) (Lona, 2015). (Sarr and Lona, 2009) point out that temperatures in West Africa, particularly in the Sahel, have been changing somewhat faster than the global trend, with increases ranging from 0.2$^{℃}$ to 0.8$^{℃}$ per decade since the late 1970s in the Sahelo-Saharan, Sahelian, and Sudanian zones. However, the evolution of rainfall in West Africa has undergone extreme variations since the 1950s, representing the highest variation observed worldwide (Janicot et al., 2011). It is recognized that West Africa was affected by a decrease in annual rainfall around the 1970s (Mahé & Paturel, 2009). However, according to the study's results (Dugue., 2012), an increase in short-duration rainfall is expected in East Africa due to the warming pattern of the Indian Ocean and an increase in extreme rainfall during cyclones reaching the eastern coast of the continent. Thus, Sarr. (2017) estimated a 12% decrease in rainfall over the Sahel by 2100. Moreover, in the Sahel, rainfall has declined by an average of 15-30% (Sarr & Traoré, 2009). According to Brooker et al. (2006), the Sahelian drought is not over, which continued until the end of 2000. Nicholson. (2005) notes the opposite and specifies the spatial variability of these changes, which differ according to the latitudinal and longitudinal position of the Sahel study area. Similarly, (Michela Biasutti, 2019) points to a return to much better rainfall conditions between 1990 and 2000 in Sudano-Sahelian Africa.

In Senegal, studies by (Sultan, 2013; Sultan et al., 2014) confirm a trend toward an increase in temperature. Maximum and minimum temperatures have increased over the period 1970-2015. For minimum temperatures, an increase of 0.5 ℃ was recorded between 1971-2000. Maximum temperatures increased by about 0.5℃ and 1.5℃, respectively, over 1971-2000 and 1981-2010 compared to 2008-2012. However, the reduction in rainfall is visible in Senegal, with episodes of intense deficits from 1970-1997 (Bodian, 2014). From 1980 to 1990 decade was particularly dry in all climatic zones in Senegal (Bodian., 2014). However, recent trends in rainfall are converging towards a slight improvement. (Sarr et al., 2012) confirmed this trend towards a return to better rainfall conditions.

Furthermore, climate projections indicate that temperatures will continue to rise by 3℃ and 2.8℃ by 2031-2050 (Sultan, 2013; Sultan et al., 2014). For precipitation, (Tall et al., 2017; Sarr A., 2017) have pointed to a sharp decrease in precipitation by 2100 under the RCP8.5 scenario. Therefore, many scientists confirm that there is an increase in temperature and a decrease in precipitation over West Africa, particularly in Mali.

1. Climate conditions and projections in Mali

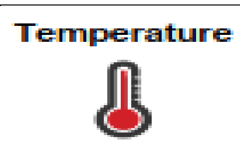
Year to year, climatic parameters vary substantially due to Mali's location in the Intertropical Conversion Zone (ITCZ), which causes the annual West African monsoon (Intelligence, 2016). As a result, Mali regularly experiences severe floods and drought, sometimes occurring within the same year (FAO, 2015; IPCC, 2014).

Between 1960 and 2015, average annual temperatures increased by 1.2℃ (FAO, 2015). Mali is expected to become even hotter, with average annual temperatures projected to rise by 0.9℃–1.5℃ by 2050 relative to the historical baseline of 1986–2005 (FAO, 2015). Increases are expected to be most significant in the southwest (Kayes, Sikasso, and Segou) and central (Mopti and Gao) regions (FAO. 2015).

According to FAO (2015), Mali experiences a multi-decadal rainfall cycle; on average, the country experienced rainfall reductions from 1950 through 1983 (an average of -4.4 mm/year) and increases from 1983 through 2015 (an average of +2.6 mm/year). On average, rainfall has decreased since the 1960s (FAO. 2015). Climate model projections disagree on whether average annual precipitation will increase or decrease in Mali by the mid-century (IRIN, 2012). On a seasonal scale, the models indicate that rainfall will become less evenly distributed across the wet season at the beginning of the wet season (June and August). This situation is projected to become slightly drier (4 percent to 5 percent reduction in rainfall). In comparison, the latter portion of the wet season (August through October) is projected to become wetter **(**6 percent to 10 percent increase in rainfall) (Ajayi et al., 2012). Desertification driven by drought, population growth, and destructive land uses also accelerated in recent years; the Sahel experiences some of the fastest rates of desertification in the world (FAO. 2015).

Changes in rainfall and temperature will also impact the water resources supply, including groundwater resources critical for domestic use, crops, and livestock (Liersch et al., 2013). Drought may simultaneously reduce groundwater recharge rates and increase the need to rely on groundwater as surface water availability declines while increasing temperatures and evapotranspiration rates, and non-climate factors (e.g., population growth) drive increases in water demand (Liersch, et al. 2012). More research is needed to understand the potential impacts on Mali's water resources. Table 3 summarizes current climate conditions and trends as well as projected changes in climate by mid-century in Mali.

Tableau 4: Climate conditions and projections in Mali

Climate parameter	**Current conditions and Recent trends**	**Projected changes by 2050**
	• Between 1960 and 2015, the average annual temperature increased by an average of $1.2^{\circ C}$ and $0.23^{\circ C}$ per decade. • Hot nights have increased in frequency and cold nights have decreased in frequency.	• Increase in average annual temperatures of $0.9^{\circ C}$–$1.5^{\circ C}$ by 2050, with more significant increases in the southwest and centralregions • Increase in the duration of heat waves and decrease in the duration of cold

		spells
	• High interannual variability in rainfall • Mali experiences a multi-decadal rainfall cycle; on average, the country experienced rainfall reductions from 1950 through 1983 (an average of • -4.4 mm/year), and increases from 1983 through 2015 (average of +2.6 mm/year) • Mali has experienced severe drought years since the 1970s, progressively becoming more frequent and longer lasting.	• More frequent and intense drought • Accelerated desertification due to increased heat and drought • Increased evapotranspiration
	• Increase in frequency of Harmattan dust storms in northern and central Mali • Recurrent floods, drought	• More frequent and intense heavy rainfall events and floods

	• Reductions in average annual rainfall since the 1960s • Substantial interannual variability in average annual rainfall • Poorly distributed rainfall in some areas of Mali • Erratic and unpredictable rainfall patterns at the seasonal level lead to early or delayed rains.	• The projected change in average annual rainfall is uncertain, although most models indicate • a projected decrease in rainfall in the north • Increase in interannual variability in average annual rainfall • Less evenly distributed wet season rainfall, with reductions (4%–5%) during the beginning and increases (6%–10%) during the end of the season

Sources: (USAID, 2018), (Holthuijzen & Maximillian, 2011) (USAID, 2012) (MES, 2008), (WB, 2019), (USAID, 2014).

2. Climate change impacts on critical vulnerable sectors in Mali

- ### Agriculture

Irrigated and rain-fed agriculture will be negatively affected by more significant climate variability, including more frequent droughts and changes in rainfall patterns, leading to reductions in production yields of corn, cotton, millet, maize, and sorghum (MEA, 2015).

- **Health**

In general, increased flooding could lead to increased diarrhea and other water-borne diseases, as floods damage the country's already insufficient sanitation and water supply infrastructure. Moreover, due to temperature increases, malaria and other diseases such as meningitis are spreading; the incidence of meningitis is moving from the country's north to the south. Furthermore, recurrent droughts and declines in productivity from rain-fed agriculture may be expected to cause a greater incidence of malnutrition (MEA, 2015).

- **Fishing**

The fishing sector could also be negatively affected by the loss of fishing grounds. Some water holes dry out with higher temperatures, and fish habitats become inhospitable with oxygen levels and increase water temperature changes. Moreover, transportation of refrigerated goods is rendered more complex with higher temperatures, as ice availability is low in the country. This condition could result in risks to human health due to unsafe food storage (MEA, 2015).

- **Energy**

In terms of energy, changes in rainfall patterns, more significant irregularity of rainfall, and decreasing precipitation may be expected to impact electricity production from hydropower severely; the Ministry of Environment and Sanitation predicts reductions in hydroelectricity of up to 22% by 2025. This change would impact the economy as a whole (MEA, 2015).

- **Water**

Impacts on water resources are and will be necessary. However, the change direction is radically different depending on the two scenarios recently elaborated for Mali (MEA, 2015). According to the first scenario, which reflects business-as-usual levels of greenhouse gas emissions, by 2025, surface water resources would decrease by 35%, and renewable groundwater sources would decrease by 13% concerning the 1961–1990 period. Combined with more frequent droughts, some surface water points would dry out in rural areas, and the water tables of rivers and lakes would decrease. This condition would, in turn, increase the concentration of water pollution and reduce water quality. Water scarcity would also lead to increases in wildfires and soil erosion and compromise food security.

According to the second scenario, in which efforts are undertaken globally to reduce greenhouse gas emissions, by 2015, water resources would increase by 18% for surface waters and by 9% for renewable groundwater resources with the 1961–1990 period (MEA, 2015). Furthermore, the scenario also suggests that more intense and frequent floods would continue to damage sanitation and water supply systems (such as in Bamako), with risks of increasing water-borne diseases such as cholera and dysentery (MEA, 2015).

o Livestock

Climatic changes and variability are already negatively affecting the livestock sector. Livestock production is decreasing and is projected to decline further due to the reduced quantity and quality of natural grasslands. The result of heightened soil erosion rates and desertification, which are linked to higher temperatures and droughts and higher temperatures will also increase disease incidence and thus induce higher cattle mortality rates (MEA, 2015). Moreover, reduced groundwater tables will lead to changes in pastoralists' migration routes, compounded by higher pressure from degraded grasslands and increased population pressure. Shifts from raising larger animals to smaller camelids and ruminants will continue, and there could be a shift from livestock rearing to sedentary agricultural production systems as well (MEA, 2015). As a result, existing conflicts between pastoralists and farmers could be heightened.

Tableau 5: Climate change impacts on critical vulnerable sectors in Mali

Sector	Likely impacts of climate change
Agriculture	General reduction of production yields across localities, particularly of corn, cotton, millet, and sorghum Associated negative effect on the country's exports and the entire economy as well as on food security and poverty Increased run-off, soil erosion, and wildfires affecting food security
Health	Increased incidence of water-borne diseases (such as cholera and dysentery) linked to stagnant waters and floods, which would damage sanitation systems or inundate safe drinking water supply infrastructure have increased frequency and length of droughts affecting food

	security and leading to malnutrition and other health issues such as diarrhea. Higher temperatures lead to the incidence of diseases such as malaria and meningitis spreading to new locations.
Fishing	Loss of fish due to inhospitable habitat Transportation difficulties caused by the impact of higher temperatures on refrigeration
Energy	Decreased rainfall, higher evaporation rates, higher temperatures, and higher variability in rainfall patterns could reduce hydroelectricity potential and predictability. Decreased fuel wood production
Water	Under one scenario: potential for reduced surface water and groundwater resources, including drying out some surface water points and decreasing rivers and lake water tables. Water quality would also decrease. Under a second scenario: potential increase in water resources and more intense and frequent floods, which would damage sanitation and water supply systems and increase health risks.
Livestock	Increases in animal mortality linked to the higher incidence of diseases due to increased temperatures Decreases in livestock production due to reduction in grasslands Reduced groundwater tables, leading to changes in pastoralists' migration routes The potential shift from livestock rearing to sedentary agricultural production systems The potential shift in livestock production from larger animals to smaller camelids and ruminants Potential exacerbation of existing conflicts between pastoralists and

	farmers

Sources: MEA, 2015; (AEDD, 2011); (MET, 2007)

E. Predicted Impacts of Climate Change on Global Agriculture, Crop Production, and Livestock

The agricultural sector is directly affected by changes in temperature, precipitation, and CO_2 concentrations in the atmosphere. However, it contributes about one-third to total GHG emissions, mainly through livestock and rice production, nitrogen fertilization, and tropical deforestation (Shyam et al., 2019). Agriculture currently accounts for 5% of world economic output, employs 22% of the global workforce, and occupies 40% of the total land area (Shyam et al., 2019). In developing countries, about 70% of the population lives in rural areas, where agriculture is the most prominent supporter of livelihoods. This sector accounts for 40% of Africa's gross domestic product (GDP) and 28% of South Asia. However, in the future, agriculture will have to compete for scarce land and water resources with growing urban areas and industrial production (Lotze-Campen, 2011).

Creating more options for climate change adaptation and improving the adaptive capacity in the agricultural sector will be crucial for improving food security and preventing future global inequality in living standards (Smith, 2012). Droughts and floods occurred locally, but they are predicted to increase in intensity and frequency over this century. Severe events can devastate agricultural environments, economies, and millions' livelihoods. Moreover, climate change and disaster risk management are not confined to only some geographic regions.

Wheeler & Von Braun (2013) point out that the patterns of models on climate change impacts on crop productivity and production have remained consistent over the past 20 years. Crop yields are expected to be most negatively affected in tropical and subtropical regions and overlap with countries that already carry a high burden of malnutrition. Projections for the near term (20–30 years) predict that climate variability and extreme weather events will increase. They affect all regions with increasing negative impacts on growth and yield, leading to increased concerns about food security, particularly in sub-Saharan Africa and South Asia (Burney et al., 2010; SREX, 2012).

Significant climate change impacts by 2030 are expected for maize, with a 30% yield reduction in South Africa and reductions in China, South, and Southeast Asia (Lobell et al., 2008). Production of wheat, rice, millet, and Brassica crops is predicted to be reduced in these regions, by up to 5% in South Asia, with severe impacts in India because of less food per capita (Bureau, 2007; Knox et al., 2012).

Desert encroachment is expected in the West African Sahel with reduced sorghum production, although millet and cowpea production may rise. In tropical West Africa, yields of peanuts, yams, and cassava are likely to decline. Central Africa may see reduced production of both sorghum and millet. East Africa may have an increase in yield for barley but a reduction for cowpea (Redden et al., 2014.).

In the Pacific Islands and other low-lying island areas, the impacts of erosion, increased contamination of freshwater supplies by saltwater incursion, increased cyclones and storm surges, heat, and drought stress are all expected to have a negative toll on food production (Barnett, 2007).

The growing season will likely lengthen at high boreal latitudes such as in Nordic Europe, Siberia, Greenland, and Canada. This situation will result in widening agricultural opportunities, albeit with possible extreme weather fluctuations. Such changes could provide opportunities for underutilized and semi-domesticated local crops. For example, fruit species from Siberia will have the opportunity to be more widely grown in new cultivation niches and also provide benefits for their healthy food properties (Holubec et al., 2015). In addition, such changes may result in the changing or developing markets for novel crops and new utilization.

1. Changing Climate

Changes in the temperature regime will significantly impact plant growth and development. Temperatures are projected to increase in the near term by a mean global average of 1∘C from 2016 to 2035 compared to the 1850–1900 period but not more than 1.5$^{∘C}$ (Kirtman et al., 2013).

The projection is that winter temperatures will increase more than summer temperatures, and near-term increases in seasonal and annual mean temperatures are expected to be more significant in the tropics and subtropics than in mid-latitudes (Kirtman et al., 2013). However, estimates from multi-model ensembles show that summer temperatures over the mid-latitudes would increase between 1–1.5∘C with the potential for more extreme events, as Mishra et al. (2008) suggested. In the long term, Collins et al. (2013) estimate that global mean temperatures will continue to increase because of greenhouse gases in the atmosphere. They are likely to exceed 2$^{∘C}$. Their projections include an increase in the frequency, duration, and magnitude of hot extremes coupled with heat stress; however, there remains the potential for cold winter extremes to occur (Collins et al., 2013). As shown by Porter et al. (2014), increased mean temperatures will affect agricultural production.

Precipitation is required to supply water for crop use to meet atmosphere demand. Two general trends are present in the global precipitation signal: an increase in annual precipitation and a shift in the seasonality of precipitation. In the near term, Kirtman et al. (2013) projected precipitation to increase in the high to mid-latitudes with a concurrent increase in evaporative demand and specific humidity. In the long-term projections of climate, Collins et al. (2013) found that precipitation would increase concurrently with the increasing mean global temperatures at the rate of 1–3% C-1 due to the increase in water vapor pressure and increased evaporation to place more water vapor into the atmosphere. In the short- and long-term, both studies projected an increase in spatial variation in precipitation along with an increasing difference between wet and dry seasons (Collins et al., 2013; Kirtman et al., 2013). Toward the end of the 21st century, evaporation trends will continue to increase because of the increasing temperatures (Collins et al., 2013). The projected differences between wet and dry seasons would signal increased variation within the season and over the years, with the potential for more extreme events in precipitation.

Hao et al. (2013) evaluated the combination of extreme temperature and precipitation events from observations from ground-based stations and a suite of climate models. They used a combination of temperature and precipitation: warm/wet (high temperature/high precipitation), warm/dry (high temperature/low precipitation), cold/wet (cold temperatures/high precipitation), and cold/dry (cold temperatures/low precipitation). These analyses compared the 1978–2004 with the 1951–1977 periods on a global scale and found increased warm/wet and warm/dry extremes. Warm/wet extremes increased in the high latitudes and tropics. In contrast, the warm/dry extremes increased in many areas, e.g., central Africa, eastern Australia, northern China, parts of Russia, and the Middle East (Hao et al., 2013). Conversely, the extremes in the cold/wet and cold/dry combinations decreased over most of the globe. The increase in the warm/wet and warm/dry extremes over agricultural areas will harm agricultural productivity and change the distribution of viable crop production.

The effects of extreme temperatures and precipitation, especially drought, have been related to reductions in crop yields (Moriondo et al., 2011; Lobell et al., 2013; Porter et al., 2013). In the 5th Intergovernmental Panel on Climate Change assessment, Porter et al. (2013) found that the production of maize, rice, and wheat would be negatively impacted in the temperate and tropical regions by increasing temperatures unless adaptation strategies were adopted. Climate changes have already begun to impact crop productivity worldwide. Understanding the interactions between carbon dioxide (CO_2), temperature, and water on plant phenology and productivity will provide a basis for developing effective adaptation strategies.

2. Temperature Effects on Plant Growth

a. Responses of Plants to High Temperatures

Temperatures are projected to increase by $1^{\circ C}$ by 2050 and as much as $5^{\circ C}$ by 2100, with an increase in extreme temperature events (Porter, 1996). Each crop species will respond to this change in temperature differently depending on its life cycle their temperature range. Each species has a defined range of maximum and minimum temperatures within which growth occurs and an optimum temperature at which plant growth progresses at its fastest rate. Hatfield et al. (2011) summarized these temperature limits for different species. Growth rates are slow as temperature increases above the optimum and cease when plants are exposed to conditions over their maximum temperature (Atkinson, 1996). Conversely, vegetative development (node and leaf appearance rate) hastens as temperatures increase up to the species' optimum temperature and then begins to decline (Atkinson, 1996; White et al., 2013).

According to Bahuguna and Jagadish (2015), vegetative development usually has a higher optimum temperature than reproductive development, and exposure of plants to supraoptimal temperatures during this stage can lead to decreased productivity. The progression of a crop through phenological phases is accelerated by increasing temperatures up to the species-dependent optimum temperature. Bahuguna and Jagadish (2015) described how temperature affects specific plant responses that offer a framework for assessing how changing temperatures under climate change would be realized.

Temperature stresses on plants affect phenology, growth, and yield (Fuhrer, 2003) and other ecosystem functions dependent upon temperature. Recent reviews by Hatfield et al. (2011) and (Rezaei et al., 2015) on the temperature effects on plants reveal that air temperatures continue to warm. The optimum temperatures are exceeded more often during the growing season, and further temperature increases will reduce yields even more than what has been observed in several studies (Gourdji, 2012). Assessments of the magnitude of the impact of high temperatures on crop yields have been determined through empirical studies. Evaluation by Lobell and Field, .(2007) showed that maize yields were projected to decrease 8.1% per $1^{\circ C}$, and Mishra et al.(2008) showed a decrease in maize yields with increases in maximum temperatures over the Midwestern United States. These observations have been conducted using long-term records on maize and wheat (Lobell and Field, .(2007); Mishra et al. (2008); Hawkins. (2013); Tack et al. (2015) show that maximum temperatures explain as much of the variation in production as precipitation. Production impacts on these crops occur when the crop is exposed to temperatures >32$^{\circ C}$ for maize and 28$^{\circ C}$ for wheat. These effects of temperature interact with drought stress, and Lobell et al. (2011) found that the impact of high temperatures was 1% per degree day with no water stress and 1.7% per degree day with water stress. This effect was observed earlier when Runge (1968) observed that maize yields were responsive to daily maximum temperature (Tmax) interactions and rainfall 25 days prior and 15 days after anthesis. These interactions revealed that when low rainfall (zero to 44mm per 8 days), the yield was reduced by 1.2 to 3.2% per 1$^{\circ C}$ rise. Conversely, when temperatures were warm (Tmax of 35$^{\circ C}$), the yield was reduced by 9% per 25.4 mm decline in rainfall. Hatfield. (2016) showed through experimental evidence that growing maize varieties under average Ames temperatures compared to standard + 4$^{\circ C}$ throughout the growing season increased the rate of phenological development and significantly reduced grain yield. Exposure to high temperature did not affect the vegetative portion of the growth cycle because leaf areas and dry weights were identical between environments; however, grain yields were reduced by over 50%. The significant impact was increased minimum temperatures and more rapid phenological development during the grain-filling stage.

Exposure to temperatures exceeding the optimum growth temperature or the maximum temperature for significant portions of the growing season will impact crop productivity.

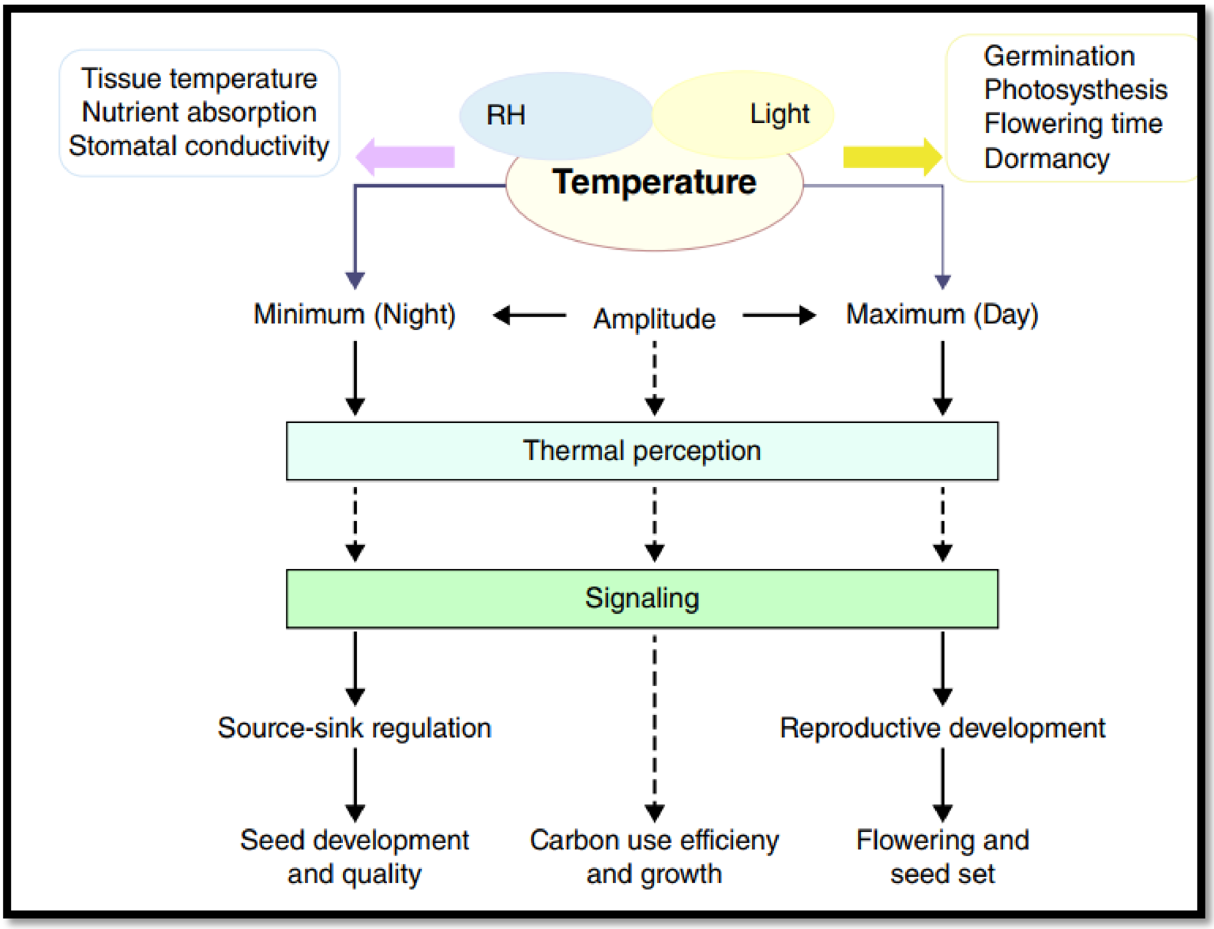
The increase in minimum temperatures has been shown to significantly impact the productivity of wheat, rice, and maize (Peng, 2004; TAO et al., 2008; Lobell et al., 2008; Peraudeau et al., 2015). This effect is related to the increase in respiration rates and plant senescence. Nagarajan. (2010) found that minimum temperatures had the most significant environmental impact on rice yield in India, while Peng et al. (2004) observed a 10% reduction in yield for every degree C increase above 22–24 $^{\circ C}$ (Peng et al., 2004). Providing for food security will require we begin to understand how and why both maximum and minimum temperatures are impacting to develop adaptation strategies to cope with climate change.

The world population will continue to grow and is expected to reach 9.1 billion by 2050 (Godfray et al., 2010). Therefore, the total food production will have to be increased by 70–100% if all these people are to be fed sufficiently (Smil, 2005). However, increasing food production to sustainably feed this increasing world population is a great challenge because of the global environmental change with increasing temperatures and extreme events threatening food production.

Agriculture is inherently sensitive to climate variability and change as a result of either natural causes or human activities (Wheeler et al., 2013). Climate change caused by human activities is expected to directly influence crop production systems for food, feed, or fodder, affect livestock health, and alter the pattern and balance of trade of food and food products. Climate change has already started affecting agricultural growth. These impacts will vary with the degree of warming and associated rainfall patterns changes, as well as from one location to another. According to the Intergovernmental Panel on Climate Change (IPCC, 2014a), climate variations affect crop production in several regions of the world, with adverse effects more common than positive, and developing countries are highly vulnerable to further negative impacts.

Climate change is estimated to have already reduced global yields of maize and wheat by 3.8% and 5.5%, respectively (Lobell et al., 2011), and several researchers predicted steep decreases in crop productivity when atmospheric temperatures exceed critical physiological thresholds of crops (Battisti & Naylor, 2009).

Climate change is already happening and represents one of the greatest environmental and societal threats facing the planet and our existence.



Source: Bahuguna and Jagadish, (2015).

Figure 11: Overview of temperature and meteorological parameters (relative humidity and solar radiation) on crucial physiological processes in plants.

b. Impact of Temperature and a Changed Climate on Crop Productivity

The temperature variations and changes in the amount and distribution of rainfall associated with increased CO_2 concentration and continued emissions of greenhouse gases will bring about changes in land suitability for crop cultivation and crop yields around the world.

According to the Intergovernmental Panel on Climate Change (IPCC, 2007b), the global mean surface temperature is projected to rise from 1.8$^{\circ C}$ to 4.0$^{\circ C}$ by 2100.

In temperate latitudes, higher temperatures are expected to be beneficial to agriculture, and as a result, the area under agricultural cropping is likely to increase. The length of the growing period will also increase at higher latitudes. Because of this, there may be an increased biomass accumulation, resulting in higher crop yields (Parry et al., 2007) predicted that world cereal production will increase from 1.8$^{\circ C}$ to between 3.7 and 4.8$^{\circ C}$ by 2080. Much of this increase will result from cropping on an additional 320 million ha in the Northern Hemisphere. However, in low latitudes, crop yields are likely to decrease, mainly because of increased temperature, which shortens the period for grain filling and sometimes stresses the plants at the time of flowering and seed-set. Moderate incremental warming in some humid and temperate grassland may increase pasture productivity and reduce the need for housing and compound feed (Parry et al., 2004). There may also be reduced livestock productivity and increased livestock mortality in semi-arid and arid pastures. In drier areas, there may be increased evapotranspiration and lower soil moisture levels (IPCC, 2001a). Because of this, some existing cultivated areas may become unsuitable for cropping, and some tropical grassland may become increasingly arid. Temperature rise will also expand the range of many agricultural pests and diseases and increase the ability of pest populations to survive the winter and attack spring crops. Generally, warming trends are likely to reduce global yields by about 1.5% per decade without effective adaptation. Extreme weather events are more likely to happen in the changed climate of the future (Gornall et al., 2010).

c. Mechanisms of Water Stress

Drought stress limits crop productivity in many agroclimatic regions of the world, and improving yield under drought is the focus of many plant breeding efforts (Cattivelli et al., 2008). Drought stress in plants is first detectable as a reduction in leaf water potential or changes in cell turgor, and the visible indicator is leaf wilting or rolling (Hsiao, 1973). These changes lead to stomatal closure because abscisic acid production affects the guard cells (Davies & Zhang, 1991). Once the stomatal conductance decreases, this reduces the intercellular CO2 concentration. In addition, a decreased mesophyll conductance affects photosynthetic metabolism (Pinheiro & Chaves, 2011), and increased leaf temperatures cause increased respiration rates (Siebert et al., 2014).

The result is a reduction in photosynthesis and a decrease in cell and plant growth (Westgate, 2004). Bandyopadhyay et al. (2012) found that across the Midwestern United States, maize yields between 1991 through 2010 were positively correlated with drought stress in the early and middle reproductive growth stages because these stages are related to grain yield. They evaluated the difference between drought and aeration stress and found drought stress was the dominant factor even though the Midwest is subjected to large precipitation amounts in the spring.

In a recent review of climate adaptation strategies for European agriculture, Semenov et al. (2014) proposed that a better understanding of higher temperatures and drought stresses during the booting and flowering periods would guide how to reduce losses in grain numbers and potential grain weight. One method of avoiding drought stress would be to improve water availability through a more extensive root system and changes in root architecture. In wheat, Lizana et al. (2013) showed that grain numbers and weight were most susceptible to reductions in water availability. Fracasso. (2016), in screening grain sorghum varieties for drought tolerance, found differences among genetic material in maintaining biomass production and tolerance indices. This situation resulted in a lower threshold of transpirable soil water and a higher capacity to recover leaf functions after drought stress. The ability of a plant to endure stress to reduce the effects of stress on grain yield in drought environments has been evaluated by Cattivelli et al. (2008), who proposed three different approaches with the potential to increase our knowledge of drought resistance in plants. They stated these approaches were:" (i) plant physiology has provided new insights and developed new tools to understand the complex network of drought-related traits, (ii) molecular genetics has discovered many QTLs (Qualitative Trait Loci) affecting yield under drought or the expression of drought tolerance-related traits, (iii) molecular biology has provided genes useful either as candidate sequences to dissect QTLs or for a transgenic approach.

Bates et al. (2014) compared genetic crosses for sugar beets for their response to imposed drought compared to full water treatments for three months of the growth cycle. Their observations revealed a differential response of the genetic material for their physiological changes. This situation affects crop growth and development. These responses were affected by leaf wilting, changes in leaf-specific weight, succulence index, leaf senescence rate, and damage to the leaf membrane Bates et al. (2014).

F. Climate change and food security

Climate change is a reality with changing CO_2, temperature, and precipitation regimes worldwide (Shyam et al., 2019). These changes are unique in space and time, and this variation adds to the challenge of providing for a food-secure world. The interactions among CO_2, temperature, and water availability reveal that increasing temperatures and drought stress offset the positive impacts of increasing CO_2 on crop productivity. Temperature and drought stress effects have their most significant effect during the reproductive stage of development. However, the effects may have been established during the formation of the number of grains or fruits. There is genetic variation in the response across different germplasm. One of the challenges will be to determine why these differences exist and how they can be exploited. This action is able not only to develop germplasm capable of being tolerant to these increasing stress levels but also to develop cultural practices that will allow the germplasm to perform at its genetic potential.

The Food and Agriculture Organization (FAO) defines food security as a "situation which exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life ."This definition of the FAO involves four essential dimensions of food supplies: availability, stability, access, and utilization (Schmidhuber & Tubiello, 2007). Agriculture is not only a source of food but also a source of income for most of the population around the world. Therefore, the critical point for food security is not whether food is available in sufficient quantity but the monetary and non-monetary resources at the population's disposal that are sufficient to allow everyone access to adequate quantities of quality food. Climate change will affect all four dimensions of food security: food availability or production, access to food, stability of food supplies, and food utilization (FAO, 2016). About 2 billion out of the global population of over 7 billion are food insecure because they fall short of one or several of FAOs dimensions of food security. However, the impact of climate change on food security differs from region to region and over time, and also on the overall socioeconomic conditions of the population (IPCC, 2001b). We agree that food is essential for human life. According to Olayemi (2012), it constitutes an essential means of life's sustenance. Due to its importance in man's life, food is rated as the most basic of all human needs. Food security has three major elements. These include food availability, food access, and food utilization (FAO, 2002). Food availability at the farming household level means assurance to access sufficient food through own production or purchase from markets, given sufficient purchasing power.

Food access is ensured when households, and all individuals within them, have adequate resources to obtain appropriate foods for a nutritious diet (Agada, M. and Igbokwe, 2016). Therefore, the third pillar (food utilization) refers to the frequency with which meals are eaten.

Food insecurity happens when food systems are stressed so that food is not accessible, available, or of sufficient quality (Beaumier, M. and Ford, 2010). The causes of food insecurity common to countries in the developed and developing world include climate change and variability, low income, and income inequality (Olagunju et al., 2012). The root cause of food insecurity is poverty, resulting in the inability of people to gain access to food (Fawole et al., 2019).

As in many developing countries, the bulk of food consumed in Mali is produced by smallholder farmers, whose small contributions are aggregated to meet the demand for food in the country, ensuring food security (FAO, 2014). However, the role of smallholder farmers in ensuring food security at the household level cannot be over-emphasized because of the number of mouths they feed (Prakash-Mani, 2013). In Mali, the large majority of the population (more than 68%), especially in rural communities, face limited access to food. This situation is mainly due to their low incomes (SAP et al., 2016). Despite this situation, rural-based people spend an essential part (43%) of their modest income on food versus 38% for the urban population and have a low consumption profile (FAO, 2013). This profile is characterized by an inadequate diet based on cereals which are the main food item and provide over 80% of dietary energy (FAO, 2013).

Mali's food-insecure households primarily focus on particular geographical regions (A. Diallo & Maxwell Torah, 2019). However, the most food-insecure households are located in many regions of Mali, including the Southern region, which is already known to be the most valuable grain area (Pedercini et al., 2012). In this region, cereals, mainly maize and sorghum, are the most cultivated crops and constitute the commonly eaten food that provides dietary energy to farmers (Diallo, 2011).

1. Climate Change and Food Availability

Climate variability and change affect agriculture and food production in complex ways. It affects food production directly through changes in agro-ecological conditions and indirectly by affecting the growth and distribution of incomes (Rosenzweig & Parry,1994). The response of crop yield to climatic variations depends mainly on the species, cultivar grown, soil conditions, the direct effect of CO_2 on plants, and other location-specific factors. The climatic changes such as atmospheric concentrations of CO_2 and O_3, temperature, and rainfall patterns are projected to directly influence the improvement rates in agricultural productivity and food availability and, thereby, global food security in the future. Rosenzweig and Parry (1994) found that enhanced concentrations of atmospheric CO_2 increase the productivity of most crops through increasing the rate of leaf photosynthesis and improving the efficiency of water use. According to them, there is a large degree of spatial variation in crop yields across the globe. In general, yields increased in Northern Europe but decreased across Africa and South America (Parry, 2007). Crop yields are also more negatively affected across most tropical areas than at higher latitudes and impacts become more severe with an increasing degree of climate change.

Furthermore, large parts of the world where crop productivity is expected to decline under climate change coincide with countries with a high hunger burden (WB, 2010). Wheeler & Von Braun (2013) concluded that there was a robust and coherent pattern of the impacts of climate change on crop productivity globally and hence, on food availability. They projected that climate change would exacerbate food insecurity in areas with a high prevalence of hunger and under nutrition. A recent systematic review of changes in the yields of the major crops grown across Africa and South Asia under climate change found that average crop yields may decline across both regions by 8% by the 2050s (Jones-Casey & Knox, 2019).

Across Africa, yields are predicted to change by –17% (wheat), –5% (maize), –15% (sorghum), and –10% (millet), and across South Asia by –16% (maize) and –11% (sorghum) under climate change. Knox et al.(2012) concluded that evidence for the impact of climate change on crop productivity in Africa and South Asia is robust for wheat, maize, sorghum, and millet and inconclusive, absent, or contradictory for rice, cassava, and sugarcane.

2. Climate Change and Stability of Food Production

The stability of food production ensures the supply of sufficient quantity as per the demand. However, global climatic conditions are expected to become more variable than the present, increasing the frequency and severity of extreme weather events such as cyclones, floods, hailstorms, and droughts. Such extreme weather events can adversely affect the stability of food production and food security by bringing more significant year-to-year fluctuations in crop yields. It is projected that the areas subject to high climate variability are likely to expand in future, whereas the extent of short-term climate variability is likely to increase across all regions globally. Droughts and floods are the dominant causes of short term fluctuations in food production in semi-arid and sub-humid areas of the world. If climate fluctuations become more pronounced and more widespread, such extreme events will become more and more severe and more frequent. In semi-arid areas, droughts can drastically reduce crop yields, livestock numbers, and productivity (IPCC, 2001b). Sub-Saharan Africa and parts of South Asia are more prone to such climatic variations, meaning that the poorest regions with the highest level of chronic undernourishment in the world will also be exposed to the highest degree of instability in food production (Easterling et al., 2007).

3. Climate Change and Access to Food

Access to food refers to the ability of individuals, communities, and countries to purchase sufficient quantities of quality food as per their demand. Over the last 30 years, falling accurate prices for food and rising real incomes have led to substantial improvements in access to food in many developing countries. This price-increased purchasing power has allowed a growing number of people to purchase more food and more nutritious food with higher contents of protein, micronutrients, and vitamins (Schmidhuber & Shetty, 2005). Fischer et al. (2005) discussed the impact of climate change on the agricultural gross domestic product (GDP) and prices. The most substantial impact of climate change on the economic output of agriculture is expected for sub-Saharan Africa. This situation means that the poorest and already most food-insecure region is also expected to suffer the most significant contraction of agricultural incomes due to climate change. Agriculture is the primary source of food and income in many developing regions. Climate change severely threatens food access for rural and urban populations by reducing agricultural production and incomes, increasing risks, and disrupting markets (Olsson, 2014).

4. Climate Change and Food Utilization

A proper utilization of food required for attaining nutritional well-being that depends upon water and sanitation will be affected by any impact of climate change on the health of the environment (Wheeler and Braun, 2013). Climate change will affect the ability of individuals to utilize food effectively by altering the conditions for food safety and changing the disease pressure from vector, water, and food-borne diseases (Schmidhuber & Tubiello, 2007). Climate change can directly affect the safety of food. The changing climatic conditions can initiate a vicious circle where the infectious disease causes or compounds hunger, making the affected populations more susceptible to infectious disease (Shyam et al., 2019). The result can be a substantial decline in labor productivity and an increase in poverty and even mortality. The increased frequency and severity of extreme weather events due to climate change such as drought, higher temperatures, or heavy rainfalls have an impact on the disease pressure, and there is growing evidence that these extreme changes affect food safety and food security (IPCC, 2007b). The report also emphasizes that increases in mean daily temperatures will increase the frequency of food poisoning, particularly in temperate regions. In addition, rising temperatures are reportedly strongly associated with increased incidences of diarrheal disease in adults and children.

Similarly, extreme rainfall events can increase the risk of outbreaks of water-borne diseases, mainly where traditional water management systems are insufficient to handle the climate extremes (IPCC, 2007b). In addition, heavy precipitations and flooding impacts will be felt more strongly in environmentally degraded areas where sanitation and hygiene are lacking. All these events will raise the number of people exposed to different diseases and thus lower their capacity to utilize food efficiently.

Wheeler & Von Braun (2013) proposed six general rules on the impact of climate change on food security and actions to address hunger:

1) Climate change impacts on food security will be worst in countries already suffering

high levels of hunger and will worsen over time.

2) The consequences of global undernutrition and malnutrition of doing nothing in

response to climate change is potentially significant and will increase over time.

3) Food inequalities will increase, from local to global levels, because the degree of climate change and the extent of its effects on people will differ from one part of the

world to another, from one community to the next, and between rural and urban areas.

4) People and communities vulnerable to extreme weather

effects will now become more vulnerable in the future and less resilient to climate shocks.

5) There is a commitment to climate change of 20 to 30 years into the future as a result

of past emissions of greenhouse gases that necessitate immediate adaptation actions

to address global food insecurity over the next two to three decades.

6) Extreme weather events will likely become more frequent in the future and will

increase risks and uncertainties within the global food system.

All of these general rules support the need for considerable investment in adaptation and mitigation actions to prevent the adverse impacts of climate change on food security and eradicate global hunger and under nutrition.

Food is essential for human survival around the world.

G. Need for Food to Feed the Nine Billion by 2050

Coupling the projections of the required food needs to feed the world population of nine billion by 2050 and beyond, projections of a changing climate increase the uncertainty about the stability of agricultural production and creates a scenario requiring an understanding of the impacts of the changing climate on crops. Estimates of the increase in global food production will be required by 2050, ranging from 60 to 110% above current levels (Tilman et al., 2011; Alexandratos and Bruinsma, 2012).

Projections by Alexandratos and Bruinsma, (2012) in which he assumed no change in population growth rate, food consumption patterns, or food waste management and estimated that cereals must increase by 940 million tons to reach 3 billion tons. For him, meat production must increase by 196 million tons to reach 455 million tons, and oil crops must increase by 133 million tons to reach 282 million tons by 2050. Analyses by Ray et al. (2013) suggested that the current rate of increase in production for maize (Zea mays L.) of 1.6%, rice (Oryza sativa L.) - 1.0%, wheat (Triticum aestivum L.) - 0.9%, and soybean (Glycine max L. Merr.) - 1.3% are inadequate to satisfy 2050 demands. To counteract these deficiencies, Ray (2014) stated that production must increase by 67% (maize), 42% (rice), 38% (wheat), and 55% (soybean) by 2050. Hubert (2010) suggested that the required increase for global maize production from 2000 to 2050 would be more than 450 million tons or nearly 30%. These production increases would result from increasing land productivity or available land resources, and increasing the available land resource is not viable (Sakschewski et al., 2014). The changing climate will disrupt these production increases, and Hatfield et al. (2014) summarized as part of the United States climate assessment that "Climate disruptions to agricultural production have increased in the past 40 years and are projected to increase over the next 25 years. These impacts will be increasingly negative on most crops and livestock by mid-century and beyond." These disruptions will come from the increased temperatures and variability in precipitation.

H. Farmers and Climate Change

One of the most significant challenges to local and global food security is the impact of an increasingly variable climate on agricultural animal and crop productivity and soil and water resources (Shyam et al., 2019). Farmer willingness and capacity to re-evaluate their farming systems and continuously adapt will affect how well we can meet this challenge (Morton & Rudel, 2014). Some social and economic factors influence farmer motivation and ability to address extreme weather and climate uncertainty (Shyam et al., 2019). These include individual and collective community experiences and indigenous knowledge about Climate and their agroecosystems, values and beliefs, social networks, access to scientific knowledge and technologies, policies, and institutional support (Morton & Rudel, 2014). Patterns of adaptation to face climate change continue to vary from modern to subsistence among the farmers. These variations are evident worldwide in developed or developing and underdeveloped countries. This situation reflects vast differences in experiences and knowledge, individual and institutional capacities to manage, and decisions to develop coping strategies. High levels of poverty, limited resources, crop yield reduction, ecosystem degradation, social and political conflicts, and weak institutions plague many rural communities, especially in underdeveloped countries, amplifying the impacts of climate change (Hisali et al., 2011). Food security at the household and village levels and for many nations is a significant concern worldwide. Further, the loss and degradation of agricultural soil and water assets due to increasing extremes in precipitation affect rain-fed and irrigated agriculture, threatening capacities to feed growing populations sustainably (Melillo et al., 2014; Sjogersten et al., 2013).

Understanding how farmers experience and make sense of Climate is the key to developing on-farm, off-farm, watershed level, regional, and global strategies to ensure agricultural productivity, long-term integrity of soil and water assets management, and resilience of rural landscapes and livelihoods. The local communities experienced and understood climate and weather conditions. The seasonal ritual of planting, harvesting, and cultivating the farm creates a climate imaginary based on the structure of the agrarian year (Shyam et al., 2019). Farmers notice when the weather and the micro-climate of their farm changes, discerning rather than recording or quantifying changes in temperature, precipitation, and the onset of the seasons" (Geoghegan & Leyson, 2012). The diverse spatial geographies in which climate change manifests itself imply that the relevant responses to the adverse impacts (as well as the opportunities) arising from climate change tend to be context-specific and highly localized (Hisali et al., 2011).

Although differential impacts of Climate and weather on geographies around the world and substantial differences in the scale of agriculture, farming practices, livestock, soil, cultural patterns, and resources, the research on farmers and climate change reveals several common themes. First, the experience of weather and Climate is local and specific to each farm enterprise (Hisali et al., 2011); (Basannagari & Kala, 2013; Sjogersten et al., 2013; Morton, 2014a; Morton et al., 2015). Second, linking local indigenous knowledge to scientific information is central to creating new knowledge that farmers trust and are willing to apply as they consider whether and how to adapt (Wolf et al., 2013). Third, water and soil resources are deeply affected by climate variability, and their degradation can be accelerated or reduced by management practices and changes in crops (Hatfield & Morton, 2013; Olson et al., 2015). Fourth, conservation and adaptive management programs and policies must be flexible so farmers can tailor new science and technologies to their local conditions (Seo, 2010; Arbuckle et al., 2013). This situation suggests that research that examines a suite of possible management practices, crop responses to too much or too little precipitation and temperature variations, and an increase in crop choices will be valuable resources in support of adaptation (Shyam et al., 2019). Fifth, one-crop farms and regions seem most vulnerable to variable conditions (Sjogersten et al., 2013). Finally, many studies find that diversified agricultural enterprises and regions may have a greater capacity to manage uncertainty and risks over time (Seo & Mendlsohn, 2008; Seo, 2010; Sjogersten et al., 2013).

Case studies worldwide help us better understand how farmers are experiencing and view this climate variability and change. They are also able to know how individually and collectively value the water, soil, and natural resources that sustain their way of life, how they are changing (or not) their management practices, and how they view the future of continuing to farm the land (Shyam et al., 2019). Accords to them, there are many reasons why it matters how farmers view climate change and how/whether they respond to a changing climate. Food and water security are essential to human survival and the capacity to thrive (Morton & Rudel, 2014). Climate and weather affect food security and employment, affecting crop yields, food prices, and the value chain of food processing, storage, transportation, and retailing (Shyam et al., 2019). Food availability, distribution, and water supply affect population migration and settlement patterns, economic and political stability, and social health and well-being. On a personal scale, managing the land, farming, and food production are not just about livelihoods but also individual and cultural identities that ensure people of rural places survive, thrive, and can plan forward into the future (Wolf et al., 2013).

1. Farmers' knowledge Of Climate

Rainfall pattern and temperature changes, or global warming, is what people most commonly associate with the change in Climate. However, IPCC scientists report that the number of cold days and nights has decreased, and the number of warm days and nights has increased globally (IPCC, 2014a).

2. Weather and Climate

Weather is the temperature, wind, cloudiness, precipitation, and humidity at a given point in time at a specific location. Climate refers to average weather conditions in a specific location over long periods (Shyam et al., 2019). Farmers do not directly experience global warming; they experience local and regional temperatures, not the global average (Sarewitz and Pielke., 2000). Climate science gathers and analyzes many weather data over long periods to understand multi-year, multi-decade patterns (Shyam et al., 2019). The discovery of climatic changes is analytical and statistical (Wilke and Morton, 2015.). While climate patterns are not readily apparent to the non-scientist, extreme weather events, disorderly seasons, and changes in the growth cycles of flora and fauna are often visible and intuitive to those who are observant (Geoghegan & Leyson, 2012; Slovic, 2009). Research indicates that, to some extent, people can accurately detect broad changes in local weather, such as seasonal precipitation and temperatures (Geoghegan & Leyson, 2012; Basannagari & Kala, 2013; van der Linden et al., 2015).

Although awareness of the weather is expected, there is mounting evidence that most people regard changes in Climate as psychologically distant and non-urgent (van der Linden et al., 2015). Furthermore, farmers in many regions of the world are even more skeptical than the general public about the immediate risk of climate change (Shyam et al., 2019). It is noticed that farmers are awarded of the environmental issues (soil degradation, desertification) around them.

Local knowledge is constructed from everyday encounters with weather and the land in how it is felt and observed (Geoghegan & Leyson, 2012). Farmers form and accumulate knowledge about local changes in their landscape and on their farms by observing the weather, animals, and plants over a few years or decades (Shyam et al., 2019). Those observations help them to make sense of their environment in the context of farming activities. How this information is synthesized affects how these observations are translated into information that can be used to develop a set of practices (e.g., crop selection, input timing, crop harvesting, planning for wet seasons, flood, and drought) (Geoghegan & Leyson, 2012; Morton, 2014a).

Farmers worldwide are awarded weather and Climate differently and interpret how they should respond based on their geographies and agricultural systems (Shyam et al., 2019). Short and long-term weather experiences, historical narratives, and knowledge of their effects on their topography, soils, and production systems are factored into decisions about workloads, available labor, markets for products, skills, and the range of alternative solutions available to adapt to changing conditions (Shyam et al., 2019). Farming activity is complex, and the variability of weather extremes often drives concerns and decision-making. For instance, drought, flooding, heavy rain, storm, and an intemperate winter can stress the housing and feeding of animals requiring immediate action to protect the animal's safety, health, and well-being. In the longer term, the trampling of wet soil by cattle leads to damaged vegetation, soil erosion, and compaction, an immediate and future problem for the productivity of constantly wet fields (Shyam et al., 2019).

Moreover, even within the same region or districts, farmers often make sense of their Climate differently. For example, in a study by Basannagari & Kala (2013), Himalayan (India) apple farmers perceived the effects of climate change along an altitudinal gradient. Most apple farmers at all elevation ranges (low hills <2500m; mid hills 2500-3000 m; upper hills >3000m) reported increased atmospheric temperature and decreased snowfall.

Farmers in the Nile Basin of Ethiopia have observed increasing temperatures over the past 20 years, and 53% have observed decreasing rainfall (Deressa et al., 2009). Chinese research in drylanddryland north Shaanxi and Ningxia revealed profound variation in knowledge about climate change, commodity prices, and social change, influencing lives and decisions about their futures (Sjogersten, S., Atkin, D., Clarke, 2013). North Central Namibia (Africa) local knowledge about their agroecological system was evenly distributed among men and women (Newsham & Thomas, 2011). Understanding local agroecological dynamics allowed farmers to adapt crop-livestock strategies to as much as a 40-50% variation in annual rainfall in many areas worldwide.

According to Arbuckle et al. (2013), even within a particular region, there can be significant variations in climate causality beliefs among agricultural scientists, climatologists, extension educators, agricultural advisors, and farmers. Over half of the agricultural scientists (50–67%) and climatologists (53%) in the US Midwest (2011–2012) reported they believed that climate change is caused mainly by human activities. In contrast, about 19% of extension educators, 12% of agricultural advisors, and 8% of farmers thought climate change was primarily caused by humans (Arbuckle et al., 2013)

Chinese farmers in dryland north Shaanxi and Ningxia (China) overwhelmingly accept that their Climate and environment are changing (Sjogersten et al., 2013). They perceived that their Climate has become generally warmer (hotter summers with less cold winters), summers drier, their water table has fallen, and biodiversity much reduced. In these drylands in North China, farmers' perceptions of climate change were linked to microclimate aridity levels in their area.

In general, farmers around the world recognize that their weather patterns are changing. However, much of the research on farmer values and beliefs find that a changing climate is not necessarily perceived as a risk to agriculture nor seen as a reason to adapt or mitigate (Shyam et al., 2019). Findings are mixed regarding the roles religious beliefs, identity, a valued lifestyle, and social values play in shaping perceptions of risk and vulnerability (Wolf et al., 2013; Arbuckle et al., 2013). However, there is a need for additional benchmark and follow-up studies on farmer beliefs and values to discover how enduring beliefs affect social norms, identity, worldviews, and lifestyle preferences that influence adaptation and mitigation efforts. The activation of values has been found to influence perceptions and interpretations of situations that lead to deliberate actions (Wolf, 2014). This action suggests that perceptions of vulnerability can be understood as shaped by internal and subjective assessments of risk (Wolf, 2014) as well as external experiences and observations of weather and Climate. Those farmers most concerned about climate risks are likely to be experiencing aridity and drought.

3. Vulnerability, Experiences of Risk, Concern about Hazards, and confidence

Exposure to extreme weather events and climate conditions and attribution of the significance of local exposure influence perceptions of risk and vulnerability, concerns about future conditions, and confidence in addressing variability (Howe et al., 2014). Vulnerability to climate change can be defined as the inability to cope with adverse climate effects as a function of exposure, sensitivity, and adaptive capacity (Below et al., 2012). Exposure, sensitivity, and adaptive capacity are linked to livelihoods and economic risk in much of the climate change literature (Wolf et al., 2013; Howe et al., 2014). Exposure represents a climate hazard, and sensitivity refers to the magnitude of the effect. For example, Howe et al. (2014) report that rural Indian respondents were more sensitive to local changes in precipitation than urban respondents. In Mali, the rural populations are more sensitive to climate risk effects than those living in urban areas; because most are economically vulnerable to climate risks. Furthermore, the farmers find a pattern of higher social vulnerability associated with perceptions of decreasing rainfall, including low perceived adaptive capacity and more incredible food and livelihood dependence on local weather (Howe et al., 2014).

Estimates of climate sensitivity of agriculture in two developing countries, Brazil and India, are measured by Sanghi & Mendelsohn (2008) by examining how net farm income and property values vary with climate and farmer reactions and adaptations. Drought, pest, and disease outbreaks affect agricultural production in both countries, with significant impacts on the volatility of global markets and food prices (Shyam et al., 2019).

Zai is one of the adaptation strategies that reduce sensitivity to precipitation and temperatures and vulnerability to reduced yields and income in many West African countries. Research in seven South American countries modeled 949 farmer adjustments to Climate and found that farmers move away from crops with low yields and substitute new crops more likely to perform better (Seo & Mendelsohn, 2008).

Seo's (2010) models find that African crop-only farms could lose up to 75% of their annual income, with significant implications for food security. The vulnerability of one-crop-only farms is a concern in Africa and China. The increasing specialization of high-value crops under the Chinese 'one village, one crop' policy has increased farm income over the last decade in some regions (Sjogersten et al., 2013). Flooding of agricultural lands along river systems is often due to prolonged high flood stages and considerable runoff in systems cut off from historical flood plains by levees and floodwalls (Olson et al., 2016; Morton, L.W. and Rudel, 2014). The 2008 IPCC report concluded that current water management practices may not be robust enough to cope with the impacts of climate change and draws specific attention to flooding risk in agriculture and ecological systems (Romero-Lankao et al., 2014). This situation is illustrated by shrimp farmers on the east coast of India, who are highly vulnerable to cyclones, floods, sea-level rise, and changes in monsoon patterns (Nagothu et al., 2012).

Flooding can do a great deal of damage to crops and farmland. Farmers often perceive drought as more problematic (Newsham & Thomas, 2011; Arbuckle et al., 2013). Water scarcity and security are local and global problems, and there are few adaptive measures available to address multi-year drought (Morton, 2014b). Namibian farmers, after two years of floods in 2008 and 2009, worried that drought was next and was concerned increased frequency of dry years could make crop farming impossible (Newsham & Thomas, 2011). Further, many farmers needed more confidence in the accuracy of their early warning ecological indicators for wet or dry rainy seasons. They lamented that TV and radio weather forecasts were too general for cropping and livestock decisions (Shyam et al., 2019).

Much more work is needed to understand the distribution of these categories of farmers in developed, developing, and underdeveloped countries with different climate hazards and economic, cultural, and geographic contexts. It is also unknown how differences in cropping systems such as crop production, new technologies, livestock (or even type of livestock), and hybrid systems or scale of the farm enterprise would affect the distributions of these categories in a region or nation-state. For example, Hisali et al.(2011) report that farmers in rural Zimbabwe did not move to adaption because they perceived the risk and their capacity to adapt to be relatively low. More research is needed to understand better the relationships among beliefs, hazard vulnerability, and support for adaptation.

I. Adapting agriculture to climate change

Adaptation to climate variability and change is defined as initiatives and measures taken to reduce the vulnerability of natural and human systems to the effects of actual or expected climate change. There are several types of adaptation: anticipatory or reactive, private or public, and autonomous or planned (IPCC, 2007b). Agriculture is a particularly vulnerable sector to climate change around the world. Most of the effects will undoubtedly be damaging to natural resources. It is, therefore, necessary to minimize these adverse effects and maximize the positive effects by relying on many developing adaptation measures specific to agricultural practices. Indeed, to cope with the adverse effects of climate change, countries need to adapt.

Adaptation to climate change is now a priority because of its likely for most African countries; it is now a priority because of its likely impact on economic life (IPCC, 2007b).

According to Gnanglé (2011), the adaptation of rural populations is a critical aspect concerning developing countries where vulnerability is high due to the low capacity of local communities. For Smit and Skinner (2020), the adaptation measures are technological development, for instance. The new crop varieties and innovations (Zai, stone line, half moon), agricultural or livestock insurance, agricultural production practices, and farm financial management. Furthermore, to mitigate the adverse effects of climate change, several experts have advocated for Africa to adopt adaptation strategies according to local conditions and needs since the nature of the risks and the livelihoods of affected groups vary from one ecosystem to another (MEA, 2015). In the Sahel, the agroecological crisis has triggered the development of sub-regional climate change policies and strategies regional policies and strategies to combat climate change (MEA, 2015).

For this reason, in September 1973, the CILSS was created. The countries concerned, including Mali, have decided to join forces to combat the Sahel's recurrent droughts and food insecurity and the development of adaptation strategies. In Mali, the actions against climate change are planned as follows: 40% target adaptation, 20% focus on mitigation, 18% on strengthening climate change governance, and 16% on specific capacity-building actions (AEDD, 2011). Therefore, we observe that the country prioritizes adaptation over mitigation. However, many adaptation actions target the most vulnerable sectors identified by the government on the ground. These sectors included agriculture, livestock, health, and water. On the other hand, transport, industry, and education are the least vulnerable sectors. Additional measures proposed by PANC (National Climate Action Plan) this focus on integrating climate change in development planning, disaster risk management, mitigation, and generating climate information and evidence of climate impacts of various sectors (Janicot et al., 2011).

Tableau 6: Priority adaptation actions by sector identified in the National Adaptation Program of Action (NAPA) in Mali

Sectors	**Adaptation priority action**
Agriculture, livestock, forestry	• Adopt enhanced and adaptable crop varieties for the main crops such as maize, sorghum, millet, and rice • Raise awareness and increase adoption of animal and plant species that are most adapted to climate conditions • Create and use better meteorological information systems (early warning systems) to inform agricultural production and contribute to food security • Diversify income-generating activities • Strengthen capacities of cereal banks • Restore degraded lands through the implementation of water and soil conventions and restoration actions to improve agriculture, forestry, and livestock rearing • Develop fodder crop species (bacteria, moucouna) • Promote food for livestock banks and intensive livestock rearing • Plan upstream land for the promotion of irrigated crops through micro-dam construction, among other actions • Equip boreholes with solar pumps or turbines (for watering livestock) • Improve catchment of runoff water and restoration of water points (backwater, ponds, and lakes) • Improve wildfire management • Promote jatropha oil.

Water resources	• Improve catchment of runoff water and restoration of water points • Equip boreholes with solar pumps or turbines
Energy	• Adopt renewable energies, namely through the use of the plant Typha australis, promotion of jatropha oil, and removal of barriers to solar energy use
Health	Established an information system on disease risks related to climate change
Other natural resources	• Raise awareness and improve regulation on the conservation of natural resources (through the development of local reforestation and agroforestry conventions)
Knowledge communications and capacity building	• Raise awareness and improve communication for building the capacity of the population on adaptation practices

Source: MEA&AEDD (2011)

1. Adaptation Factors

Adaptations to climate change are adjustments in natural and human systems made in response to actual or expected climatic stimuli or their effects (Deressa et al., 2009). Adaption intends to moderate shock or exploit beneficial opportunities. Therefore, no adaption responses are current status quo management, with farmers making no adjustments or minimal adjustments in response to climatic conditions. Hence, incremental adaption can run from expansive actions designed to expand infrastructure and production to capture economies of scale, to accommodating change such as changing water management practices, to reducing the farm effort, investments, and resource ownership (Wheeler et al., 2013). According to them, incremental adaption usually involves increased investment in time, equipment, and management changes but seldom involves significant decision-making. For them, transformational actions can involve changing land use, such as significant shifts from agriculture to wetlands or forests or discontinued farming. Transformation occurs when economic, ecological, or social conditions make the current system untenable and represent a significant change in livelihood, location, and identity (Wheeler et al., 2013).

The decision to adjust or substantively adapt agriculture practices in response to changes in precipitation, temperatures, humidity, and extreme weather events is affected by institutional infrastructures and policies at national, district, and local levels (Guha-Sapir et al., 2012). According to Guha-Sapir et al. (2012)., in their work in Tanzania, found that rural infrastructure (primarily rural road construction), efficient use of inputs, women's education level, social capital, agricultural extension, and micro-credit access influenced adaptation. Australian accommodation strategies primarily focus on improving irrigation infrastructure and management practices with an emphasis on more water-efficient crops (Wheeler et al., 2013). However, there is substantial evidence that farmers' response to changing climate and choice of adaptation strategies entails more than net farm revenues. Social and environmental factors, public policies, technology development, matching scientific investigations with farmer needs, and expanded information and financial resources are all factors that have been found to influence farmer willingness and capacity to adapt.

Other social and economic factors found to be significant such as the gender, age, the wealth of the head of household, farm ownership, household size, farmer's current position in the life cycle, experience, education, health status, distance to markets, access to credit, availability of resources including extension as well as social capital (Deressa et al., 2009). The asset value of livestock to the farm household is a widely recognized reason to keep livestock in African and other developing countries (Rufino et al., 2011). An essential source of family wealth, livestock provide animal power, manure for soil fertility maintenance, and a store of cash value (Deressa et al., 2009; Seo, 2010; Seo et al., 2010). Therefore, the social capital represented by private social networks and information institutions has three distinct roles in adopting agricultural technologies. These networks are conducted for financial transfer, exchange of information about new technologies, and facilitation of cooperative collective efforts.

Moreover, in many developing countries, agriculture is a central sector of the economy. For example, agriculture in Ethiopia represents 52% of the GDP and 85% of foreign exchange earnings and employed about 80% of the population in 2004 (Deressa et al., 2009). Research in the Nile Basin of Ethiopia finds farmer responses to climate change range from no adaption (42%), tree planting (21%), soil conservation (15%), change to different crop varieties (13%), change planting dates-early or later (5%) and irrigate (4%) (Deressa et al., 2009). Farmers who did not adapt offered many reasons: lack of information, lack of money, shortage of labor, shortage of land, and poor potential for irrigation. According to Newsham and Thomas (2011), report short-term strategies to address food insecurity varied in undeveloped countries and were less effective as population density increased. These short-term coping strategies involved sharing food with family and neighbors, selling cattle, hunting wild animals, increasing consumption of hardier resources such as leaves, digging wells for water, applying for government assistance, and purchasing food to compensate for the shortfall.

2. Climate-Related Hazards

Over the past decade, more than three-quarters of global disasters have been triggered by climate and climate-related hazards such as drought, storms, and floods (Gopalakrishnan, 2013).

3. Climate Change Mitigation, Adaptation, and Resilience

Never before in the history of humanity has there been a focus by scientists and farmers on securing future food production around the world. However, poor people and farming communities living in regions already impacted by climate change are already developing effective community-based adaptation strategies (Ensor, J. and Berger, 2009; IFAD, 2010). In other areas identified as being at high risk from the effects of climate change, farmers' communities and villages are being assisted in developing Climate-Smart Villages. In contrast, others are working to achieve more resilient landscapes by strengthening technical capacities, institutions, and political support for multi-stakeholder planning and governance for Climate-Smart Landscapes (Scherret, 2012). The challenge is to actively seek strategies to adapt to climate change and ensure that productivity can keep pace with the growing population's demand within a finite natural resource base (Reynolds & Ortiz, 2010). This situation will require an integrated approach, among other things, and will benefit from the availability of stress-tolerant trees-tolerant species. Therefore, the strategies must be linked to efficient and sustainable crop and natural resources management enabled by adequate poly support. Hence, this requires a concerted worldwide effort by farmers, scientists, donors, and development agencies, because of the need to meet the growing demand for food by ensuring resilient agricultural and food systems.

Closing the yield gap and increasing crop production will play a pivotal role in greater access to the world's genetic resources and their enhanced utilization by farmers and breeders of genetic methods worldwide (Shyam et al., 2019). In addition, a better understanding of crop physiology and genetic sequencing technology means that a more targeted approach to selection across multiple traits is now possible, leading to the development of new crop varieties for future challenging environments (Godfray et al., 2010). This will necessitate much greater utilization and sharing of the plant genetic diversity that currently exists in the more than 1700 gene banks globally by the world's plant breeders (Guarino & Lobell, 2011; McCouch et al., 2013).

a. Mitigation

Reynolds & Ortiz (2010) highlight that crop production mitigation strategies include improved soil management practices; mulch and cover cropping; conservation tillage; more efficient N utilization, improved crop cultivation techniques, and improved manure management practices that will reduce methane and nitrous oxide emissions. These will require new crop varieties, different crop combinations, and management systems where agronomic practices have been modified (Hodgkin, T. and Bordoni, 2012). In addition, crop production systems may mitigate climate change by breeding crop varieties with reduced carbon dioxide and nitrous oxide emissions (Reynolds & Ortiz, 2010).

b. Adaptation and Resilience

The increased use of agricultural biodiversity, especially plant genetic resources, will play an essential role in improving the adaptability and resilience of agricultural systems (Lin, 2011; Hodgkin & Bordoni, 2012).

Lin (2011) highlights that crop diversification can increase adaptation and resilience in various ways, including the enhanced capacity to suppress pest and disease outbreaks and buffering crop production from the impacts of more significant climatic variability and extreme weather events. For example, areas with greater diversity were found to be more resilient and to recover more rapidly in Honduras following recent hurricanes (Hodgkin & Bordoni, 2012). In addition, a recent worldwide review of 172 case studies and project reports demonstrates that agricultural biodiversity contributes to adaptation and resilience through a range of strategies that are often integrated. That includes the protection and restoration of ecosystems, the sustainable use of soil and water resources, agroforestry, diversification of farming systems, adjustments in cultivation practices, and crops with various stress tolerances and crop improvement (Mijatovic et al., 2013).

While certain levels of adaptation will be achieved by moving new crops and crop varieties to more favorable environments, crop improvement through plant breeding and the incorporation of new genes will be as significant (Guarino & Lobell, 2011). Hodgkin and Bordoni (2012) highlight crop traits for adapting to changing climate and production environments: pollination and the setting of seed under elevated temperatures and enhanced resilience and adaptability in the face of increasingly variable production conditions and increased frequency of extreme events.

We must make much better use of the genetic diversity that currently exists, both in gene banks and in situ.

Burke et al. (2009) have examined the likely future shifts in crop climates in sub-Saharan Africa and explored the priorities for crop breeding and the conservation of crop genetic resources for agricultural adaptation. They conclude that most African countries will have novel climates in at least 50% of their current cropping area by 2050. In addition, there will often be analog climates already existing in the current climates of at least five other countries; this highlights the critical role of the international movement of germplasm in future adaptation (Shyam et al., 2019). Reliance on three kinds of cereal (rice, maize, wheat) and other carbohydrate-rich staples might be sufficient to attain food security. However, nutritional security is to be addressed as well. Diverse diets that include a range of grains, pulses, fruit, and nutrient-dense vegetables constitute a common-sense approach to good health (Fanzo et al., 2013).

The neglected and underutilized species diversity and their range of adaptive traits and characteristics represent an essential resource for climate change adaptation. Unfortunately, they remain largely ignored by researchers and policymakers. Increased efforts will be needed to secure the diversity of crops and their wild relatives.

Climate change threats posed to crop diversity and CWR will require enhanced complementary actions for both in situ and ex-situ conservation, which will need to be adapted to face the growing threats posed by environmental and climate change (Hodgkin & Bordoni, 2012).

c. System Adaptation or Transformation

While variations in climate and extreme weather events will continue to be experienced locally in different ways, there is strong evidence that future local and global climates will become increasingly uncertain and unpredictable compared to past years (Hatfield et al., 2014; IPCC, 2014b). Therefore, there is increased regional and seasonal variability in water resources, changes in pressures associated with weeds, diseases, and insect pests, and the timing and coincidence of pollinator lifecycles. Furthermore, we observe prolonged exposure to extreme temperature increases, production costs, and loss of productivity in animal husbandry. Through these changes, some incremental press processes and pulse events that transform through and the shocks will continue to affect the agroecosystem and the human-social functions that are the foundation of food security (Morton, L.W. and Rudel, 2014). Agricultural scientists, farmers, agribusiness, and policymakers are challenged to understand these patterns, adjust and adapt technologies and management practices, and develop appropriate public policies in timely ways (Shyam et al., 2019).

Weather and climate and their impacts on soil, water, environment, health, food security, and vegetation are central to agriculture for continents. All successful farmers worldwide know the characteristics of their climate and pay close attention to weather and climate patterns as they make daily and longer-term decisions. Adaptive management responses can delay and reduce some of the climate and variable weather impacts in a specific area. Individual farmers and agricultural regions in many areas have adapted in incremental ways to current change situations. However, delayed or non-response by farmers to a changing climate presents a significant threat to food production and food security in the long term. It is still being determined whether current rates of adaptation and social-economic systems will keep pace with the rate of climate change in the coming decades.

Changing climatic conditions are exposing farm households and their communities to the ever-increasing risk and threatening the resources of livelihoods worldwide that depend on agriculture for food security and income (Hisali et al., 2011). Thus, poor farm households with limited knowledge, skills, and financial resources are vulnerable to food insecurity. Many contextual objective factors, subjective internal beliefs, and perceptions of risk shape vulnerability and barriers to adaptation. The challenge is to not replace a bottom-up-extension and local knowledge with top-down approaches that push for rapid modernization that displace local knowledge with technicians at the cost of reducing farmers' agroecosystem knowledge and confidence (Newsham & Thomas,2011). Local knowledge, land skills, and codes of behavior based on values and historical experience and practice play roles in capacity and willingness to adapt. Scientists, indigenous knowledge, and farmers' and communities' values, beliefs, and practices must be considered legitimate for adaptation. Food security and threats to households' livelihoods are tangible vulnerabilities. Loss of tradition, value, and community unity that underpin food security are social, intangible, and subjective but emotionally objective and implicit influences on behaviors and adaptation (Wolf et al., 2013). Local, regional, and global climate change policies need to address these values explicitly if efforts for planned adaptation are to be perceived as legitimate and effective by those affected.

Many research centers in Africa, South America, and Asia are linking research on crop varieties and management to local variations in culture, climate, traditional knowledge, and practices to improve food security in their regions (Shyam et al., 2019). Therefore, there are CGIAR

Consortium Research Centers such as CIAT (International Center for Tropical Agriculture), CIMMYT (International Maize and Wheat Improvement Center), ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), ILRI (International Livestock Research Institute), ICRAF (World Agro Centre), and IITA(International Institute for Tropical Agriculture) are focused on equipping and providing access to rural poor farmers information, seeds, technologies, and technical support to reduce climate-related crop failures and improve economic livelihoods (Shyam et al., 2019). In addition, the CCAFS (Climate Change, Agriculture and Food Security) (https://www.cgiar.org/.../climate-change-agricultureand-food-security) is conducting gender analysis and research to discover mechanisms that would improve gender-related acceptance and use of new information (Shyam et al., 2019).

Moreover, the gender strategy initiative acknowledges the cultural variations among rural people. It provides tools and processes for each region to develop gender-appropriate resources in conjunction with crop and livestock knowledge useful for effective adaptation to changing weather and climate conditions (Shyam et al., 2019). The global efforts to mobilize Climate Smart Agriculture (CSA) are being seeded by local NGOs that connect local farmers, farm organizations, agribusiness, academic institutions, seed companies, foundations, and other NGOs. Promotion of CSA is taking hold in many parts of the world, from Climate Smart Villages (CSV) in developing and developed countries to a newly formed North America Climate Smart Agriculture Alliance in the United States (Shyam et al., 2019). According to him, in 2011, a Climate Smart Village project was launched involving 15 climate-smart villages in West and East Africa and South Asia, with more villages in Latin American and Southeast Asia added in recent years. This initiative intends to leverage local values and indigenous knowledge with science and technology tools to help smallholder farmers take practical steps to change their agricultural practices to increase dependable flood supplies and improve livelihoods. In Mali, workshops and town hall meetings are the first steps to getting local villagers involved. Thus, partner organizations and researchers work side-by-side with farmers to provide valuable or suitable and essential resources to help them identify appropriate and acceptable climate-intelligent options.

According to Shyam et al. (2019), in Kenya's Lower Nyando valley, farmers are experimenting with alley cropping of maize, sorghum, and other cultivated crops planted between rows of multi-purpose trees (ccafs.cigar.org/climate-smart-villages). Therefore, the processes are designed to be participatory and inclusive of women and vulnerable groups (Shyam et al., 2019).

A growing body of literature argues that trade policies have weakened agricultural capacity in developing countries. The push to sell produce on international markets ties livelihoods to highly volatile international food prices and can lead farmers to abandon crops better adapted to their local conditions in favor of cash crops (Newsham & Thomas, 2011). In reality, farmers need accessible, affordable scientific information and technology resources to combine with their knowledge to adapt to climate change's effects. A specific context and real-time advice will become even more critical as farmers try to keep up with new weather patterns (Olson et al., 2015; Schiermeier, 2015). Global, national, and even regional forecasts often need to reflect local conditions. "Agricultural forecasts are notoriously difficult because they face multiple tiers of uncertainty: in how climate will change regionally, in assumptions about what crops might be planted, in the availability of fertilizers, and economic projects" (Schiermeier, 2015, p. 397). Global circulation models (GCM) need help predicting precipitation on a country basis (Sanghi & Mendelsohn, 2008). Among farmers' most significant needs are for downscaled, local forecasts to guide short and medium-term decision-making.

Sand international social science findings suggest that farmers benefit when they have a variety of practical and feasible adaptive management practices appropriate to their locale and the farm enterprise from which to choose (Morton et al., 2015; Below et al., 2012). However, much more research in this area is needed if we are to understand the motivations and abilities of farmers to adapt and the keystone factors driving capacity to change (Shyam et al., 2019). According to them, coupled human agroecosystem research is also needed if we concurrently increase productivity and protect the soil and water resources needed for future productivity.

CHAPITER 2: RESEARCH METHODOLOGY

This chapter will develop the general methodology for the different objectives of this study.

The approach used was focused on two ways as quantitative and qualitative technics. It was carried out in three phases: documentary research, primary and secondary data collection, and treatment.

2.1 Documentary research

This part is an important moment for each scientific work. It allows a better understanding of the research topic and better circumscribes the theme in time and space concerning work already carried out in the research area and elsewhere worldwide. This documentary research has been concerned general and specific books, theses, dissertations, journals, and scientific articles. In addition, some institutions were visited, such as the Malian meteorological agency, the National direction of agriculture, the Rural Economic Institute, Faculty of Science and Technics.

2.2. Data and information collected

Several types of data were used to carry out this research. These are climatologic data (temperature, precipitation, and evapotranspiration) extracted from the dataset of the meteorologic agency of Mali and concerned two stations, namely Koutiala and San, in the study area from 1989 to 2019. The agricultural data (maize crop) were collected from the database of the National Direction of Agriculture (DNA) for the period 1989 to 2019. The availability of data can explain the choice of this period. The field survey was also done through a structured questionnaire with a sampling of 455 respondents. The socio-demographic data comprises data relating to the population (RGPH, 2009) and field surveys.

2.3. Survey data collection methods

In order to collect the information inherent in this research, primary data were obtained through a field survey conducted using a questionnaire. This collection tool was developed based on variables.

2.4. Selected variables

The variable is the translation of the concepts used in a study into operative elements suitable for classification. More explicitly, the variable is any factor that can take one or more different properties or values (Lamboni et al., 2016). In this work, two types of variables are considered, namely independent variables or explanatory variables and dependent variables to be explained.

2.4.1. Independent variables or explanatory variables

The independent variables are still called explanatory variables. In the context of this research, the variables considered are Age, sex, education level, main activity, etc.

- **Age:** It is a factor that can affect the household crops production
- **Sex:** It is a variable that allows, in African societies, the division of tasks.
- **Level of education:** is a parameter that enters into the evaluation of a farmer's capacity to assimilate, accept and adapt to new agricultural technics.
- **Religion:** is a parameter that highlights the behavior of actors in the face of facts whose socio-cultural changes intervene in the exercise of their agricultural activities.
- **Households' size:** this variable shows us the number of persons in a household.
- **Farm size:** is about the size of cultivated land by farmers
- **Main activity:** The main activity is a parameter that allows us to see if the perception of the population depends on rainfall variability.
- **Climate parameters** (temperature, precipitation, and evapotranspiration)

2.4.2. Dependent variables or explained variables

Dependent variables are explained variables. For this research, the dependent variables retained are crop production and food security.

- **Crop production:** This depends on the potential of the physical environment, the material means of production, and climate variability or change (climate parameters conditions).
- **Food security:** is dependent on the household socio-economic characteristics and climate parameters.

2.5. Pre-field survey

The pre-investigation is preliminary work to the actual investigation. It took place from 15 to 22nd October 2021 and targeted agricultural households based on random sampling. This pre-survey consisted of field visits to 8 randomly selected villages. It also allowed for interviews with farmers, presidents of village development committees, village chiefs, and government and NGO workers. This phase enabled the realities of the rural area, agricultural production, and food security, and also to be aware of the threat of climate variability and change in those areas to reorient the survey questionnaire, target the resource persons concerned by the survey and readjust the hypotheses. In addition, this pre-survey enabled the survey sample to be drawn.

2.6. Sampling procedure and sample size

The target population for the survey was mainly the rural population, heads of agricultural households at least 18 years of age or above.

A multistage sampling technique was used to select the respondents in the study area.

- **In the first stage**, two agro-climatic zones are purposively selected out of the four agro-climatic zones in Mali, given Sudanian and Sudano-Sahelian zones. These two agro-climatic zones (Sikasso and Segou regions) were chosen because they are the most significant agricultural areas in Mali, the most populated population zones, and the most affected area faced by climatic risks such as flooding and drought, respectively.

- **In the second stage,** one (1) region was purposively selected from each agro-climatic zone, that is given respectively Segou and Sikasso, because of their accessibility, vulnerability to climate-related disasters (flood and drought), and also their geographical positions in the country.

- **In the third stage**, one district was randomly selected from each selected region, given, respectively, San and Koutiala districts.

- **In the fourth and last stage**, based on the high number of farmer households in each district, a proportionate technique was used through the following formula below to select the sampling size of households for this study.

$$n = \frac{N}{1+Ne^2} \qquad \textbf{(1)}$$

- By applying the SLOVIN formula:
- With **n**: expected sample size
- **N:** total number of households: 51, 136 (CPS, 2017)
- **e**: error (7%)

2.7. Field survey

This survey collected quantitative and qualitative data. Indeed, the questionnaire was developed based on the selected variables, the research objectives, and the hypotheses.

The questionnaire consists of farmers' socio-economic characteristics and perceptions of climate variability and change. We have also assessed their strategies or mechanisms for managing climate variability or change and also their food security status. The data from these surveys were obtained from a population sample of households.

For administering the questionnaires to the heads of households, who are the primary duty bearers in this society, the random sampling method was preferred because it gives all individuals an equal chance of being included in the sample.

Among the households surveyed, information on age, gender, household size, farm size, level of education, etc., was collected. For this study, the sampling size obtained is 455 respondents.

2.8. Field observation

Field observation is an indispensable tool for data collection; it was possible simultaneously during the fieldwork. It was based on the observation of the landscape in various aspects. The first step is observing the physical landscape, the natural setting where agricultural activities occur. This phase makes it possible to identify and analyze the adaptation strategies developed by the farmers to face climate variability or change. Then, observing the agrarian landscape allowed for appreciating the dynamism of the agricultural spaces, the farming systems, and technics and also to see the impacts of climate risks on natural resources.

2.9. Interview

These interviews provided additional information unavailable in libraries, institutes, and research centers. Indeed, the resource persons interviewed are the agricultural technicians, the forest protection agents from government services, NGOs agents such as World Vision (WV), World Agroforestry Center (ICRAF), Oxfam, AMEED, village leaders (chief of village, and the leads of young men and women), and household heads.

Interviews with these resource persons provided additional information on farmers' perceptions of climate variability or change and their impacts on crop production, natural resources, livestock production, and food security in the study area.

2.10. Choice of main crops

Mali's diet is mainly based on cereals (maize, sorghum, millet, and rice). Therefore, the crops grown in the southern parts of Mali (Koutiala and San districts) are primarily cereals.

In the framework of this research, two crops were selected, such as maize for the Koutiala district and sorghum for the San district. However, this research did not include cash (cotton, for example). Instead, maize and sorghum crops were selected according to their food and economic importance to the study area's households and their resilience to climate variability or change.

2.11. Difficulties encountered

Surveying 455 household heads in eight (08) villages took much work. Despite using a participative approach, we faced challenges such as insecurity issues, farming activity periods, and a high number of weekly markets in the study area. Thus, respondents' access could have been more challenging because of the cited issues.

The difficulties encountered are academic, natural, and human, such as:

- Difficult to access data on climate and agricultural production from 1989 to 2019;
- Difficulties of geographical access to the selected villages due to the poor states of roads and terrorist attacks;
- It is not easy to access the respondents because of their farming activities and participation in many weekly markets around their area in both districts.

2.12. Partial conclusion

This section specified the conceptual and methodological framework for this research. This conceptual framework covered the problem, the objectives, the hypotheses, the clarification of concepts, and the review of the literature.

The methodological framework based on field investigations was defined to collect the climatic and agricultural data and assess the farmer's perception of food security status, climate variability, and change and the adaptation strategies adopted.

CHAPTER 3: PHYSICAL AND HUMAN CONDITIONS IN KOUTIALA AND SAN DISTRICTS

This chapter presented the study area of the thesis. It was based on the area's geographical location, hydrography, climate, vegetation, and economic activities.

3.1. Localization of study area

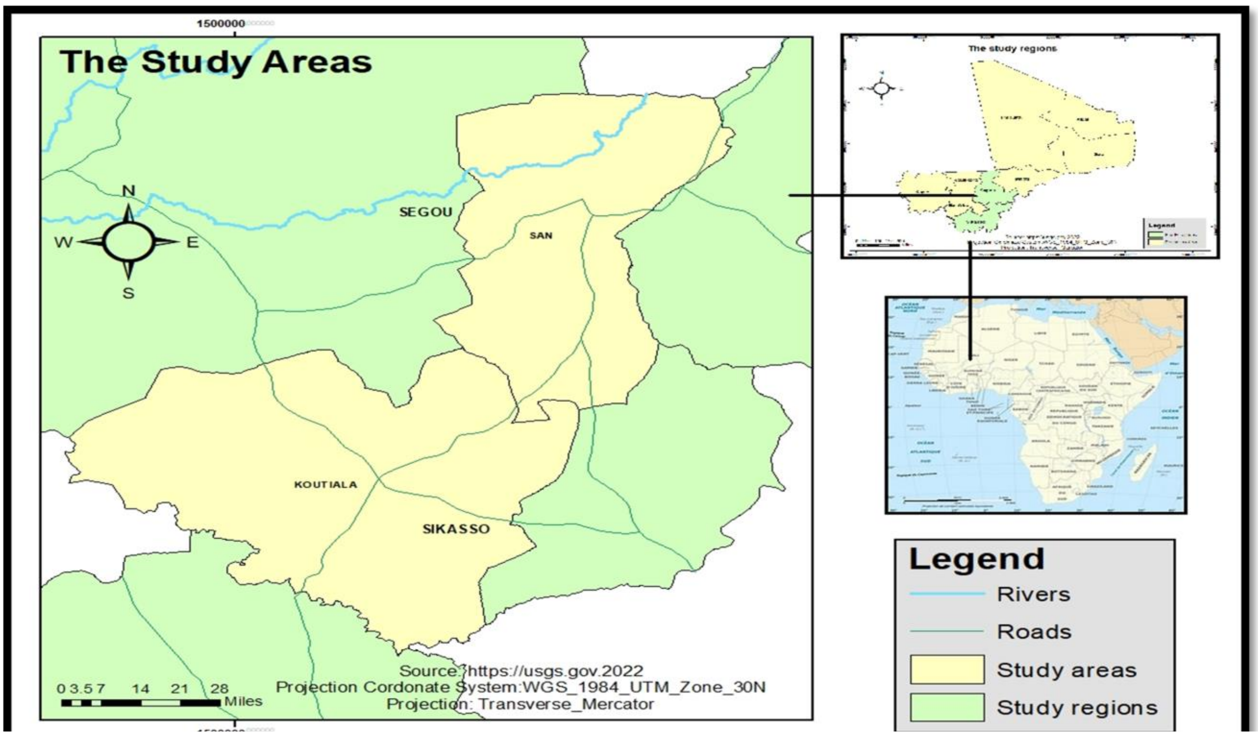
This study is implemented in two districts of Mali, namely Koutiala (Sikasso region) and San (Segou region). This area (Southern Mali) occupies 13.5% (approximately 160.825 km^2) of the Malian territory and represents 50% of the cultivable lands of the country, and holds 40% of the Malian population (ME, 2017).

Koutiala District is in the heart of the old cotton basin and occupies the western part of the Sikasso region. It is bounded on the north by San District, northwest by Bla, and southwest by the Dioïla District, to the south by the Sikasso and Republic of Burkina Faso district, and on the east by the District of Yorosso. The geographical location of the district is 12°23′N 5°28′W.

The Koutiala district covers an area of 8,740 km2 with a population of 797927 inhabitants.

San district is part of the semi-arid zone and is characterized by a Sudan-Sahelian climate. It has a surface of 7,262 km^2 with a population of 335,000 inhabitants. Its location is 13° 10' 44.2" N 5° 0' 58.2" W.

The following map presents the study areas where this study was conducted.



Source: Personal work

Figure 12: Map of the study area

3.2. Hydrography

Koutiala district has neither a river nor large lakes, yet we can distinguish between surface water and wells, generally fed by rainwater. The district has neither a river nor large lakes, yet we can distinguish between surface water and wells, generally fed by rainwater (RGPH, 2009; Mali-Meteo, 2019; INSTAT, 2009).

The topography of the Koutiala and San districts involves plateaus, sloping lands, and lowlands. The soil textures are predominantly clay, sandy loam, and sandy soils. Sandy soils have deficient organic matter and low infiltration capacity. Due to their poor level of fertility and poor water retention capacity, sandy soils are mainly favorable to millet production, which tolerates low fertility and water scarcity. Cotton, sorghum, and maize are grown in sandy loam soils and clay because of the higher quality of these soils (Coulibaly et al., 2011).

3.3. Vegetation

The vegetation is sparse and mainly in the form of isolated trees or savannah-parkland with predominantly Acacia albida (Balazan), Balanites aegyptiaca (Zekene), or Adansonia digitata (Zira). In the cropped fields, the most common tree species which are protected by local laws – are the shea-nut tree (*Vitellaria paradoxa*), neré (*Parkia biglobosa*), and baobab (*Adansonia digitata*). The fruits are used as a snack, especially during periods of food shortages, for instance, at the beginning of the rainy season. They are an essential ingredient of local diets and serve as vegetable fat, for example, in combination with millet as a frying medium or added to porridge (Lusby, 2006). The fruits' collection, processing, and commercialization are almost exclusively under the control of women (Elias, 2006; Sidibe et al., 2017).

3.4. Climate

The climate is tropical sub-Saharan and characterized by two seasons in a year: a dry season from November to April and a rainy season from May to October.

The rainfall in Koutiala ranges from 750 to 1000 mm per year. The rainy season lasts from June to October, with rainfall peaking in August. The dry season comprises a relatively cold period from November to February and a hot period lasting from March to May. The average maximum temperature is 34°C during the rainy season and 40°C during the hot, dry period (Bandiougou et al., 2017). The district has neither a river nor large lakes, yet we can distinguish between surface water and wells, generally fed by rainwater (*RGPH 2009, Mali-Meteo 2019,* Institut National de la Statistiques, République du Mali, 2009).

San district has a tropical dry wither with an average maximum temperature of 44°C, and the lowest temperatures are 13°C. This district is hot on average all year round, with the warm months being March and May. November to February is the most incredible month. The rainy season peaks in June, July, August, and September. The annual average rainfall is around 500 mm per year (*RGPH 2009, Mali-Meteo 2019,* Institut National de la Statistiques, République du Mali, 2009).

3.5. Economy activities

Agriculture is the main activity of the population in both districts. The main crops cultivated by farmers are millet, sorghum, maize, and rice, which form the basis of the diet. Market gardening and fruit growing also provide additional income. Livestock breeding, fishing, and handicrafts are the occupations of the population that are part of the local economy. Poultry farming, beekeeping, and fish farming are developing more slowly.

Koutiala and San districts are one of the largest cereal production zones in the country. Millet, sorghum, and maize are the main staple foods produced in those zones. Rice is also grown in the zones. These crops serve for home consumption as well as being marketed. Both cereal and cotton are produced under rain-fed conditions. Koutiala is the main cotton-growing area, producing 200,000 tons during the CMDT season of 2008/2009. Cereals are grown in rotation with cotton, which allows them to benefit from the residual effect of fertilizers used in cotton.

CHAPTER 4: HISTORICAL TRENDS OF CLIMATE PARAMETERS FROM 1989 TO 2019

An article has been published from this chapter.

DOI: 10.4236/ajcc.2022.113011

Abstract

The yearly temperature, precipitation, and evapotranspiration are significant variables in Mali. However, from north to south, their distributions are unevenly dispersed. Evapotranspiration and air temperature are expected to rise due to climate change. Additionally, it raises the likelihood of heat waves brought on by droughts and intense rainstorms. Among all hydrologic extremes, drought is regarded as a natural disaster. It seriously harms the ecology, agriculture, and ways of life that rely on water resources. The current study assessed how drought indices changed in the Koutiala and San areas between 1989 and 2019.

The MK test has been used to analyze trends in monthly precipitation, temperature, and evapotranspiration. Based on the analysis's findings, the Koutiala and San districts' climate has been categorized as moderate to severe drought. However, this outcome demonstrates changes in SPEI patterns in both districts. In the Koutiala and San districts, the monthly precipitation pattern was noticeably declining. In contrast, both districts' monthly evapotranspiration and temperature showed an upward tendency.

The standardized anomaly index (SAI) evaluated the research area's temperature fluctuation. According to the Mann-Kendall test, the mean annual temperature indicated statistically significant warming in each district.

Keywords

Climate Parameters, SPEI, Trend, Mann-Kendall, Koutiala, San,Mali

4.1. INTRODUCTION

The scientific community and decision-makers are gravely concerned about how climate change affects both natural and anthropogenic ecosystems (IPCC, 2018; Ouhamdouch et al.,2020; Bahir et al., 2020). The Intergovernmental Panel on Climate Change (IPCC, 2018) has estimated that human activity has contributed to global warming of 1 °C above pre-industrial levels, ranging from 0.8 °C to 1.2 °C. If this warming keeps increasing at the current rate, it might reach 1.5 °C between 2030 and 2052. (IPCC, 2018). Increased demand for water resources, decreased agricultural production, and, most significantly, the emergence of vector-borne and water-borne diseases are just a few ways this climate change could influence a wide range of industries and activities (IPCC, 2014). A constant rise in temperature may also intensify the hydrological cycle and increase the frequency of extreme weather occurrences (Chaouche et al., 2010; Tao et al., 2015; Rahman et al., 2018; Wilcox et al., 2018; Ouhamdouch et al., 2020). Droughts are predicted to become more frequent and intense in many parts of the world, including Africa, due to climate change. Rural communities are destroyed by drought and experience widespread hardship. In the study area, we have observed the frequent occurrence of drought.

In the West African Sahel, an increasing trend was seen in both maximum and minimum temperatures for all three ecological zones (Sudanian, Sahelian, and Sahel-Saharan), with minimum temperature increasing at a faster rate, according to a publication by CEDEAO-Club Sahel/OCDE/CILSS on Climate and Climate Change (CEDEAO-Club Sahel/OCDE/CILSS, 2008). The endurance of dry years from 1970 to 1993 was observed in the isohyet shift southward by around 200 km (Toure et al., 2017; L'Hôte et al., 2002). (Diouf, 2000). According to Touré et al. (2017), another type of variability that alternates between arid and wet years started in the region after 1993. Furthermore, the same author notes that while the Western Sahel tends to remain in a state of dryness, the east is gradually returning to wetter conditions. Although there have been some notable increases and decreases in annual precipitation, recent studies in Africa have examined daily climate trends and extreme indices to find these changes (New et al., 2006; Alexander et al., 2006; Donat et al., 2014). In some places of Africa, particularly concerning water supply, the effects of climate change are highly significant and even drastic, according to the Fourth Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2018). In other words, many African nations, particularly those in the Sahel, are already dealing with semi-arid conditions and desertification, which are recurring droughts and complete reliance on precipitation for agriculture (IPCC, 2018). These studies also found increases in most extended wet spells, high daily precipitation amounts, and average rainfall intensity.

According to Paschal et al. (2019), agriculture makes up most of Africa's economy and accounts for 30% of its annual gross domestic product (GDP). Agriculture's success is essential for ensuring food security and reducing poverty because it generates more than 80% of rural informal employment and contributes to 65% of Africa's total exports (Asafu-Adjaye, 2014). Mali's economy mainly depends on the primary sector because 68% of the working population is employed in agriculture, forestry, livestock, and fisheries. However, this industry depends on exogenous elements, namely environmental conditions related to the climate, frequent droughts and floods, and producers' varying technical and economic capacities (ENSAN, 2016).

Mali is a landlocked nation, and because of its geography, socioeconomic standing, and climate-sensitive economy, it is thought to be one of the nations most susceptible to climate stress. Eighty percent of Malians rely on agriculture for their livelihoods, and this sector is particularly vulnerable to the Sahelian region's frequent droughts and unpredictable rains. Additionally, recurrent extreme events like the devastating floods in 2007 and the five significant droughts from 1987 to 2007 impede households from recovering and escaping poverty (USAID, 2018b).

Today, Mali's agricultural production methods are seriously threatened by climate change (Bouba et al., 2018). For instance, we see variations in rainfall patterns in the study area. This condition causes flooding and drought. The World Bank (2019) estimates that 400,000 people in Mali, mainly in the southern regions, live where there will likely be water shortages every year. The extreme weather occurrences (drought, flooding, high temperatures, and strong winds), as well as the rise in rainfall and temperature fluctuation as a result, have an impact on crops, livestock, food security, and other livelihoods for the primarily poor populace in Mali (Bouba et al., 2018). Between 1950 and the middle of the 1980s, rainfall in Mali dropped sharply, somewhat rebounded in the 1990s, and then started to fall again in the 2000s (Fact Sheet, 2012). Drought issues that take many forms affect agricultural production systems in most of Mali's regions. The most frequent and dangerous dry spells occur at the season's start and end (Bouba et al., 2018).

Rising temperatures and more unpredictable rainfall due to climate change are predicted to make Mali's agroecological zones more vulnerable, which will significantly negatively impact food security and economic growth (Butt & McCarl, 2006; Dell et al., 2012). According to climate change forecasts from the Hadley Center Coupled Climate Model (HADCM) and Canadian Global Couple Climate (CGCM), the average temperature in Mali may rise by 1 to 2.75 degrees

Celsius by 2030 and by 2 to 4 degrees Celsius before 2060. (Butt et al., 2005; Butt & McCarl, 2006; Konate, 2010). However, by 2025, agricultural production will experience 20% to 60% yield losses due to these changes in rainfall characteristics (Butt et al., 2005). Additionally, the biophysical foundation is quite evident because plant physiology and water balance are strongly impacted by rainfall features, notably water availability and evapotranspiration (Dell et al., 2012).

Despite numerous attempts by scientists to address climate variability and change, this phenomenon continues to affect the livelihoods of the Malian population. As a result, this chapter will demonstrate how the study area's temperature, precipitation, and evapotranspiration vary over time. This chapter's objective is to give scientific knowledge to researchers, students, farmers, and NGO organizations so they can forecast these factors and strengthen their coping mechanisms for dealing with their effects.

4.2. Material and Methods

4.2.1. Overview of the study area

This study is implemented in two districts of Mali, namely Koutiala (Sikasso region) and San (Segou region). This area (Southern Mali) occupies 13.5% (approximately 160.825 km^2) of the Malian territory and represents 50% of the cultivable lands of the country, and holds 40% of the Malian population (ME, 2017) (see figure 12 above).

Koutiala District is in the heart of the old cotton basin and occupies the western part of the Sikasso region. It is bounded on the north by San District, northwest by Bla, and southwest by the Dioïla District, to the south by the Sikasso and Republic of Burkina Faso district, and on the east by the District of Yorosso. The geographical location of the district is 12°23′N 5°28′W.

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Climatic data taken into account are precipitation, temperature (minimum and maximum), and evapotranspiration from 1989 to 2019. These data were taken monthly. They are from two meteorological stations, namely Koutiala and San.

The National Direction of Meteo provided the climatological data used in Mali (NDM).

4.2.2. Climate data analysis

4.2.2.1. Temporal Trend Analysis

For the analysis of temporal trends in maximum, minimum temperature, precipitation, and evapotranspiration, the Mann-Kendall test (Mann, 1945; Kendall, 1975; Calogero et al., 2011), a nonparametric method for trend analysis, was used. It should be noted that the Mann-Kendall statistics test is non-dimensional. It does not offer any quantification of the trend's scale in the units of the time series under study. It instead measures the correlation of the variable with time. It offers information on the direction and a measure of the significance of observed trends. The Mann-Kendall statistic test S is given as follows:

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} Sign\left(x_i - x_j\right) \qquad \textbf{(2)}$$

where xi and xj are the data value at the time i and j

where n is the length of the dataset

Where $sign\left(x_i - x_j\right)$ is the sign function which can be computed as:

$$Sign\left(x_i - x_j\right) = \begin{cases} 1 & \text{if } \left(x_i - x_j\right) > 0 \\ 0 & \text{if } \left(x_i - x_j\right) = 0 \\ -1 & \text{if } \left(x_i - x_j\right) < 0 \end{cases} \quad \textbf{(3)}$$

For n > 10, the test statistic Z approximately follows a standard normal distribution:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases} \quad \textbf{(4)}$$

In which Var(S) is the variance of statistic S.

A positive value of Z indicates an increasing trend, and a negative value indicates a decreasing trend. The null hypothesis, Ho, that there is no trend in where $sign\left(x_i - x_j\right)$ is the sign function can be computed as:

$$Sign\left(x_i - x_j\right) = \begin{cases} 1 & \text{if } \left(x_i - x_j\right) > 0 \\ 0 & \text{if } \left(x_i - x_j\right) = 0 \\ -1 & \text{if } \left(x_i - x_j\right) < 0 \end{cases} \quad \textbf{(5)}$$

For n > 10, the test statistic Z approximately follows a standard normal distribution:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases} \quad \textbf{(6)}$$

In which Var(S) is the variance of statistic S.

A positive value of Z indicates an increasing trend, and a negative value indicates a decreasing trend. The null hypothesis, Ho, that there is no trend in the records is either accepted or rejected depending on whether the computed *Z* statistics are less than or more than the critical value of *Z* statistics obtained from the standard distribution table at the 5% significance level (Some, 2013).

$/Z/ > Z(1 - \alpha/2)$, the null hypothesis of no autocorrelation and trend in the data-set is rejected, in which $Z(1 - \alpha/2)$ corresponds to the normal distribution, with α being the significance level.

If the data has a trend, the magnitude of the trend can be denoted by trend slope β (Sen, 1968; Theil, 1950).

$$\beta = Median\left[\frac{x_i - x_j}{i - j}\right], \forall j < i \quad \textbf{(7)}$$

x_i and x_j are data values at time t_i and t_j ($i > j$), respectively.

4.2.2.2. Standardized Anomaly Index (SAI)

For each station, the annual mean temperature, mean annual minimum temperature, and mean maximum temperature series were analyzed for fluctuation using Standardized Anomaly Index (SAI), a commonly used index for regional climate change studies (Babatolu and Akinnubi, 2013). Station temperature is expressed as a standardized departure ***xi*** from the long-term mean (i.e., the mean of the base period), calculated as:

$$xi = \frac{r - ri}{\sigma} \quad \textbf{(8)}$$

Where **r** is the mean temperature of the year, **ri** is the long-term mean, and **σ** is the standard deviation of annual mean temperature for the long term.

A period when below the long-term average was dominant is considered a cooling period, and a period when the above long-term average was most persistent is a warming period.

4.2.2.3. Standardized Precipitation Evapotranspiration Index (SPEI)

The SPEI index is a standardized monthly climatic balance computed as the difference between cumulative precipitation and potential evapotranspiration.

SPEI, a modified drought index that includes the effect of global warming on drought severity, was first proposed by (Vicente-Serrano et al., 2010). SPEI uses "water balance" (*D*) as an input variable, is aggregated at different timescales (1, 3, 6,9,12, and 24 months), and these resulting values fit the probability distribution function (e.g., log-logistic) and then normalized the water balance to obtain the SPEI. The difference (*D*) between precipitation (*P*) and *PET* for the month is given in the equation below.

$$D = P - PET \quad \textbf{(9)}$$

where D is the difference

where P is the precipitation

where PET is the Potential Evapotranspiration

The calculated D values are accumulated at different time scales

$$D_n^k = \sum_{i=0}^{k-1} P_{n-1} - \left(PET\right)_{n-1} \quad \textbf{(10)}$$

where k is the timescale (months) of accumulation and n is the calculation month.

All negative SPEI values indicate the occurrence of drought, while all positive values stand for wet periods (McKee et al. & Kleist, 1993; Komuscu, 1999). The choice of the timescale depends on the interest of the research. This study used the 12-month timescale to compute SPEI values from 1989 to 2019.

Tableau 7: Establishment of drought level according to SPEI index values

Color	Categories	Index values	Color	Categories	Index values
	Exceptionally drought	≤ -2.326		Highly wet	+0.524 to +0.935
	Extremely drought	-1.645 to -2.326		Moderately wet	+0.935 to +1.282
	Severely drought	-1.282 to -1.645		Considerably wet	+1.282 to +1.645
	Moderately drought	-0.935 to -1.282		Extreme wet	+1.645 to +2.326
	Minor drought	-0.524 to -0.935		Exceptionally wet	≥2.326
	Near Normal	+0.524 to -0.524			

Source: McKee et al. (1993)

Each color refers to the corresponding category of moisture conditions.

4.3. Results and Discussion

4.3.1. Trends Analysis of Climate Parameters with Mann-Kendall Test

Monotonic increasing or decreasing trends in annual maximum, minimum temperature, evapotranspiration, and precipitation were tested from 1989 to 2019 in the study area using Mann-Kendall test (Z-statistic) and Sen's slope estimator (Q). Annual trends of climate parameters obtained by Mann-Kendall and Sen's slope estimator are given in Table 8.

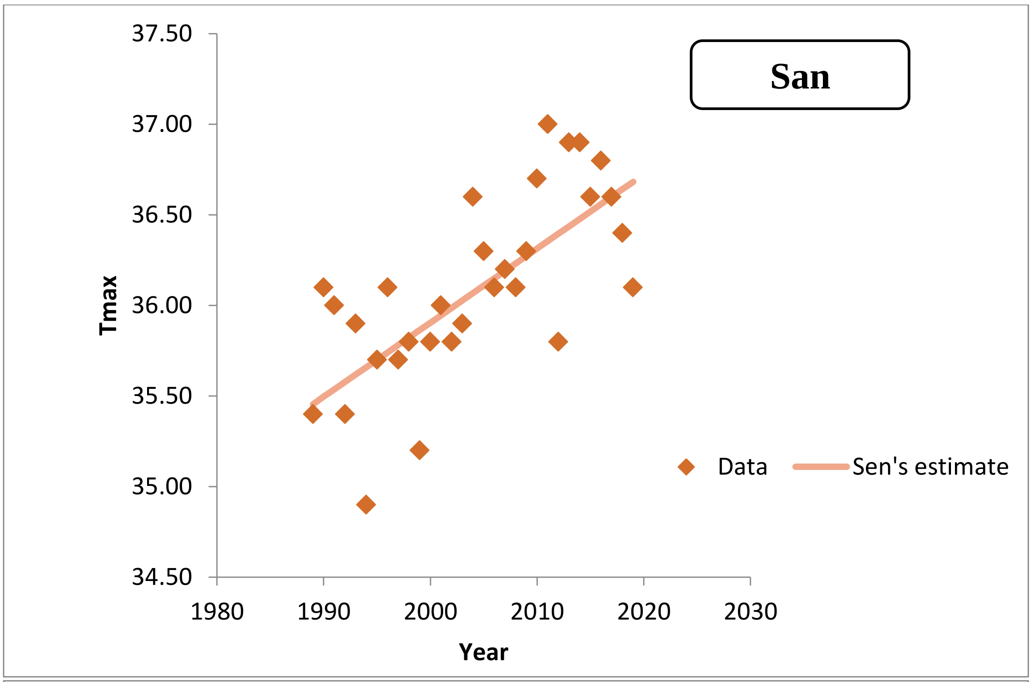
A positive value of Z indicates an increasing trend, and a negative value indicates a decreasing trend (Kendall, 1975b). Therefore, Figure 4 shows a highly significant increase trend in maximum temperature (Z=3.97, Z=4.01) recorded in Koutiala and San districts, respectively. At the same time, there was a highly significant increase trend in minimum temperature in the Koutiala district (Z=2.89) and an extremely significant increase trend in mini- mum temperature in the San district (Z=3.82). However, the temperature recorded is above the mean (34˚C and 36˚C) in both districts. Similar results were obtained by Collins et al. (2011), in which an increased trend in air temperature has been reported in different parts of the world, including the tropical African region. Collins et al. (2011) reported a significant increasing trend in temperature for all of Africa, as well as the Northern Hemisphere Africa, Southern Hemisphere Africa, tropical Africa, and subtropical Africa. Since 1975, temperatures have increased by more than 0.8˚ Celsius (˚C) across most Mali, with typical warming rates more significant than 0.2˚C per decade (Fact Sheet, 2012). This transition to an even warmer climate could reduce crop harvests and pasture availability, amplifying the impact of droughts. According to CEDEAO- Club Sahel/OCDE/CILSS (2008) on Climate and Climate Change, in the West African Sahel, an increasing trend was observed in both maximum and minimum temperatures for all three ecological zones (Sudanian, Sahelian, and Sahel-Saharan) with minimum temperature increasing at a faster rate. This temperature increase can result in reduced fodder yield, an increase in evapotranspiration, a possibility of migration and conflict between livestock and crop farmers, as well as in the economic, physical, and psychological costs (Thornton et al., 2009; Sirohi, S., & Michaelowa, 2007). Further, this temperature increase also impacts human health (McMichael et al., 2012).

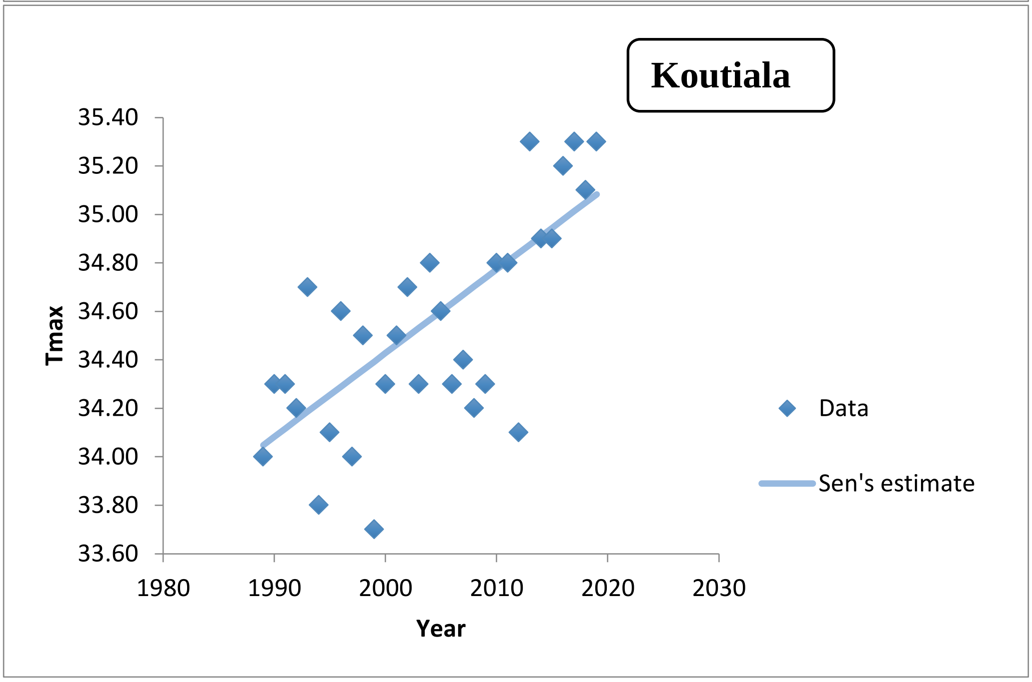
Tableau 8:: Trend analysis values of annual climatic variables in Koutiala and San districts

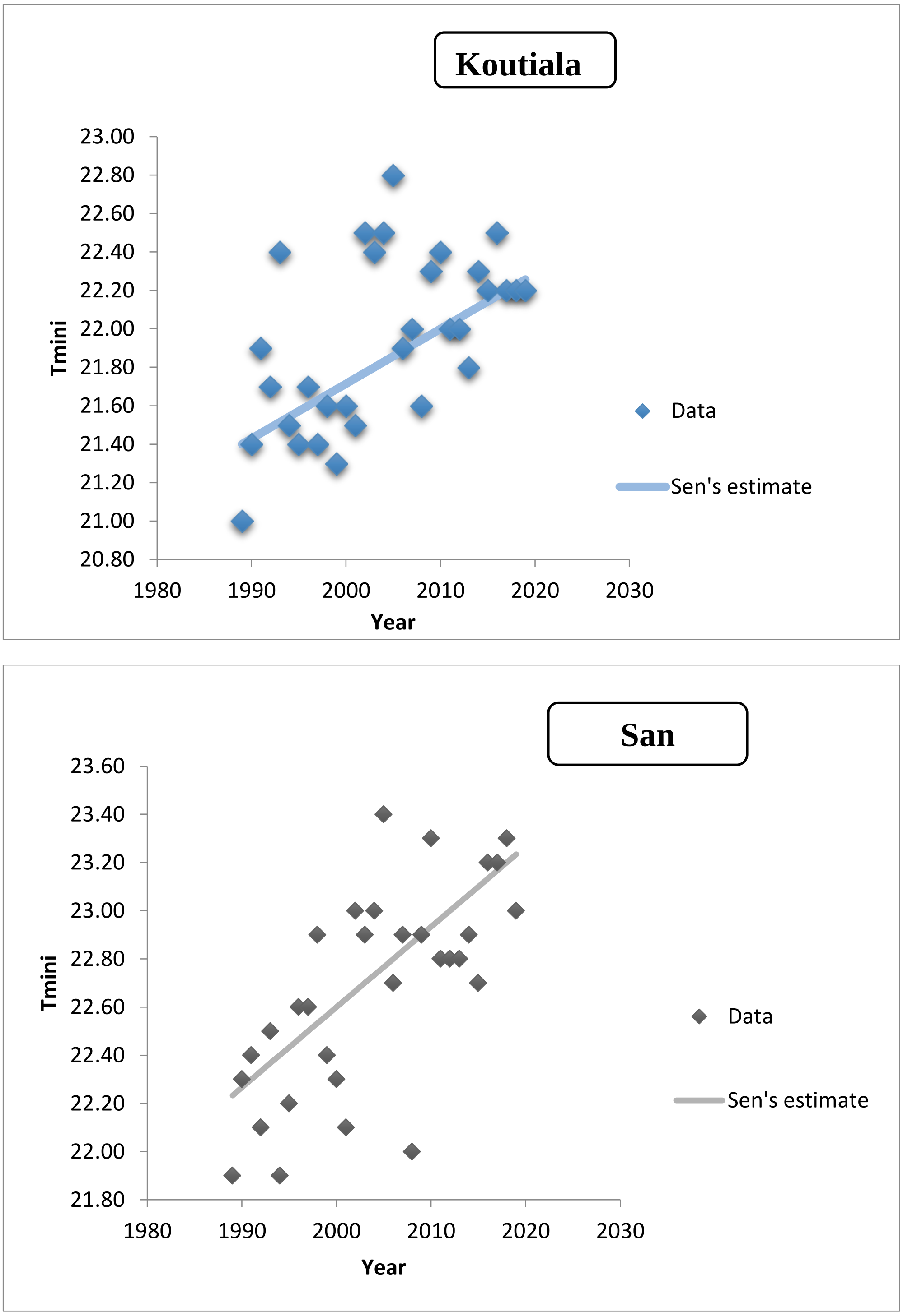
Time series	First-year	Last year	n	Koutiala			San		
				Mann-Kendall test		Sen's slope estimate	Mann-Kendall test		Sen's slope estimate
				Test Z	Sig.	Q	Test Z	Sig.	Q
Temperature maximum	1989	2019	31	3.97	***	0.034	4.01	***	0.041
Temperature minimum	1989	2019	31	2.89	**	0.029	3.82	***	0.033
Precipitation	1989	2019	31	0.95	n.s	3.118	0.99	n.s	3.546
Evapotranspiration	1989	2019	31	3.47	***	16.600	2.65	**	11.380

Source: Personal work.

* Statistically significant trend at *p*-value = 0.05 with 90% confidence level; ** highly statistically significant trend at *p*-value = 0.01 with 95% confidence level; *** extremely statistically significant trend at *p*-value = 0.001 with 99% confidence level. n.s: Non-significant.


San
37.50
37.00
36.50
36.00
35.50
35.00
34.50
Tmax
1980
1990
2000
2010
2020
2030
Year
Data
Sen's estimate


Koutiala
35.40
35.20
35.00
34.80
34.60
34.40
34.20
34.00
33.80
33.60
Tmax
1980
1990
2000
2010
2020
2030
Year
Data
Sen's estimate

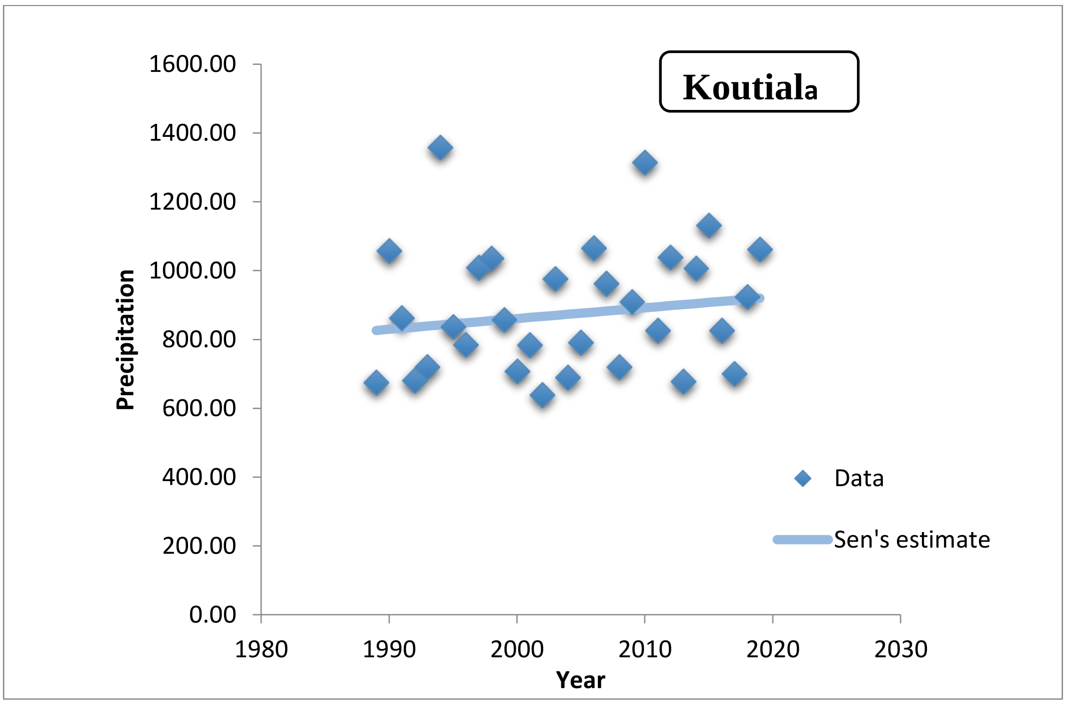


Source: Personal work.

Figure 13. The maximum and minimum temperature trend from 1989 to 2019 in Koutiala and San districts.

Figure 14 indicates that there was no significant trend in precipitation (Z=0.95 and Z = 0.99) in both districts. This result is consistent with the third national communication of the

UNFCCC in Mali (UNFCCC, 2017). It indicates that the trends in climatic parameters clearly showed a decrease in rainfall and an apparent increase in mean annual temperature. It is reported in the report on Mali's ExpectedDetermined Contribution presented at the COP21 in Paris that situation is more difficult as climate scenarios for the year 2100 predict an average temperature increase of 3˚C and a decrease in rainfall of 22% over the whole country. Rainfall represents a meteorological element that best defines the climate of the tropics and Mali. Therefore, the decreases in rainfall impact human activities by relying on rain-fed agriculture. The crop cycles follow the rhythm of rainfall. Precipitation is the primary source of water during refilling and layers. Therefore, if any precipitation ever were to change, the consequence would be multiple for human life. Elsewhere, increased frequencies of extreme rainfall events such as prolonged dry or wet spells mean weaker productive systems. This decrease in annual total rainfall is confirmed in most of Africa (Frappart et al., 2009; Ozer et al., 2009; Hountondji et al., 2011). A similar finding was observed in the overall reduction in rainfall in the studies over the Sahel (Biasutti, 2013; Mohamed, 2011; Ackerley et al., 2011; Lebel, T., & Ali, 2009; Nicholson et al., 2000). It was also found in the study done by (New et al., 2006; Donat et al., 2014) non-significant but in total rainfall positive trends from heavy events for the West Africa and Southern Africa region.



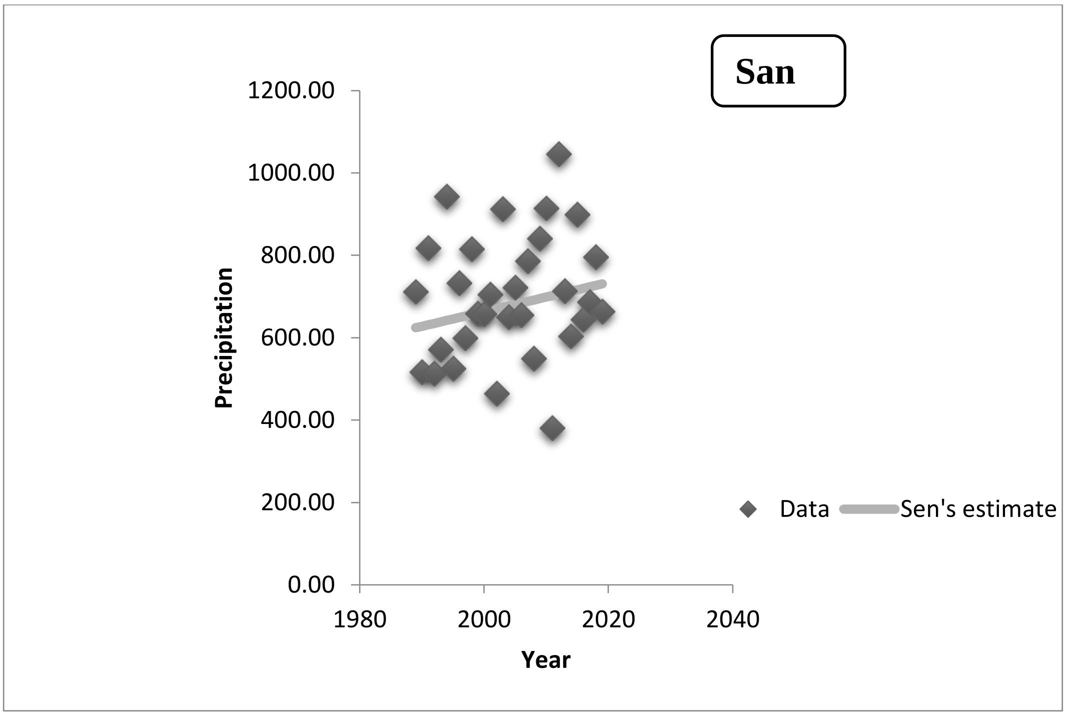
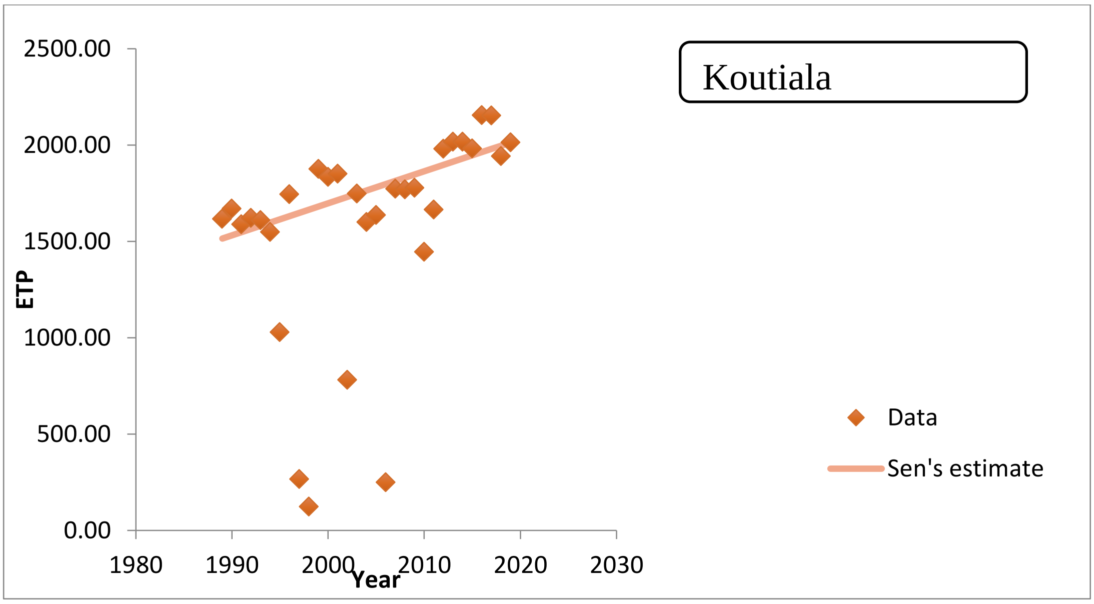
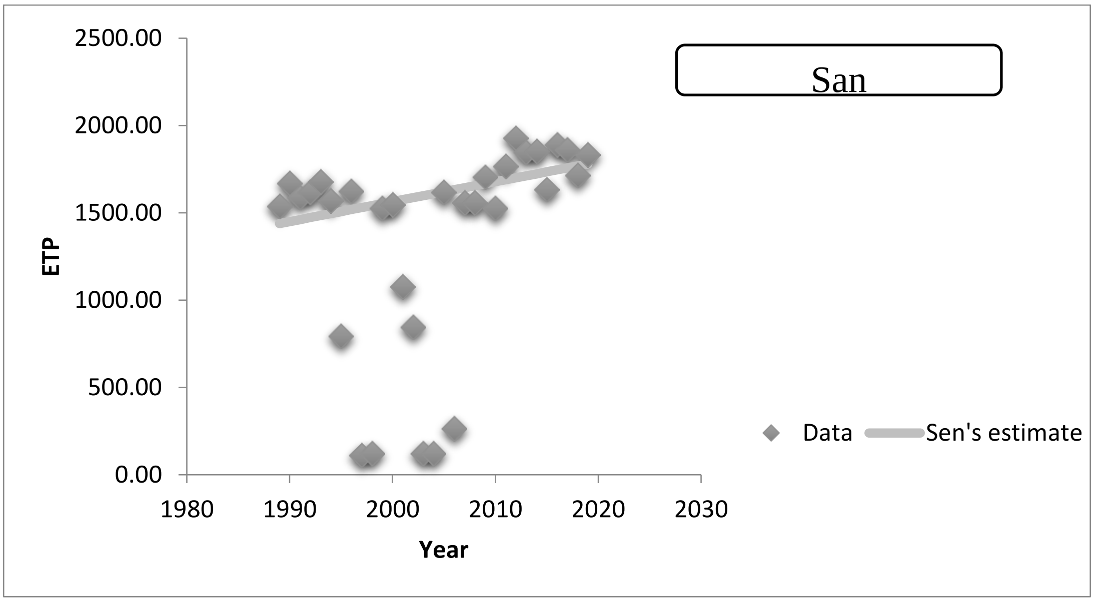


Figure 14: Trend of Precipitation from 1989 to 2019 in Koutiala and San districts

Figure 15 revealed a highly significant increasing trend of evapotranspiration (Z = 3.47) recorded in the Koutiala district. At the same time, this figure showed a significantly increasing evapotranspiration trend in the San district. Therefore, this result shows the increase in maximum and minimum in both districts (Figure 15). This result confirms the studies by Abiye et al. (2019) and Diaye et al . (2020), according to which the temperature (maximum and minimum) is the main factor of variation of evapotranspiration during the periods 1906 - 2015 and 1984 - 2017 in West Africa. According to Komlan et al.(2017), there was an increasing trend of annual evapotranspiration at the rate of 1.4, 1.2, 4.4, and 2.6 mm/year in Senegal. Osbahr et al. (2011) showed that temperature increases led to increasing evapotranspiration rates linked to the faster depletion of soil water. Researchers found that high levels of soil water depletion resulted from high evapotranspiration rates, usually leading to crop wilting and causing crop failure, which the farmer may attribute to a decline in rainfall (Halimatou & Kalifa, 2016).





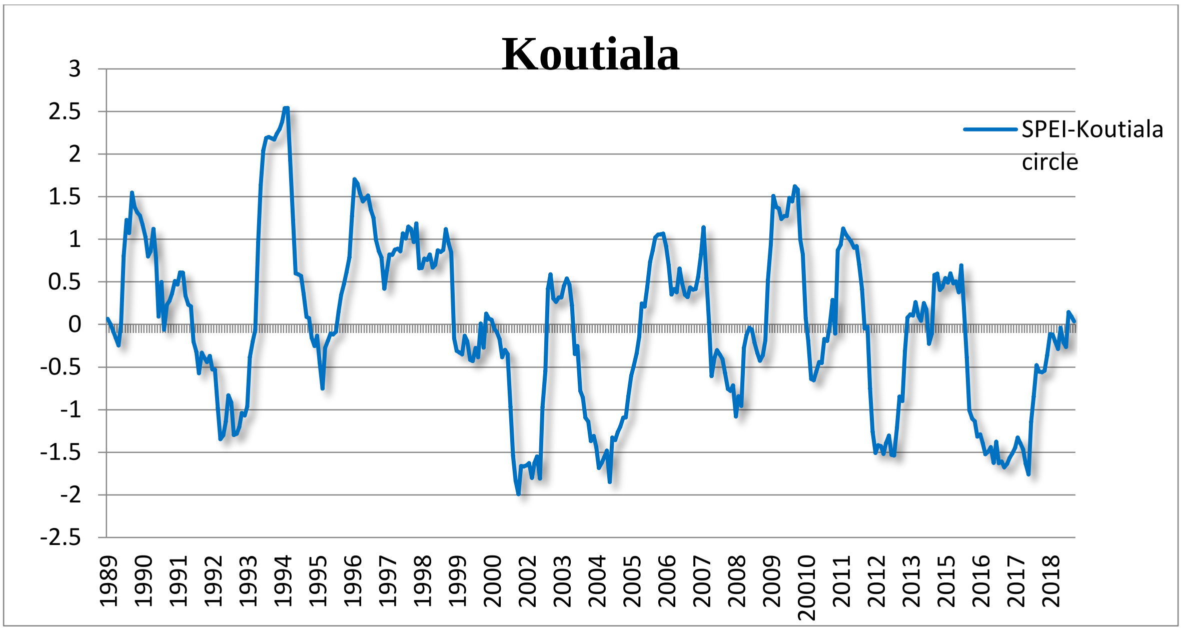
Source: Personal work

Figure 15: Trend of ETP from 1989 to 2019 in Koutiala and San districts

4.3.2. Standardized Precipitation Evapotranspiration Index (SPEI) Analysis

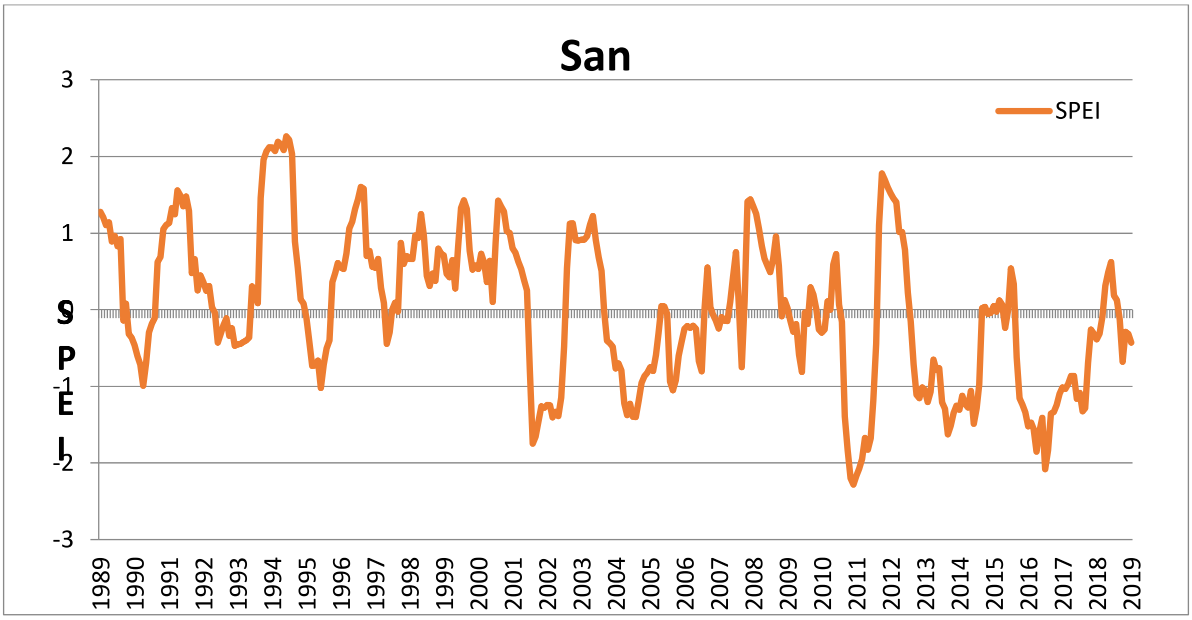
Figure 16 shows a continuous evolution of SPEI at different levels in the Koutiala district. Therefore, from 1989 to 2019, an exceptional wet condition occurred in 1994 (+2.53). Furthermore, extreme wet conditions were observed in 1996 (+1.62) and 2010 (+1.62). While in 2013 (−1.52), 2017 (−1.63), 2002 (−1.80), and 2001 (−1.99), an exceptional dry condition was observed.

Figure 17 revealed that in the San district, there was an exceptional wet condition that occurred in 1994 (+2.26). Moreover, in 2011 (+1.77), an extremely wet condition was observed. In 1996 (+1.60) and 1991 (+1.55), this district's wet condition considerably increased. While in 2001 (−1.74) and 2010 (−2.19), an extreme drought conditions occurred. In 1990 (−0.99), 1995 (−1.01), and 2004 (−1.37), a moderate drought condition was measured.



Source: Personal work.

Figure 16: Standardized Precipitation Evapotranspiration Index (SPEI) in Koutiala district.



Source: Personal work.

Figure 17: Standardized Precipitation Evapotranspiration Index (SPEI) in San district.

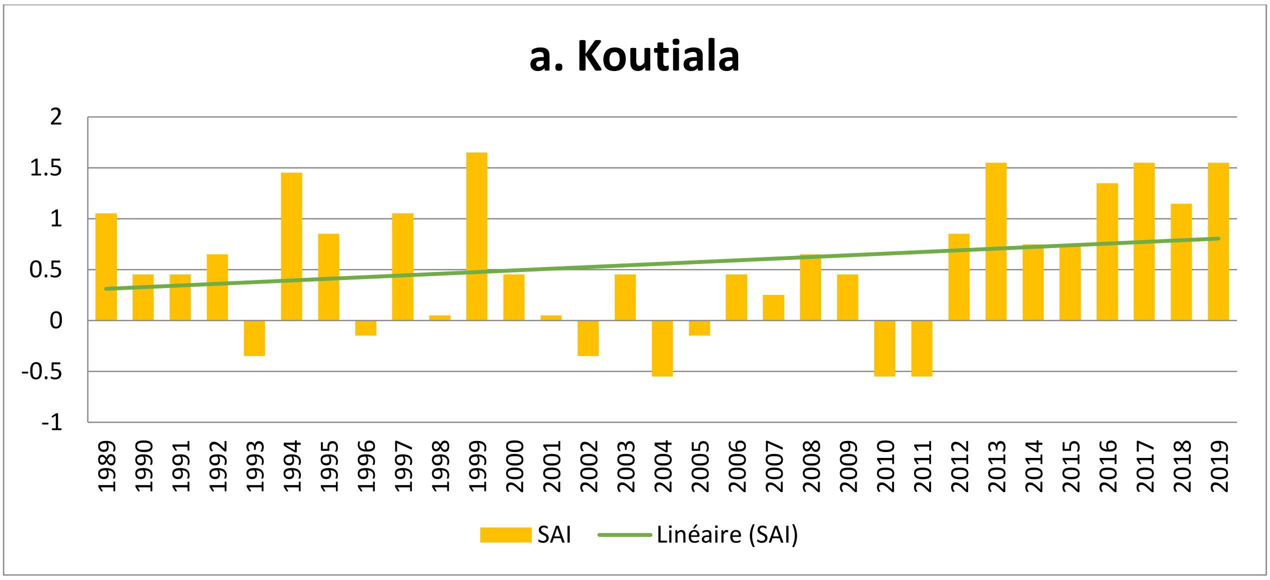
In both districts, we observed an extended frequency and duration of drought during the last two decades (from 2001 to 2019). This situation shows the probability of drought occurrences in those districts. However, this result clearly shows the SPEI pattern changes in both districts. Thus, the drought is a major cause of agricultural, economic, food security, and environmental damage in those areas. Therefore, in both districts, there is a long period with a shortage of precipitation. However, it is difficult to determine the onset, extent, and end of precipitation in those areas. Droughts are recurrent hazards in Mali, as in the wider Sahel region. They have contributed to severe food crises in 1972 - 1974, 1983 - 1985, 2002 - 2003, 2011 - 2012, and 2015 - 2018, partly due to the 2015/2016 El Niño induced drought (World Bank, 2019). Livestock is an essential component of the agricultural economy of Mali, and they are adversely affected during droughts. According to Williams et al. (2011), warming-induced drought stress is evident in recent studies that have analyzed drought impacts on net primary production and tree mortality. Empirical studies have demonstrated that higher temperatures increase drought stress and enhance forest mortality under precipitation shortages (Adams et al., 2009). Warming processes are also probably the triggering factors of the decline in world agricultural production observed in the last years (Lobell et al., 2011). Therefore, to illustrate how warming processes reinforce drought stress and related ecological impacts worldwide, Breshears (2005) enunciated the term global-change-type drought to refer to drought under global warming conditions.

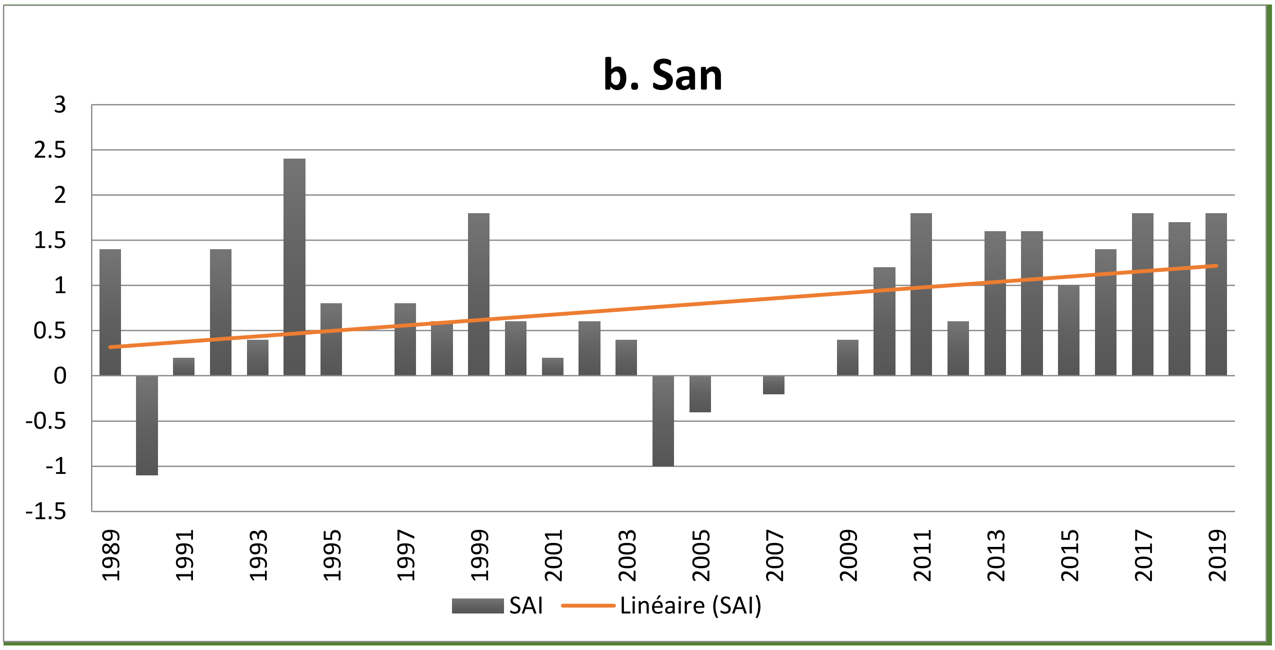
The extended frequency of dry conditions in both districts confirms that there is a probability of drought in this study area in every season. That is due to the changes in rainfall patterns in those areas. At the same time, wet spells occur in those areas sometimes during the season due to climate variability. This result is consistent with the finding from Traore et al. (2015); nearly all farmers claimed that dry spells during the rainy season became longer in the Koutiala district. These perceptions correspond with weather records at N'Tarla, showing that dry days increased significantly between 1965 and 2005 ($p < 0.05$). According to Traore (2014), there is an increase in temperature during the dry season as well as the rainy season. Sultan & Janicot (2003) indicate that the first rains are only sometimes followed by the complete start of the monsoon in Sub-Sahara Africa. Dry spells can occur afterward, for instance, during the early stages of crop growth, so that seeds may not germinate properly or germinated plants may die off. However, if sowing is delayed, the land may be too wet.

Frequent dry spells with high evapotranspiration demand may lead to a decrease in the yield of up to 40% because of insufficient water supply during the grain filling stage (Barron et al., 2003). Consequently, the significant increase in the number of dry days during the rainy season and its impact on yield makes it one of the essential characteristics of climate change in southern Mali. In both districts (Koutiala and San), the farmers identified the late start and early end of the rainy season, the decrease in annual precipitation, the increase in temperature, and the increased occurrence of dry spells as a crucial indicators of climate change (Diarra, 2021). Significant relationships between observations and farmer perceptions of climate change were found in several African countries (Apataet al., 2009; Deresa et al., 2010). For example, according to Ekpoh & Nsa (2011), Some of the consequences of drought in northern Nigeria include ecosystems modification, dislocation of social and economic activities, crop failure, livestock death, declining water table, including shortage of water for domestic, and industrial, accumulation of water deficiency during crop growing, water deficiency of water storage in the river, streams and other reservoirs and increased temperature and sedimentation of surface water as a result of increased evaporation and transportation of loose soil particles.

4.3.3. Standardized Anomaly Index (SAI) of mean temperature in Koutiala and San districts from 1989 to 2019

The temperature anomalies in the Koutiala and San districts during 1989-2019 are described for the mean annual temperatures. Figure 18 (a-b) shows the values of SAI for the mean temperatures at Koutiala and San districts, respectively. Therefore, in the Koutiala district, there was an increase in temperature (figure a) from 1989 (1.05 °C) to 2019 (1.65 °C). At the same time, an increase in temperature (figure b) was observed in the San district from 1989 (1.4 °C) to 2019 (1.8°C). Whereas, from 2001 (0.05 °C) to 2005 (-0.14 °C), there was a decrease in temperature (figure a) in the Koutiala district. In the San district, a decrease in mean temperature (figure b) was observed from 2004 (-1 °C) to 2007 (-0.2°C).





Source: Personal work

Figure 18: Standardized Anomaly Index of annual average temperature in the Koutiala and San districts

We note that the long-term average temperature is generally rising in both districts (Koutiala and San). Temperature indicators reveal a rising trend in the two areas from 1989 to 2019 (figures 9-10). This result is in line with 2013 IPCC findings, which claim that the average annual global temperature increased by 0.85 °C from 1880 to 2012 and that the rate of surface temperature increase since 1880 has been 0.06 °C per decade, with a remarkably rapid increase of 0.16 °C per decade since 1970. (Blunden, 2014). These findings agree with the IPCC's 2007 assessment that the average annual temperature in Mali has risen by 0.7°C since 1960, or an average rate of 0.15°C per decade. However, the growth rate in Mali is brisk from April through June, when it is the hottest and driest. As a result, droughts have become more common, particularly in the nation's Sahara and Sahel regions, where population movement has surged. In Mali, the number of hot days has not changed considerably, but the frequency of hot nights has significantly increased, except from December to February. According to IPCC projections (2007a), the average annual temperatures in Mali are expected to rise by 1.2 to 3.6°C by the 2060s and 1.8 to 5.9°C by the 2090s. This rate of warming is anticipated to be consistent throughout all seasons. According to the exact estimate, more frequent El Nio events may also result in more frequent and severe droughts in Mali, which would have a significant impact on disaster preparedness and response.

4.4. Partial conclusion

Mali's agriculture is still dependent on a complex system whose output is still heavily dependent on climatic risks despite the significant agro-pastoral potential. Instead, productive resources should be utilized to their fullest extent. Even if there is currently irrigable potential, agriculture is susceptible to climate change. However, it is essential to analyze meteorological data (temperature, precipitation, and evapotranspiration) trends for better management of agricultural activities. The results showed that the study area's maximum and minimum temperatures, precipitation, and evapotranspiration are all increasing (from 1989 to 2019). However, evapotranspiration, maximum and minimum temperatures, and this tendency are all significant. However, the trend for precipitation in both districts is insignificant.

The dry spells and rising temperatures are also quite concerning since they suggest higher evapotranspiration, which impacts crop output. Numerous studies of a scientific nature predict that in the future, the temperature will rise and the amount of precipitation will decline. The wet and dry conditions in the research region from 1989 to 2019 have been evaluated using the standardized precipitation evapotranspiration index (SPEI). However, the findings showed that the research area experiences climate variability and change. Furthermore, both areas experience dry spells rather frequently. Thus, drought is one of the natural disasters that has been seen to impact the livelihoods of the inhabitants in the studied region. As a result of the country's overall climate change and fluctuation, floods occasionally occur in such locations. Natural disasters are likely to become more frequent and severe due to the projected rises in Mali's maximum and minimum temperatures and reduced or unpredictable rainfall. The frequency and effects of these disasters could rise without better planning and control.

Local decision-makers may find the data provided by this study to help monitor floods and droughts. Therefore, agricultural planning and governmental policies in this research region should be based on current trends in rainfall, temperature, and evapotranspiration. Therefore, it is advised that this study be expanded to cover the entire country and other drought and flood-prone areas and examine the impact of climatic variation and change on crop productivity.

CHAPTER 5: INFLUENCE OF AGRO-CLIMATIC PARAMETERS ON MAIZE AND SORGHUM PRODUCTION OVER THE PERIOD OF 1989 TO 2019

Abstract

In most developing nations, raising farm-level production has historically been the primary technic for enhancing the food sector. Mali's top four cereal crops grown and consumed are millet, sorghum, maize, and rice. Those plants are regarded as rain-fed plants. However, climate variability and change impact their productivity and growth. The hazards caused by climate change, such as the increase in temperature, rainfall pattern changes, drought, and flooding, impact crop yield. This study looked at how recent climate change has affected the output of maize and sorghum in the Koutaiala and San areas between 1989 and 2019. Climatic parameters and crop production were analyzed using data from crops in the National Direction of Agriculture database from 1989 to 2019 in Koutiala and San districts in Mali.

The results show that the monthly average temperature significantly impacts the yield of sorghum and maize. In the Koutiala district, it is demonstrated that there is a link between maize output and the mean temperature for June, July, August, and September (Table 10). Over the years 1989 to 2019, this link is significant at the p0.01 level in September and the p0.05 level in August. In the San district, between 1990 and 2017, there was a negative link between sorghum output and the average June, July, and September temperatures (-161, -207, and 254).

Monthly average precipitation plays a crucial role in sorghum and maize production. The average rainfall in June (-120) and August (-083) was negatively correlated with the production rate of maize in the Koutiala district. Sorghum production and precipitation in the San district are negatively correlated in June (-198), July (-083), August (-406), and September (-294). On the other hand, the amount of maize grown in the Koutiala district was positively correlated with the region's average rainfall between July (0.319) and September (0.76).

Keywords: Temperature, Precipitation, Maize, Sorghum, Koutiala, San, Mali

5.1. Introduction

There are several ways in which climate parameters, such as temperature, precipitation, and

sunlight can affect crop production. In general, warmer temperatures can benefit crop growth, accelerating plant development and increasing photosynthesis. However, extremely high temperatures can harm crops, causing stress and reducing yields. Similarly, shallow temperatures can damage crops, particularly during critical growth stages. In addition, climate change substantially impacts human health, hydropower, water resources, and food security locally and globally (Magadza, 2000). Therefore, climatic parameters, such as solar radiation, air humidity, precipitation, temperature, and wind speed, often determine the global distribution and productivity of crops and livestock (Ajadi et al., 2011). Hence, climate change and variability are foreseen to, directly and indirectly affect the existing agricultural production systems, potentially threatening local, regional, and global food security (Ajadi et al., 2011). Climate variability and change impacts are region-dependent (Dastane, 2013).

Adequate water availability is essential for crop growth, as plants need water for photosynthesis and to transport nutrients. However, more water is needed to ensure crop growth. Excess water can lead to soil erosion and the development of diseases, while insufficient water can cause plants to become drought-stressed and ultimately die. In areas where rainfall is the limiting factor for production, increasing rainfall amount and distribution with little or no change in rainfall intensity and atmospheric temperature may increase crop yield. In contrast, an excessive increase in rainfall intensity beyond the soil's infiltration rate may lead to runoff losses and erosion (Hawkins, 1981). Furthermore, deficient rainfall can affect agricultural production due to the loss of the top fertile soil (Wenbin et al., 2015). Similarly, according to Tesfamariam et al.(2015), an increase in temporal rainfall amount beyond the soil's capacity to retain water in the active root zone may lead to excessive nitrate leaching beyond the reach of the plant roots. Consequently, excessive nitrate leaching beyond the crop root system leads to nitrogen deficiency (reduced crop production), and the leached nitrate may cause groundwater contamination (Suresh & Indrajeet, 2017). In contrast, a reduction in the amount and distribution of rainfall during the sensitive growth stages of crops has detrimental effects on crop yield (Tesfamariam et al., 2015). Similar to rain, a change in atmospheric temperature impacts crop yield. For instance, an increase in temperature from 30 to $\geq$ 35 °C during the reproductive stage in most photoperiod-sensitive crops will adversely affect the pollen viability, fertilization, and consequently grain formation, hence leading to a decrease in productivity (Hatfield et al., 2008 in Hatfield et al., 2011).

The impacts of climate change on crop production can no longer be ignored as they have already become critical areas of scientific concern (Yinhong et al., 2009). Moreover, such impacts are becoming increasingly significant in arid and semi-arid areas, particularly in Africa, which comprises 66% of the total land area and harbors approximately 200 million people (Molua et al., 2010). For example, from year to year in Mali, climatic parameters vary substantially due to the country's location in the Intertropical Conversion Zone (ITCZ), which causes the annual West African monsoon (Intelligence, 2016). As a result, Mali regularly experiences severe floods and drought, sometimes occurring within the same year (FAO, 2015; IPCC, 2014).

Mali's observed climate impact is attributed to the rise in temperature because there is no discernible expected change in rainfall there. This view is consistent with Schlenker and Lobell's (2010) finding that a change in temperature by one standard deviation has a smaller marginal impact than a change in precipitation by one standard deviation. Although the consequences of a change in rainfall are predicted to be smaller than those brought on by a change in temperature, they can still have an impact. Salack and Sarr (2006) found that a future change in rainfall significantly impacted the adverse consequences of a temperature increase (+1.5$^{℃}$) for a millet variety in Niger, with crop yield losses of 59% and 26% for decreasing and rising rainfall, respectively. According to Roudier et al. (2011), variations in rainfall, which are currently unclear in climate projections, could either exacerbate or lessen the impact of temperature changes, depending on whether they increase or decrease. Between 1960 and 2015, average annual temperatures increased by 1.2°C. Mali is expected to become even hotter, with average annual temperatures projected to rise by 0.9°C– 1.5°C by 2050 relative to the historical baseline of 1986–2005. Increases in temperatures are expected to be greatest in the southwest (Kayes, Sikasso, and Segou) and central (Mopti and Gao) regions (FAO, 2015). According to FAO (2015), Mali experiences a multi-decadal rainfall cycle; on average, the country experienced rainfall reductions from 1950 through 1983 (an average of -4.4 mm/year) and increases from 1983 through 2015 (an average of +2.6 mm/year). On average, rainfall has decreased since the 1960s.

Climate change impacts on crop yield studies for Africa illustrate a large dispersion of yield changes ranging from -50% to +90% under various climate change scenarios (Roudier et al., 2011). Generally, the reported changes in crop yield are primarily negative (Challinor et al., 2007). In West Africa, the predicted impact is more significant in Sudano-Sahelian countries, with an average yield loss of 18% compared with an average yield loss of 13% in southern Guinean countries (Sultan et al., 2013). According to Butt et al. (2005a), this difference is likely due to the drier and warmer climate in the more northerly countries. In Mali, future crop yields will vary between –17% and +6% at the national level. Thus, the negative impacts of climate change on crop productivity increase in severity as warming intensifies, highlighting the importance of coping with global warming.

Maize and sorghum have been produced and consumed much larger quantities in Mali. Given the potential of maize and sorghum, developing and better organizing their subsectors can increase revenues for farmers and create profitable opportunities for other actors in the subsector (traders, marketers, processors, industries, and consumers). Most (almost 80 %) of Malian farms are cultivated under dryland conditions (BCRA, 2006). The most economically essential drylands cereals are millet and sorghum. The Key food security crops, maize, sorghum, and millet, are primarily consumed by farmers who produce them in various forms, including a stiff porridge called "tô," gruel, couscous, floury and fermented beverages, and fried dough.

The crops are considered rain-fed crops. Therefore, their growth and productivity are influenced by climate variability and change. With the issues of climate change, those crops are affected by climate-related hazards such as drought and flooding. In particular, climate variability significantly impacts maize and sorghum production emanating from seasonal rainfall and temperature, which are responsible for the shifting of the seasons. Most studies on climate change's impact on crop production in Mali were based on models (such as crop processing, statistical, and econometric models). These models must determine the dominant weather variable(s) contributing to the change observed in maize and sorghum production under different climate conditions. This study aims to determine the dominant climatic parameter influencing maize production in Koutiala and San districts. Acknowledging that most of the climate variables are beyond the farmers' control, this study seeks to contribute towards achieving proper climate adaptation practices by farmers to minimize the adverse effects of climate change on maize and sorghum production.

5.2. Material and Method

5.2.1. Overview of the study area

The Koutiala (Sikasso area) and San Mali districts are this study's locations (Segou region). This region (Southern Mali) has 40% of the Malian population, accounts for 50% of the nation's arable land, and takes up 13.5% (or around 160.825 km2) of the country's total land area (ME, 2017). (figure 12).

The Koutiala District, located in the western portion of the Sikasso region, lies at the center of the former cotton basin. It is bordered on the north by the San District, on the northwest and southwest by the Bla and Diola Districts, on the south by the Sikasso District and the Republic of Burkina Faso, and on the east by the Yorosso District. The district is 12°23′N 5°28′W in latitude and longitude, respectively. With a population of 797927 people, the Koutiala district has an area of 8,740 km2.

The climate in San District, which is in the semi-arid region, is Sudan-Sahelian. With a surface area of 7,262 km2, it is home to 335,000 people. Its coordinates are 13° 10' 44.2" N and 5° 0' 58.2" W.

There are two seasons per year in the tropical sub-Saharan climate: a dry season from November to April and a wet season from May to October.

Between 750 and 1000 mm of rainfall is recorded at Koutiala each year. June through October is considered the rainy season, with August being the wettest month. The dry season consists of a hot phase extending from March to May and a cold period from November to February. During the wet season, the maximum temperature on average is 34 °C (RGPH 2009, Mali-Meteo 2019, Institut National de la Statistiques, République du Mali, 2009).

Tropical dry weather prevails in San District, with typical maximum temperatures of 44°C and minimum temperatures of 13°C. The warmest months in this district are March and May, with temperatures being warm on average all year round. The coldest months are from November to February. The peak months of the rainy season are June, July, August, and September. According to RGPH 2009, Mali-Meteo (2019), Institut National de la Statistiques, Republic of Mali (2009), the yearly average rainfall is about 500 mm.

Cereals make up the majority of the diet of Mali (maize, sorghum, millet, and rice). As a result, grains comprise most crops farmed in Mali's southern regions (Koutiala and San districts).

For this study, two crops, maize for the Koutiala district and sorghum for the San district, were chosen. However, the currency (like cotton) was excluded from this study. These crops (maize and sorghum) were chosen based on their capacity for resistance to climatic variability and change and their food and economic value to the households in the research area.

The Koutiala and San districts' geography comprises plateaus, sloping lands, and lowlands.

The primary soil types are the clay, sandy loam, and sandy soils. Sandy soils have little organic matter and little ability for infiltration. Sandy soils are primarily favorable for millet cultivation because they can endure low fertility and water scarcity despite their poor fertility and poor water retention capacity. Due to the superior quality of these soils, loam, sandy soils, and clay are used to cultivate cotton, sorghum, and maize (Coulibaly et al., 2011).

One of the largest cereal production zones in the nation is Koutiala and San. Those regions' three main staple foods are millet, sorghum, and maize. The zones also contain rice fields. These crops are both for sale and domestic consumption. Rain-fed conditions are used to produce both cereal and cotton.

- **Climate data**

Climatic data taken into account are precipitation, temperature (minimum and maximum), and evapotranspiration from 1989 to 2019. These data were taken monthly. They are from two meteorological stations, namely Koutiala and San.

The National Direction of Meteo provided the climatological data used in Mali (NDM).

- **Long-term crop data**

The National Direction of Agriculture (DNA) provided the agronomic data from 1989 to 2019 (30 years).

Tableau 9:: Agricultural data for Koutiala and San districts

Years	Koutiala	San
	Maize production T/ha	Sorghum production T/ha
1989	7165	6432
1990	7147	6597
1992	8873	6473
1993	8368	5080
1994	9213	6000
1995	9086	6657
1996	12223	5450
1997	16272	8470
1998	16075	7000
1999	18787	9000
2000	7632	7000
2001	11913	5600

2002	8891	6400
2003	17544	8200
2004	11491	15600
2005	18994	18400
2006	20052	17000
2007	17159	19340
2008	15984	5200
2009	15245	7400
2010	14389	5700
2011	12987	9000
2012	21379	8200
2013	19828	2000
2014	25326	9450
2015	19932	6700
2016	23173	8200
2017	25235	7100
2018	26352	8365
2019	24654	9250

Source: National Direction of Agriculture (DNA)

5.2.2.Method of data analysis

- **Correlating crop production and agro-climatic parameters**

Pearson correlation analysis was done between climate parameters (average monthly temperature, precipitation,and precipitation) and maize and sorghum production in the Koutiala and San districts, respectively.

5.3. Results and Discussion

Temperature is an essential factor influencing maize and sorghum production. Table 10 shows a positive correlation between maize production and the average temperature in June, July, August, and September in the Koutiala district. This correlation is significant at the $p<0.01$ level in September and $p<0.05$ in August from 1989 to 2019. On the other hand, the same table reveals that there is a negative correlation between sorghum production and the average temperature in June (-161), July (-207), and September (-254) over the period from 1989 to 2017 in the San district. In contrast, the correlation is positive (0.004) between sorghum production and the average temperature in August (table 10).

Precipitation plays a crucial role in sorghum and maize production. The average rainfall in June (-120) and August was negatively correlated with the production rate of maize in the Koutiala district (-083). Sorghum production and precipitation in the San district are negatively associated in June (-198), July (-083), August (-406), and September (-294). The amount of maize grown in the Koutiala district was positively correlated with the region's average rainfall between July (0.319) and September (0.76) (table 10).

Tableau 10:Pearson correlation between maize and sorghum production rate with the monthly average temperature and precipitation for 1989 to 2019 in Koutiala and San districts

Districts	Maize/Sorghum Temperature				Maize/Sorghum Precipitation			
	June	July	August	September	June	July	August	September
Koutiala	.316	.449*	.475**	.369*	-.120	.319	-.083	.076
San	-.161	-.207	.004	-.254	-.198	-.083	-.406*	-.294

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level

Rising greenhouse gas concentrations, such as CO_2, generally impact climate change. Therefore, the production of maize and sorghum is impacted by this rise in CO_2 in both direct and indirect ways. Because more CO_2 may improve photosynthetic and water use efficiency. The direct effect, also known as the CO_2 fertilization effect, may increase maize growth by roughly 14% with a doubling of ambient CO_2 (Dhakhwa et al., 1997, Poorter, 1993). The indirect effect, known as the weather effect, affects maize yield through solar radiation, precipitation, and temperature. For example, due to the shorter phenological periods, maize yields typically decline with increased temperature (Brown & Rosenberg, 1997).

The monthly average rainfall in June (-120) and August (-083) was negatively correlated with the production rate of maize in the Koutiala district. The variability of rainfall patterns in this area can explain this Situation. In addition, June is considered the start period of the rainy season in this zone. In general, we observe a high frequency of dry spells in this period. This Situation negatively affects the crops' growth and development. The negative correlation between rainfall and maize production in August in the Koutiala district can be understood by the peak rain during this month. However, the crops received too much rain beyond the normal. This Situation causes the extended frequency of wet spells and affects crop yield. At the same time, a positive correlation was observed between maize production and precipitation in July (.319) and

September (.076). During these months, the rainfall has a good distribution in this zone. Therefore, the plant received the optimal amount of water to ensure its growth and development.

We observe a negative correlation between sorghum production and precipitation during the growing season (June: -.198; July: -.083; August: -.406*; September: -.294) in the San district. The high variability of rainfall patterns in this area can explain this Situation. A significant negative correlation was observed between sorghum production and rainfall in August (-.406*). This Situation can be understood by the peak rain registered this month. Therefore, the plant can be affected by the effects of wet spells.

Our findings align with earlier research that found relatively strong relationships between precipitation in August and the production of maize and sorghum, which accounted for 64% of the observed variability in the average maize and sorghum production (Žalud et al., 2017). Rainfall can, in theory, have a good or negative impact. An increase in precipitation may result in a reduction in the current water stress. However, increased precipitation may increase nitrogen leaching, resulting in a negative correlation (Brown & Rosenberg, 1997). Furthermore, the climate variability and change in the study area can be linked to global warming effects. This Situation may cause water scarcity, making it more expensive and difficult to sustain crops. According to Gro Intelligence (2016), climatic parameters vary substantially due to Mali's location in the Intertropical Conversion Zone (ITCZ), which causes the annual West African monsoon. As a result, Mali regularly experiences severe floods and drought, sometimes occurring within the same year (FAO, 2015; IPCC, 2014b). The rainfall deficits have as a corollary the variability of the characteristics of the agricultural season, including the start and end dates and the occurrence of dry sequences (Bouba, 2014).

The monthly average temperature positively correlates with maize production during the growing periods of maize (June: .316; July: .449*; August: .475**; September: .369*) in the Koutiala district. At the same time, this positive correlation between temperature and sorghum production has only observed in August (.004) in the San district. This positive correlation between maize production and temperature can be explained by the geographical location of this area, where its average temperature is around 34°C. This level of temperature may be suitable for maize growth and development. The positive correlation between sorghum production and temperature is observed only in August. This Situation can be due to a rainfall peak this month. Thus, this Situation can affect the temperature rinsing. The average temperature has a negative correlation between sorghum production in June (-.161), July (-.207), and September (-.254) in the San district. This Situation can be explained by the high average temperature (36°C) observed in this area. This level of temperature may not be suitable for sorghum growth and development. It can increase the water stress for the plant. Our results are consistent with this finding that an increase in temperature from 30 to ≥ 35 °C during the reproductive stage in most photoperiod-sensitive crops will adversely affect the pollen viability, fertilization, and consequently grain formation, hence leading to a decrease in productivity (Hatfield et al., 2008 in Hatfield et al., 2011). A significant factor in poorer crop yield is the shorter flow time due to water shortage, which shortens the window of opportunity for biomass and assimilates accumulation for use in grain filling. Crops need water when it is hot outside. According to Waha et al. (2013), an increase in temperature reduces biomass by speeding up crop respiration and restricting photosynthesis. An increase in maturation rates is mainly caused by moisture stress (Singh & By, 1998.). According to Conen et al. (2006) and Knorr et al. (2005), a temperature increase may speed up soil carbon decomposition. However, some studies have shown that this decomposition may be insensitive due to biological adaptation (Luo et al., 2001) or the influence of other factors like nutrient availability (Kirschbaum, 2000). Additionally, temperature variations may shorten the growing season, boost potential evapotranspiration, and bring plants closer to toxic thresholds (Easterling et al., 2007; Solomon et al., 2007). Furthermore, our findings have demonstrated that the productivity of both sorghum and maize was adversely influenced by global warming, increasing the danger of low crop yield.

5.4.Conclusion partial

Numerous earlier research on the effect of global warming on crop production in Mali has used techniques including crop processing, statistical models, and econometric models. So far, the research on identifying a suite of agro-climatic factors that affect the production of sorghum and maize has primarily needed to be improved. This study contributes to this vital topic by investigating the dominant climatic variables influencing maize and sorghum production in Koutiala and San districts. It is evident from this study that in the context of global warming, an increase in temperature leads to a higher rate of evapotranspiration. On the other hand, a decrease in precipitation leads to prolonged drought conditions, negatively impacting maize and sorghum production. Finally, further studies are recommended to investigate the influence of other non-climatic factors, such as farmers' decision-making process, who may have yet to be informed due to access to climate change information.

However, it is essential to note that aside from the agroclimatic parameters, other factors that influence maize and sorghum production in Mali include land available for production, farm management decisions, government decision, topography, and soil type.

The information provided through this study can help support local-level decision-makers in monitoring floods and drought. Therefore, this study area's agricultural planning and government policies should be based on recent rainfall, temperature, and evapotranspiration trends. In addition, this study should be extended to other drought and flood-prone areas all over the country. The impact of climate variability and change on crop yield should also be investigated.

CHAPTER 6: ASSESSMENT AND DETERMINATION OF FACTORS AFFECTING HOUSEHOLDS' FOOD SECURITY STATUS

An article has been published from this chapter.

DOI: 10.12691/jfs-10-3-2

Abstract

Climate variability and change pose a severe threat to global food security around the world. This climate change leads to extreme events such as droughts and flooding. This situation has become more pronounced in Mali. However, most Malian households are vulnerable to coping with the effects of those events. This climatic disturbance affects all sectors in Mali, such as agriculture and livestock. Thus, those sectors are the primary sources of food production for many households in the country. Several factors contribute to food insecurity in many areas of Mali, including drought, flooding, low agricultural yield, terrorist attacks, and power instability. Among the affected areas in Mali, there are Koutiala and San districts. The main goal of this study is to assess the level of households' food security status in the Koutiala and San districts. The specific objectives are: (i) to assess the households' food security index in the study area; (ii) to determine the main factors that drive the households' to food insecurity; and (iii) to identify the households coping strategies to face food insecurity. Therefore, a field survey was conducted with a sampling of 455 households' from eight (8) villages (M'Pessoba, TarassoII, Sougoumba, N'Tosso, Tene, Sourountouna, Koro, and Dieli) within Koutiala and San districts. Therefore, CARI (Consolidated Approach to Reporting Food Security Indicators) was used to measure the household's food security status. SPSS software was used for data processing. The findings show that most households have an acceptable (99.8%) score in the food consumption score and only a poor (0.2%) score. In the households' food expenditure share, 100% spend less than 50% on food. The results show that (97.8%) of households are marginally food secured, only (2%) of them are food secured, and (0.2%) are moderately food insecure.

The cows' ownership and work for cash were the main factors of households' food security which had a positive influence on households' food security.

The main constraints faced by households' food security were the increase in agricultural inputs price (91%), the difficulty of food availability (89.5%), an increase in food price (88.1%), rainfall variability (84.2%), income reduction (79.1%), debt payback (52.5%), effects of natural disasters (drought, flood) (50.8%), and human insecurity (46.4%). The food insecurity coping strategies based on food consumption were to borrow food (36%), reduce the amount of food consumed by adults to feed children (31%), reduce the number of meals per day (28%), use less popular and expensive foods (23%), limited the size of portions during meals (22%), and going a whole day without eating (9%). Moreover, the food insecurity coping strategies are based on households' livelihoods, such as emergency (64.4%), crisis (33.6%), stress (1.8%), and none strategy (0.2%).

Keywords: households', food security, climate change, CARI, Mali, Koutiala, and San

6.1. Introduction

The IPCC report published in 2013 stated that the world might reach "a threshold of global warming beyond which current agricultural practices (IPCC, 2013a). That can no longer support large human civilizations" by the middle of the twenty-first century (Field et al., 2014).

The West African Sahel became a globally recognized political entity following the famine in the early 1970s (Mann, 2015). The aggravated greenhouse gas-induced warming of the tropical oceans (Giannini & Saravanan, 2003; Held et al., 2005; Du & Xie, 2008). Continued drought is not a warranted outcome of global anthropogenic interference with the climate system (Giannini et al.,2013), as the most recent years of repeated regional flooding suggest (Tschakert et al., 2010). However, the magnitude and severity of the Sahelian drought of the 1970s and 1980s and its impact on agricultural development strategies and food security provide an opportunity to examine the relationship between climate and livelihoods and to build an evidence base of adaptation options available to at-risk populations in a context of increasing exposure and sensitivity to a highly variable climate.

The Malian economy is still largely dependent on agriculture, measured by the contribution of agriculture to the national gross domestic product (36.9% in 2006; WB, 2015). A majority of the population engages in agriculture (66% in 2006; World Bank, 2015) and derives the most significant fraction of income from agricultural production. This activity is about the median value of 70% of income among the rural households surveyed here. Mali and its neighbors are among a minority of sub-Saharan African countries that have met or surpassed the target of 10% of government expenditures going to agricultural development set by the Africa Union's Comprehensive Africa Agriculture Development Program (World Bank, 2015). However, among the stable crops cultivated, apart from irrigated rice, agricultural production in Mali is rain-fed. Therefore, it is susceptible to climate (Butt et al., 2005; Government of Mali, 2007). As a result, Malian households have been exposed to shocks and stress in the last decades, such as irregular rainfall, droughts, flash floods, strong storm and winds, pests, and poor harvests.

On the other hand, cereal production has increased at the same rate as the population over the last decade, with imports contributing to only 5% of the national cereal budget, and dependence on food aid has decreased from 4 kg of cereal per person in 1990 to 0.5 kg/person in 1999 (FCPNET, 2011). These aspects all contributed to the resilience shown by Malian households to the 2008 global food price crisis (Moseley, 2011; Smale et al., 2011). These aspects all contributed to the resilience shown by Malian households to the 2008 global food price crisis (Moseley, 2011; Smale et al., 2011).

These shocks, coupled with the effects of the ongoing terrorist attacks till 2012, have increased households' vulnerability to poverty and food insecurity for the whole country. This study aims to determine the households' food security situation in Koutiala and San districts to make vital decisions about coping to face those effects.

The results of this study will be helpful for the Government, World Food Program (WFP), Food and Agricultural Organisation (FAO), scientists, students, farmers, and other humanitarian and development partners.

6.2.Material and method

6.2.1. Overview of the study area

The Koutiala (Sikasso area) and San Mali districts are this study's locations (Segou region). This region (Southern Mali) has 40% of the Malian population, accounts for 50% of the nation's arable land, and takes up 13.5% (or around 160.825 km2) of the country's total land area (ME, 2017). (figure 12).

The Koutiala District, located in the western portion of the Sikasso region, lies at the center of the former cotton basin. It is bordered on the north by the San District, on the northwest and southwest by the Bla and Diola Districts, on the south by the Sikasso District and the Republic of Burkina Faso, and on the east by the Yorosso District. The district is 12°23′N 5°28′W in latitude and longitude, respectively. With a population of 797927 people, the Koutiala district has an area of 8,740 km2.

The climate in San District, which is in the semi-arid region, is Sudan-Sahelian. With a surface area of 7,262 km2, it is home to 335,000 people. Its coordinates are 13° 10' 44.2" N and 5° 0' 58.2" W.

There are two seasons per year in the tropical sub-Saharan climate: a dry season from November to April and a wet season from May to October.

Between 750 and 1000 mm of rainfall is recorded at Koutiala each year. June through October is considered the rainy season, with August being the wettest month. The dry season consists of a hot phase extending from March to May and a cold period from November to February. During the wet season, the maximum temperature on average is 34 °C (RGPH 2009, Mali-Meteo 2019, Institut National de la Statistiques, République du Mali, 2009).

Tropical dry weather prevails in San District, with typical maximum temperatures of 44°C and minimum temperatures of 13°C. The warmest months in this district are March and May, with temperatures being warm on average all year round. The coldest months are from November to February. The peak months of the rainy season are June, July, August, and September. According to RGPH 2009, Mali-Meteo (2019), Institut National de la Statistiques, Republic of Mali (2009), the yearly average rainfall is about 500 mm.

Cereals make up the majority of the diet of Mali (maize, sorghum, millet, and rice). As a result, grains comprise most crops farmed in Mali's southern regions (Koutiala and San districts).
For this study, two crops, maize for the Koutiala district and sorghum for the San district, were chosen. However, the currency (like cotton) was excluded from this study. These crops (maize and sorghum) were chosen based on their capacity for resistance to climatic variability and change and their food and economic value to the households in the research area.
The Koutiala and San districts' geography comprises plateaus, sloping lands, and lowlands. The primary soil types are the clay, sandy loam, and sandy soils. Sandy soils have little organic matter and little ability for infiltration. Sandy soils are primarily favorable for millet cultivation because they can endure low fertility and water scarcity despite their poor fertility and poor water retention capacity. Due to the superior quality of these soils, loam, sandy soils, and clay are used to cultivate cotton, sorghum, and maize (Coulibaly et al., 2011).
For this study, a household questionnaire was developed. This questionnaire was used to collect data on the socio-economic characteristics of households, household food consumption, and constraints affecting households. For data collection, the tools for processing and analyzing the data were computer software, notably: CommCare for data collection, SPSS for statistical data analysis, and Microsoft Office (Excel, word) for graphics, tables, and the preparation of the dissertation document.

6.2.2. Analysis method of data

- **Households' food security index**

We use the CARI approach, newly published by WFP in February 2014, to understand food security in all its dimensions. This approach makes it possible for this approach allows food security indicators to be combined systematically and transparently in order to establish an explicit classification of households.

Based on CARI, each surveyed household was classified according to a composite food security index: food secure, borderline food secure, moderately food insecure, or severely food insecure. The classification algorithm considers the household's current food consumption and its potential to sustain its consumption in the future. As shown in table 3, the food insecurity index results from the combination of the diversity and Frequency of household food consumption in the last seven days before the survey, the share of expenditure that the households allocate to food, and coping strategies to face food insecurity in the last 30 days before the survey.

- **Households' food consumption score (FCS)**

The Food Consumption Score (FCS) is a composite score based on the diversity, Frequency, and relative nutritional importance of different food groups. That assesses the Frequency of consumption of foods and food groups in the seven days before the data collection and the food sources. It is obtained through the following formula:

$$\mathbf{FCS} = \mathrm{aicerealexicereale} + \mathrm{aivegetablexivegetable} + \mathrm{aifruitxifruit} + \mathrm{aianimalxianimal} + \mathrm{aisugarxisugar} + \mathrm{aimilkximilk} + \mathrm{aioilxioil} \quad \mathbf{(11)}$$

Where **ai =** Weight of each food group

xi = Frequency of food consumption (number of days that feed i was consumed in the last 7 days).

The score is compared with predefined thresholds to classify households into food consumption profiles, as shown in Table 11.

Tableau 11: Predefined thresholds for food consumption profiles

Thresholds	Profile	Thresholds taking into account a daily consumption of sugar and oil (7 days per week)
0 – 21	Food consumption Poor	0 - 28
21,5 - 35	Food consumption at the limit	28,5 – 42
>35,5	Acceptable food consumption	> 42,5

Source: (WFP, 2009)

The profile of each household is then converted into the four levels CARI scale, as shown in the Table 13.

- **Households' food expenditure share**

When the survey cannot generate data on the poverty line, economic vulnerability is measured using the food expenditure share indicators. This indicator (share of food expenditure) is constructed by dividing total food expenditure by total household expenditure.

$$\textbf{food expenditure share} = \frac{\text{food\_monthly}}{\text{food\_monthly} + \text{nonfood1\_monthly} + \text{nonfood2\_monthly}} \qquad \textbf{(12)}$$

- **Household coping strategy categories**

The ability of households to respond to shocks depends on their level of natural, material, economic, human, social, and political assets. It also depends on their production, income, and consumption level and how they can diversify their sources of income and consumption to mitigate the effects of disasters that may occur at any. This indicator is calculated from the coping strategies used by households in the 30 days prior to the survey. WFP recommends that a total of 10 strategies (4 stress, three crisis, and three emergency strategies) be considered according to the local context, using the reference list of livelihood-based coping strategies. The classification of households into the different strategy categories is based on the principle of the most severe coping strategy used by the household. In the CARI scale, households that have not used any selected strategies are considered food secure. In contrast, households using the stress, crisis, or emergency strategies are classified as borderline food secure, moderate food insecure, and severe food insecure, respectively.

The strategies selected for this study are presented in Table 12.

Tableau 12: List of strategies selected for the livelihoods-based coping strategies

Strategies	**Categories**
Reducing expenditure on non-essential items (drinks, ceremonies, clothes, meat, sugar, more expensive staple foods)	Stress
Sales of animals (at levels that maintain the sustainability of the herd)	Stress
Borrowing food or money	Stress
Sale of non-productive goods (jewelry, clothes.)	Stress
Consumption or sale of seeds	Crisis
Reduced expenditure on production inputs (fertilizer, veterinary care.)	Crisis
Reduced spending on health, education	Crisis
Excessive sale of livestock (breeding stock)	Urgency

Sale or mortgage of productive assets (land, tools.)	Urgency
Recourse to illegal activities (prostitution, theft)	Urgency

Source: (WFP, 2014)

- **Food security index**

The households' food security index is obtained from an algorithm based on simple averaging calculations using the scores achieved for each indicator on the four-point scale. Households classified as food secure, borderline food secure, moderately food insecure, and severely food insecure take scores of 1, 2, 3, and 4, respectively. Specifically, the ranking of each household is based on a simple average of the Current Status score (consumption score) and the Survival Capacity score. The latter score is a simple average of the food expenditure share score and the asset depletion score (Table 13). The average obtained is rounded (between 1 and 4), and this figure represents the household's food security index.

The CARI reporting table, the final product of the CARI method, summarises the distribution of the different food security indicators and indices. Table 13 presents a typical CARI reporting table constructed from standard WFP indicators.

Tableau 13: CARI reporting template with standard WFP indicators

Domain		Indicator	Food secure (1)	Marginally food secure (2)	Moderately food insecure (3)	Severely food insecure (4)
Current status	Food consumption	Food consumption score	***Acceptable***		***Borderline***	***Poor***
Coping Capacity	Economic vulnerability	Food expenditure share (of total expenses)	***Part<50%***	***50-65%***	***65-75%***	***Part >75%***
	Asset depletion	Livelihood coping strategy categories	***None***	***Stress***	***Crisis***	***Emergency***
Food insecurity Index						

Source: WFP (2014)

- **Factors affecting the households' food security**

This part was approached through an inventory of the different factors that affect household food security and the links between them through correlation and binary regression analyses to identify the determinants of household food insecurity.

Therefore, we preceded the Chi2 test at the 5% level to check the significance of the links between the different factors (variables) and household food security.

P-value ≤ α: variables show a statistically significant association (reject H0) α: significance level of 0.05.

Suppose the p-value is less than or equal to the significance level. In that case, the null hypothesis can be rejected and conclude that there is a statistically significant association between the variables.

P-value > α: impossible to conclude that the variables are associated (do not reject H0)

If the p-value is above the significance level, the null hypothesis cannot be rejected because it does not have enough evidence to conclude that the variables are associated.

Multi-variate analysis was done using a binary logistic regression model with household food security as the variable to be explained. The structure of the model representing the food security index is quantitative.

$$\boldsymbol{p = \Phi(\beta X i) = \frac{Exp(\beta Xi)}{1+\mathrm{Exp}(\beta \mathrm{Xi})}} \quad \textbf{(13)}$$

With P as the dependent variable taking the value 1 if the households are food secure and 0 otherwise, βi is the vector of parameters to be estimated, Xi is the vector of household explanatory variables Φ (βXi), the probability that the household is food secure and Exp is exponential.

The evaluation of the model was based on likelihood tests (double log-likelihood and goodness-of-fit). The parameters of regressions are tested according to Wald statistics, which is distributed through chi2 with a degree of freedom.

- **Households' coping strategies to face food insecurity**

The methodology adopted for this section is structured as follows: in the face of shocks and food shortages, households do not remain passive but try to shocks and food shortages, households do not remain passive but try to adapt by developing strategies. The analysis of household coping strategies are based on the CARI approach, which distinguishes four categories of strategies (no strategy, stress strategies, crisis strategies, and emergency strategies).

- **Food coping strategies**

In the event of shocks, households resort to coping strategies to build resilience. The Frequency of these strategies is assessed over seven days of consumption**.**

Households resort to coping strategies such as resorting to less preferred foods, borrowing food, reducing the meals per day, limiting the number of borrowing food, reducing the number of meals per day, limiting the size of portions during meals, reducing the amount of food consumed in favor of children, sending household members away to eat, and going a whole day without eating.

- **Non-food coping strategies**

Concerning the use of non-food strategies, households were classified into 4 groups according to the CARI approach:

- **Those who did not use non-food** strategies during the reference period;
- **Stress strategies:** stress strategies lead to a reduction in the ability to cope with future shocks (Selling household assets/property such as radio and furniture; borrowing money; spending savings; having sold more non-productive animals than non-productive animals than usual);
- **Crisis strategies:** Crisis strategies directly affect future productivity. These include selling productive assets or means of transport (e.g., bicycles, wheelbarrows); reducing essential non-food expenditures such as education, health care, and education wheelbarrow); reducing essential non-food expenditures such as education and health; withdrawing children from school;
- **Emergency strategies:** emergency strategies affect the future capacity to produce and are more difficult to and are more difficult to reverse than the previous ones. These include resorting to begging; selling the last productive females; selling the house, selling the house, the plot of land, or the field.

6.3.Sampling procedure and size

The multisampling procedure was employed. In the first step, the study area (Koutiala and San districts) was selected purposively due to the presence of the leading agricultural farmers and their high vulnerability levels to climate variability and change. Eight (8) villages (M'Pessoba, Sougoumba, N'Tosso, Tarasso II, Sourountouna, Tene, Koro, and Dieli) were in the second step randomly selected from both districts in the southern part of Mali. Therefore, we have also considered the different districts' agroecological, socio-economic, and environmental attributes. This work was facilitated by supporting the area's agricultural, forestry, livestock, and NGO services. The third and last step was conducting the household surveys using the random sampling approach. Therefore, we have used semi-structured questionnaires for the survey, with a total of 455 household heads as sampling.

The number of households (n) to be surveyed was determined by the Slovin 1960 (Slovin, 1960) formula above (1)

Tableau 14: Households sampling selection procedure

Number	Selected agro-climatic zones	Selected region	Selected circle	Number of households/circle	Sampling household	Selected villages	Selected sampling household head
Sahara zone	**Sudan-Sahelian zone**	Segou	San	23, 399	179	Tene	59
Sahel zone						Sourountouna	33
Sudan zone						Koro	55
						Dieli	32
Sudan-Guinean zone	**Sudan-Guinean zone**	Sikasso	Koutiala	27, 737	276	N’Tosso	38
						Sougoumba	80
						Tarasco II	59
						M’Pessoba	99
4	2	2	2	51, 136	455	8	**455**

6.4.Results and Discussion

The analysis of food insecurity in this report is based on the conceptual framework for food insecurity and vulnerability analysis adopted by World Food Program (WFP) in 2014.

The final product of the approach developed, called CARI, is a food security reporting table that allows for the presentation of results and the combination of food security indicators (food consumption score, food expenditure share, and livelihood coping strategy categories). Central to this approach is an explicit classification of households into four groups (food secure, borderline food secure, moderately food insecure, and severely food insecure). This classification estimates food insecurity within the target population calculated at the national or sub-national level or for other strata (e.g., livelihood activities, gender of household head).

1. Households' food security index

- **Households' food consumption score (FCS)**

Table 5 shows that the proportion of households with an acceptable food consumption score is 99.8%. Averages of 0.2% of households have a severe food consumption score in both districts.

- **Households' food expenditure share**

Regarding the households' food expenditure (table 5), 100% of households were less than 50% of total expenditure shares in both districts.

- **Livelihood coping strategy categories**

The results (table 15) reveal that more than half (64.4%) of households have an emergency coping strategy category, (33.6%) crisis, (1.8%) stress, and only (0.2%) none strategy in both districts.

Table 15 presents the population's prevalence rates of different types of food insecurity. Based on this approach, the analysis of the survey data shows that (97.8%) of households are marginally food secure, (2%) of households are food secure, and (0.2%) of households are moderately food insecure in Koutiala and San districts, respectively.

This pattern of results shows that a significant proportion of the population is food insecure and could quickly fall into severe food insecurity in the event of shock affecting their livelihoods. Moreover, the difficulties inherent crisis that the country is going through has weakened the livelihoods of households and considerably reduced their capacity to cope with shocks.

Tableau 15: Consolidated Approach for Reporting Indicators (CARI) of Food Security in the study area

Domain		Indicator	Food secure (1)	Marginally food secure (2)	Moderately food insecure (3)	Severely food insecure (4)
Current status	Food consumption	Food consumption score	*Acceptable* 99.8 %		*Borderline* 0	*Poor* 0.2%
Coping Capacity	Economic vulnerability	Food expenditure share (of total expenses)	*Part<50% 100 %*	*50-65% 0*	*65-75% 0*	*Part >75% 0*
	Asset depletion	Livelihood coping strategy categories	*None 0.2 %*	*Stress 1.8 %*	*Crisis 33.6 %*	*Emergency 64.4 %*
Food insecurity Index			*2 %*	*97.8%*	*0.2%*	*0*

Source: Personal work

2. Determinants of households' food security

- **Determinants**

The results show (table 16) that the explanatory variables (age of households', education level, family size, marital status, religion, bird ownership, sheep ownership, farm size, use of improved varieties of crops, fishing activity, hand worker, exodus, and financial help) have no significant correlation with food security index. These variables do not have effects on households' food security. However, households that own cows and work for cash have a positive influence on households' food security (table 16).

Tableau 16: Main factors that correlate with households' food security in the study area

Variables in the Equation	Coefficients	Error Standard	Statistics of Wald	Probability.
Age	.000	.036	.000	1.000
Level of education	.404	.370	1.196	.274
Family size	-.093	.101	.845	.358
Marital status	.114	.694	.027	.870
religion	.539	.745	.524	.469
Bird ownership	.025	.019	1.819	.177
Sheep ownership	-.064	.045	1.996	.158
Cow ownership	.080	.031	6.715	.010**
Farm size	17.389	6.1343	.000	.998
Improve varieties	-.824	.804	1.048	.306
Fishing	-1.403	1.844	.579	.447
Hand worker	-15.747	1.1904	.000	.999
Exodus	1.290	1.181	1.194	.275
Financial help	-1.416	.921	2.363	.124
Work for cash	1.233	.693	3.164	.075*

Source: Personal work

**** Significant at the 5% level**

*** significant at the 10% level**

- **Constraints faced by households food security**

Table 17 shows that the increase in agricultural inputs price, the difficulty with food availability, increase in food price, rainfall variability, income reduction, debt payback, effects of natural disasters (drought, flood), and human insecurity were observed as the main constraints to food production for the respondent with the percentages of (91%), (89.5%), (88.1%), (84.2%), (79.1%), (52.5%), (50.8%), and (46.4%) respectively(table 7). These constraints have been known to be a severe challenge to food production in recent years due to climate change.

Tableau 17: Constraints faced by households in Koutiala and San districts

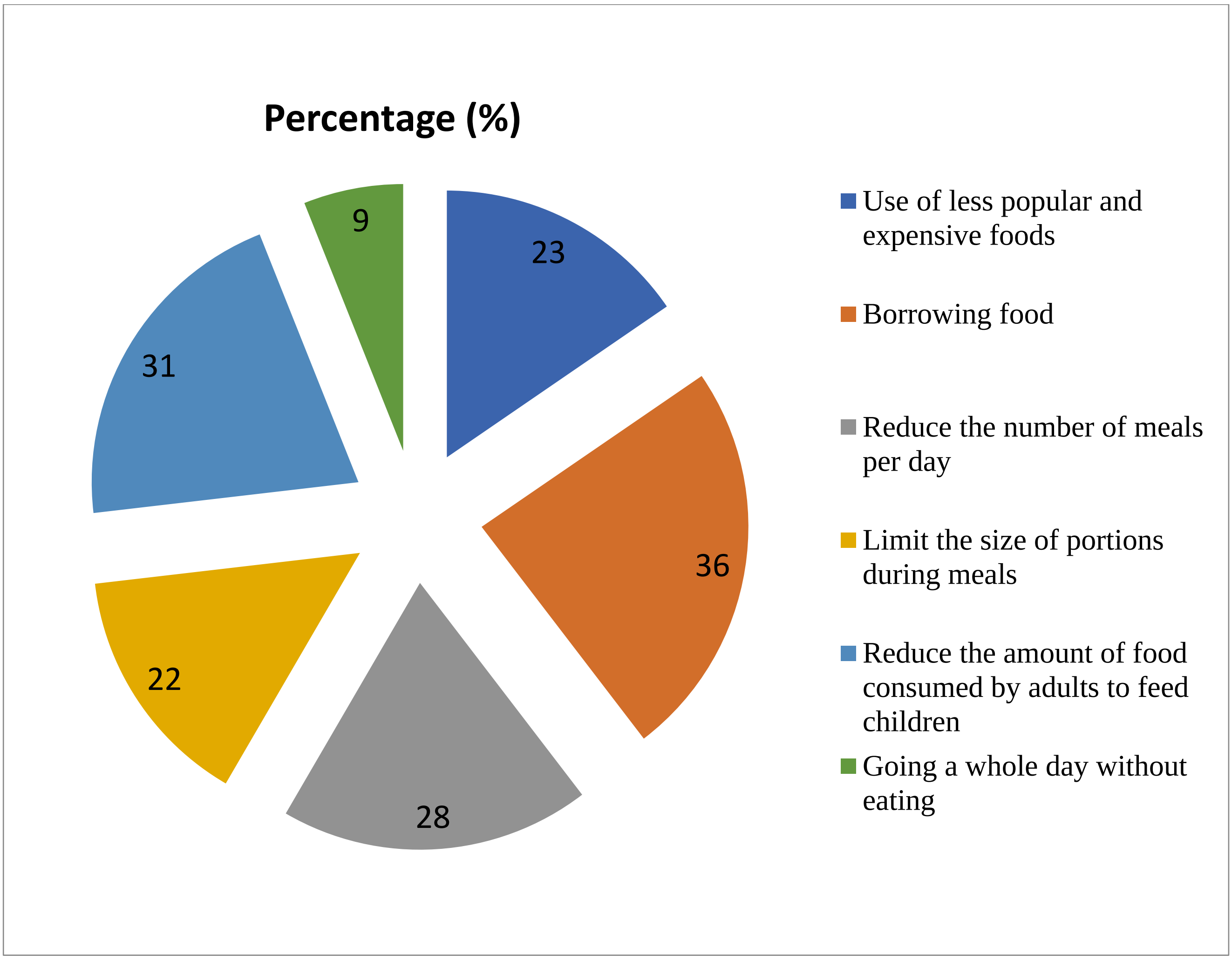
Variables	Big shock	Low shock	Not a shock
	%	%	%
The difficulty of food availability	9.5	89.5	1.1
Income reduction	79.1	20.4	.4
Increase in food price	88.1	11.6	.2
Increase in agricultural inputs price	91.0	8.8	.2
Human insecurity on the ground	46.4	10.1	43.5
Debt payback	42.9	52.5	4.6
unemployment	36.9	57.1	5.9
Effects of natural disasters (drought, flood)	50.8	45.9	3.3
Rainfall variability	84.2	14.3	1.5

Source: Personal work

3. Households' coping strategies to face food insecurity

- **Food insecurity coping strategies through food consumption**

In the seven days prior to the survey, households have used one or more of the following coping strategies, including borrowing food (36%), (31%) reducing the amount of food consumed by adults to feed children, (28%) reducing the number of meals per day, (23%) use of less popular and expensive foods, (22%) limited the size of portions during meals, and (9%) going a whole day without eating (figure 19).



Source: Personal work

Figure 19: Household food coping strategies

- **Food insecurity coping strategies through livelihoods**

Shocks, whether natural or otherwise, can devastate household food security. However, households can use various coping strategies to overcome hardship. The index of livelihoods-based adaptation in an emergency is high (64.4%) than in a crisis (33.6%), stress (1.8%), and no strategy (0.2%).

- **Stress strategies:** stress strategies lead to a reduction in the ability to cope with future shocks (Selling household assets/property such as radio, furniture); borrowing money; spending savings; having sold more animals non-productive than usual);
- **Crisis strategies:** crisis strategies directly affect future productivity. It is a question of selling productive goods or means of transport (bicycle, wheelbarrow); reducing essential non-food expenditures such as education and health; withdrawing children from school;

- **Emergency strategies:** emergency strategies affect the future capacity to produce and are more difficult to reverse than emergency strategies. These include resorting to begging; selling the last productive females; selling the house, the plot of land, or the field.

Tableau 18: Implementing livelihoods-based adaptation strategies

Non-food coping strategies	Percentage (%)
Reduces non-food expenditures on health (including medicines) and education (**Crisis**)	58
Sold productive goods or means of transport (sewing machine, wheelbarrow, bicycle, bus) (**Crisis**)	47
Sold more (non-productive) animals than usual (**Stress**)	22
Send members of the household to eat elsewhere (**Stress**)	8
Spent savings (**Stress**)	29
Borrowed money (**Stress**)	53
Sold the house or land (**Emergency**)	10
Removed children from school (**Crisis**)	5
Sold the last female animals (**Emergency**)	20
Mended/begging (**Emergency**)	4

Source: Personal work

The results (table 15) show that the households have an excellent food consumption score of (99.8%) acceptable. The sound level of food consumption results from a reasonably good level of consumption of the different product groups that make up food consumption. Indeed, the results indicate a good level of food consumption of the different product groups by all households. In this group, staple foods are consumed daily by this group of households, which also have a reasonable consumption of animal protein. Only (0.2%) have a poor food score. These results corroborate Komi's (2017) funding, showing that (84%) of households have an acceptable food consumption score in the Prefecture of Tône in Togo. Moreover, these results are contrary to those of previous studies, notably those by WFP (2015) in Burundi on the food security monitoring system (60% acceptable, 30% borderline, 10% poor) and WFP (2018) in Senegal on the rapid analysis of food security in the north (67.1% acceptable, 19% borderline, 13.9% poor). Furthermore, the results show that nine out of ten households (97.8%) are marginally food secure which means that the households can meet their essential food and non-food needs without resorting to atypical coping strategies. This situation could be explained by the good agricultural season of the year behind (2019-2020). Then, their family stocks were sufficient against only (2%) of those who are food secure and (0.2%) of those who are borderline food insecure, which shows that households have just adequate food consumption without resorting to irreversible coping strategies. These results contradict previous studies, notably by Komi (2017) in Togo. He observed that the food situation and coping strategies for facing food insecurity in the Prefecture of Tône, Togo are the follows: (27.8%) of households were food secure, (42.6%) were borderline food insecure, (26.0%) were moderately food insecure, and (3.6%) severely food insecure. According to one of the precious studies by WFP (2015) on the analysis of urban vulnerability in the cities of Antananarivo, Toamasina, and Toliara in Madagascar showed that (37.73%) of food secure, (43.88%) of borderline food secure (18.39%) of moderately food insecure and 0% were severely food insecure.

Regarding households' food expenditure share, the results reveal that (100%) of households spent less than 50% on food. That means that most of the food consumed by households was from their production. This study's findings agree with the one from Samake (2020) in Mali, which showed that (99%) of households spent less than 50% on food. However, our results are contrary to the findings of Komi (2017). He showed that (38.5%) of households spent on food, (and 27,8%) of them spent more than (75%) of their income on food in the Prefecture of Tône in Togo.

The coping food index counts the Frequency and severity of behaviors that people engage in when they do not have enough food or behaviors that people engage in when they do not have enough food or money to buy food (Maxwell & Caldwell, 2008).

In order to improve their level of food consumption, (64.4%) of households resorted to food coping strategies. For instance, (36%) of them borrowed money. Borrowing money and credit can minimize the ability of households to cope with food and non-food deficits during shocks. (31%) reduced the amount of food consumed by adults to feed children, (28%) reduced the number of meals per day. This situation shows the shortage of stocks and also the difficulty of access to food by the household. To a report by CSAO-OCDE/CILSS (2009) in Mali, households eat an average of three meals a day, except in the northern regions where 40-50% of households eat two meals or less (nomadic lifestyle). (23%) use less popular and cheaper foods. (22%) limited the size of portions during meals, and only (9%) of them went a whole day without eating. This strategy indicates the economic vulnerability of households to cope with the shocks. These results contradict the WFP (2014) Vulnerability and Food Security and Nutrition Analysis (VFSNA) in Senegal. They showed that (43%) of households consumed less preferred foods, (29%) borrowed food or sought help from a friend or relative (30%) of households had limited the size of portions during meals, (22%) had reduced the number of meals per day, and (17%) have reduced adult consumption in favor of children. According to WFP (2017) (59.5%) of households consumed less preferred foods, (60.1%) borrowed food or asked for help from a friend or relative, (47.9%) of households limited the size of portions during meals,(38%) reduced the number of meals per day, and (62.6%) reduced consumption by adults in favor of children.

The results of the analysis showed that about households' socio-economic characteristics, only those who have cow ownership and work for cash have a statistically significant association with households' food security status. Although, there are differences observed with age, marital status of the head of household, household size, level of education, religion, farm size, bird ownership, and sheep ownership. These factors could not predict a household's food situation since their association with household food situation is only a chance effect.

In the study area, various constraints impact the households' food security status,

including economic, social, and environmental factors.

Economic constraints include poverty and low income, which make it difficult for households to afford enough food to meet their needs. In addition, high food prices and lack of access to credit are also barriers to household food security.

Social constraints include more education, limiting households' ability to make informed food purchases, and nutrition decisions. In addition, poor infrastructure, such as a lack of roads, transportation, or storage facilities, makes it difficult for households to access food.

Environmental constraints include natural disasters, such as droughts, and floods, which disrupt their food production and distribution systems. Climate change is also a growing concern for household food security, as it can lead to more frequent and severe natural disasters and changes in the availability and quality of food.

Political instability or lack of effective governance makes it difficult for households to access food.

Suppose food consumption-based strategies do not solve the food problems. In that case, households are forced to use livelihood-based strategies, such as emergency strategies adopted (64.4%), that affect the future capacity to produce and are more difficult to reverse. The households involve begging; selling the last productive females; selling the house, the plot of land, or the field house. Some use crisis strategies (33.6%), directly affecting future productivity. It is a matter of selling productive goods or means of transport (bicycle, wheelbarrow), reducing essential non-food expenditures such as education and health, and withdrawing children from school. Only (1.8%) of them use stress strategies that can cope with future shocks (selling household assets/goods, radio, furniture); borrowing money; spending savings; having sold more non-productive animals than usual). According to WFP (2018), its rapid survey of household food security in the city of Ndjamena came up with contrary results, with (50%) of no strategy in the 3rd Arrondissement,(22.9%) stress in the 10th Arrondissement, (13.3%) crisis in the 6th Arrondissement, and (14.3%) emergency in the 10th district. This situation conducts the households' to sell their precious livelihoods to cope with the lack of food. These results do not corroborate those of the harmonized framework analysis of October 2016, which placed the prefecture of Tône in the pressure phase (DSID, 2016), showing that (27.8%) of households were under stress, (26%) were in crisis and (3.6%) in an emergency.

6.5. Partial Conclusion

This study is intended to be a snapshot of the food situation and coping strategies for food insecurity in the Koutiala and San districts. Although, it has limitations. It has achieved its overall objective of contributing to a better understanding of the food situation and strategies of the local population of contributing to a better understanding of the food situation and household coping strategies for coping with food insecurity and resolving the problem of the lack of surveys or studies on food security in a recognized vulnerable area as Koutiala and San districts.

The study reveals that the majority (97.8%) of households are marginally food secure, and only (2%) of households are food secure. This result shows that those households cannot afford some non-essential food expenditures without resorting to inappropriate coping strategies.

The main factors of food security are the increase in agricultural inputs price, the difficulty for food availability, an increase of food price, income reduction, debt payback, rainfall variability, increase in temperature, effects of natural disasters (drought, flood), and human insecurity. The recurrence of food insecurity in the Koutiala and San districts results from several structural and cyclical factors. The state of poverty experienced by households, the low level of access to essential social services and protection, the poor modernization of agriculture and livestock systems, the demographic explosion, and the effects of climate change keep households in a permanently vulnerable situation. In addition, global warming significantly impacts households' food security in the study area, defined as the availability, access, utilization, and stability of food supplies. The following are some possible effects of global warming on food security:

- Changes in temperature and precipitation patterns can lead to crop failures and
- reduced yields, leading to food shortages in the study areas.
- Extreme weather events, such as droughts, floods, and heatwaves, are expected
- to become more common as the planet warms, negatively impact crop
- production, and contribute to food insecurity.
- Warmer temperatures can also lead to the spread of pests and diseases that can
- damage crops, further reducing yields and contributing to food insecurity
- Changes in temperature and precipitation patterns can also affect the growth and
- availability of wild foods, such as nuts, berries, and seafood, can be an
- essential food source for some communities.

However, it is clear that global warming presents significant risks to the availability, access, utilization, and stability of food supplies, and addressing this issue will require concerted efforts to adapt to and mitigate the impacts of climate change.

It is crucial to adopt a

multifaceted approach that addresses economic, social, and environmental factors to address these constraints for improving the households' food security status. This situation can

include policies and programs to improve incomes, education, and infrastructure, as well as

efforts to reduce food waste, increase food production, and adapt to climate change.

Understanding these constraints can help policymakers and stakeholders develop

targeted interventions to improve household food security.

CHAPTER 7: DETERMINATION OF THE PERCEIVED AND OBSERVED CLIMATE RISKS BY FARMERS AND THEIR IMPACTS ON LAND COVER

Abstract

Climate change has a significant impact on agriculture and farmers in Mali. As a result, the purpose of this study was to evaluate how Koutiala and San farmers perceived climate fluctuation and change. Farmers' opinions of climate variability and change, the impact of weather factors on crop output, and the importance of land cover for coping with climatic anomalies were nevertheless identified using open conversation and survey methodologies.

Extreme weather events (drought, flooding, and storms), changes in temperature and precipitation patterns, changes in the timing of seasons, an increase in pests and diseases, and degradation of the soil and vegetation are just a few of the perceived and observed climate risks that farmers may encounter.

We examined the land use and land cover changes in the research area from 1989 to 2019 concerning the LU/LCC (land use/land cover changes). As a result, in the Koutiala and San districts, we observed a decline in the amount of wooded savannah. We did see, however, that the shrub savannah grew in the Koutiala district, but it shrank in the San district. Between 1989 and 2019, the number of farms grew gradually in both districts. In the Koutiala district, there was an increase in bare soil, whereas in the San district, there was a decrease in it. Between 1989 and 2019, an increase in building levels was noted in both districts.

Keywords: Perception, Climate risks, farmers, Land Use/Land Cover, Koutiala, San, Mali

7.1. Introduction

Climate change causes extreme weather and unpredictable events which impact and increasingly affect crop growth, availability of soil water, soil erosion, droughts and dry spells, floods, and sea level rise with prevalent pest infestations and diseases (Adejuwon, 2004, 2004; Traore,2014). Many studies have shown that climate change will highly affect the African continent and will be one of the most challenging issues for future economic development, particularly in sub-Saharan Africa (Roudier et al., 2011). Because most of the population relies on natural resources, they are often practically affected by climate variability and change, especially the poorest (Morton, 2007). Particularly, smallholder farmers in sub-Saharan Africa are strongly impacted (Sivakumar et al., 2005).

Local societies already have in-depth knowledge of climate change and variability as parts of their local ecological knowledge is obtained and transferred through generations (Traore, 2014). Several scholars on climate change perception deal with precipitation and temperature in terms of the annual amount, length, and rainfall distribution (Deressa et al., 2009). Meteorological data and satellite images are used to confirm local farmers" assessment of climate change. However, some authors emphasized the need to consider the climate in the broader context, such as health or policies (Mubaya et al., 2012; Traore, 2014). According to Parry *et al.* (2007), climate change and agriculture are interrelated processes, both of which take place globally. It is predicted that global warming will significantly affect agriculture (McCarthy et al., 2001; Funk et al., 2010). Therefore, there is a need to know how farmers perceive climate, climate changes, and the environment (Kemausuor et al., 2011). Perceptions of farmers of climate variability and how these perceptions determine the choice of coping or adaptation strategies (Vedwan, 2006) have been investigated by previous studies in the West African Sahel (Akponikpè et al., 2010; Kyekyeku, 2012; Traore et al., 2014; Bouba, 2014). Climate change confirmed by most of the farmers, up to 98 % of respondents, was dependent on the geographical area and prevailing climate across five countries of West Africa (Akponikpè*et al.,* 2010). In Mali, farmers understand climate change and variability primarily based on weather-crop interactions and extreme events associated with climatic fluctuations. Therefore, many mentioned more erratic rainfall patterns, decreased rainfall amounts, increased temperatures, winds, and radiation. In Mali, small-scale rural farmers depend on the agricultural sector, which depends on rainfall for crop production. According to (Butt et al., 2005), national agricultural production earnings in Mali will likely decrease from US$ 417 million in 1996 to US$ 256 million by 2030 because of climate change. Sahelian rural populations' livelihoods strongly rely on natural resources, which are already facing many challenges due to their harsh environment (desertification, recurrent droughts, and sometimes floods) and poor socio-economic conditions (Mortimore & Adams, 2001).

In many developing countries, one of the principal driving forces of global environmental change is Land use and land cover (LULC) change (Botlhe et al., 2019). According to Wondie et al.(2011), the LULC change is impacting many sectors of the economy. Changes in the LULC component could be observed spatially and temporally. This condition is mainly due to the intensity of land use and the extent of the area (Diancoumba et al., 2022). LULC changes from a few months to several years on the temporal scale, characterized by short-term and long-term changes, respectively (Lambin & Ehrlich, 1997). The long-term change is of primary concern and the most significant for global environmental change (Diancoumba et al., 2022). Many authors have investigated the long-term LULC change to evaluate the sustainability of natural resources (Scanlon et al., 2005; Lin et al., 2018; Ashaolu et al., 2019). Most of the previous studies' results clearly show that the causes of LULC change are many being of natural and anthropogenic effects (Tamba & Li, 2011; Pervez & Henebry, 2015; Yin et al., 2017; Diallo et al., 2019). Some of the human effects are the causes of increases in population growth rate, rural-urban migration, agricultural expansion, deforestation, and climate change (Toure et al., 2017). Urbanization is the most irreversible form of land use. In developing countries, especially in Africa, urban land expansion has been observed since the 1980s, which is more related to urban population growth than the growth in the Gross Domestic Product (GDP) (Ashaolu et al., 2019). In West African countries, large extents of natural land cover classes have been replaced by human-influenced landscapes mainly dominated by agriculture (CILSS, 2016). Most rural populations migrate for better survival opportunities (Babel & Pandey, 2011). Consequently, to feed the growing population, the agricultural land area has been increased to meet the demand for food (Jamtsho & Gyamtsho, 2003). However, all these phenomena could lead to LU/LC changes. In Mali, due to the increase in population growth rate leading to an essential pressure on agricultural sectors to satisfy the food demand, the portions of savannah and forest land have decreased by 23% from 1975 to 2013 (CILSS, 2016).

Therefore, this study aimed to assess Koutiala and San farmers’ perceptions of climate variability and change and their impact on land cover. However, using open DiscussionDiscussion and survey techniques, farmers' perceptions of climate variability and change, the impact of weather aspects on crop production, and land cover for dealing with climate anomalies were identified.

7.2. Material and Methods

7.2.1. Overview of the study area

This study was conducted in Mali's Koutiala (Sikasso area) and San(Segou region) districts. Southern Mali contains 50% of the country's arable land and 40% of the nation's population and amounts to 13.5% (or around 160.825 km2) of the nation's total land area (ME, 2017) (See Figure 12).

The former cotton basin is located in the Koutiala District, in the western part of the Sikasso region. Its northern boundary is formed by the San District, its western and southern boundaries by the Bla and Diola Districts, its southern boundary by the Republic of Burkina Faso, and its eastern boundary by the Yorosso District. The district's latitude and longitude are 12°23′N and 5°28′W, respectively. The Koutiala district has 797927 inhabitants and a land area of 8 740 km^2.

Sudan-Sahelian weather prevails in San District, which is located in a semi-arid area. It has a surface area of 7,262 km2 and 335,000 inhabitants. Therefore, its coordinates are 13° 10' 44.2" N and 5° 0' 58.2" W.

There are two seasons per year in the tropical sub-Saharan climate: a dry season from November to April and a wet season from May to October.

Between 750 and 1000 mm of rainfall is recorded at Koutiala each year. June through October is considered the rainy season, with August being the wettest month. The dry season consists of a hot phase extending from March to May and a cold period from November to February. During the wet season, the maximum temperature on average is 34 $^{℃}$ (RGPH 2009, Mali-Meteo 2019, Institut National de la Statistiques, République du Mali, 2009).

Tropical dry weather prevails in San District, with typical maximum temperatures of 44$^{℃}$ and minimum temperatures of 13$^{℃.}$ The warmest periods in this district are March and May, with temperatures being warm on average all year round. The coldest months are from November to February. The peak months of the rainy season are June, July, August, and September. According to RGPH 2009, Mali-Meteo (2019), Institut National de la Statistiques, Republic of Mali (2009), the yearly average rainfall is about 500 mm.

Plateaus, sloping lands, and lowlands make up the topography of the Koutiala and San districts. Clay, sandy loam, and sandy soils are the three main soil types. Sandy soils are low in organic matter and have poor infiltration capabilities. Since millet can tolerate low fertility and water scarcity despite sandy soils' poor fertility and weak water retention capacity, they are primarily advantageous for millet agriculture. Cotton, sorghum, and maize are grown on loam, sandy soils, and clay because of the excellent quality of these soils (Coulibaly et al., 2011).

Koutiala and San districts are the most extensive cereal-producing regions in the country. Therefore, millet, sorghum, and maize are the three main staple foods farmed there. Rice crops can also be found in the zones. These crops are used for domestic consumption as well as for sale. Cotton and cereal are both produced in rain-fed environments.

Using open discussions and survey techniques were conducted at Koutiala and San. Four hundred fifty-five (455) farmers' households' heads were randomly selected in the villages and were interviewed using a structured questionnaire.

A group of discussions (FGD) with farmers was organized to discuss climate (change), the impact of weather events on farmers' livelihoods', and existing adaptation measures to face climate variability and change. From each village (8 villages), farmers (9 persons per village) were invited to join the meeting. Those persons were selected according to their leadership, to an existing farm typology based on land holdings, ownership of farming assets (plow, seeder, and cultivator), and many cattle.

The number of households head (n) to be surveyed was determined by the Slovin (1960) formula above (1).

The structured questionnaire collected information on farming systems, farmers' perceptions of climate change, and concerns about climate change. The questionnaire was designed in English and French, but interviews were conducted in the local language, *Bambara.*

Interviews were conducted from January to March 2021. The questionnaire was pretested for its suitability before interviews. The pretesting includes behavior coding of interviewer/respondent interactions, interviewer debriefings, respondent debriefings, and the analysis of item non-response rates and response distributions.

7.2.2.Method of data Analyses

Data from the questionnaire were coded and also analyzed using the Statistical Package for Social Sciences (SPSS version 21) and Excel software. Descriptive statistical tools such as means, standard deviations, frequencies, and percentages were used to summarize and categorize the information gathered.

The Supervised Classification method, using Envi 4.5 Software coupled with ArcGIS 10.3, was applied to subset Landsat images from 1989 to 2019 in the Koutiala and San districts.

7.3.Results and DiscussionDiscussion

7.3.1. Characteristic socio-economic of households'

In the study area, all of the household's heads (100%) are men. The distribution of respondents in terms of age is shown in the following table. It reveals that more than half of the respondents (51.4%) were between the age group of 41 and 60 years, (32.7%) of them were between the age group of 18 to 40 years while (15.4%) and (0.4%) of the respondents were between the age categories of 61 to 80 years and 81 to 83 years respectively (table 19).

The majority of the respondents are married, according to Table 19 (91.7 %). When separated are (2.2%), divorced (2.4%), and widowed (3.5%).

Regarding household family size, 15.4%, 29.6%, and 45.6% of households have an average of six to eleven occupants each (2 -5 persons). Mali's average household size is between 10 and 20 people.

38.2% of respondents still need to get a high school diploma. However, only 7% have a secondary education, and 19.5% only have a primary education.

According to Table 19, all respondents (100%) engage in farming as their primary activity, and 94.7% engage in livestock-related activities. In addition, while slowly taking place in the study region, activities include fishing, trading, and manual labor.

Tableau 19: Socio-economic characteristics of households heads

Variables	Frequency	Percentage
	Age	
18 to 40	149	32.7
41 to 60	234	51.4
61 to 80	70	15.4
81 to 83	2	.4
	Sex	

Male	455	100.0
Female	0	0
Household size		
2 to 5	70	15.4
6 to 11	208	45.6
12 to 17	135	29.6
18 to 22	31	6.8
>22	11	2.4
Marital status		
Married	418	91.7
Divorce	11	2.4
Separated	10	2.2
Widower	16	3.5
Level of education		
Primary school	137	19.5
Secondary school	49	7.0
Not educate	269	38.2
Main activities		
Farming	455	100
Livestock	432	94.7
Fishing	10	2.2
Trading	6	1.3
Artisan	7	1.5

Source: Field survey (2021)

Less than 60-year-olds and male-headed households make up the majority of the population in the Koutiala and San districts. The majority of people living here are in male-headed households. Female-headed homes were nonexistent in the research area because, under their culture, men support women for survival. In Mali, the majority of households are run by men (94.5%), according to the National Food and Nutrition Security Survey (ENSAN, 2020), which shows stability for this indicator compared to the previous surveys (93.7%) and 93.4% in September

2019 and February 2018. In this area, a home typically held six to eleven people. The findings of Toure et al. (2017) are at odds with this outcome.

Agriculture is the primary economic activity in the studied area. The staple foods of the diet include millet, sorghum, maize, and rice, the principal crops. Fruit farming and market gardening are additional sources of income. The local economy is based on the population's activities in livestock rearing, fishing, and handicrafts. Fish farming, poultry farming, and beekeeping are all developing more slowly. (WB, 2015) claims that agriculture is the backbone of the Malian economy, contributing 50% of GDP and employing a sizable share of the labor force. The main subsistence crops farmed in Mali are rainfed millet, maize, and sorghum, while cotton and rice, the latter of which is irrigated, are the main commercial crops (World Bank, 2015). Cereals make up the majority of the Malian diet.

Cattle are an essential part of the Mali farming system. Farmers frequently invest their earnings in cattle in the study region, which also serves as a social asset. According to Sanogo (2010), 80% of farmers utilize animal traction for soil preparation, weeding, and sowing and own at least one pair of oxen, a cultivator, and a seeder (Sanogo, 2010). To cultivate their farm manually, however, households without access to oxen or equipment hire or borrow these items from neighbors or other families. Therefore, the use of fallow has decreased in the research area since the introduction of animal traction in crop production. Today, most of the land ideal for agriculture has been developed, especially that adjacent to the villages.

7.3.2. Perception of change in different climate indicators by the heads of households

The information provided by the 455 heads of households surveyed was combined to produce this result (table 20). The rainy season, the dry season, the signals of these seasons, and the types of crop varieties planted 30 years ago and now are how the producers interpret climatic variability and change.

Thirty years ago, the rainy season began in May for most (93.6%) of the farmers surveyed (table 9). However, only 4.4% of respondents claimed that the rainy season began in June. 93.9 percent of farmers believe that the current year's rainy season begins in July. 86.6 percent of respondents noted that the rainy season finishes in October when asked about the end of the rainy season 30 years ago. In September, just 10.1% of them said that. 86.6 percent of respondents claim that the rainy season ends early, in September, while 10. percent claim that it does so in October. Additionally, practically all farmers (91.7%) claim that the rainy seasons have grown shorter and more variable between years. They also claim (89.7%) that it rains less and less during these seasons. Finally, 6.1% of farmers claimed that the rainy season is becoming wetter. According to respondents, dry episodes appear more frequently and are getting longer on average (56.1%).

Most responders (91.2%) concur that the temperature is rising, whereas (98%) contend that the amount of rainfall is falling.

(89%) of respondents believe that waterways start to dry out sooner than they do. A meager (6.6%) of farmers claimed that nothing had changed.

Most responders (98%) agree that 30 years ago, the vegetation in their area was in good condition. Furthermore, 99.5% of them think that the current state of the vegetation is deplorable.

Erosion is a phenomenon that is happening more frequently. However, the majority of responders (87.7%) said erosion does indeed exist in their region. Greater over half (56.8%) of respondents indicated that the land has less degradation, while (37.9%) of respondents indicated that the land is more degraded. Most respondents (93.4%) concur that the research area's soils are less fertile. Among them, only 6.6% claimed that the soils were fertile before. Most respondents (80%) concur that the forest's current livelihoods are being harmed in terms of its resources.

Tableau 20: Climate change indicators observed by farmers

Climate change indicators	**Percentage**
The beginning month of the rain season 30 years ago	
Avril	1.5
May	93.6
June	4.4
July	0.2
The beginning month of the rainy season currently	
May	2.2
June	93.9
July	3.7
End of the rainy season 30 years ago	

August	1.1
September	10.1
October	86.6
November	2.0
End of the rainy season currently	
August	1.1
September	86.6
October	10.1
November	2.0
Beginning of the rainy season becomes more in more:	
Early	7.0
Late	91.7
Normal	1.1
The ending of the rainy season becomes more in more	
Early	89.7
Late	3.9
Normal	6.1
The average number of dry spells during the rainy season	
Increase	56.1
Decrease	43.6
Temperature	
Increase	91.2
Decrease	8.8
Rainfall	
Increase	2
Decrease	98
Flooding	
increase	94.7
Decrease	5.3
Drying up of waterways	

Earlier	89.0
Later	4.4
No change	6.6
State of vegetation 30 years ago	
Good	98
Degraded	1
No change	1
The current state of vegetation	
Good	.4
Degraded	98.5
No change	.9
Water erosion	
Increase	87.7
Decrease	12.3
Land degradation	
More degraded	39.7
Less degraded	56.8
Not change	3.3
The current state of soil fertility	
More fertile	6.6
Less fertile	93.4

Source: Field survey (2021)

A late start or an early end of the rainy season, the occurrence of dry spells during the crop growing season, and low seasonal rainfall were the central weather anomalies mentioned by farmers. According to them, those risks have adverse impacts on the production of their crops when asked about how they perceive climate variability and change (Table 21). Furthermore, they believed crops were harmed by strong winds and high temperatures (table 21). In general, low seed germination, complete crop failure owing to drought, or damaged crops due to severe winds all impacted crop productivity.

Tableau 21: Perception of change in different climate indicators by farmers' in the study area

Weather indicator	Impacts
The deficit in seasonal rainfall amount	Crop water deficit resulting in yield loss
Low start and early end of the rainy season	Crop water deficit resulting in yield loss, long cycle varieties fail.
Low rainfall	Spreading manure is less effective, and manure decomposition slows down and reduces manure quality.
Dry spells at the end of the season or early cessation of the season	Crop water deficit resulting in poor crop maturation
Prolonged dry spells in the early stages of the rainy season	Crop deficit resulting in seedling death
Strong wind	Soil erosion resulting in low soil fertility
High temperature	Crop heat stress and resulting yield loss

Source: Focus Group Discussions (FGDs) (2021)

The Koutiala and San districts' smallholder farmers are aware of climate fluctuation and change, mainly due to their priceless observations of the length of the rainy season, soil fertility, crop production, vegetation cover, flooding, temperature, and drought. As a result, various modifications were noted using farmers' experience as a tool for weather forecasting. These included shifts in the plants' blossoming seasons, animal migration, particularly that of some birds, strong wind and wind direction changes, and high temperatures. This view aligns with the widespread belief that the climate is changing (IPCC, 2007b; Orinda & Eriksen, 2005; Lobell et al., 2013; Alexander, 2013). Additionally, studies on farmers' perceptions of farming in semi-arid environments in Africa (Nyanga et al., 2011; Osbahr et al., 2011) and semi-arid Zimbabwe (Moyo et al., 2012) revealed similar results. However, the results of this study showed that smallholder farmers in the Koutiala and San districts perceive that the climate is changing and will negatively impact agricultural and livestock productivity. As shown by the acquired data, there are differences in the perceptions of the farmers in the research area. As a result, farmers in the study area noted several changes. Furthermore, crop failure and food shortage are frequently attributed to climate change and fluctuation (Bouba, 2014; Mishra et al., 2008; Benjamin Sultan et al., 2005).

7.4. Land use and land cover changes in the Koutiala and San districts

7.4.1. Land use/ land cover changes in the Koutiala district in 1989, 1999, and 2019

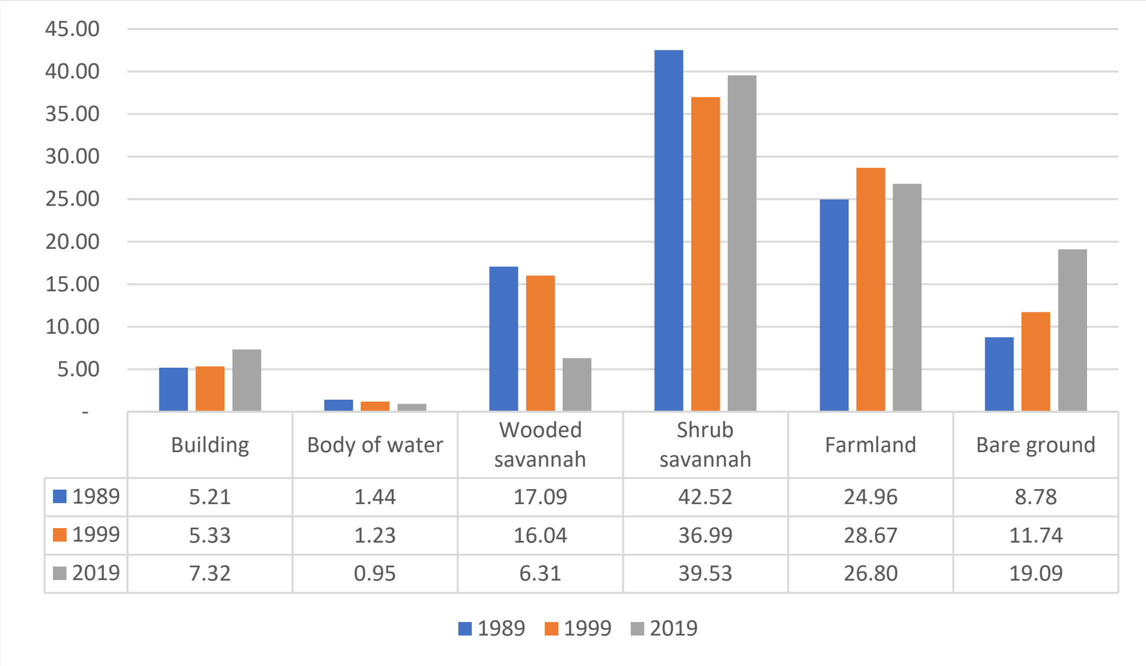
Building level did not vary significantly between 1989 (5.21%) and 1999 (5.33%), as seen in Figure 20. While in 2019, we noticed a rise in building level (7.32%). From 1989 until 2019, the water body stayed the same.

In terms of the changes in the wood savannah level, we observed (17%) change in 1989 and 16% in 1999. While in 2019, we noticed a (6.31%) reduction in the wood savannah.

In 1989, a high proportion of shrub savannah (42.52%) was observed. In contrast, this unit experienced a fall in percentage in 1999 (36.99%). However, the proportion of shrub savannah grew in 2019 (39.53%).

In 1999 and 2019, there was a high percentage of agriculture (28.67%), while in 1989, there was a low percentage (24.96%).

The increase in bare soil from 1989 (8.78%) to 2019 (19.09%) is depicted in Figure 13.



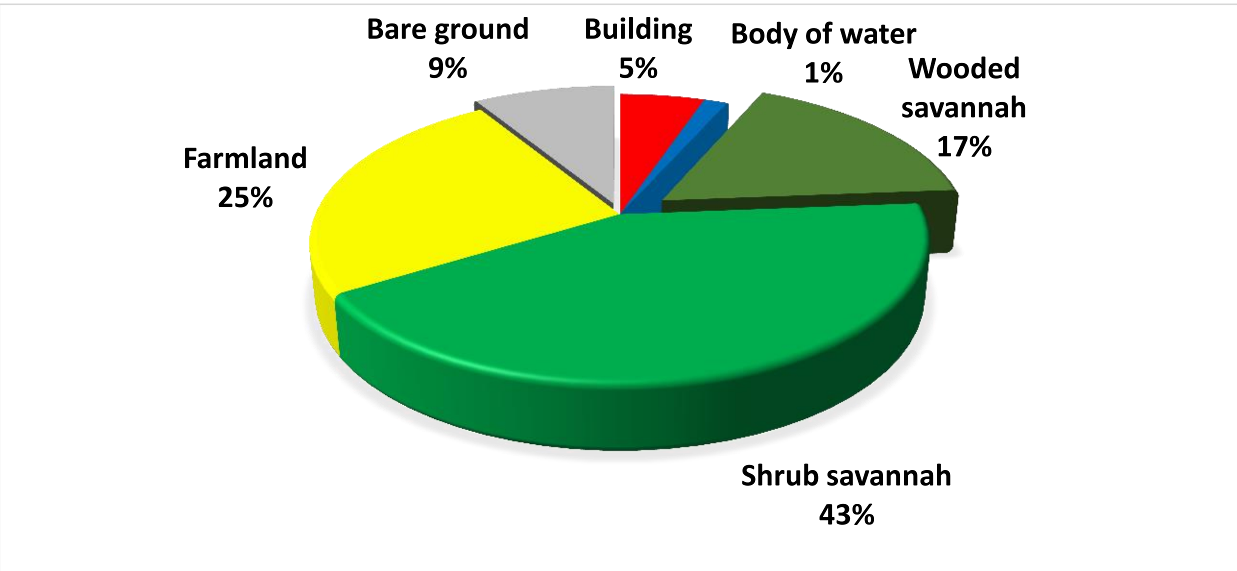
	Building	Body of water	Wooded savannah	Shrub savannah	Farmland	Bare ground
1989	5.21	1.44	17.09	42.52	24.96	8.78
1999	5.33	1.23	16.04	36.99	28.67	11.74
2019	7.32	0.95	6.31	39.53	26.80	19.09

Source: Personal work

Figure 20: Land use/ land cover changes in the Koutiala district in 1989, 1999, and 2019

7.4.2. Classification of land occupation units from 1989 to 2019in the Koutiala district

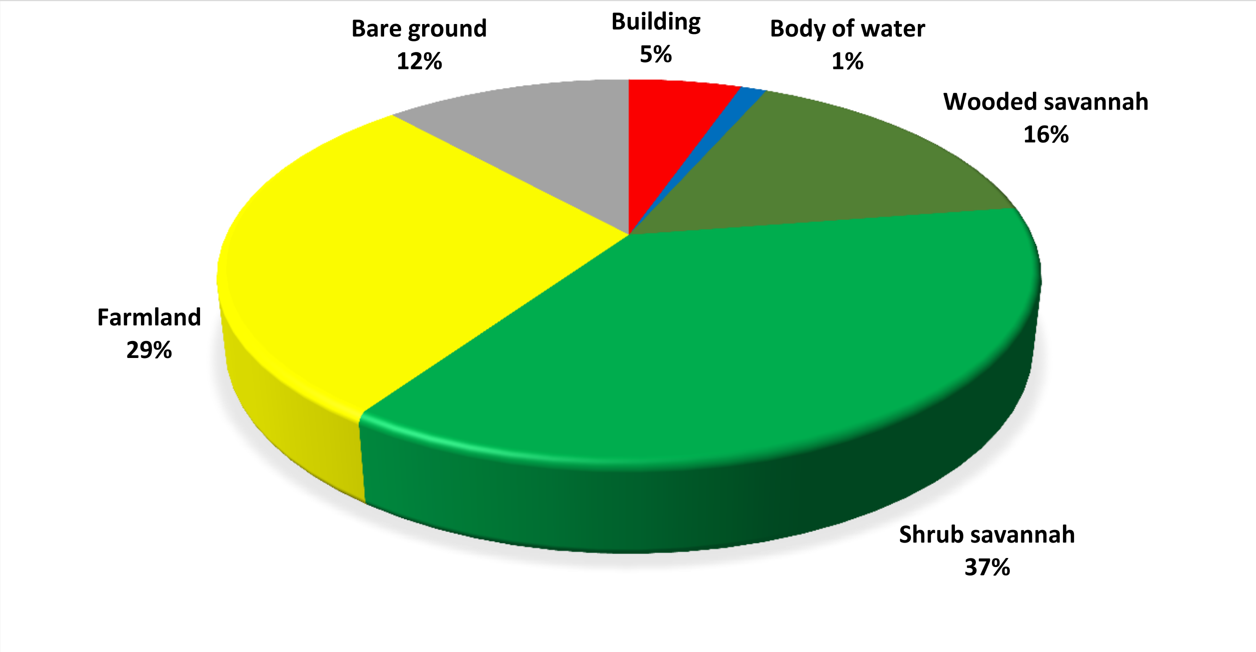
In 1989 (figure 21), the Koutiala district's shrub savannah had the highest percentage of occupied land (43%), followed by cropland (25%), timber savannah (17%), bare soil (9%), buildings (5%), and water bodies (1%).



Source: Personal work

Figure 21: Classification of land occupation units in 1989, Koutiala districts

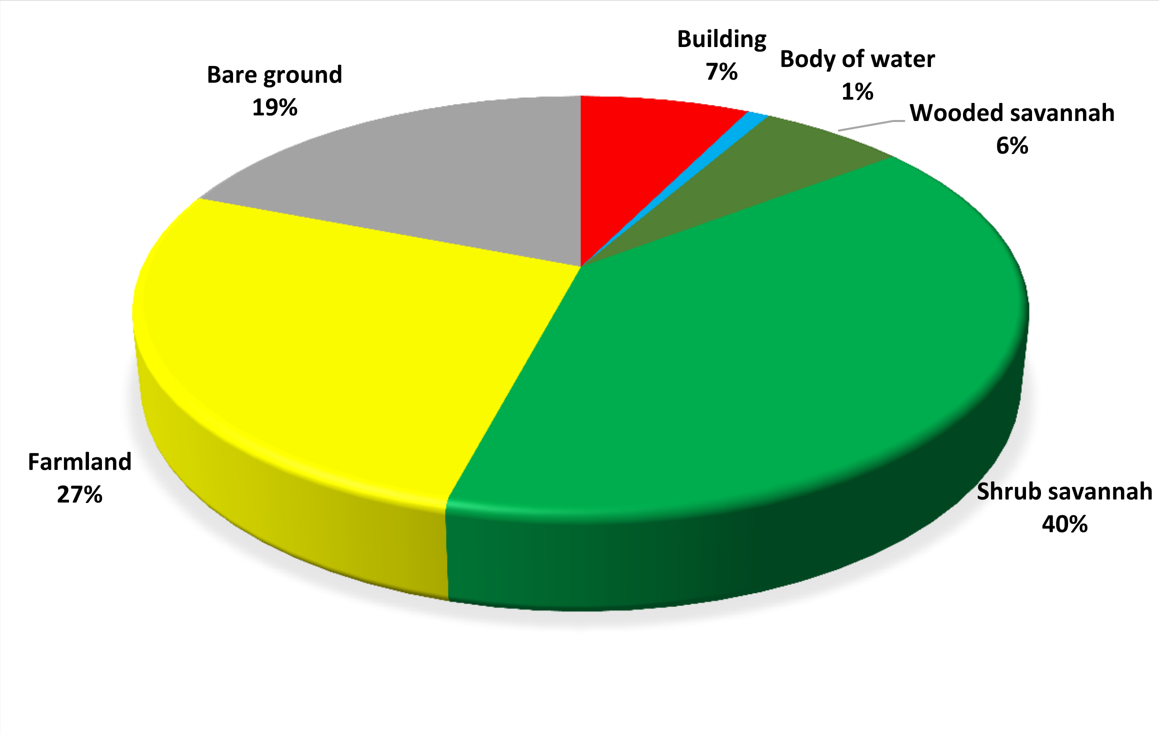
According to a figure from 1999 (figure 22), the shrub savannah (37%) took the top spot, followed by farmlands (29%), wooded savannah (16%), bare soil (12%), buildings (5%), and water bodies (1%).



Source: Personal work

Figure 22: Classification of land occupation units in 1999, Koutiala districts

Figure 23 shows the trend of shrub savannah (40%) and wood savannah (6%), farming (27%), bare soil (19%), structures (7%), and waterbodies (1%), respectively.



Source: Personal work

Figure 23: Classification of land occupation units in 2019, Koutiala districts

7.4.2.1. Land use/ land cover changes in the San district in 1989, 1999, and 2019

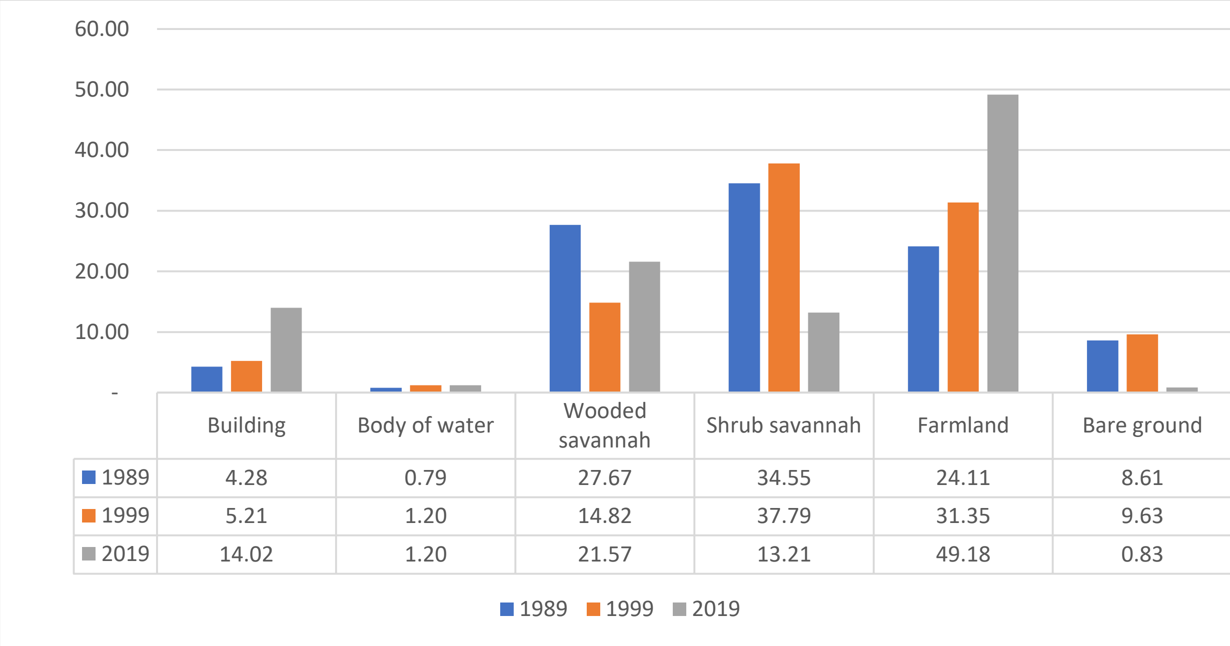
Figure 24 depicts a steady increase in building from 1989 (4.28%), to 1999 (1.20%), to 2019 (14.02%). From 1989 to 2019, there has been no alteration to the water body in the San district.

The wood savannah decreased from 1989 (27.67%) to 1999 (14.82%), and a slight increase was seen in 2019. (21.57%).

In proportion, we noticed a rise in the shrub savannah from 1989 (34.55%) to 1999 (37.79%). In contrast, 2019 had a decrease in this proportion (13.21%).

According to the graph, cropland increased steadily from 1989 (24.11%) to 2019 (49.18%).

Between 1989 and 1999, bare soil increased (9.63%). While in the San district, its level declined (0.83%) in 2019.

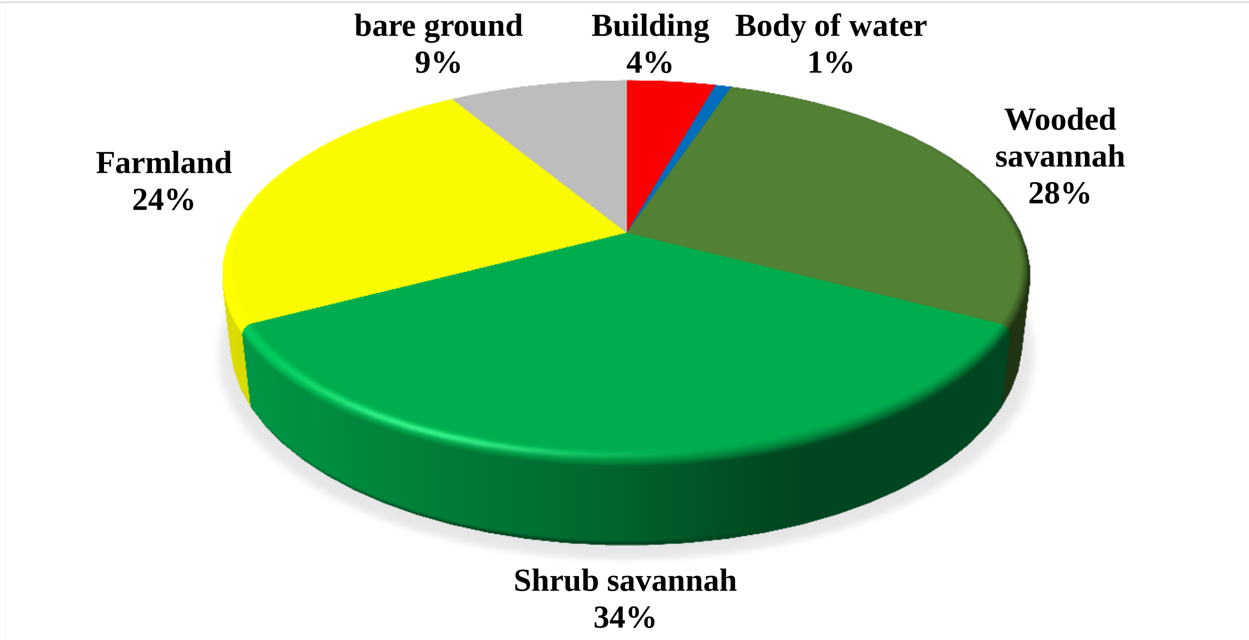


Source: Personal work

Figure 24: Land use/ land cover changes in the San district in 1989, 1999, and 2019

7.4.2.2. Land use units classification in San district

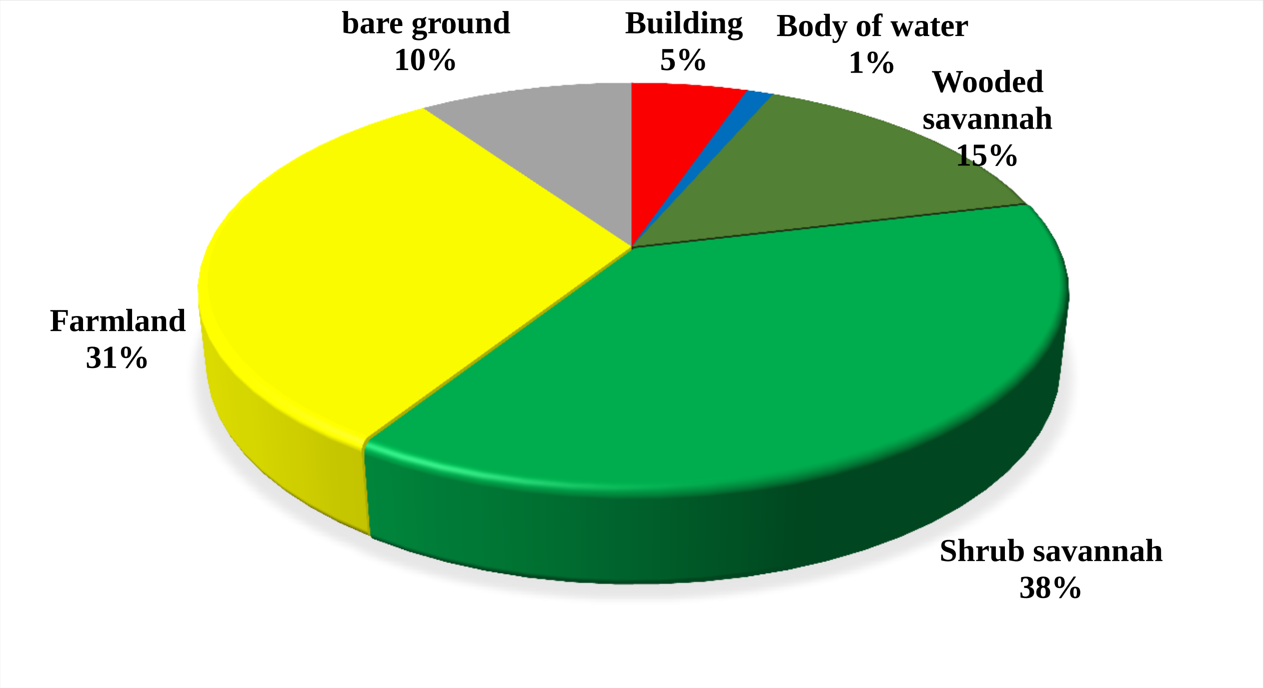
Figure 25 shows that in the San district in 1989, shrub savannah held a commanding 34% of the first class, followed by wood savannah (28%), farming (24%), bare soil (9%), buildings (4%), and water bodies (1%).



Source: Personal work

Figure 25: Classification of land occupation units in 1989, San district

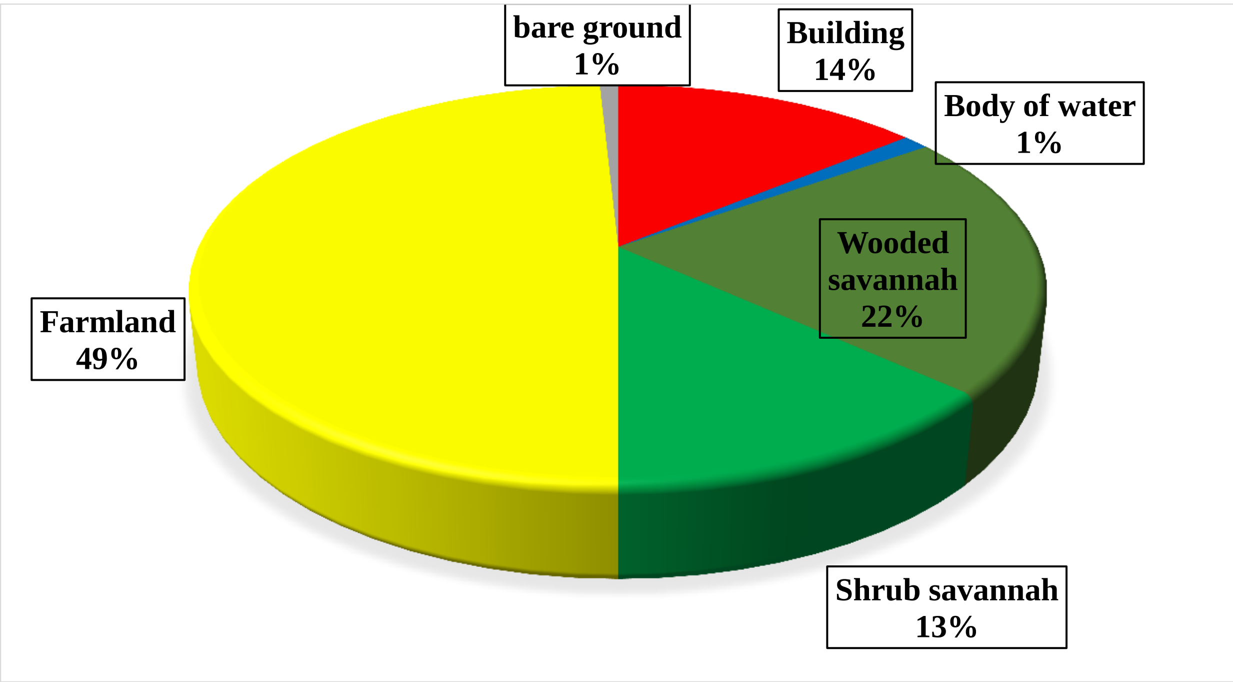
Figure 26 demonstrates that in the San district, shrub savannah (38%) occupied the highest percentage of land in 1999, followed by cropland (31%), timber savannah (15%), bare soil (10%), buildings (5%), and water bodies (1%).



Source: Personal work

Figure 26: Classification of land occupation units in 1999, San district

Farmland (49%) was categorized as first-class land in 2019, along with timber savannah (22%), buildings (14%), shrub savannah (13%), water bodies (1%), and bare soil (1%). (Figure 27).



Source: Personal work

Figure 27: Classification of land occupation units in 2019, San district

7.4. Discussions

Various factors, including economic development, political policies, and social changes, can increase the study area's building levels. In the context of global warming and climate risks, over-urbanization can be caused by several factors, including:

- **Migration:** Climate change is likely to lead to increased frequency and severity of extreme weather events such as floods, droughts, and heat waves, which can displace people from their homes and communities. As a result, many people may migrate to urban areas for safety and opportunity.
- **Economic Development:** Urban areas are often seen as centers of economic development and opportunity, and as such, people may move to cities in search of better jobs, higher wages, and improved living standards.
- **Government policies** often promote urbanization to boost economic development, attract investment, and generate tax revenue. This situation can lead to the development of urban areas and population growth in urban areas.
- **Infrastructure development:** Improved infrastructure such as transportation, housing, and access to services in urban areas also attract people to move to these areas.

However, over-urbanization can exacerbate the impacts of climate change, as it can lead to increased greenhouse gas emissions from transportation and buildings and strain resources such as water and energy. In addition, urban areas can also be more vulnerable to extreme weather events due to the concentration of infrastructure and population. Therefore, it is crucial to approach urbanization and development with a strategic plan considering economic and climate risks.

In Mali, surface and groundwater levels are impacted by climate variability and change. However, this situation can be explained by the Koutiala and San districts' climate parameters variation from almost 30 years ago. In the Koutiala and San districts, there was an increase in temperature, evapotranspiration, and a decrease in precipitation patterns. These situations affect the water resources in these areas.

The difference in population growth rate can explain why wooded areas increased in 1989 but decreased in 1999 and 2019, respectively, because there were fewer people in 1989 than in 1999. As a result, most people in Mali use the wooded savannah to make firewood, generate revenue, and build homes. As a result, the wood savannah is badly impacted by all these practices. Additionally, the attacks and threat of terrorism in the Koutiala district in 2019 prevented the farmers from cultivating their land. As a result, they were reliant on the wooded savannah for their subsistence.

In the case of the shrub savannah, the slow rate of population expansion in the Koutiala district helps to explain the high proportion of shrub savannah in 1989. The farmers abandoned their farms due to the terrorist attacks. This condition threats this region and might be used to justify the increase in this unit in 2019. Generally speaking, we discovered a shrub savannah within the farmlands in this region. However, following the terrorist attacks, farmers faced a problem in preparing their lands for crop growth.

The high rate of population growth in the Koutiala district can be used to explain the increase in agricultural land between 1999 and 2019. The Koutiala district is also considered the center of cotton production in Mali. This situation makes the crop one of the cash crops grown in Mali. The CMDT is in charge of this crop. This business was founded in 1974. A farmer will have easy access to agricultural inputs (seed, chemical fertilizers) with subsidized prices if he or she starts growing this product (cotton). The same business (CMDT) permits farmers to produce maize as a food crop.

The detrimental effects of climate change and anthropogenic shocks on the land cover can be used to explain the rise in bare soil in the Koutiala district between 1989 and 2019. These shocks cause damage to the land, the vegetation, and the fertility of the soil. However, it is believed that those soils need to be improved for growing crops.

The wood savannah changed less throughout the first ten years. The growth of the farmlands in the San district can account for that. However, natural resources like timber savannahs might also suffer a negative impact from climate effects.

The growth of wooded savannah areas in 2019 may be attributable to the beneficial effects of the initiatives taken by the government, NGOs, and other groups (tree planting, early warning systems, supported natural regeneration, and land restoration. However, from 1989 to 1999, the shrub savannah expanded continuously. The low population growth rate during this period can be used to explain this. While various reasons, including the growth of cultivated farmlands, soil and vegetation deterioration, a high frequency of bushfires, and others, can be linked to the abrupt decline in shrub savannah.

Between 1989 and 2019, the amount of farmland in the San district increased. The rapid population expansion, simple access to agricultural inputs, financial resources, availability of extension services, and assistance from the government and non-profit organizations can all contribute to this increase of acreage (World Vision, ICRAF, ICRISAT, Sahel ECO).

The amount of exposed soil in the San district increased between 1989 and 1999. Although it fell in 2019, the high frequency of climatic shock occurrence (soil erosion, run-off) in this region can explain the rise in bare soil. These cause soil to degrade and become infertile. On the other hand, in 2019, we noticed less exposed soil. The actions (soil restoration, intelligent soil management, and growth of agriculture) carried out by the government and NGOs can be used to explain this drop.

We saw how the effects of global warming on the land cover were present in the study area. The distribution and number of plant species have changed due to changing precipitation patterns and rising temperatures, one of the most significant effects of global warming on vegetation and water resources. As a result, ecosystems' structure and composition may change, which leads to some species going extinct. For instance, rising temperatures and altered precipitation patterns may encourage the growth of some grass and shrub species at the expense of trees, turning forests into grasslands.

7.5. Partial conclusion

In the Koutiala and San areas, farmers are aware of the effects of climate change and variability and see it as a severe threat to their way of life. As a result, farmers have witnessed climatic variability and change in the study area. Mainly through their observations of the duration of the rainy season, soil degradation and sterility, decreased crop yields, degraded vegetation, flooding, rising temperatures, decreased precipitation, and they observed drought. As a result, various modifications were noted using farmers' experience as a tool for weather forecasting. These included shifts in the plants' flowing periods, animal migration, particularly that of some birds, strong wind and wind direction changes, and high temperatures.

The land cover in the research area is significantly impacted by climate and anthropogenic shocks. We saw increased agricultural land, bare soil, and building level from the satellite image processing. However, in the Koutiala and San districts, there was a decline in the wooded and shrubby savannah and water resources.

CHAPTER 8: IDENTIFICATION AND ASSESSMENT OF THE ADAPTATION STRATEGIES IMPLEMENTED BY FARMERS

Abstract

Farmers throughout the world are facing significant challenges due to climate change. According to numerous research, the African continent would be severely impacted by climate change. These climatic changes and climate unpredictability may present complex problems for agricultural production in the future, economic growth, and food security generally, and notably in the region of Saharan Africa. The purpose of this study was to assess the adaptation strategies employed by farmers in the Koutiala and San areas. With the aid of a questionnaire, 455 farmers were questioned. The findings indicated that farmers had created several adaptation techniques to deal with local climate change. As a result, most respondents adopted techniques such as using chemical and organic fertilizers, better crop varieties, crop rotation, aided natural regeneration, and stone bunds. These technologies are also the most efficient in their eyes. In addition, farmers create certain off-farm enterprises in response to the consequences of climate change or fluctuation. These practices are intended to help people deal with the effects of these shocks. Trading (75.9%), vegetable producing (69%), cattle (65.7%), fishing (57.6%), and working for pay (50.8%) are hence those activities.

Keywords: Adaptation strategies, Climate Change, Agriculture, farmers, Koutiala, San, Mali.

8.1. Introduction

The rural population's economy and food security strongly depend on farming in the Sudano-Sahelian countries (Bouba, 2014). Rain-fed agriculture produces nearly 90% of food and feed and is the primary livelihood activity for 70% of the population (Bouba, 2014). In Mali, cereal production increased over the last two decades from 1.9 million tons in 1990/1 to 4.1 million tons in 2008/9, corresponding to an annual increase of 4.6% (Staatz et al., 2011). On the other hand, cotton (*Gossypium hirsutum* L.) is responsible for the largest share of foreign currency revenues from agriculture in Mali (Devèze, 2006; Nubukpo & Keita, 2006). The income from cotton finances much of the rural infrastructure, literacy programs for farmers, and funding for farmer organizations and extension programs (Bouba, 2014). According to him, producing cotton also gives farmers access to chemical fertilizer and other inputs that are provided on credit by the cotton companies. However, some of the fertilizers obtained on credit are diverted for the production of maize (*Zea mays* L.). Moreover, maize and other cereals are grown in rotation with cotton benefit from the residual effects of the fertilizer used on cotton (Piéri, 1989).

The essential cereals grown in Mali in terms of both areas cropped and total production are millet (*Pennisetum glaucum* (L.) R.Br.), maize (Zea mays L.), and sorghum (*Sorghum bicolor* (L.) Moench). The capacity of the cropping systems to support local food security depends mainly on the seasonal patterns of rainfall, which vary enormously between years (Benjamin Sultan et al., 2005). However, seasonal rainfall amount, intra-seasonal rainfall distribution, increased temperature, and dates of onset/cessation of rain influence crop yields and determine the agricultural calendar (Maracchi, 2000). The rainy season is short and varies in length, with the number of rainy days varying from year to year (Mouhamed et al., 2013). High evaporation losses (up to 50% of annual rainfall) and dominance of sandy soils with low water holding the capacity result in soil water shortage during the growing season, when rains are erratic (Barron et al., 2003).

Risk-avoiding strategies become more pertinent but also challenging when future climate projections of the Sudano-Sahelian region are considered (Bouba, 2014). The region is likely to get hotter due to global warming (Butt et al., 2005). High temperatures occurring in combination with drought (Semenov et al., 2007) will lead to increased crop water stress and therefore cause scalding in cereals (Burke et al., 2009), disturb flowering, and strongly reduce crop yields (Fisher, 2005).

With the realization of the potential impacts of climate change, mitigation and adaptation strategies have attracted much interest from the multidisciplinary research community (Adger et al., 2009; Below et al., 2012; Fussel, 2007; Mendelsohn & Dinar, 1999). However, all those strategies are vital for communities reliant on agricultural production as this sector depends substantially on climate-sensitive resources.

A coping appraisal is one central element of protection motivation theory (PMT) (Floyd et al., 2000; Maddux & Rogers, 1983; Roggers, W., 1975). Rogers (1975) originally developed PMT to deal with the relationship between fear appeal and attitude change climate. He then revised his theory and added the coping appraisal process (Roggers, 1983). In PMT, coping appraisal is the central process that occurs right after threat appraisal (Milne et al., 2000) and only starts with a threshold level of threat (Grothmann & Reusswig, 2006).

There are several studies examining farmers' perception of the concept of climate change (Le Dang et al., 2014; Deressa et al., 2009; Diaye et al., 1991; Gbetibouo, 2009; Maddison, 2007; Mertz et al., 2009; Neeraj Vedwan & Rhoades, 2001). Different aspects of adaptation to climate change in agricultural settings have also been extensively investigated (Apata et al., 2009; Below et al., 2012; Bradshaw et al., 2004; Bryan et al., 2009; Deressa et al., 2009; Hassan, 2008; Seo & Mendelsohn, 2008; Howden et al., 2007). However, to understand the protection motivation and adaptive behavior of farmers, it is required to examine how farmers perceive climate change and how they appraise their private adaptive measures (Le Dang et al., 2014). Currently, investigation of the appraisal of coping and adaptive measures in climate change research is limited. It has been discussed in only a few studies. One study focused on residents in Cologne, Germany, and flood risks (Grothmann, 2006). Another presented two case studies: one with farmers in Zimbabwe and drought risk, and the other with ordinary people and flood risks (Grothmann, 2005).

In Mali, the land and crop management practices based on adjusting the planting date and choice of improved variety are the adaptation strategies most readily available to farmers to deal with the effects of climate variability and change. However, quantitative information for these options is scant for them. Therefore, this study aimed to identify and assess Koutiala and San farmers' adaptation practices to overcome or reduce the negative impacts of global warming and agro-climatic risks on their farming systems and livelihoods.

8.2. Material and Methods

8.2.1. Overview of the study area

The study was conducted in the regions of Koutiala (Sikasso area) and San Mali (Segou region). Southern Mali contains 50% of the country's arable land, 40% of the nation's population, and amounts for 13.5% (or around 160.825 km2) of the nation's total land area (ME, 2017). (See Figure 12).

The former cotton basin is located in the Koutiala District, which is in the western part of the Sikasso area. Its northern boundary is formed by the San District, its western and southern boundaries by the Bla and Diola Districts, its southern boundary by the Republic of Burkina Faso, and its eastern boundary by the Yorosso District. The district's latitude and longitude are 12°23′N and 5°28′W, respectively. The Koutiala district has 797927 inhabitants and a land area of 8 740 km^2.

Sudan-Sahelian weather prevails in San District, which is located in a semi-arid area. It has a surface area of 7,262 km2 and 335,000 inhabitants. 13° 10' 44.2" N and 5° 0' 58.2" W are its coordinates.

In the tropical sub-Saharan climate, there are two seasons each year: a dry season from November to April and a wet season from May to October.

Koutiala records between 750 and 1000 mm of precipitation annually. The rainy season is often seen as lasting from June through October, with August being the wettest month. A hot phase that lasts from March to May and a cold phase that lasts from November to February make up the dry season. According to RGPH 2009, Mali-Meteo 2019, Institut National de la Statistiques, Republic of Mali, 2009, the highest temperature on average during the wet season is 34 °C.

San District experiences tropical dry weather with average high temperatures of 44°C and lowest temperatures of 13°C. The area experiences mild temperatures on average throughout the year, with March and May being the warmest months. The months from November to February are the coldest. The wet season's busiest months are June, July, August, and September. The annual average rainfall is approximately 500 mm, according to RGPH 2009, Mali-Meteo (2019), Institut National de la Statistiques, Republic of Mali (2009).

The face-to-face structured interviews were done from December 2021 to March 2022.

The household farmers were given a brief introduction to climate change and its interpretations prior to the screening questions being asked in order to conduct the field survey. Even though many homes were visited, only 455 agricultural households were interviewed. The household heads were the interview subjects, while the farm house served as the study's analytical unit.

The structured questionnaire primarily assesses risk perception and adaptation to climate change. The majority of the information in this study came from questions about the appraisal of climate change adaptation, knowledge, belief in climate change, farm characteristics, and family characteristics.

In order to evaluate adaptation assessments, farmers were tasked with identifying the adapted practices and rating the effectiveness of each adaptive measure.

8.2.2.Method of data analysis

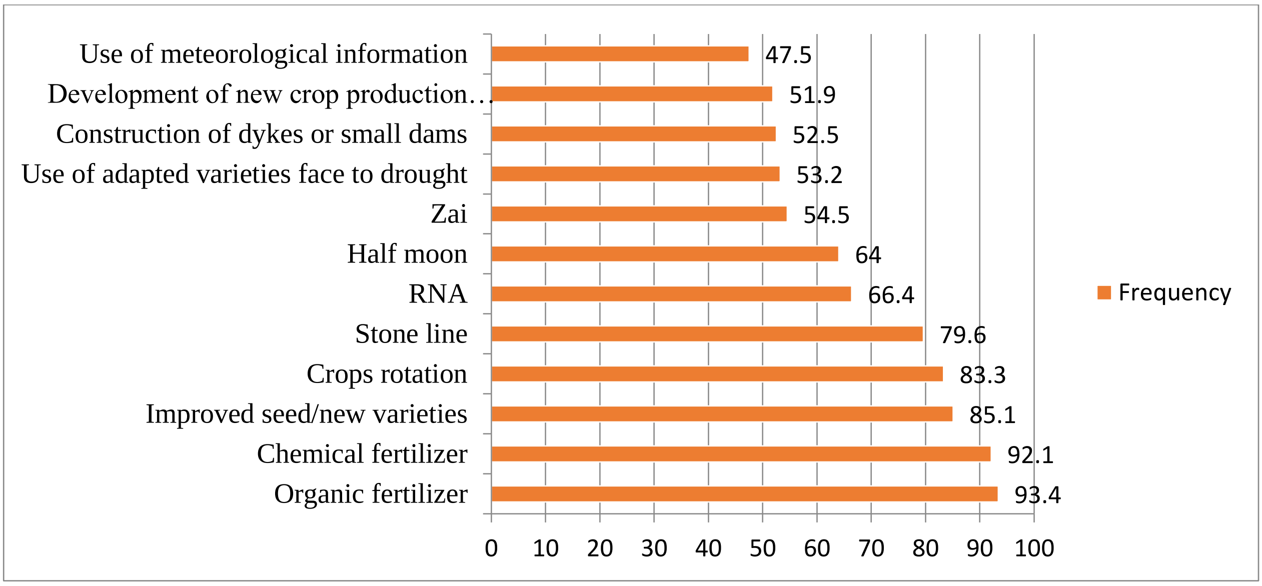
Data from the questionnaire were coded and then analyzed using the Statistical Package for Social Sciences (SPSS version 21) and MS Excel software. Descriptive statistical tools such as means, standard deviations, frequencies, and percentages summarize and categorize the information gathered.

8.3. Results and Discussion

8.3.1. Adaptation and coping strategies put in place by farmers to face climate shocks

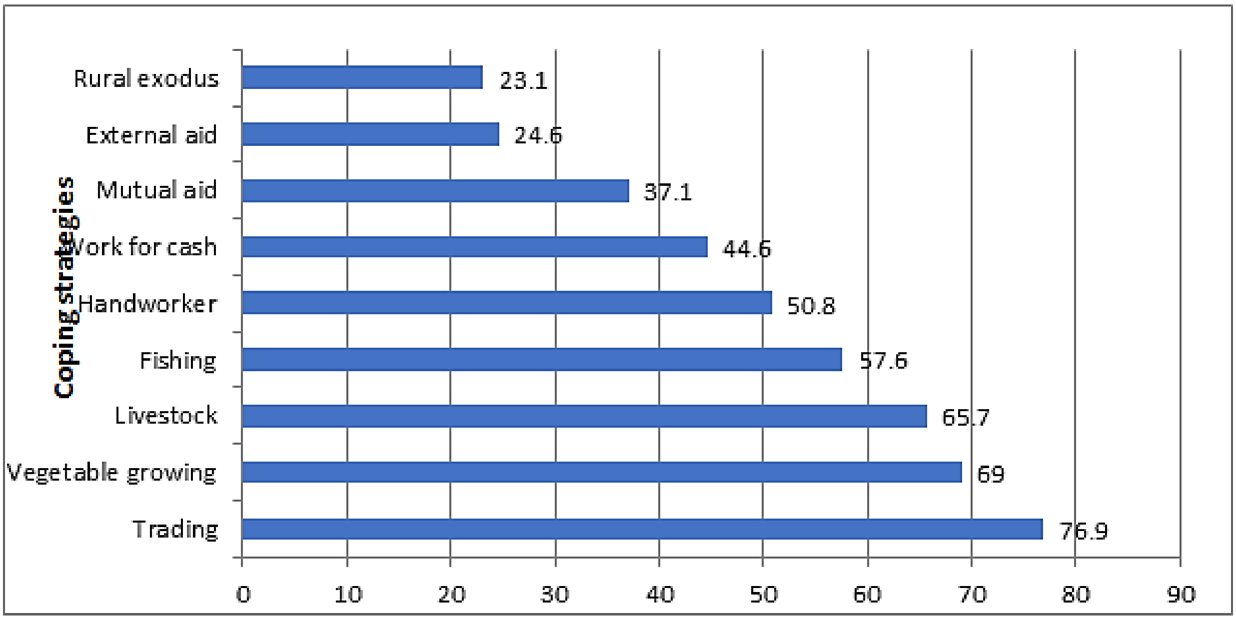
The many adaptation strategies farmers employ to deal with climate change and variability are shown in Figure 28. As a result, most respondents (93.4%) use chemical fertilizers, and the majority (92.1%) use organic fertilizers. Furthermore, more than half of the responders (51.9%) use the latest crop production technologies.

Figure 29 shows that, in order to lessen the effects of climate change, the majority of respondents engage in a variety of non-farm activities to augment their income, including small business (trade) (76.9%), vegetable production (69%), cattle (65.7%), and fishing (57.6%). In contrast, a tiny percentage of respondents support rural-to-urban migration as a coping strategy.



Source: Personal work

Figure 28:Adaptation strategies to face climate variability and change by farmers'



Source: Personal work

Figure 29: Households' farmers coping strategies to face the impacts of climate shocks

Descriptive statistics show that households' farmers in the study area have responded to the effects of climate variability and change in many ways. If agricultural conditions deteriorate, households participate in both on- and off-farm activities to supplement their household earnings and food security. As a result, most respondents asserted that they had used various coping and adapting strategies. However, this conclusion shows that more than a single strategy is needed for dealing with the effects of climatic shocks because combining several strategies is more likely to be effective than one. One of the primary coping methods used by households in response to climate fluctuation and change was the adoption of crop seed types. In contrast, studies on coping mechanisms by Asnake (2012) in Ethiopia, Quay (2008), and Kyekyeku (2012) in Ghana showed a range of diverse coping methods in response to climate change, the majority of which were linked to the coping mechanism discovered in the study.

In order to cope with the effects of global warming and agro-climatic risks, households in the Koutiala and San districts employed various adaption strategies, according to the study's findings. As a result, the employment of chemical and organic fertilizers, improved crop types, crop rotation, trading, vegetable cultivation, and the sale of cattle were the key tactics used by farmers. This evidence shows that climate shock is not recent in the Koutiala and San regions. However, those coping strategies are not strange and are very similar to those employed elsewhere. For example, Nhemachena and Rashid (2008) discovered that 11 African countries used various adaptation strategies to combat climate change. These included diversifying production, using better varieties, altering planting dates, increasing irrigation, using insurance, water conservation, praying, and soil conservation. The adaptation strategies employed in different regions or countries are typically determined by household farmers' level of economic development in terms of technical and financial capabilities, institutional assistance (government and NGOs), and traditions. Because of this, each region favors the adaptation strategies that are the most similar.

In order to reduce risk and adapt to climate unpredictability, farmers often space out the sowing dates and disperse early and late crop maturity types across the terrain (Ouattara et al., 1998). This approach demonstrates that farmers have a sizable requirement for climate information at an intra-seasonal time scale. The ability to make timely decisions and plan tactical crop management would benefit from reliable seasonal weather forecast data. Unfortunately, seasonal African rainfall is somewhat erratic (Cooper et al., 2008).

It is crucial to improve seasonal weather forecasting capabilities and offer effective agrometeorology extension services if agricultural communities can adjust to climatically unpredictable futures. In order to strategically plan crop management, farmers might alter the planting and fertilization dates for their crops using this seasonal climatic information. Our findings show that the season's delayed onset impacted its length, allowing farmers to adjust their management by planting shorter-duration varieties when the rains began to fall later.

For the use of the longer-term data on the nature of climatic variability and change, farmers may be able to develop new agricultural systems and management techniques that are better adapted to the environment. In order to deal with more frequent dry spells, for instance, land management using contour ridging (Gigou et al., 2006) channels rainwater on the field between the ridges, where it filters into the soil and minimizes runoff. Furthermore, an alternative management strategy based on a high plant density and the application of crop growth regulators was evaluated for cotton systems (Barrabe et al., 2007; Rapidel et al., 2006). With this novel technique, the crop covers the ground earlier, the production cycle is shortened by 10 to 20 days, inducing an adaptive response to climate fluctuation and change, and yield improvements of roughly 30 to 40% are achieved (Rapide et al., 2009; Traore, 2011).

8.3.2. The performance of adopted technologies by farmers to face climate variability and change

Table 22 shows that among the adopted technologies used by farmers (99.1%, 99.8%, 98%, 96%, and 90%), organic fertilizer, better crop types, use of stone bunds in farms, crops rotation, and assisted natural regeneration assistance (ANR) are the most beneficial.

The averages and standard deviations of perceived self-efficacy are shown in Table 22.

The most outstanding average (3.00) was found in improved crop varieties, followed by chemical (2.95), organic (2.99), crop rotation (2.97), assisted natural regeneration (2.98), and stone bunds (2.00).

Tableau 22: Effectiveness of adopted technologies by farmers'

Descriptive Statistics					
Strategies assessed	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Organic fertilizer	455	2	3	2.99	.093
Chemical fertilizer	455	2	3	2.95	.219
Improved varieties	455	2	3	3.00	.047
Crop rotation	455	2	3	2.97	.173
Assisted natural regeneration	455	2	3	2.98	.139
Stone bunds	455	1	3	2.00	.115

Source: Personal work

The majority of farmers in the study region now cultivate superior varieties of crops like groundnuts, sorghum, and maize. They assert that this adoption aims to increase agricultural output so that it can better satisfy the population's needs for food by modifying their crops to climate variability or change. As a result, it is the most effective. Such improved kinds are also more pest- and disease-resistant. Our findings concord with the European Union (2015) report that claimed that diversifying agricultural production through introducing new crops or varieties or reintroducing traditional crops has positive effects on biodiversity and ecosystem services. It also reduces the possibility of a crop failing and increases the agroecosystem's ability to respond to biotic and abiotic stressors.

For a variety of reasons, including their availability, affordability, value in restoring the soil, ability to maintain soil moisture and nutrient levels, performance on crop yield, improvement of food production, promotion of bio-production, protection of the environment, and others, the majority of farmers in the study area used organic fertilizers. This result backs the findings of Puneet et al. (2012), who discovered that farmers use various techniques to increase food production on a small plot of land. One of the best methods is to apply various kinds of inorganic and organic fertilizers to the soil, which preserves the nutrients in the soil. As a result, it makes it possible for crops to proliferate, prosper, and resist pests, diseases, and dry spells. However, this approach is necessary to ensure sustainable agricultural productivity and reduce potential risks.

In West Africa, particularly in Mali and Burkina Faso, farmers have employed assisted natural regeneration (ANR) extensively. This approach relies on nature's ability to rebound, only stepping in when necessary. Therefore, rather than replacing plants, the advantage of this technology is to accelerate. It is appropriate for use with tried-and-true techniques for managing natural resources. The farmers that participated in the poll feel that this technology aids in business diversification and income growth. They claim that crop output can be increased by fertilization and land restoration. This result is consistent with Dugan's observations (2003); a silvicultural technique known as assisted natural regeneration, initially developed for tropical forests with weak natural regeneration, is used to combat deforestation and environmental degradation. Even though the method is founded on the ecological principle of secondary forest succession, stimulates the regeneration of local species, and depends on organic processes.

One of the farming techniques that farmers in the study area use the most is crop rotation. They assert that this technique will help their farm have fewer pest and disease infestations. Another hand, this technique benefits switching from one crop to another, such as the rotation of groundnut and maize. The groundnut may, therefore, independently fix atmospheric azote (N) in the soil. Therefore, this azote can aid in the rotation of the maze.

For this reason, Mali farmers usually use this method. This outcome is consistent with Leke et al. (2017) finding that the expanding global population and related environmental problems make ensuring food security and safety a top priority. Recently, there has been much discussion in Cameroon about farmers' reliance on chemical fertilizers to boost production, especially in peri-urban regions where the demand for staple foods is growing.

To increase the fertility of their soil and the output of their crops, farmers use chemical fertilizers. However, chemical fertilizer is produced, and its nutrients are created in a factory using chemical processes and compared to synthetic materials like composted manure used to make inorganic fertilizer. However, many farmers employ chemical fertilizers because they are easily absorbed and customized for farmed plants. It is a complete fertilizer containing nitrogen (N), phosphorus (P), and potassium (K). For this stage of plant development, these are the essential chemical elements. However, some barriers prevent farmers' adoption due to its high price and limited access. According to a survey by AGRICFOODSA (2018), the most crucial elements in agriculture lead to many farmers using chemical fertilizers (2018). In order to feed populations. Fertilizer chemicals must be utilized to ensure food security. Therefore, entrepreneurs who can supply fertilizer chemicals to the market are what we need to ensure that our growing nations remain nourished and healthy.

In Mali's agricultural regions, stone bunds are being used increasingly frequently. In the research area, most farmers genuinely respect this technology. The interviewed farmers claim this tactic has many advantages, such as increased farm biodiversity, soil and water conservation, and improved crop output. This result is consistent with Farming First Research's (FFR) 2012 research, which indicated that the most common technique employed by farmers in sub-Saharan West Africa for lowering runoff and preventing erosion is the construction of stone bunds around fields. As a result, numerous governmental and non-governmental groups are actively promoting the development of this technology and offering technical and logistical assistance for harvesting and transporting stones.

8.4. Partial conclusion

Quite a few farmers today believe that climate change and variability severely threaten their capacity to make a living. According to their argument, using organic and chemical fertilizers, enhanced varieties, crop rotation, stone bunds, and Assisted Natural Regeneration is just a few adaption strategies that can help agricultural practices. These technologies are seen as helpful by them in coping with local climate variability and change. Most of them use drought-tolerant varieties, and rational planting dates and crop types with short maturing times were the most widely adopted adjustments to the seasonal variation of the current weather. According to most participants in our focus group discussions (FGDs), better management can increase crop yields. However, the viability of different options depends on the accessibility of labor, equipment, and inputs like mineral fertilizer and short-duration varieties, which can be challenging. Educating farmers about the weather- and climate-related issues, such as the start and end of rainy seasons, is also crucial to enhancing their capacity for adaptation.

Farmers develop alternate strategies (off-farm activities) to deal with the adverse effects of climatic shocks by diversifying their sources of income. However, most of them engage in non-farming activities, including trade, vegetable cultivation, and animal husbandry as coping techniques.

GENERAL CONCLUSION AND RECOMMANDATIONS

For this study, we did the trend of historical climate parameters (temperature, precipitation, and evapotranspiration), the standardized precipitation index (SPEI), the standardized anomaly index (SAI), and how they correlate with maize and sorghum production for 1989 to 2019 the in Koutiala and San districts, respectively. In the study area, climate variability is the critical driver for rain-fed agriculture, the country's most common agricultural practice. Generally, the average temperature and rainfall are not necessarily good indicators of a good rainy season or are associated with good crop production. However, we observed an increasing trend in temperature and evapotranspiration and decreasing trend in precipitation. Overall, a moderate drought occurred in both districts. The result of SAI showed an increase in temperature index in both districts. Temperature plays a significant role in agricultural crop development and preservation. Biologically, temperature profoundly affects plant physiology, such as high temperatures altering plant cells and decreasing crop yields. Because temperature determines plant growth cycles, seasonal variations and temperature extremes pose dangers to crop production. Moreover, Our results reveal that the agro-climatic parameters (temperature and precipitation) affect maize and sorghum production. These constraints, directly and indirectly, affect the households' food security in the study area.

Farmers are aware and conscious of climate variability and change and view it as a real risk to their livelihoods in the Koutiala and San districts. However, farmers' have observed climate variability and change, principally through their precious experiences by appreciating the length of the rainy season, soil degradation and infertility, crop yield reduction, vegetation degradation, flooding, increased temperature, decreased rainfall, and frequent drought occurrence. Therefore, some changes were observed through farmers' knowledge as factors used to predict the weather. These included changes in the flowering period for some trees in those districts, animal migration, especially some birds, strong wind and direction, and high temperatures.

Farmers perceived an increase in unfavorable weather conditions, confirmed through our analysis of observed historical data in the Koutiala and San districts, showing an increase in inter-annual rainfall variability and the number of dry spells during the growing seasons.

The climate and anthropogenic shocks negatively affect the land cover in the study area. We observed the increase in farmlands, bare soil, and building level through the satellite images treatment. At the same time, we observed a decrease in wood savannah and shrub savannah in the Koutiala and San districts. This result can be used for predicting future LULC changes.

From the finding, most households have an acceptable food consumption score but cannot afford some non-essential food expenditures without resorting to inappropriate coping strategies. The results show that the majority of households are marginally food secured. Through this study, we found that many constraints are faced by households' food security, such as the increase in agricultural inputs price, an increase in food price, effects of natural disasters (drought, flood), rainfall variability, and an increase in temperature. Therefore, households' most used coping strategies include using part of their savings to buy food, borrowing money, and relying on less preferred or less expensive food. They also use other strategies based on their existing livelihoods, such as borrowing money, selling productive goods or means of transport (sewing machines, wheelbarrows, bicycles, buses), selling more (non-productive) animals than usual, and practice of begging.

Nowadays, farmers are aware and conscious of climate variability or change and view it as a real risk to their livelihoods. According to them, agricultural practices could be improved by using various adaptation strategies such as adopting organic and chemical fertilizers, using improved varieties, crop rotation, stone bunds, and Assisted Natural Regeneration (ANR). For them, those technologies are adequate to face climate variability or change in their area. Most use the drought tolerant variety; short maturing crop varieties and appropriate planting dates were the commonly preferred adaptation strategies to year-to-year variability in the current weather conditions. In addition, farmers develop other strategies (off-farm activities) to cope with the adverse effects of climate shocks—however, most practice off-farm activities such as trading, vegetable growing, and livestock.

After analyzing the historical climate parameters in Koutiala and San districts, we have the opportunity to understand the farmers' perceptions of those districts on climate change or variability. Thus, it is clear that climate change is a reality for farmers as it is scientifically proven. Therefore, training farmers on essential aspects of weather and its variability, especially on agro-climatic risk management (onset of rains, dry spells, wet spells, flooding), is critical to enhancing farmers' adaptive capacity to climate shocks.

Based on our research results, we formulate some recommendations for the government, scientists, and farmers. Therefore, We recommend various ways in which households can mitigate the negative impacts of global warming and agro-climatic risks on their food security, such as:

- Diversify their sources of food: By relying on a variety of different sources of food,
- households can reduce their vulnerability to disruptions in the supply of any one
- particular type of food.

- Increase their use of drought-resistant and heat-tolerant crops: There are many
- varieties of crops that are more resistant to drought and extreme heat, which can be
- more resilient in the face of changing climate conditions.
- Invest in irrigation and water storage infrastructure: In areas where water is scarce, households can invest in irrigation systems and water storage infrastructure to
- ensure a reliable water supply for their crops.
- Practice sustainable agriculture: By using sustainable farming practices, such as
- reduced tillage, agroforestry, cover cropping, and integrated pest management, households can increase the resilience of their farms to the impacts of global warming and agroclimatic risks.
- Participate in risk-sharing mechanisms: There are many risk-sharing mechanisms, such as crop insurance and weather index-based insurance, that can help households protect their livelihoods and food security in the face of global warming and agroclimatic risks

In addition, we recommend some following adaptation mechanisms that will be helpful for Malian small-scale farmers to deal with the impacts of climate variability and change. Developing resilient agriculture requires more important government, scientists, and international agencies investments. Therefore, we recommend some main actions such as:

- **Foster the use of climate information to inform decision making**

Inter-annual rainfall variability is a major constraint to agricultural sustainability in the Sahel. Since climate change will exacerbate this problem, using seasonal climate forecasts to inform farmers, herders, and other users will be necessary to avoid surprises, allow reasonable use of favorable conditions and make the right decisions in case of an impending drought. e collaboration with regional and international climate research centers must be reinforced to acquire timely weather information.

- **Promote improved agricultural technologies**

There is a solid need to accelerate the adoption of new technologies and varieties, and more so that we understand that climate change will add new constraints to agricultural production. These include using drought-tolerant and drought-escaping crops/varieties in areas where water deficits will be more pronounced due to low rainfall or high evapotranspiration. Crop diversification is necessary and should be based on the potential of the different agroecological zones. Where water retention and supplemental irrigation are possible, agricultural production can be significantly boosted by using high-yielding varieties together with organic and inorganic sources of fertilization.

- **Invest in soil and water conservation**

Soil and water management strategies are necessary for two reasons. First, they are helpful for sustainable crop production. Second, the techniques used have great potential in buffering against drought and floods, which are likely to be more frequent with climate change. The degraded soils of the Sahel, such as the "zipelle" of Central Burkina Fasso, need to be restored to allow crop production, control desertification, and restore biodiversity. Simple techniques such as Zai, half moon, or mund bunds have efficiently concentrated water and increased yields, especially in drought conditions.

- **Develop small-scale irrigation schemes**

An urgent need is to increase the area under irrigation in the Sahel. The focus should be on areas where surface water is available. e boring of wells also can contribute to the development of horticulture. However, bearing in mind that global warming could exacerbate the scarcity of water resources through reduced rainfall/runoff and higher evaporation regimes, technologies such as micro-irrigation that allow the economical use of water should be considered.

- **Invest in pest and disease control**

Pests and diseases threaten food security in the Sahel, and climate change may aggravate the situation. For example, many observers linked the early invasion of the Sahel by the desert locust in the summer of 2004 to climate change. However, only some countries can address the locust problem independently, given its scope and ecology. Therefore, a concerted effort, bringing together all Sahelian and North African (Algeria and Morocco) countries, supported by the United Nations agencies such as FAO and donor countries, will be needed to eradicate the problem.

- **Develop low-cost post-harvest technologies**

Damage to grain stocks by insects and other storage pests is responsible for a significant share of production losses. The small-scale African farmers are permanently haunted by the fear of losing their harvests to storage pests, forcing them to sell their grains quickly when the price is lowest. Paradoxically, they will have to purchase those same grains at very high prices later in the year. A warmer climate is likely to increase this pressure since the reproductive cycle of these insects might be shortened. One way of getting peasant farmers out of this trap, hence reducing their vulnerability, is to reinforce their ability to store food using cheap conservation technologies. Techniques such as drum storage, solar disinfection, bagging technology, and improved ash storage have real potential (Murdock et al., 2003).

- **Promote agroforestry**

Agroforestry research and development needs to be strengthened, given the various roles it can play in mitigating the adverse effects of climate change. Policies should be put in place to rehabilitate degraded parkland systems and to accelerate the adoption of new technologies that can make a difference, preferably based on indigenous trees and shrubs. Promising technologies include the intensive planting of fodder trees such as *Pterocarpus erinaceus,* live hedges to support the development of off-season market gardening, windbreaks for wind-induced soil erosion control, and improved fallow to enhance soil fertility and reduce

soil losses. e Sahel Eco-Farm is a good model of an agroforestry system that could be scaled up in the region. The role of trees in improving microclimate, reducing soil erosion, and generating income will be more critical in the advent of climate change.

- **Develop processing industries**

Developing agro-processing industries is necessary for the quest for food security in Africa, specifically in the Sahel. These are necessary because they bring value addition to coarse grains and relieve rural women from drudgery and allow them to participate more effectively in income-generating activities. The primary objective is to improve the nutritional conditions of the hunger-prone populations of the Sahel. However, given the importance of livestock and the severe fodder shortages in the dry season, the use of millet or sorghum as animal feed will have to be explored.

- **Foster institutional linkages for agricultural sustainability**

The diffusion of technologies to reduce vulnerability needs the participation of a wide range of stakeholders, partners, and institutions. Since climate change may exacerbate rainfall variability, a close collaboration between meteorological and agricultural services will be necessary to use climate forecasts effectively. Extension services need to be strengthened, and agents provided with the necessary equipment and logistics to reach farmers more easily. Experience in Mali and other parts of Africa has shown the vital role of NGOs in rural development. A healthy collaboration between extension services, NGOs, and community-based organizations such as youth associations and women's groups may be more fruitful. To avoid intergenerational conflicts, religious and customary chiefs should also be consulted right from the beginning of the process. On-farm research involving farmers should be encouraged as much as possible since it creates a sense of ownership, facilitates technology uptake, and saves time and resources. Policies should also be put in place to encourage the private sector's contribution, for example, by signing contracts with research organizations.

- **Develop special rural micro-credit schemes for small-scale farmers**

Because of the need for adequate rural financial facilities, smallholder farmers have often been bypassed by new technologies. The agricultural banks that exist usually target big commercial farms. Micro-credit schemes such as the Rural Finance and Community Initiatives Project in Gambia should be revisited. Mali has also developed a credit program to finance income-generating activities.

- **Improve information delivery**

Information delivery is critical in enhancing the adaptive capacities of rural areas to climate change. Information on weather or new technologies can be transmitted to the farmers using rural radios and other media, such as mosques (for Muslims) and other gatherings, such as traditional beer-drinking ceremonies. The rapid development of mobile telephony is now opening up new opportunities and should be exploited fully to reach otherwise remote and unreachable areas. Encouraging farmers' field days have also proven effective for the rapid spread of new technologies.

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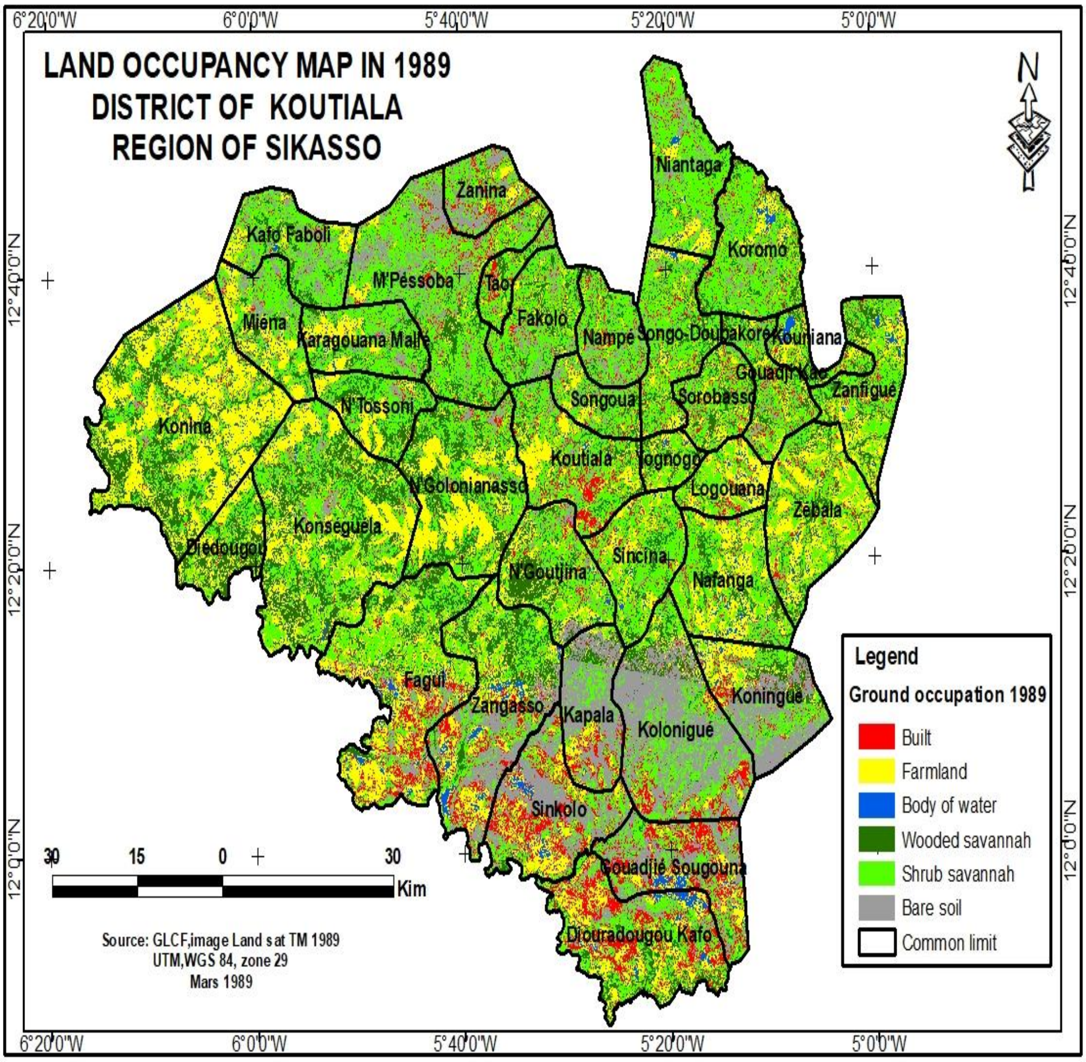
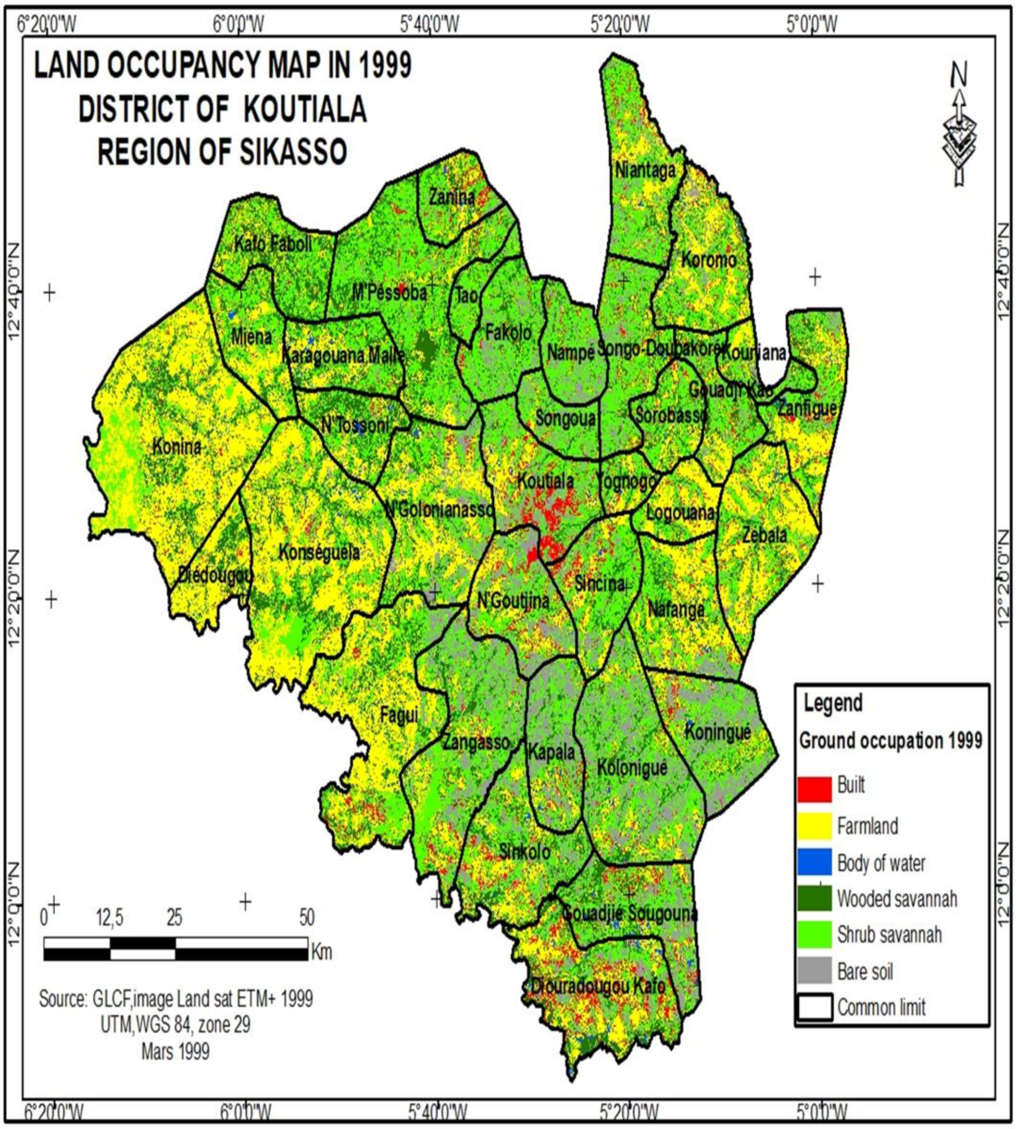
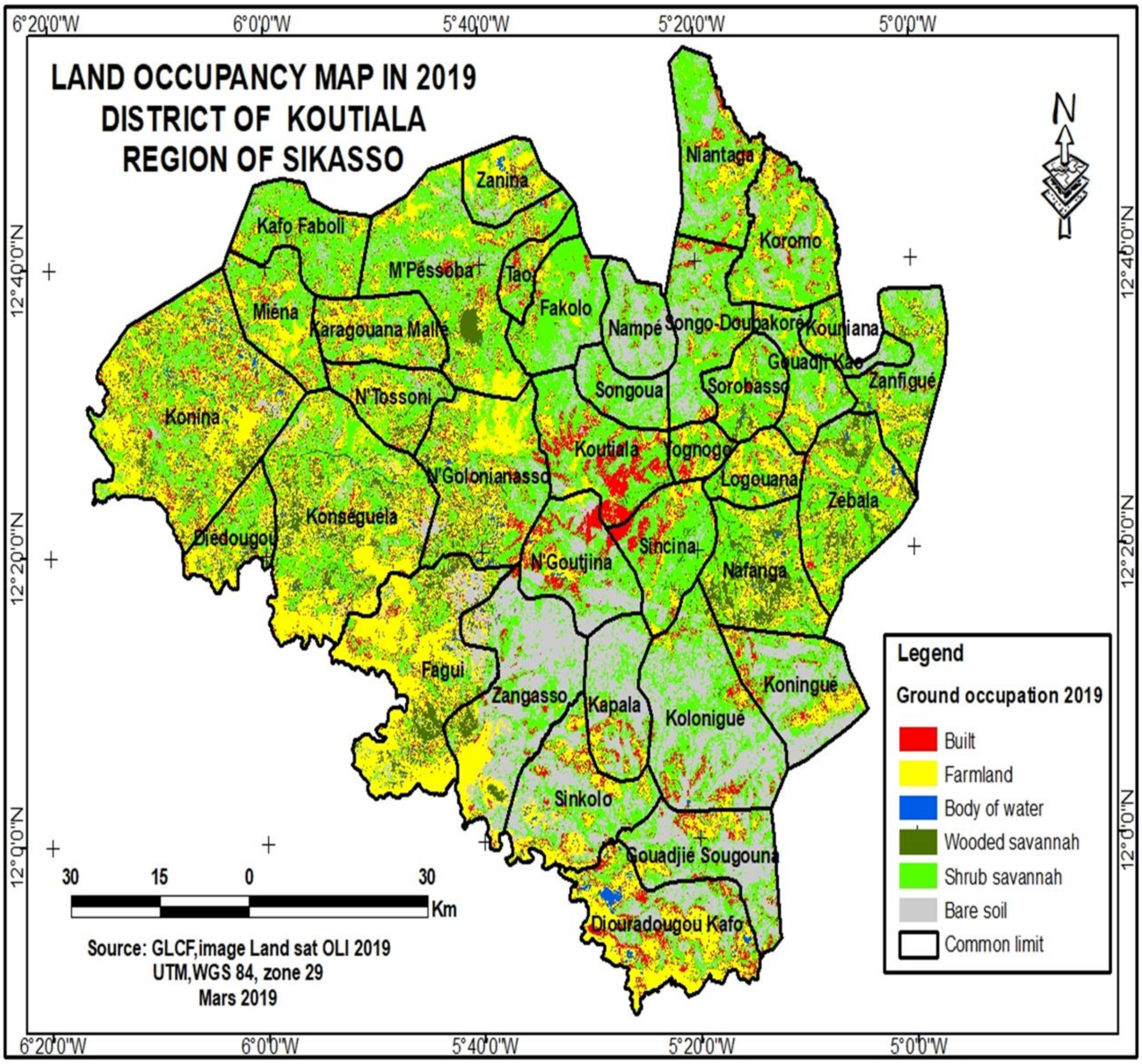
ANNEXES

Annexe 1: LU/LC

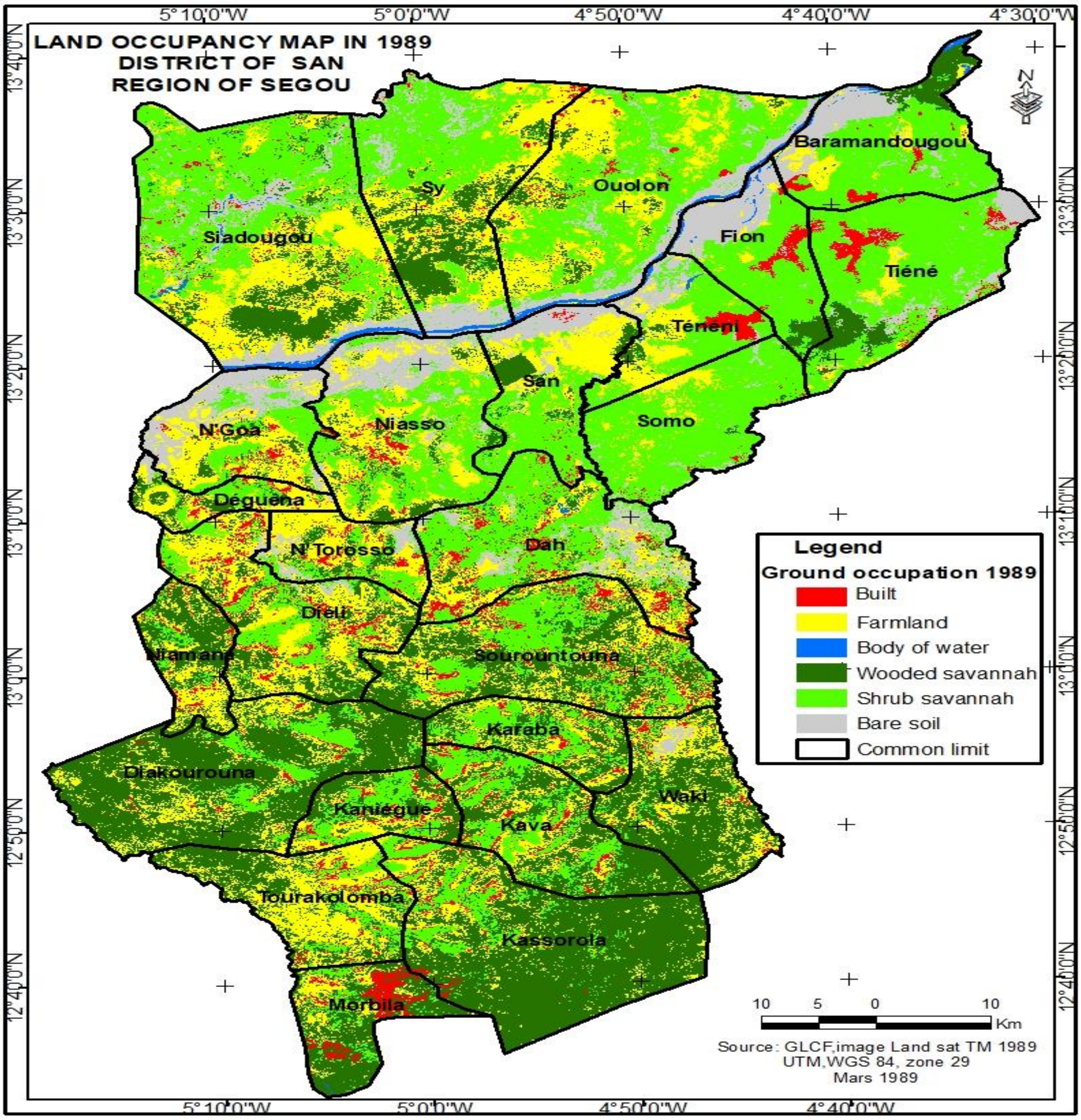
Koutiala district

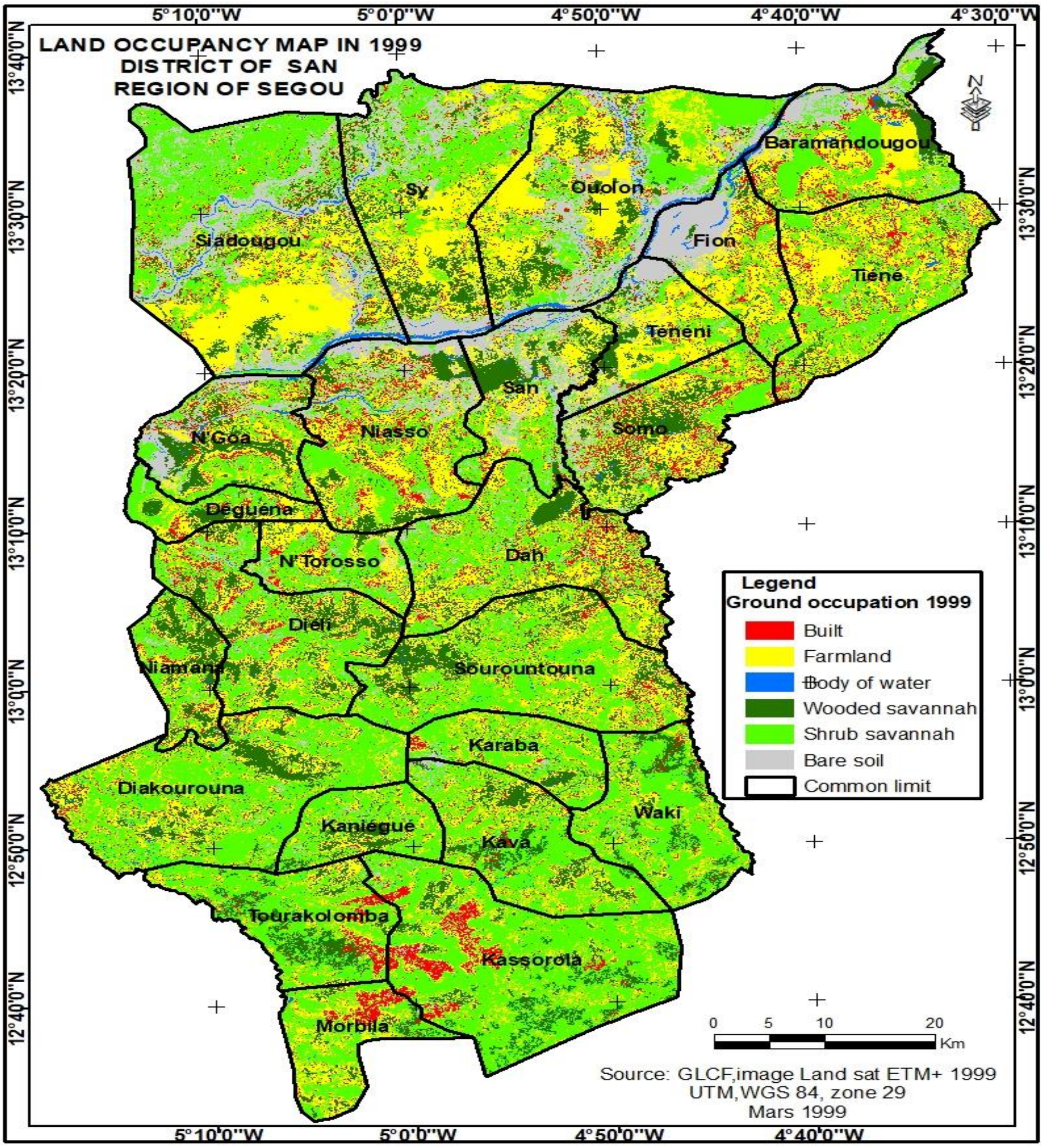



LAND OCCUPANCY MAP IN 1999
DISTRICT OF KOUTIALA
REGION OF SIKASSO
6°20'0"W
6°0'0"W
5°40'0"W
5°20'0"W
5°0'0"W
12°40'0"N
12°20'0"N
12°0'0"N
N
Niantaga
Zanina
Kafo Faboli
Koromo
M'Pessoba
Tao
Fakolo
Miena
Karagouana Mallé
Nampé
Songo-Doubakoré
Kouniana
Gouadji Kao
Zanfigue
Songoua
Sorobasso
N'Tossoni
Konina
Koutiala
Tognogo
N'Golonianasso
Logouana
Zebala
Konséguéla
Diédougou
Sincina
N'Goutjina
Nafanga
Fagui
Koningué
Zangasso
Kapala
Kolonigué
Sinkolo
Gouadjié Sougouna
Diouradougou Kafo
0 12,5 25 50
Km
Source: GLCF,image Land sat ETM+ 1999
UTM,WGS 84, zone 29
Mars 1999
Legend
Ground occupation 1999
Built
Farmland
Body of water
Wooded savannah
Shrub savannah
Bare soil
Common limit

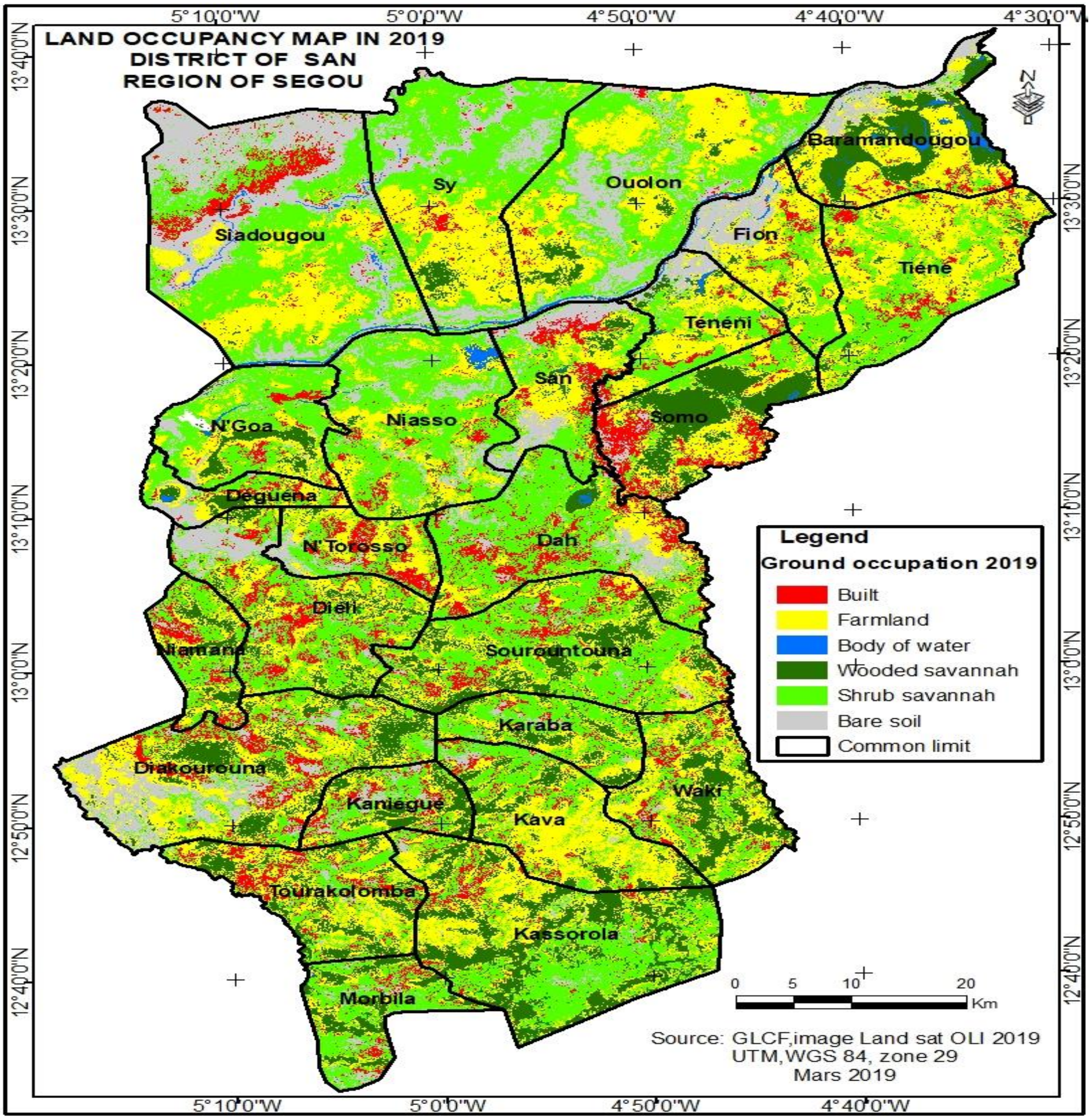

LAND OCCUPANCY MAP IN 2019
DISTRICT OF KOUTIALA
REGION OF SIKASSO
6°20'0"W
6°0'0"W
5°40'0"W
5°20'0"W
5°0'0"W
12°40'0"N
12°20'0"N
12°0'0"N
N
Niantaga
Zanina
Koromo
Kafo Faboli
M'Pessoba
Tao
Miéna
Fakolo
Nampé
Songo-Doubakoré
Kouniana
Karagouana Mallé
Gouadji Kao
Songoua
Sorobasso
Zanfigué
N'Tossoni
Konina
Koutiala
Yognogo
Logouana
N'Golonianasso
Zebala
Konséguéla
Diédougou
Sincina
N'Goutjina
Nafanga
Fagui
Zangasso
Kapala
Kolonigue
Koningué
Sinkolo
Gouadjié Sougouna
Diouradougou Kafo
30
15
0
30
Km
Source: GLCF,image Land sat OLI 2019
UTM,WGS 84, zone 29
Mars 2019
Legend
Ground occupation 2019
Built
Farmland
Body of water
Wooded savannah
Shrub savannah
Bare soil
Common limit

San district/LU/LC





LAND OCCUPANCY MAP IN 1999
DISTRICT OF SAN
REGION OF SEGOU
5°10'0"W
5°0'0"W
4°50'0"W
4°40'0"W
4°30'0"W
13°40'0"N
13°30'0"N
13°20'0"N
13°10'0"N
13°0'0"N
12°50'0"N
12°40'0"N
Baramandougou
Sy
Ouolon
Siadougou
Fion
Tiéné
Teneni
San
N'Goa
Niasso
Somo
Déguéna
N'Torosso
Dah
Diéli
Niamana
Sourountouna
Karaba
Diakourouna
Waki
Kaniégué
Kava
Tourakolomba
Kassorola
Morbila
Legend
Ground occupation 1999
Built
Farmland
Body of water
Wooded savannah
Shrub savannah
Bare soil
Common limit
0 5 10 20
Km
Source: GLCF,image Land sat ETM+ 1999
UTM,WGS 84, zone 29
Mars 1999


LAND OCCUPANCY MAP IN 2019
DISTRICT OF SAN
REGION OF SEGOU
5°10'0"W
5°0'0"W
4°50'0"W
4°40'0"W
4°30'0"W
13°40'0"N
13°30'0"N
13°20'0"N
13°10'0"N
13°0'0"N
12°50'0"N
12°40'0"N
Baramandougou
Sy
Ouolon
Siadougou
Fion
Tiéné
Teneni
San
Niasso
N'Goa
Somo
Deguena
N'Torosso
Dah
Dieli
Niamana
Sourountouna
Karaba
Diakourouna
Waki
Kaniegue
Kava
Tourakolomba
Kassorola
Morbila
Legend
Ground occupation 2019
Built
Farmland
Body of water
Wooded savannah
Shrub savannah
Bare soil
Common limit
0 5 10 20 Km
Source: GLCF,image Land sat OLI 2019
UTM,WGS 84, zone 29
Mars 2019

Annexe 2: questionnaire

Objective 2: Assessment of households' food security

Consommation alimentaire

Combien de jours au cours des 7 jours précédents, les membres de votre ménage ont-ils mangé les aliments suivants, préparés et /ou consommés à la maison et de quelle source provenaient-ils ? (Utiliser les codes ci-dessous, mettre 0 si l'aliment n'a pas été consommé au cours des 7 derniers jours) Note pour les énumérateurs: Déterminer si la consommation de poisson, de lait était seulement en petites quantités.			
Catégories d'aliments		1.03- Nombre de jours où l'aliment a été consommé pendant les 7 derniers jours Si 0 jours, ne pas mentionner la source principale.	1.04- Comment cet aliment a-t-il été acquis? Donner la principale source de l'aliment au cours des 7 derniers jours
1	**Céréales et grain :** Riz, pâtes, pain / gâteau et/ou beignets, sorgho, mil, maïs, fonio	/___/	/___/
2	**Racines et tubercules :** pommes de terre, igname, manioc, patate douce blanche, taro et/or autres tubercules	/___/	/___/
3	**Légumineuses / noix :** haricots, niébé, arachide, lentilles, noix, soja, pois d'Angole et/ou autres noix	/___/	/___/
4	**Légumes orange (légumes riches en Vitamine A):** carotte, poivron rouge, courge, patate douce orange	/___/	/___/
5	**Légumes à feuilles vertes:** épinards, brocoli, amarante et/ou autres feuilles vert foncé, feuilles de manioc	/___/	/___/
6	**Autres légumes:** oignon, tomates, concombre, radis, haricots verts, pois, laitue, etc.	/___/	/___/
7	**Fruits oranges (Fruits riches en Vitamine A):** mange, papaye, abricot, pêche	/___/	/___/
8	**Autres fruits:** banane, pomme, citron, mandarine	/___/	/___/
9	**Viande:** chèvre, bœuf, poulet, porc, sang, (viande en quantité, non pas simplement comme condiment)	/___/	/___/
10	Foie, rognons, cœur et/ou autre viande d'organe	/___/	/___/
11	**Poisson / coquillage:** poisson dont le ton en boîte, escargot, et/ou autres fruits de mer (poisson en quantité, non pas simplement comme condiment)	/___/	/___/
12	**Œufs**	/___/	/___/

13	**Lait et autres produits laitiers:** lait frais / aigre, yogourt, fromage, autres produits laitiers (margarine/beurre exclus ainsi que la petite quantité de lait pour le thé et le café)	/___/	/___/
14	**Huile/matières grasses/beurre:** huile végétale, huile de palme, beurre de karité, margarine, autres huiles / matières grasses	/___/	/___/
15	**Sucre ou sucreries:** sucre, miel, confiture, gâteau, bonbons, biscuits, viennoiserie et autres produits sucrés (boissons sucrées)	/___/	/___/
16	**Condiments/épices:** thé, café/cacao, sel, ail, épices, levure/levure chimique, tomate/sauce, viande ou poisson comme condiment, condiments incluant des petites quantités de lait/thé, café.	/___/	/___/
Codes d'acquisition des aliments 1 = Production propre (récoltes, élevage) 2 = Pêche / Chasse 3 = Cueillette 4 = Prêts		*5 = Marché (achat avec des espèces)* *6 = Marché (achat à crédit)* *7 = Mendicité* *8 = Troc travail ou biens contre des aliments*	*9 = Dons (aliments) de membres de la famille ou d'amis* *10 = Aide alimentaire de la société civile, ONG, gouvernement, PAM, etc.*

La valeur du panier alimentaire (dépenses alimentaires)

		Votre ménage a-t-il acheté un des aliments suivants pendant les 30 derniers jours pour la consommation domestique ? Si 'non', mettre '0' et passer à la question suivante. Si 'oui', demander à la personne interrogée d'estimer la dépense totale (en espèce et à crédit) pour cet aliment pendant les 30 derniers jours. (enregistrer les dépenses en monnaie locale)		Valeur estimée des aliments non achetés consommés pendant les 30 derniers jours (cette question fait référence à la consommation indiquée au point précédent)
		(espèces, monnaie locale)	**(crédit, monnaie locale)**	**(monnaie locale)**
1	Céréales (maïs, riz, sorgho, blé, pain)			
2	Tubercules (patate douce, manioc)			
3	Légumineuses (haricots, pois, arachide)			
4	Fruits et légumes			

5	Poisson/Viande/Œufs/ Poulet			
6	Huile, matières grasses			
7	Lait, fromage, yogourt			
8	Sucre/Sel			
9	Thé/Café			
10	Autres repas/snacks consommés hors de la maison			

Dépenses non alimentaire des ménages

	Avez- vous acheté les articles suivants pendant les 30 jours pour votre consommation domestique? Si non, indiquer 0 et aller à l'article suivant	Estimation des dépenses pendant les 30 derniers jours (enregistrer les dépenses selon la monnaie dans laquelle elles ont été faites)	Au cours des 6 derniers mois combien avez-vous dépensé pour chaque article /activité/service suivant? Utiliser le tableau suivant, indiquer 0 si aucune dépense n'est faite.		Estimation des dépenses pendant les six derniers mois
		(monnaie locale)			**(monnaie locale)**
1	Alcool/Vin de palme & Tabac		**9**	Dépenses médicales, soins de santé	
2	Savon & articles pour les soins de santé		**10**	Vêtements, chaussures	
3	Transport		**11**	Education, frais d'inscription, uniforme, etc.	
4	Fuel (bois, paraffine, etc.)		**12**	Remboursement des dettes	
5	Eau		**13**	Célébrations / évènements sociaux	
6	Electricité/Eclairage		**14**	Intrants agricoles	
7	Communication (téléphone)		**15**	Epargne	
8	Loyer		**16**	Construction/réparation	

Stratégies de survie basées sur les moyens de subsistance (léger)

Au cours des 30 derniers jours, un membre de votre ménage a-t-il mené une des actions suivantes pour faire face à un manque de nourriture ou un manque d'argent pour acheter de la nourriture ?	1 = Non, car je n'ai pas manqué de nourriture 2 = Non, car j'ai déjà vendu ces avoirs ou mené cette activité au cours des 12 derniers mois et je ne peux pas continuer à le faire 3= Oui 4= Non applicable
1.1 Vendu des actifs/biens du ménage (radio, meuble, réfrigérateur, télévision, bijoux etc...)	
1.2 Réduit les dépenses non alimentaires de santé (dont de médicaments) et d'éducation	
1.3 Vendu des biens productifs ou des moyens de transport (machine à coudre, brouette, vélo, car, etc...)	

1.4 Dépensé l'épargne	
1.5 Emprunté de l'argent / nourriture auprès d'un prêteur formel /banque	
1.6 Vendu la maison ou du terrain	
1.7 Retiré les enfants de l'école	
1.8 Vendu les derniers animaux femelles	
1.9 Mendié	
1.10 Vendu plus d'animaux (non-productifs) que d'habitude	

Objective 4: Identify and assess the performance of current adaptation measures implemented by farmers

Technologies utilises par les producteurs	**1.** Jamais	**2.** Souvent	**3.** Toujours
1- Zai			
2- Demi-lune			
3- RNA			
4- Variete proce			
5- Furmure orgique			
6- Engrais chimique			
7- Cordon pierreux			
8- Rotation des cultures			
9- Construction de diguette ou petits barrages			
10- Construction des retenus d'eau			
11- Plantation des varietes résistantes a la secheresse			
12- Diversification de la production agricole			
13- Utilisation des informations agro-meteorologicales			
14- Développement			

des nouveaux systemes de production			
15- Mise en place des banques alimentaires			
16- Culture fourragère			

Strategies d'adaptation	**Jamais**	**Souvent**	**Toujours**
Commerce			
Elevage			
Peche			
Maraichage			
Artisanat			
Cooperative			
Exode rural			
Aide de l'exterieur			
Travail pour l'argent			
Entraide			