IMPACT OF CLIMATE CHANGE ON AGROPASTURE IN MALI AND ADAPTATION STRATEGIES

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Thesis of the Doctoral Research Programme of the West Africa Climate Systems, under the West Africa Science Service Centre on Climate Change and Adapted Land Use, in the Department of Meteorology and Climate Science submitted to the School of Postgraduate Studies in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy in Meteorology and Climate Science of the Federal University of Technology, Akure, Nigeria.

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Declaration

I hereby declare that this Thesis was written by me and is a correct record of my own work. It has not been presented in any previous application for any degree of this or any University. All citations and sources of information are clearly acknowledged by means of references.

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Certification

We certify that this Dissertation entitled "Impact of Climate Change on Agropasture in Mali and Adaptation Strategies" is the outcome of the research carried out by Assa TAPILY under the WASCAL DRP-WACS in the Department of Meteorology and Climate Science of the Federal University of Technology, Akure.

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Abstract

In Mali, like other developing countries, agropastoralists are particularly vulnerable to the effects of climate change. This study was conducted to examine the impacts of climate change on crop yields (sorghum and groundnut) and to assess the adaptability of agropastoralists to the impacts of climate change. To this end, an analysis of daily rainfall and temperature data covering 60years (1960 to 2020) from the Ségou, Sikasso and Bamako stations was carried out using Instat+ v3.36, Rstudio, XLSTAT and Rclimdex software. Four climate models were used for the climate projection, (GFDL-ESM4, INM-CM4-8, INM-CM5-0 and NorESM2-MM) of phase 6 of the coupled model intercomparison project (CMIP6) under scenarios SSP2-4.5 and SSP5-8.5 of the annual rainfall, solar radiation and temperature for a period of 2021-2050 and 2070-2100 in the region of Ségou, Niono, Sikasso, Kolondieba and Bamako. MAKESENS was used for the realization of a linear model to estimate the magnitude of the trend in the time series. Field survey were conducted among 355 agropastoralists in three regions of Mali to assess the impacts and adaptation strategies of agropastoralists. The analysis of climate data shows a downward trend for rainfall. As for temperature, there was an upward trend in the series from 1960 to 202 at the station of Ségou, Sikasso and Bamako. Intercomparison of coupled models (CMIP6) under scenarios SSP2-4.5 and SSP5-8.5 of annual rainfall, solar radiation and temperature in the near future period 2021-2050 and far future 2070-2100 in the region of Ségou, Niono, Sikasso, Kolondieba and Bamako was conducted. According to the scenario SSP2-4.5 in the near future period 2021-2050 an upward trend in average annual temperatures of 0.14°C for five localities of Mali (Ségou-Niono, Sikasso-Kolondieba and Bamako) compared to the scenario SSP5-8.5 with an upward trend of 0.43°C. Scenario SSP5-8.5 in the far future period, 2070-2100 revealed an upward trend in annual average temperatures of 0.27°C. On the other hand, for the scenario SSP5-8.5 the upward trend is 0.58°C. Experimental tests were carried out on sorghum and groundnut crops during the 2021 agricultural campaign. Six varieties of sorghum CSM63E, CSM388, DT-15, KIT19, Tiandougou-Coura and Soubatimi and two varieties of groundnut (ALLASSON Fleur 11 and ICVG 26024) were studied. The DSSAT Model was used to calibrate and simulate crops yields and also determine crop growth of the six sorghum varieties studied. The calibration has been carried out to determine the genetic coefficients of these four based on the results obtained from the experiments. The climate projection of crop yields from 2015-2099 in the different regions of Mali for a spatial model was evaluated. It indicates a low tops weight simulated yield with an average of 9761kg/ha and 17% coefficient of variation for five varieties (CSM388, DT15, KIT19, Soubatimi and Tiandougou-coura). As for CSM63E gave a better tops weight of 10141kg/ha with 17.20% coefficient of variation. As for grain yield shows a higher yield of 3449 kg/ha for fives varieties (CSM388, DT15, KIT19, Soubatimi and Tiandougou-coura) with 18% coefficient of variation unlike CSM63E which has the lowest yield 1694kg/ha with 10%.

Dedication

After giving thanks to God; I dedicate this humble work to:

My father Hama Malam who encouraged me so much;

My late mother Mairama Boureima, may her soul rest in peace which I would have liked to see her live this day;

My uncle Mamadou Kané and my aunt Maman Aïssata Diakité for their multiple advice and support;

My husband Boubacar Diarra for his invaluable encouragement and support;

My brothers, sisters and friends for their moral support and for having believed in my ability to complete this doctoral training;

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List of Acronyms and Abbreviations

AEDD: Environment and Sustainable Development Agency

ANR: Assisted Natural Regeneration

Ca: Calcium

CC: Climate Change

CEC: Cation Exchange Capacity

CEDA: Environmental Data Analysis

CMIP: Coupled Model Intercomparison Project

CMS: Cropping System Model

CV: Coefficient of Variation

CWAM: Tops weight at maturity

DAP: Days After Planting

DRP: Doctoral Research Program

DS: Days

DSSAT: Decision Support System for Agrotechnology Transfer

ECOWAS: Economic Community of West African States

EDS: Environmental Data Service

ENSO: El Niño-Southern Oscillation

FAO: Food and Agriculture Organization of United Nations

FUTA: Federal University of Technology Akure, Nigeria

GDP: Gross Domestic Product

GFDL-ESM: Geophysical Fluid Dynamics Laboratory Coupled Model - Earth System Model

GM: General Mean

HHI: Harvard Humanitarian Initiative

HWAM: Yield at maturity

HWUM: Unit weight at maturity

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

IER: Institute of Rural Economy

INM-CM: Institute for Numerical Mathematics - Climate Model

IPCC: Intergovernmental Panel on Climate Change

IRD: Institute of Research for Development

MDAT: Maturity Date

MDATS: Maturity Days After Planting Simulated

NEPAD: The New Partnership for Africa's Development Agency

NERC: Environmental Data Service

NorESM-MM: Norwegian Earth System Model - Model is the Medium-resolution

NPK: Nitrogen Phosphorus Potassium

PANA: Programmes d'Action Nationaux aux fins de l'Adaptation

Q: Slope

SSPs: Shared Socioeconomic Pathways

SSPs: Shared Socioeconomic Pathways

UEMOA: West African Economic and Monetary Union

UNDP: United Nations Development Programme

UNEP: United Nations Environment Programme

UNESCO: United Nations Educational Scientific and Cultural Organization

UNFCCC: United Nations Framework Convention on Climate Change

UNOCHA: United Nations Office for the Coordination of Humanitarian Assistance

USAID: Agency for International Development

WACS: West African Climate Systems

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

Z: Test statistic

α: Confidence level

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Climate change is expected to influence severely every country in the world, due to an increase in greenhouse gases, the cause of climate warming, the combustion of oil, gas and coal, whether to generate electricity or heat, or for industrial use (Erwin, 2009). Many scientists have noted that in the next century the earth's temperature will increase by several degrees due to the increase in the greenhouse gas concentration in the atmosphere (Res et al., 1996). In a complex manner climate change will affect agriculture, food production and availability. It can also affect directly by changes in agroecological conditions and by affecting indirectly production system, distribution of incomes and growth.

The various effects of that are frost-free season (and growing season) will lengthen, changes in precipitation patterns, more droughts and heat waves until we find a new balance. However climate change is positively expected to be a driving factor of migration in the future, because of displacement due to extreme weather events and sea-level rise, and/or deteriorating agricultural productivity (IPCC, 2007a). These impacts will include changes in the productivity of rainfed crops and forage, reduced water availability and more widespread water shortages, and changing severity and distribution of important human, livestock and crop diseases. Major changes can thus be anticipated in livestock systems, related to livestock species mixes, crops grown, and feed resources and feeding strategies (Harvell et al., 2002). Climate change may bring about substantial shifts in disease distribution. Higher temperatures may increase the rate of development of pathogens or parasites that spend some of their life cycle outside their animal host, which may lead to larger populations (Harvell et al., 2002). There is increasing evidence that climate change will strongly affect the African continent and will be one of the challenging issues for future development, particularly in the Sahelian regions.

In sub-Saharan Africa, households are seriously dependent on their natural resource base to provide food and income for the family, and the availability of such resources is reliant on favourable seasonal weather conditions (Debela et al., 2015). Climatically more variable regions of sub-Saharan Africa, where dryland farming systems are common, rely heavily on rains only (rainfed farming systems). Food is one of society's key sensitivities to climate. A year of not enough or too much rainfall, a hot spell or cold snap at the wrong time, or extremes, like flooding and storms, can have a significant effect on local crop yields and livestock production (Altieri and Koohafkan, 2008). Modern farming technologies and techniques have helped to reduce this vulnerability and boost production (Slingo et al., 2005).

Several studies concluded that the poorest countries would be hardest hit, with reductions in crop yields in most tropical and subtropical regions due to reduced water availability, and new or altered insect pest incidence (Nath and Behera, 2011; Suryavanshi et al., 2012; Shivanna, 2022). In Africa and Latin America many rainfed crops are near their maximum temperature tolerance, so that yields are likely to fall suddenly for even small climate changes. A reduction in agricultural productivity of up to 30% for the 21st century is projected (Gornall, et al., 2010) and the fishing industry will also be severely affected in some places. Climate change induced by increasing greenhouse gases is likely to affect crops differently from region to region.

According the Fourth Report of the Intergovernmental Panel on Climate Change (IPCC, 2007b), the impacts of climate change are particularly severe and even drastic for African countries, which mostly are developing countries, where poor communities are highly dependent on the direct use of local natural resources, and where widespread poverty limits the capacity to cope with climate variability and natural disasters (St.Clair and Lynch, 2010). Climate variability is important in a context of vulnerability due to the many risk factors. In addition, it has often been found that the African continent is particularly vulnerable to the impacts of climate change due to widespread poverty, periodic droughts, uneven land distribution and heavy dependence on rainfed agriculture (Descheemaeker et al., 2018). Under its current climate, Africa is already facing recurrent food crises and water scarcity which are exacerbated by rapid population growth. Climate change will thus act as an additional stress in the future of African economies and livelihood (Appleyard, 1985). Africa with the lowest global greenhouse gas emission rate (4%) is portrayed as the continent most vulnerable to future climate shocks or climate extremes that are reflected in the devastating effects of droughts and increasingly severe flooding. The IPCC report shows many aspects of this vulnerability (IPCC, 2007c). First of all, agriculture is a major sector for the continent, and it is even the sector most sensitive to climatic hazards, when we see the distribution of rainfall, or major crops such as corn, consumed a just about everywhere, or wheat in northern Africa. The yields of these crops drop significantly, despite the fact that research is constantly working to develop more resilient varieties. Since 1960 agricultural yields have fallen significantly (Totin et al., 2020).

Mali is currently experiencing rapid population growth. The Population Reference Bureau estimates that by 2050 the population of Mali which is currently 18.9 million will reach about 45 million (Walker, 2016). The impacts of this population growth will be felt in fertile lands and in regions that are rich in resources. Especially, in the south of Mali such as Sikasso which is the most populated region. A growing population requires equitable use and management of natural resources to meet subsistence and food security needs (Rüttinger et al., 2015). However, Mali is extensively perceived to increase the inter-annual variability of the rainy season as climate change becomes increasingly unpredictable, having a probability of increased season variability, with an increase in the number of drought periods during the rainy season and also an increase in temperature which persists in the country. Indeed, the country is confronted by various climatic phenomena and livelihoods threatened by drought that aggravates the loss of agricultural production or lower yield. Conflicts between ranchers and farmers and the impact of climate change are among the main problems facing the agricultural sector (Mertz et al., 2009).

In Mali, agricultural production is based mainly on rainfall, and therefore very sensitive to climate change. Climate change will certainly have a significant impact on this production sector by causing changes in crop yields, water availability, pests and diseases, livestock health and other biophysical factor. As a consequence, changes in agricultural productivity will have a dominant effect on production incomes and on food security in general. This is by modifying agricultural production and reducing access to growing and grazing areas, which leads to increased food insecurity. While not directly related to climate change, this example, combined with previous droughts, illustrates how climate change can affect people's livelihoods and food security (Mitra, 2017).

Mali, a vast continental country, is very vulnerable to climate variability and change, as are other Sahelian countries. Developing countries, such as Mali, are particularly at risk because of their low incomes, low human capital, and economic vulnerability. In Mali, natural resources are shrinking due to multiple pressures related to human activities and natural factors such as climate hazards. According to AEDD (2011), the main climate challenges facing the country include droughts, floods, strong winds, high temperature variations. Climate change threatens the primary sector (agriculture, ranching, poaching and fishing) and forestry, all of which are leading sectors for the country's economy. Health, water resources, infrastructure, and industry and mining are also exposed to climate change (AEDD, 2011). Nonetheless, the country's fragility, its dependence on climate-sensitive sectors such as agriculture, livestock, its history of conflicts for resource use between farmers and pastoralists, and its low levels of development makes it highly vulnerable to climate change and variability.

In Mali, agriculture and pastoral activities occupy 80% of the population. Notwithstanding, only a quarter of the country receives enough rain to support extensive farming and there are only 2% of the land that is favourable to intensive farming (USAID, 2016). In Mali, as in most developing countries, agro-pasture is particularly affected by the effects of climate change. Despite the important role agriculture and livestock play in the economy and the maintenance of livelihoods, these sectors now face many challenges, including those posed by climate change. Indeed, Africa is one of the regions considered to be most vulnerable to the effects of climate change because of its high dependence on natural resources and its limited capacity to cope with climate variability and extreme weather phenomena (IPCC, 2014).

The climate change scenarios foresee not only a continuation of warming, but also an increase in climate extremes, in particular drought phenomena, although uncertainties remain on the results of the rainfall projections in West Africa and the Sahel (IPCC, 2007b). The impacts of these phenomena on the agricultural and livestock systems of the continent, and in particular in its Sahel portion of the Sahara, has already been felt since the droughts of the 1970 with the consequent reduction in the quality of agricultural production, feed and feed resources, as well as increased livestock disease and low productivity in Sahel countries such as Mali (PANA, 2006). Agriculture and livestock in this country are the main activities and employ almost 87% of the working population, and their contribution to the constitution of Gross Domestic Product (GDP) is very important. Although these sectors remain vulnerable, the impacts of climate change on the livelihoods of agro-pastoralists (Debela et al., 2015), particularly those where drought leads to famine and poverty, are not yet well understood mainly because of the multitude of factors contributing to agro-pastoral poverty (Debela, 2017).

In the face of unprecedented socio-environmental changes, risk and threat to climate effects, Sahelian agro-pastoralists react with transhumance which is one of the ways to adapt to the high climate variability and the threat of drought that the Sahel has practiced for more than 50 year in an economic context, social and political that is more mobile (Kampmann and Kirui, 2021). Indeed, scientific study has shown that between 1950 and 2010, population growth can deteriorate ecosystems with the climatic conditions that pose a great challenge to the Sahelian rural world, especially on the readiness to meet food needs (Balehegn, 2015).

The growing need for arable land is realized through an increase and a grabbing of land formerly devoted to livestock. Such a situation makes it possible to better understand the reasons for the conflict between crop farmers and livestock keepers due to the use of space and resources which are perceived to belong to both groups object (Gonin, 2016).

The conditions of vulnerability create an ongoing difficult situation for ago-pastors, a situation that cannot be mastered without efficient external support and without their firm commitment to sustainable local development. The purpose of this study is to provide guidance on key issues highlighting challenges. In order to learn more about the reality of climate change in agro-pastoral environments, there is a need to find impact of climate change on agro-pasture as well as adaptation strategies in Mali.

1.2 Aim of Research

The aim of this research study is to examine the impacts of climate change on the yield of Sorghum and Groundnut and assess the adaptability of agro-pasture to the climate change impacts.

The specific objectives are:

(i) examine the impact of climate change on agro-pastoral activities in Mali

(ii) evaluate the potential impacts of climate change on the yield of crops with emphasis on sorghum and groundnut and

(iii) assess the vulnerability of agro-pastoralists to the climate change.

1.3 Problems and justification of Study

Sub-Saharan Africa is particularly vulnerable to climate change as it already suffers from high temperatures, unpredictable rainfall and higher ecological pressures worse than other continents (IPCC, 2014a). Africa also shares with other developing countries a particular vulnerability to climate change due to geographical exposure, low incomes and increased dependence on climate-sensitive sectors such as agriculture, the livestock keeping and fishing. Climate change will have a very large impact on animal production because of its impact on livestock feed and productivity. Higher temperatures and lower precipitation lead to lower crop and rangeland yields and contribute to the degradation of rangeland. Higher temperatures also reduce the amount ingested by animals and lower feed conversion rates (Walker and Rowlinson, 2007). Decreased rainfall and increased frequency of droughts lead to lower primary productivity of rangelands, risk over grazing and soil degradation; aggravation of food insecurity and conflicts of access to scarce resources (Rowlinson et al., 2008). The period of plant growth is shortening on many pastures, especially in sub-Saharan Africa. Climate change plays a significant role in the spread of vector-borne diseases and animal parasites, which will have a more serious impact on the most vulnerable men and women in the livestock sector (Escarcha et al., 2018).

According to DeFries et al., (2015) all plant species will experience metabolic and physiological changes due to climate change, but these effects will differ by species. For these researchers, precipitation and average temperatures exert a considerable influence on the type of ecosystem that can develop in a given area. Any change in these variables will lead to changes in ecosystems, their composition (flora and fauna) and their ability to adapt to new conditions. The impacts of climate change are increasingly felt on agriculture in developing countries. Most of these impacts are attributed to increased temperature and precipitation variability. Although agriculture has shown, throughout history, a great ability to adapt to changing conditions, with or without a conscious response from farmers, the current changes have exceeded the autonomous limits of adaptation, and requires supportive policies to enable farmers to cope with these changes (Iglesias et al., 2007).

Faced with all these challenges, the objectives of the study are relevant, namely the impacts of climate change on crop yields (sorghum and groundnut) using the DSSAT model and also the analysis of the adaptability of agro-pasture.

1.4 Justification for choice of crop

Mali's economy is primarily based on agriculture and agropastoralism. Agriculture accounts for more than 35 percent of Gross Domestic Product (GDP) and 80 percent of livelihoods (FAO, 2017). The country’s adverse climatic conditions, along with its political and institutional instability, threaten key sectors of agriculture and health. Mali consists of two main regions (North and South), each with different conditions for agricultural production. The North is the region most challenged by drought, desertification and population migration (FAO, 2017).

Sorghum and millet are strategic crops for food security in much of the Sahel. About half of the farming population grow sorghum and millet crops, which together account for 5-7 percent of all full-time jobs in the country. Sorghum and millet contribute 5 percent to the gross domestic product and account for about 15 percent of consumption shares (in monetary terms) in Mali. These crops are highly adapted to the low rainfall and light soil types that prevail in the Sahel (Kaminski and Elbehri, 2013).

Sorghum is a highly reliable crop that grows well in hot, dry environments. It is "climate change-ready", and provides food security and income for millions of poor farmers living in such locations. Five hundred **(**500) million people rely on sorghum as a dietary staple food (Proietti et al., 2015; ICRISAT, 2020; Khoddami et al., 2021). Sorghum is also a source of feed and fodder for livestock, and enables smallholders to diversify into more lucrative crop/livestock systems. While sorghum is valued primarily as a staple food that provides a critical source of calories, it also serves as a good source of protein, fibre and important micronutrients, especially for growing children.

Africa is the second largest groundnut producing continent accounting for about 40% and 31% of the global area and production, respectively. West and Central Africa region accounts for more than 70% of the groundnut production in Africa where the crop is cultivated by smallholder farmers. Groundnut is a major cash crop for many households (ICRISAT, 2020 b).

The groundnut stems are used as fodder for animals. It is currently grown on about 21.8 million hectares worldwide. Global annual production totalled 38.6 million tons, 95 percent of which occurred in developing countries (FAO, 2011). In West Africa, although Nigeria and Senegal are the largest producers of groundnut, Mali and Niger are also important producers. In Mali groundnut is grown on 0.29 million ha with an average production and productivity of 0.26 million tonnes/ha and 880 kg/ha, respectively (FAO et al., 2012).

1.5 Limitations/Scope of the research work

A number of limitations are considered in this research, insecurity, in particular jihadism activities in the Republic of Mali in order to reach as many localities as possible in the context of surveys of agropastoralists. The socio-political situation in Mali as well as the Economic Community of West African States (ECOWAS) and West African Economic and Monetary Union (UEMOA) sanctions have impacted the flow of financial movement.

CHAPTER TWO

2.0 LITERATURE REVIEW

The United Nations Framework Convention on Climate Change (UNFCCC, 1992a), in its Article 1, defined climate change as: "climate changes that are attributed directly or indirectly to human activity altering the composition of the global atmosphere and that are in addition to the natural variability of climate observed for comparable periods". IPCC argued that climate change refers to any change in the climate for time, whether due to natural variability or human activities. Sall et al., (2011) found that climate change is one of the biggest concerns in the world. Human activities have contributed significantly to the increase in the concentration of greenhouse gases in the atmosphere, thereby altering the planet's ecological balance as Figure 2.1 illustrates. Lobell and Schenker (2011) showed that climate change will reduce global agricultural yields by 2% per decade during the 21st century, while global demand will increase by 14% per decade during the same period until 2050. The same authors stated that climate change is already having a significant impact on agriculture, and livestock production is still expected to have a direct and indirect impact on food production.

Figure 2.1 . Climate change effects Source: Sustainable Energy & Environment Coalition WASHINGTON, D.C. (10 March 2023)

Today, it is almost impossible to avoid the consequences of climate change that risk increasing the vulnerability of the world's populations, especially those of the Sahel countries demonstrated by (IPCC, 2014b). This transition zone, between the Saharan domain in the north and the savannahs of the Sudanese domain, is one of the most fragile regions of the world in the face of the effects of climate change. O'Meagher (2005) argues that short-term natural extremes such as storms and floods, interannual and decadal climate variations as well as large-scale circulation changes such as the El Nino Southern Oscillation all have important effects on crop, pasture, and forest production. For example, El Nino-like conditions increase the probability of farm incomes falling below their long-term median by 75% across most of Australia's cropping regions, with negative impacts on gross domestic product ranging from 0.75% to 1.6%. However, the survival of Sahelian communities depends, for the most part, on the exploitation of natural resources, particularly through agriculture and livestock farming, which are subject to climate fluctuations that are difficult to predict. In such conditions, it is expected that rainfed crop production will become increasingly risky and farmers will shift to livestock keeping. This trend is likely to be reinforced by the increasing demand for livestock products in the region as stated by Gitz et al., (2016). However, notwithstanding the importance of the sector, livestock has received very little attention in regional policy documents aimed at climate adaptation as indicated by (Escarcha et al., 2018).

The agriculture and livestock sector are a dominant part of the economy in most African countries and provides the majority of jobs and livelihoods. Therefore, there is an urgent need to develop new strategies to improve agricultural productivity (NEPAD, 2013). Consequently, its impacts must be systematically integrated into policies. IPCC (2007a) declared that developing countries are particularly vulnerable as their economies are generally more dependent on climate-sensitive natural resources and also because they are less able to cope with the impacts of climate change.

Pricope et al., (2013) proved that yields from Africa's rainfed agriculture could decrease by as much as 50% in the next 30 to 35 years. These decreases in yields will largely be driven by droughts especially in the already dry and hot regions such as Africa and the Sahel. However, effective adaptation efforts might reduce the magnitude of the impact (Pricope et al., 2013). These climate disruptions increase the vulnerability of strategic sectors and create new challenges for the African economy. As a result, it is estimated that by 2100, West Africa will suffer the highest agricultural losses in the world (between 2 and 4% of its GDP) with 75% of the African population potentially exposed to hunger (FAO, 2010).

UNDP-UNEP, (2011) demonstrated that climate change will exacerbate many current environmental risks and introduce others that will interact. For example, the effects of extreme weather events will be exacerbated by higher ground temperatures, reducing the ability of crops to cope with water stress. The yield of the main crops currently under cultivation (wheat, rice, maize) are expected to fall, particularly in tropical and temperate regions as demonstrated in Figure 2.2. Eitzinger et al., (2017) argue that climate change may gradually increase inter-annual variability in crop yields. This may lead to higher commodity prices, because annual agricultural commodity requirements are increasing. FAO, (2019) indicated that climate change along with population growth, poverty alleviation, environmental degradation and global food insecurity is one of the defining challenges of the 21st century. Several studies show the potential impacts of climate change on agriculture that may add significant challenges of ensuring food security and reaching global development goal (Sultan and Gaetani, 2016).

The quantity and quality of products, the sustainability of production and the natural resource base on which livestock production depends can be affected by climate change climate is an important determinant of agricultural productivity. Sejian et al., (2013) opined that climate change is expected to have a significant impact on livestock production systems. In addition, global demand for animal protein will increase as populations become more affluent and diets change as illustrated by Figure 2.3. As a result, livestock production plays and will continue to play a key role in the food supply chain. While growing demand creates opportunities and income for small, marginal and landless farmers, the negative environmental impacts of livestock production, including greenhouse gas emissions, are increasing globally (Godde et al., 2021).

Figure 2.2 Impacts of climate change on crop yields (which lead to drought and flood) (Aderibigbe, 2018) (10 march 2023)

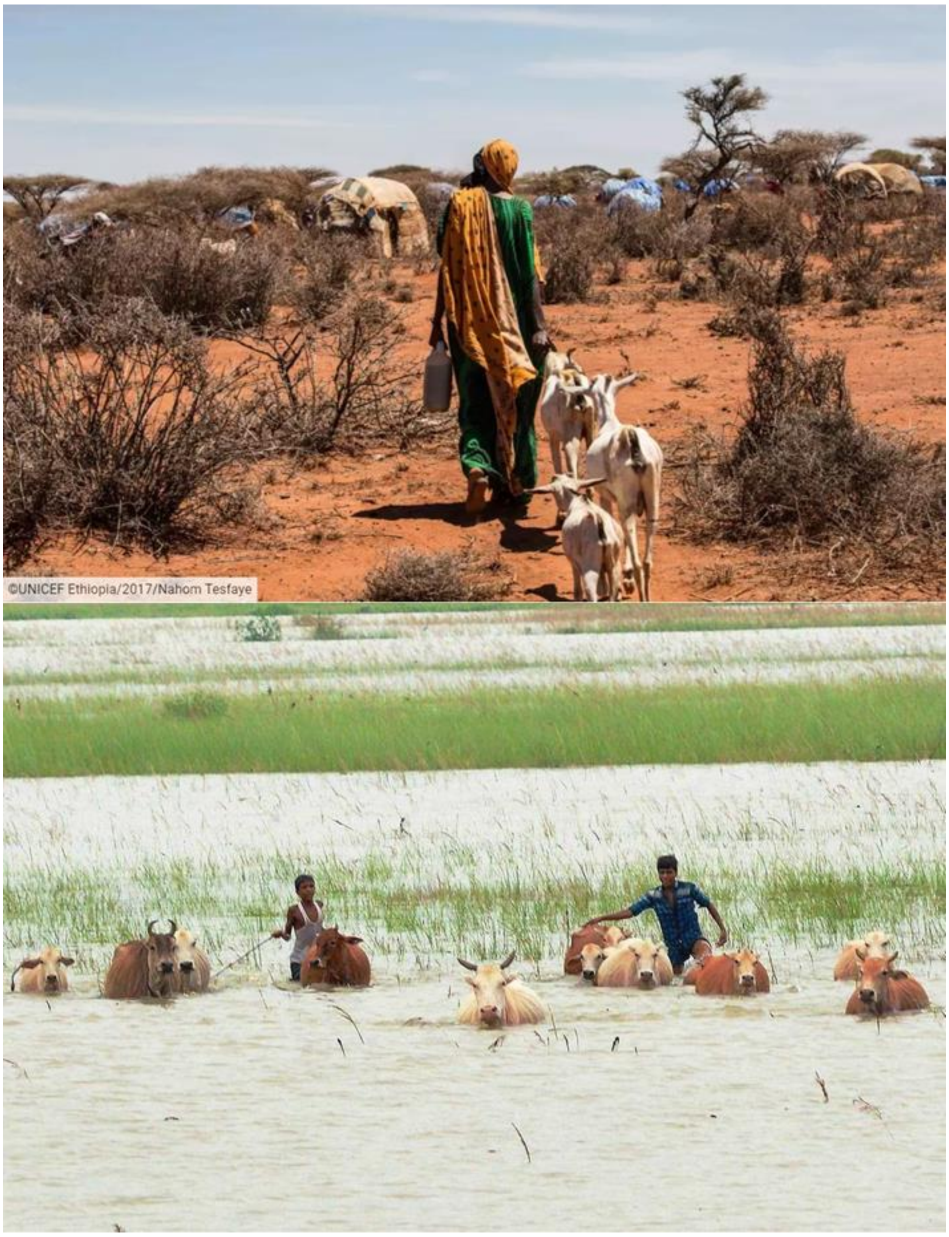


Figure 2.3. Impacts of climate change on animals
(Anyadike, 2017; Mazumdar, 2020) (10march 2023)

Changing climate variability may have critical effects on food security; in addition to impacts on food availability. Variability may strongly affect the stability of food supplies and vulnerable people's ability to access food at affordable prices (Schmidhuber and Tubiello, 2016).

Hopkins and Del Prado, (2007) showed that climate change can be expected to have several impacts on feed and grazing including; changes in herbage growth, changes in composition of pastures and herbage quality. Thornton et al., (2009) found that this may modify animal diets and compromise the ability of smallholders to manage feed deficits. Descheemaeker et al., (2018) showed that soil fertility management adaptation package increased the number of animal and caused a small increase in livestock productivity. The inclusion of grain and forage legumes with the crop diversification package increased milk productivity and net revenues more profoundly by 30%. This was attributed to the alleviation of dry-season feed gaps, which also reduced the sensitivity to climate change compared to the current system.

The development of new crop varieties including types, cultivars and hybrids, has the potential to provide crop choices that are better suited to temperature, moisture and other conditions associated with climate change. This involves the development of plant varieties that are more tolerant to climatic conditions such as heat or drought through conventional breeding and genetic engineering.

The Zai technique is a water harvesting method where plants are planted in small man-made depressions that stores water. The Zai technique, a traditional land rehabilitation technique in Burkina Faso, has the potential to rehabilitate degraded drylands effectively and to restore soil fertility to the benefit of farmers living in drylands. As illustrated in Figure 2.4 .small pits 20-30cm in diameter and 10-20cm deep are dug into degraded soils, often hardpans (Balehegn, 2015). At the bottom of the pit farmers place about two handfuls of organic material (animal dung or crop residues). Pearl millet or sorghum seeds are planted in these pits as soon as rainfall starts.

Taonda et al., (2003) proved that water harvesting alone with stone bunds did not improve yields but the combination of water harvesting with stone bunds or Zai technique plus manure doubled sorghum yields than when compared to the control. Similarly, Zougmoré et al., (2003) showed that combining Zai technique with phosphorus fertilizer significantly increased sorghum yield compared to Zai without fertilizer or manure and therefore, can reduce risks of crop failure in erratic rainfall year.

Ike (1986) and Lal (1989) showed that conservation tillage is a viable practice for soils of the humid and sub-humid areas of Africa. Naab et al., (2012) argue that experiments in the sub-humid and humid tropics of Africa have demonstrated the potential for no tillage systems to maintain higher soil carbon levels compared to conventional cultivation. Conant and Paustian, (2002) estimated that much of the land in Africa in degraded categories is savannah and grassland, reflecting the role of livestock and grazing in land degradation processes. Vågen et al., (2005) stated that restoration of degraded soils is a development strategy to reduce desertification, soil erosion and environmental degradation, and alleviate chronic food shortages with great potential in sub-Saharan Africa. Porter and Semenov, (2005) found that climate variability and extreme events can also be important for yield quality. Protein content of wheat grain has been shown to respond to changes in the mean and variability of temperature and rainfall.

Figure 2.4 Zai technique to restore degraded drylands and increase soil fertility)
Source: (Girard, 2015)

UNFCCC study identified two strategies to address climate change, namely mitigation and adaptation. Adaptation has become increasingly important in addressing climate change and a crucial strategy to combat poverty. Adaptation to climate change refers to adjustments in natural and human systems in response to current or expected climate change stimuli or effects (UNFCCC, 1992b).These adjustments hinder, hinder or manage to take advantage of the opportunities created. In the context of development there is a need to focus more on planned adaptation as local efforts are no longer sufficient with the impact of climate variability. Climatic conditions have a determining influence on natural ecosystems and human societies (Vries et al., 2014; Sintayehu, 2018). As far as natural environments are concerned, climate is one of the main factors influencing the distribution and abundance of the number of different plant and animal species (Clarke and Gaston, 2006; Yilmaz et al., 2017). The climate is also the basis of several socio-economic activities and contributes to the cultural identity of peoples, the yield and the yield of livestock and crops (Negash and Niehof, 2004; Koohafkan and Altieri, 2011). The increase in average temperatures can lead to a greater abundance pest of crops, modify their distribution. Changes in water regimes, which will affect water levels and quality, are likely to increase water use conflicts for domestic and agricultural purposes (Mafie, 2022; Shrestha, 2019). An increase in extreme weather events could amplify land erosion and lead to a reduction in soil quality and its agronomic potential. In light of current climatic conditions and future projections, the search for policies to support agro-pastoral systems to adapt to climate change is required. This research work will integrate agricultural and livestock adaptation measures to ensure food security and prevent the risks of food crises in the short and medium term.

CHAPTER THREE

3.0 MATERIALS AND METHODS

The methodology focused on primary data collection to secondary data collection. Secondary data is information that has already been collected for a different purpose than the study being conducted and is available for a second use.

3.1 Methodology of literature review for secondary data

A review of the literature was carried out through an analysis of theoretical approaches, case studies and study reports, various manuals and internet sites (cf. bibliography).

Objective 1 methodology: Examine the impact of climate change on agro-pastoral activities in Mali.

For the statistical analyses, Instat+ version 3.36 software was used. The software was used to organize the data and make agro-climatic analyzes of trends, risks, climatic extremes, statistical calculations and graphical representations.

The XLSTAT software was also used to perform rainfall and temperature rupture tests. The Excel spreadsheet was used for the entry, processing and analysis of the figures and the production of figures and graphs.

The meteorological data collected was used for the various analyses of the agro-climatic parameters.

The analyses were used to characterize and understand various climatic processes related to weather and to follow the fluctuations of meteorological elements for the long term. The analyses were carried out on:

- the precipitation anomaly and the trend of rainfall accumulations, as these play an important role in local agricultural and pastoral production, but also in the productivity of resources exploited by agropastoralists;
- the trend of the duration of the rainy seasons, the number of rainy days and the dry sequences in order to analyse the impact of climate change on agropastoralists;
- the calculation of the length of the rainy seasons through the start and end dates of the rainy season;
- the trend of maximum and minimum temperatures in order to assess local warming and deduce their impacts on the activities of agropastoralists with the software.

3.2 Standard anomaly analysis method (Lamb indices)

The study of climate variability and change was approached by the calculation of Lamb index which made it possible to identify the major trends in the time series (Salvati et al., 2019). It is calculated using the weighted moving average method. To better observe the periods of deficit and surplus at the interannual scale, the calculated moving averages have been centered and reduced using the standardized formula, defined as a reduced centered variable and which is the ratio of the deviations from the mean for the standard deviation.

To determine the surplus or deficit periods compared to the 1961-1990 normal, the Lamb index was used (Lamb, 1983).

$$\mathbf{I} = \frac{\mathbf{Xi} - \bar{\mathbf{X}}}{\boldsymbol{\sigma}} \qquad \textbf{3-1}$$

Where I is the standardized anomaly (Lamb index), Xi is the variable studied for the weather or rainfall of the year (i), $\bar{X}$ is the average of the reference period considered or average of interannual rainfall, σ is the standard deviation of the reference period or the interannual rainfall for the reference period.

3.2.1 Criteria method for agro-climatic parameters

3.2.1.1 Start and End dates of the rainy season

The criteria used to calculate the start date of the season are the rains are considered satisfied when a rain of at least 20 mm has been recorded from May 1 in one or two consecutive days without a dry episode more than 10 days is observed within 30 days of (Sivakumar, 1988, 1993).

For the end date of the rainy season, the criteria are based on the water balance. The rainy season is considered to end, from September 1 when the soil water reserve is depleted by daily evapotranspiration of 5 mm and becomes constantly less than or equal to 0.05 mm. (Landry et al., 2017).

3.2.1.2 Length of the season

Regarding the length of the season, it corresponds to the difference between the end date and the start date of the season at a given station (Balme, 2005; Ozer, 2007).

3.2.1.3 Mann Kendall trend test

Seasonal drought is when there is an episode of dry spells lasting more than 10 or 15 days which occur during the critical phases of plant development (during the vegetative or reproductive period). Drought also corresponds to the longest number of consecutive days without rain observed during the season or for part of the season towards the beginning, in the middle or towards the end of the seasons (Douguedroit, 1980, 1990).

For this purpose, a day is considered rainy when the rain collected on this day is greater than or equal to 0.85 mm.

The Mann Kendall test of the non-parametric type; it makes it possible to measure the degree of significance of the trend observed in the series (Lawin et al 2011). For its implementation, one calculates for each term Xi of the series of n terms, the number Mi of preceding terms which are lower than it. The statistic dn is called degree of sequence given by equation (3.2) is the sum of the numbers thus calculated.

$$\mathbf{dn = \sum_{1}^{n} Mi} \qquad \textbf{3-2}$$

For a large enough number n of year of observations, dn follows a normal distribution (null hypothesis of no trend) with an expected value of the mean given by equation (3.2) and (3.3) a variance given by the equation.

$$\mathbf{E(dn) = \frac{n(n-1)}{4}} \qquad \textbf{3-3}$$

$$\mathbf{Var(dn) = \frac{n(n-1)\,2(n+5)}{72}} \qquad \textbf{3-4}$$

The null hypothesis is rejected if for a large number of U(dn). The critical value of U(dn) is given by the probability table of a reduced Gauss law (Langdon, 1992), the null hypothesis is accepted or rejected. The difference between the means of two series will be significant at the 5% risk if U is greater than 1.96 and highly significant at the 1% risk if U is greater than 2.57. If so, it means that there is a significant increase for U(dn)>0 or a significant decrease for U(dn)<0 in the data series U(dn) is given by proposed by Goossens and Berge, (1987).

The dm value will be compared to E(dn) by the statistic:

$$U(dn) = \frac{(dn - E(dn))}{\sqrt{Var(dn)}} \qquad \textbf{3-5}$$

The null hypothesis is rejected at the threshold of α = 5%, if U(dn) exceeds the critical value 1.96. If this is the case, it means that there is a significant increase for U(dn) > 0 or a significant decrease for U(dn) < 0 in the data series.

This trend is highly significant if U(dn) exceeds the critical value 2.57 at the threshold of α =1%.

3.2.1.4 Rupture analysis method

We determined the break year for the climatic (rainfall and temperature) and agro-climatic (beginning and length of the season) parameters using statistical tests.

The rupture tests have made it possible to identify the pivotal year of climate change. They supplement the calculations of climatic indices. The existence of sudden changes in the climatic series is a possible cause of the heterogeneity of the series (Steinberg et al., 2005; Kouassy et al., 2016). These break tests are based on the Bayesian method of Lee and Heghinian, Pettitt and Hubert segmentation. Their application is carried out using the KhronoStat 1.01 software developed by the French Institute of Research for Development (IRD).

The Lee and Heghinian and Pettitt tests detect a maximum break while the Hubert segmentation detect several breaks if they exist in a time series of data (Chargui et al., 2018; Bougara et al., 2020).

3.2.1.5 The method of determining the break year in the time series

To check the relevance of the trend observed in the evolution of a time series, two tests are used: The non-change in the pace (homogeneity) of the series apply the nonparametric test of Pettitt (1979). This test makes it possible to apprehend the breaking points in the pace of a series in order to classify it into sub-series. The Pettitt rupture detection test whose null hypothesis consists of the instability in the equality of the means of two sub-series from the series (Demarree, 1990; Coops, 1992; Mallakpour and Villarini, 2016). The XLSTAT software was used for the Pettitt test.

3.2.1.6 Methodology used for Climate Projection

For the future projection, four climate models were used (GFDL-ESM4, INM-CM4-8, INM-CM5-0 and NorESM2-MM) from the Coupled Model Intercomparison Project Phase 6 (CMIP6) to calculate the averages of different variables (precipitation, solar radiation and temperature) in order to avoid errors in the results. In addition, a random choice affected in order to perform future climate projection in the area of Sikasso, Kolondieba, Ségou, Niono and Bamako. The variability and the future climatic trend were determined on the different climatic parameters such as rainfall, temperature and solar radiation. Annual rainfall, temperature and solar radiation data from 2021 to 2100 have been uploaded to the Center for Environmental Data Analysis (CEDA) archive site of CMIP6 which is part of NERC's Environmental Data Service (EDS) a network of data centers forcing all aspects of environmental science (https://data.ceda.ac.uk/badc/cmip6/data/CMIP6/ScenarioMIP).

The Coupled Model Intercomparison Project (CMIP6) models under Shared Socioeconomic Pathways (SSPs) scenarios (SSP24.5 and SSP58.5) which represent respectively moderate and high emission scenarios were used to project future climate change. The comparison of two scenario models was made on each variable in relation to the amount of rainfall, the degree of temperature as well as solar radiation. These three variables are important to use in the context of studies on the activities of agropastoralists.

The choice of the CMIP6 model under scenarios (SSP2-4.5 and SSP5-8.5) is to better understand past, present and future climate changes resulting from natural, unforced variability or in response to changes in radiative forcing in a multi-model context. That SSP scenarios predict how climate will change in response to socio-economic indicators such as population, economy, land use and energy changes. However, SSP2-4.5 and SSP5-8.5 might be the best choice since the climate signal is the strongest in these emission scenarios.

MAKESENS was used to calculate the annual trend statistics. MAKESENS performs two types of statistical analysis. First, the presence of a monotonically increasing or decreasing trend is tested with the nonparametric Mann-Kendall test and the slope of a linear trend is estimated with the nonparametric Sen method (Çiçek and Duman, 2015; Thenmozhi and Kottiswaran, 2016; Rahman et al., 2017).

Sen's slope method was used for a linear model to estimate the magnitude of the trend in the time series.

3.3 Impacts of climate change on crop yields in Mali

Objective 2 methodology: Evaluate the potential impacts of climate change on crop yields (sorghum and groundnut) in Mali;

Two types of work were carried out within the framework of this objective: namely the conduct of an experiment on the cultivation of sorghum and groundnut and the use of DSSAT. Six varieties of sorghum and two varieties of groundnut were used to conduct the experiment.

As part of this scientific research, daily rainfall and temperature data (maximum, minimum) from the localities of Bamako, Ségou and Sikasso in Mali were used, for a period from 1960 to 2021. The data were collected from the National Meteorological Directorate of Mali and from the Sotuba station at the Institute of Rural Economy.

Work on experimental trials was conducted in the field on sorghum and groundnut crops within the Sotuba Research Center. The collection of 11 soil samples was done to carry out analyses at the Soil-Water-Plant Laboratory of the IER to determine the characteristics of the soil. Soil sample in each replicate was made up from sampling along the diagonals at one level of depth (0-20 cm) to determine the physical characteristics: Percentage of sand, silt and clay; the chemical characteristics: pH water, pH KCl, total nitrogen in %(w/w), assimilable phosphorus, K. Ca (meq/100g) and Mg (meq/100g), CEC, C/N ratio and organic matter content.

3.2.2 Methodology used for sorghum experiment

The purpose of the experiment was to study the impacts of climate change on the yield of sorghum and groundnuts.

3.2.2.1 Sorghum experimental processes

The experimental design was Fisher blocks in four replicates giving a total of 24 plots for each block. A total of two blocks were installed containing a total of 48 plots, which were sown on two different dates (Table 3*:1*). A lag of 15 days was observed between sowing. The total area of the blocks was 1404 m² or 702 m² per block for 27 m in length and 26 m in width. The elementary plots were made up of six lines with each line being was 5m in length, 0.35m in diameter and 0.25m in height. The spacing between the pockets was 0.30m and between the lines, 0.75m. The distance between repetitions was 1m (Figure 3.2).

3.2.2.2 Selection criteria

The selection criteria for the 6 different varieties (CSM63E, CSM388, DT15, KIT19, Soubatimi and Tiandougoucoura) are among others:

- The ability to resist and adapt to the impacts of climate change such as reduced rainfall and increased temperature;
- Availability and adaptability to the growing area;
- The available area dedicated to experimentation;
- Time to conduct the experiment;
- The budget for conducting the experiments.

For more information on the 6 different varieties see appendix, Table 5.0*:2*

3.2.2.3 Conduct of the test

The Seed Selection focused on 6 different varieties which are: CSM63E, CSM388, DT-15, KIT19, Tiandougou-Coura and Soubatimi. The plots for the experiment after their identification and land preparation were ploughed with the tractor. Sowing was done on ridges at the rate of 4 seeds per pocket. The seeds were treated with fungicide insecticide (Apron star) at a rate of 10 grams for 4 kg of seeds. Thinning was carried out 15 days after sowing at the rate of 2 plants per pocket. The first weeding was done 15 days after sowing and the second weeding 45 days after sowing. Organic manure (Profeba) was added 15 days after sowing, at a rate of 1 ton/ha (1000kg/ha) as well as the cereal complex NPK at a rate of 100kg/ha each was given as complex fertilizer (17-17-17). Urea was added 45 days after sowing at a rate of 23kg N/ha. The plots were treated with appropriate products such as Emacot when the plants were attacked by pests (caterpillar). From each replicate, a soil sample was collected diagonally from experimental site (Sotuba) at a level (0-20cm) and analyses at the laboratory of Soil-

Water-Plant of Institute of Rural Economic (IER) in order to determine the characteristics of the soil (Figure 3.1 (on the top corner left)). The soil is characterised by physical characteristics (percentage of sand, silt and clay), and chemical characteristics pH water, pH kCl, % total nitrogen, available phosphorus, K. Ca (meq/100g) and Mg (meq/100g), CEC, C/N ratio and organic matter content (Figure 3.1 on the top corner right and down). The harvest was made at physiological maturity and the threshing after drying of the harvested panicles.

Figure 3.1. Taking soil samples with an auger for analysis (on the top corner left) and the analytical determination on soil texture (on the top corner right and down)

Table 3:1. Mass plan of the experimental plots of the six varieties of sorghum

Repetition 1					
1	2	3	4	5	6
CSM63E	CSM388	DT-15	KIT19	Tiandougou-Coura	Soubatimi
Repetition 2					
7	8	9	10	11	12
DT-15	Soubatimi	Tiandougou-Coura	CSM63E	KIT19	CSM388
Repetition 3					
13	14	15	16	17	18
Soubatimi	KIT19	CSM63E	Tiandougou-Coura	CSM388	DT-15
Repetition 4					
19	20	21	22	23	24
Tiandougou-Coura	CSM63E	Soubatimi	CSM388	DT-15	KIT19

Legend:1 à 24 = are the numbers of the plots in which the different varieties are sown.

Evaluation of economic profitability

At harvest, the total production of each variety was evaluated as well as the yield to assess the economic profitability.

Figure 3.2 Sorghum cultivation on ridge an area of 1404 m^2 and first weeding after sowing

Figure 3.3 Monitoring D-T15 and Tiandougou-coura varieties of sorghum during the heading phase which were sown on July 17, 2021

3.2.2.4 Work monitoring and crop observations

Monitoring and observations focused on: date of sowing, date of flowering and maturity, number of seeds per pocket, population per pocket, spacing between rows, spacing between pockets/cm, depth of sowing /cm, height of plants, number of tillers, thousand grain weight, grain weight, straw weight and 1000 grain (Figure 3.3).

3.2.3 Methodology used for the groundnut experiment

The purpose of the experiment was to study the impacts of climate change on the yield of groundnuts.

3.2.3.1 Groundnut experimental processes

Two varieties of peanuts were tested in the plots: Fleur 11 and ICVG 26024. The experimental device was the Fisher block in three repetitions for each type of variety (Table 3*:2*). The work was carried out on an area of 187m². The elementary plots were made up of 11 lines of 5m each. The sowing depth was 2cm, the spacing between the pockets was 0.10m and between the rows 0.5m. The spacing between the bands was 1m. The distance between the repetitions was 1m and as well as between the elementary plots (Figure 3.4).

3.2.3.2 Conduct of the test:

The plots for the experiment after their identification and land preparation were ploughed using a tractor. Flat seeding was applied at the rate of 2 seeds per pocket. The seeds were treated with Apron star is a (fungicide/insecticide seed spray for the control of late blight and seedling damping-off and for the protection of seeds and seedlings from early season pests and soil-borne diseases in beans, sorghum, maize, cotton and vegetables (Aderibigbe, 2018; Aune et al., 2017)) at a rate of 10 grams for 4 kg of seeds. The treatment of the plots after sowing was done with Alligator (pre-emergence herbicides) and Glyphosate Isopropyl ammonium (total systemic herbicide). The first weeding was done 15 days after sowing and the second weeding 45 days after sowing. The trials on the peanut varieties were carried out for natural production without soil amendment with mineral or organic fertilizers. The harvest was made at the physiological maturity of the plant.

3.2.3.3 Work monitoring and crop observations

Monitoring and observations focused on: date and end of sowing, date of flowering and maturity, number of seeds per pocket, population per pocket, spacing between rows, spacing between pockets/cm, depth of sowing/cm, plant height, grain weight, straw weight and 1000 grain (Figure 3.5).

Table 3:2. Block plan of the plots of the experimental device of the two varieties of groundnut

Repetition 1 for groundnut varieties	
1	**2**
Fleur 11	ICVG 26024
Repetition 2 for groundnut varieties	
3	**4**
ICVG 26024	Fleur 11
Repetition 2 for groundnut varieties	
5	**6**
Fleur 11	ICVG 26024

Legend: 1 à 6 = are the numbers of the plots in which the different varieties are sown.

Figure 3.4 Delimitation and sowing of the groundnut plot an area of $187m^2$ of the experimentation system

Figure 3.5 Monitoring of Fleur11 and CGLI 26024 varieties of groundnut during the flowering and maturity phase which were sown on July 18, 2021

3.2.3.4 Methodology used for DSSAT model

The DSSAT Model was used to simulate and determine crop growth of the six varieties of sorghum studied. The meteorological data (rain, Tmax, Tmin, solar radiation relative humidity and evaporation) collected were processed and imported into the DSSAT followed by calibration which was carried out for the 6 varieties of sorghum CSM388, CSM63E, DT-15, KIT19, Soubatimi and Tiandougou Coura.

Genetic coefficients for CSM388 and CSM63E varieties were previously determined through field experiments in Mali (Akensye et al., 2017; Adam et al., 2018). For the other four varieties, notably DT-15, KIT19, Soubatimi and Tiandougoucoura, the genetic coefficients were not known. Work has been carried out to determine the genetic coefficients of these four based on the results obtained from the experiments that were carried out in the field during the 2021 agricultural season at the Sotuba agronomic research center.

The calibration was carried out in three steps based on i) morphological information (time to anthesis, time to maturity), ii) total biomass, iii) grain yield. In addition, the 1000 grain weight was calibrated. The basic idea of the calibration was to modify the most important genetic coefficients so that the simulated and measured data matched as closely as possible.

To perform the sensitivity calculation, a total of 21 coefficients were modified, including 11 coefficients in the crop file in DSSAT (CUL- P1, P2, P20, P2R, PANTH, P3, P4, P5, PHINT, G1 and G2) (Table 3:3) and 10 in the ECO file (TBASE, ECONAME, TBASE, TOPT, GDDE, RUE, KCAN, STPC, RTPC, TILFC and PLAM) (Table 3:4). The calculation made it possible to know the most important and which have the greatest impact on the growth parameters, the most important coefficients of which have been calibrated.

Growth parameters were used for calibration i.e., time to anthesis, time to maturity, total biomass, grain yield and 1000 grain weight.

Therefore, the first step in the calibration was to determine the relative impact of the different coefficients on the simulated results. This procedure is called "sensitivity analysis". A relatively simple approach was to modify the genetic coefficients one by one by a given percentage (eg -10%) and observe the effect on important growth parameters. If changing a coefficient by -10% results in a yield change of, say, 1%, that coefficient will be relatively unimportant for the yield calibration and will not be used for the calibration process. If a -10% change results in a 50% yield change, for example, this coefficient will be relatively important for the yield calibration and will be used for the calibration process. The relative effect of the different coefficients depends on the varieties, but also on the experimental setup (climate, soil, etc.) and was redone for each experiment.

A setup was made with a correct standard run for the field experience for one of the varieties (with correct meteorological data, soil data, management data…). In this case, CSM63E was used because the genetic parameters have already been determined. The sensitivity analysis was carried out for the CSM63E variety, the sorghum variety of the experiment which was available in DSSAT. The following formula was applied to calculate the relative impact of the different coefficients on the simulated results. The standard: simulated result (e.g. yield) with standard coefficients. Modified result: simulated result with modified coefficients (one at a time).

$$\boldsymbol{sensitivity = \frac{(standard - modified\ result)}{standard} \cdot 100} \quad \textbf{3-6}$$

Table 3:3. Sorghum genetic of eleven coefficients in the *.CUL file (definition)

```
*SORGHUM CULTIVAR COEFFICIENTS: SGCER047 MODEL
!
! COEFF       DEFINITIONS
! ========    ===========
! VAR#        Identification code or number for a specific cultivar.
! VAR-NAME    Name of cultivar
! EXPNO       Number of experiments used to estimate cultivar parameters
! ECO#        Ecotype code for this cultivar, points to the Ecotype in
!             the ecotype file
! P1          Thermal time from seedling emergence to the end of the
!             juvenile phase (expressed in degree days above TBASE
!             during which the plant is not responsive to changes
!             in photoperiod
! P2          Thermal time from the end of the juvenile stage to tassel initiation
!             under short days (degree days above TBASE)
! P2O         Critical photoperiod or the longest day length (in hours) at
!             which development occurs at a maximum rate. At values higher
!             than P2O, the rate of development is reduced
! P2R         Extent to which phasic development leading to panicle
!             initiation (expressed in degree days) is delayed for each hour
!             increase in photoperiod above P2O
! PANTH       Thermal time from the end of tassel initiation to anthesis (degree days
!             above TBASE)
! P3          Thermal time from to end of flag leaf expansion to anthesis (degree days
!             above TBASE)
! P4          Thermal time from anthesis to beginning grain filling (degree
!             days above TBASE)
! P5          Thermal time from beginning of grain filling to physiological
!             maturity (degree days above TBASE)
! PHINT       Phylochron interval; the interval in thermal time between
!             successive leaf tip appearances (degree days)
! G1          Scaler for relative leaf size
! G2          Scaler for partitioning of assimilates to the panicle (head).
```

Table 3:4. Sorghum ecotype of ten coefficients in the *.ECO file (definition)

```
*SORGHUM ECOTYPE COEFFICIENTS: SGCER047 MODEL
!
! COEFF   DEFINITIONS
! =====   ===========
! ECO#    Code for the ecotype to which a cultivar belongs (see *.cul file)
! ECONAME Name of the ecotype, which is referenced from the cultivar file
! TBASE   Base temperature below which no development occurs (oC)
! TOPT    Temperature at which maximum development occurs for vegetative stages (oC)
! ROPT    Temperature at which maximum development occurs for reproductive stages (oC)
! GDDE    Growing degree days per cm seed depth required for emergence (degree days/cm)
! RUE     Radiation use efficiency (g plant dry matter/MJ PAR)
! KCAN    Canopy light extinction coefficient for daily PAR
! STPC    Partitioning to stem growth as a fraction of potential leaf growth
! RTPC    Partitioning to root growth as a fraction of available carbohydrates
! TILFC   Tillering factor (0.0 no tillering; 1.0 full tillering)
! PLAM    Plant leaf area maximun (Initial leaf area)
```

3.4 Vulnerability of agropastoralists to the climate change and adaptation strategies

Objective 3 methodology: Investigate the vulnerability of agro-pastoralists to the climate change and discuss possible adaptation strategies:

For this specific objective, the research made it possible to identify and prioritize the adaptation strategies of agropastoralists taking into account the vulnerability of communities.

Household surveys were used as a methodology during this work. To this end, a questionnaire was developed, programmed and administered through the Kobocollect tool to target groups (agro-pastoralists) and other actors in the field of climate change.

The choice of localities was based on the importance of agro-sylvo-pastoral activities in the different regions of the Republic of Mali. As for the choice of villages in the municipalities at the level of the various targeted regions, it was made taking into account the accessibility due to insecurity (jihadism and banditry) of which more than 2/3 of the country escapes the control of the Malian authorities.

Quantitative and qualitative surveys were carried out among the target groups as well as other actors in the field of climate change. The surveys were conducted using phones with the Kobocollect app installed. They involved 355 people, 39.15% of whom were women, in 33 villages in 22 communes in 14 circles (cercles) and 10 regions of Mali (i.e. 52.26% forage rate for the regions of Mali). The field survey work was supervised remotely but also through field supervision missions in the regions of Sikasso, Bougouni, Koulikoro and Kita.

The interviews carried (Reference to the questionnaire in the appendix) out made it possible to collect the essential information required on:

- Modes of exploitation and management of natural resources (water, land and vegetation), agricultural production systems (plants and animals), non-agricultural production systems;
- The natural, social, human and physical resource determining the conditions of agropastoralists;
- Agropastoralists perception of climate change concerning the rainy season, temperature, water resources and their impacts on resources;
- Evaluation of endogenous adaptation strategies (strengths and weaknesses)

3.2.4 Information Gathering, Analysis and Data Processing Tools

In this study, computer tools and applications (data storage, processing and analysis software) will be used to analyse and process the different data. Among the tools, the main ones and their essential functions are briefly described.

3.2.4.1 Modelling DSSAT

DSSAT_CSM (Cropping System Model)

Today, more than ever, increasing food production and security depends on the rational use of resources. In addition, issues such as climate change, climate variability, soil carbon sequestration and the long-term impact on food production, food security and environmental sustainability have become important. Many weather, soil, genetic and management factors influence a crop's response to irrigation, fertilizers and other management practices. The identification of appropriate crop management strategies in these uncertainties has major economic and environmental implications. Computer simulation models of the soil/plant/atmosphere system with user-friendly GIS can make a valuable contribution both to deepen our understanding of the processes that determine crop responses and to predict crop responses cultures, crop performance, resource utilization and environmental impacts for different environments and management scenarios. They can also be used to determine the potential impact of climate change on production (Hoogenboom, G., C.H. Porter et al., 2019).

DSSAT-CMS Model (The Decision Support System for Agrotechnology Transfer Cropping System Model)

Agrotechnology Transfer Decision Support System is a set of computer programs designed to simulate the growth of agricultural crops. This model simulates the growth, development and yield of a crop that grows on a uniform surface of land under prescribed or simulated management and changes in soil water, carbon and nitrogen that occur in the culture system for time. The DSSAT is that crops are planted, managed and harvested based on the crop system information provided as inputs to the model (Jones et al., 2003). The DSSAT model was used to simulate the yield of sorghum and groundnuts and compare the values with the filed experiments.

3.2.4.2 CMIP6: Coupled Models Inter-Comparison Project of Phase 6

It is to better understand past, present and future climate change resulting from natural, unforced variability or in response to changes in radiative forcing in a multi-model context. This understanding includes assessments of model performance for the historical period and quantifications of the causes of the spread in future projections. Idealized experiments are also used to improve understanding of model responses. In addition to these long-time scale responses, experiments are carried out to study the predictability of the climate system at various time and space scales as well as to make predictions from observed climate states (https://www.wcrp-climate.org/wgcm-cmip). The CMIP6 data was used for future climate projection under two scenarios (SSP2-4.5 and SSP5-8.5 in this study.

- The comparison of two scenario models was made on **each variable** in relation to the **amount of rainfall**, the **degree of temperature** as well as **solar radiation**. However, these three variables are important to use in the context of studies on the activities of agropastoralists.

3.2.4.3 Shared Socio-economic Trajectories (SSPs)

Shared Socio-economic Trajectories (SSPs) are scenarios of global socio-economic changes projected up to 2100. They are used to derive scenarios of greenhouse gas emissions with different climate policies. Scenarios with intermediate and very high greenhouse gas (GHG) emissions (SSP2-4.5 and SSP5-8.5) and CO2 emissions that approximately double by 2100 and 2050. Emissions vary between scenarios depending on socio-economic assumptions, climate change mitigation levels and, for aerosols and non-methane ozone precursors, air pollution controls (IPCC, 2021).

SSP2-4.5: Intermediate scenario

Socio-economic factors follow their historical trends, without significant change. Progress towards sustainability is slow, with disparate development and revenue growth. In this scenario, temperatures increase by 2.7°C by the end of the century.

SSP5-8.5: Very high scenarios

Current levels of CO2 emissions will roughly double by 2050. The global economy is growing rapidly, but this growth is fueled by the exploitation of fossil fuels and energy-intensive lifestyles. The SSPs were used in this study for were used to project future climate change and make a comparison of two scenarios (SSP2-4.5 and SSPP5-8.5) which represent respectively moderate and high emission scenarios.

KoboCollect

KoboCollect or KoBo Toolbox, is an open-source platform designed for rapid data analysis, information gathering in the field, through the use of mobile devices or tablets, which offers a range of options allowing users to conduct complex research, monitor projects, map information in disaster areas, conflicts and in general in contexts where it is necessary to investigate quickly and systematically (Bokonda et al 2020; Nampa et al 2020; Jackson et al 2021).

KoBo Toolbox is continuously developed by the Harvard Humanitarian Initiative, distributed and supported by the United Nations Office for the Coordination of Humanitarian Assistance (UNOCHA). Being an open-source tool, it can be integrated into other types of applications, allowing them to be used together, making it efficient and versatile. Kobo collect was used for collecting data from agropastoralists through survey by programming questionnaires on tablet/smart phone in this study.

Instat+

Instat+ is a general statistical package (Taye et al., 2013; Beyene, 2015). It is useful for researchers mainly in climatic data analysis. Developed by Statistical Services Centre at Reading University, UK. It is simple enough to be useful in teaching statistical ideas, yet has the power to assist research in any discipline that requires the analysis of data.

Instat+ provides a relatively gentle introduction to using statistics packages, and can be a useful "stepping-stone" towards other, commercial, statistics packages. Instat+ is designed to support the teaching of statistics. It includes features to help explain many of the key concepts, such as confidence intervals, that users often find confusing. Furthermore, its teaching menu provides a resource pack of ideas, some that use Instat, but many that can be used with any statistical software (Daba, 2018; Jackson et al., 2021; Usman and Mamman, 2022).

Instat+ includes many special facilities for the processing of climatic data, supported by a 400-page guide, included with the package as a help file. Instat was used for statistical analysis of climatic data. Organize the data and perform agro-climatic analyzes of trends, risks, climatic extremes, statistical calculations and graphical representations in this study.

Genstat

Genstat is a statistical software package with data analysis capabilities, particularly in the field of agriculture (Akinnagbe and Baiyeri, 2011; Adzitey et al., 2014; June, 2016; Odong et al., 2019). It was developed in 1968 by Rothamsted Research in the UK and was designed to provide modular design, linear mixed models and graphical functions. Genstat was used to perform statistical analysis of data from field experiment of crop yield (sorghum and groundnut) in this study.

ArcGIS

ArcGIS (or "ArcMap") is GIS software for viewing, managing, creating, and analyzing geographic data (Adzitey et al., 2014; Ngwuta et al., 2016) By using ArcGIS, you can understand the geographic context of your data, allowing you to see relationships and identify patterns in new ways. ArcGIS was used to perform spatial simulation of future climate projection of crop yield for the different regions in Mali.

Rstudo

Rstudio R is a program developed under Rstudio (Pesaran, 2014; Watkins, 2020). This software makes it possible to carry out statistical analyses of climatological data: onset and end date of the season, duration of the season, accumulation of precipitation of the season and analysis of dry sequences, control of data quality (rain, Tmax, Tmin), calculate climate indices, analyse standard anomalies, analyse agro-climatic parameters, analyse agro-cli parameters Analysis of agro-climatic parameters.

Office Software

(Word, excel) for processing,

3.2.5 Selection and Mapping of the Study Area

3.2.5.1 Demographic and Geographic Situation of Mali

Mali is a landlocked West African country located between the 10th and 25th degrees of north latitude and between the 4th and 12th degrees of west longitude and covers an area of 1,241,238 km^2 with a population of 20,250,833 (estimated, 2020). It shares 7,420 km of borders with 7 neighboring countries: Algeria in the north, Niger and Burkina Faso in the east, Côte d'Ivoire, Guinea in the south, Mauritania, and Senegal in the west. Mali is divided into ten regions and one district. These subdivisions are named after their main city. It has 703 communes.

The country has three climatic zones: (Error! Reference source not found.)

- The northern two thirds of the country, entirely desert, belong to the southern Sahara, with annual rainfall of less than 127 mm This region is crossed by nomads with their herds (Mougin et al., 2009; Hereher, 2011);
- The centre: the Sahelian region, relatively dry (with relatively insufficient tropical rain), is covered with steppe gradually replaced by savannah towards the south. The Niger Valley is cultivated thanks to some development work: rice, cotton, shea, groundnut, millet, sorghum, corn; (average precipitation in between 300 and 600 mm). However, these amounts can vary greatly from year to year;
- The Sudanese region is an area with precipitation of 1,400 mm per year and average temperatures between 24°C and 32°C (Tekete and Koita, 2010; Bokar et

al., 2012). It is, in its northern part, covered with savannah becoming increasingly dense and gradually turning into forest towards the south (Bucini and Lambin, 2002; Laris, 2011).

The relief is slightly accentuated. The alluvial plains, very vast, are however dominated by some limestone and sandstone plateaus (Mandingo and Dogon plateaus) (Gabriel, 1987; Traore et al., 2016). Mali's highest peak is Mount Hombori at 1,155 m (Walther et al 2009; Hallett, 2018; Apriliani et al., 2021).

3.2.5.1.1 Languages and Communities

French is the official language, but the most widely used is Bambara, which is spoken by more than 50% of the population (Lodhi, 1990). The latter, along with 12 others (bobo, bozo, dogon, peul, soninké, songhaï, (or songoy), sénoufo-minianka, tamasheq, hassanya, khassonké, mandinka and maninkakan) are recognized by the State as national languages. The 1987 census recorded the language spoken by people for the age of six. Bambara is largely in the lead (38.3%), followed by Peul (11.7%), Dogon (6.9%), Songhaï (6.3%) and Soninke (12.3%) (Christin and Hug, 2012). Mali has retained important elements of its traditional cultures. The griots (or «Djéli») still carry out their functions as poetic musicians transmitting the history of the country and of the people for several generations (Ebine, 2019).

3.2.5.1.2 Economy

Mali is a developing country whose economic structure is strongly dominated by the primary and tertiary sectors. About 10% of the population is nomadic and 80% of the working population works in agriculture or fishing (Silvius et al., 2000). Industrial activity is concentrated around agricultural activities. Agricultural production is mainly based on cereals, which constitute the bulk of the food base. These cereals are mainly millet, sorghum, rice, maize, fonio and wheat. There are also some tubers such as yam, potato and cassava. One of the crops that has had some increase in production is fruit and vegetable production. Bananas, mangoes and oranges are an important export to European and Arab countries (Zainal et al., 2011).

Mali is known for its wealth of precious stones and various fossils as natural resources. Of all the known mineral resources in the country, only gold is currently subject to intense exploitation. Gold is the country's largest export source (Africa's third largest gold producer after South Africa and Ghana, the ninth largest in the world) (Mainguy, 2011), followed by cotton (world's 12th largest producer in 2004) and livestock (a major livestock producer and exporter in the region), iron (Behrendt, 2006). Other products such as groundnuts (300,000 - 400,000 tonnes produced in 2003) are highly exported (Pound and Phiri, 2010). Tourism, which is still confined to a few areas, has been growing in recent years. These include UNESCO World Heritage sites: the Dogon Country, Timbuktu, Djenné, the Tomb of the Askia in Gao. Some of these sites have been desecrated in Timbuktu and Gao since the occupation by Islamists in July 2012.

In 2017, the contribution of the primary sector represented 38.34% of GDP with a large share for agriculture (19% of GDP) and In 2019, it is estimated at 38.43% GDP (Moretti et al., 2004; Hage and Hage, 2014). With strong irrigable potential, the country has the resources to become one of the agricultural mainstays of West Africa. By diversifying the bases of production and building on accelerated, sustainable growth, creating jobs and income-generating activities, Mali expects to achieve growth rates of more than 7% per year (UMOA, 2020).

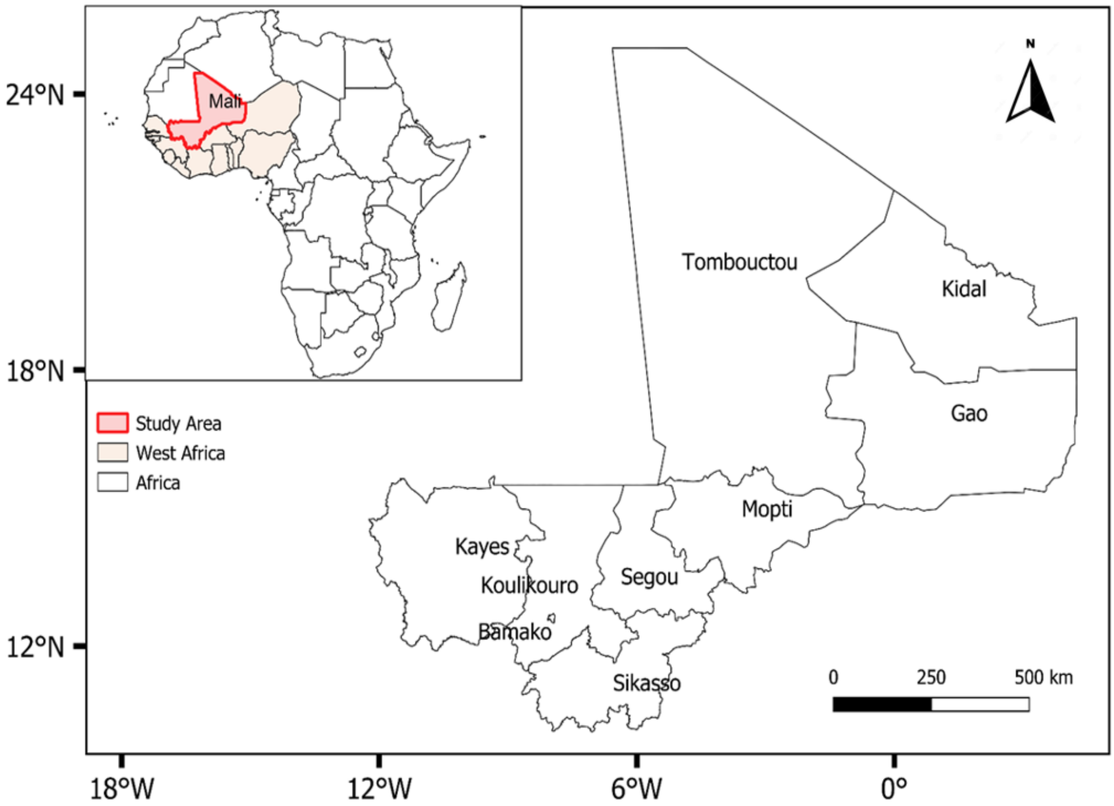


Figure 3.6 Map of study area

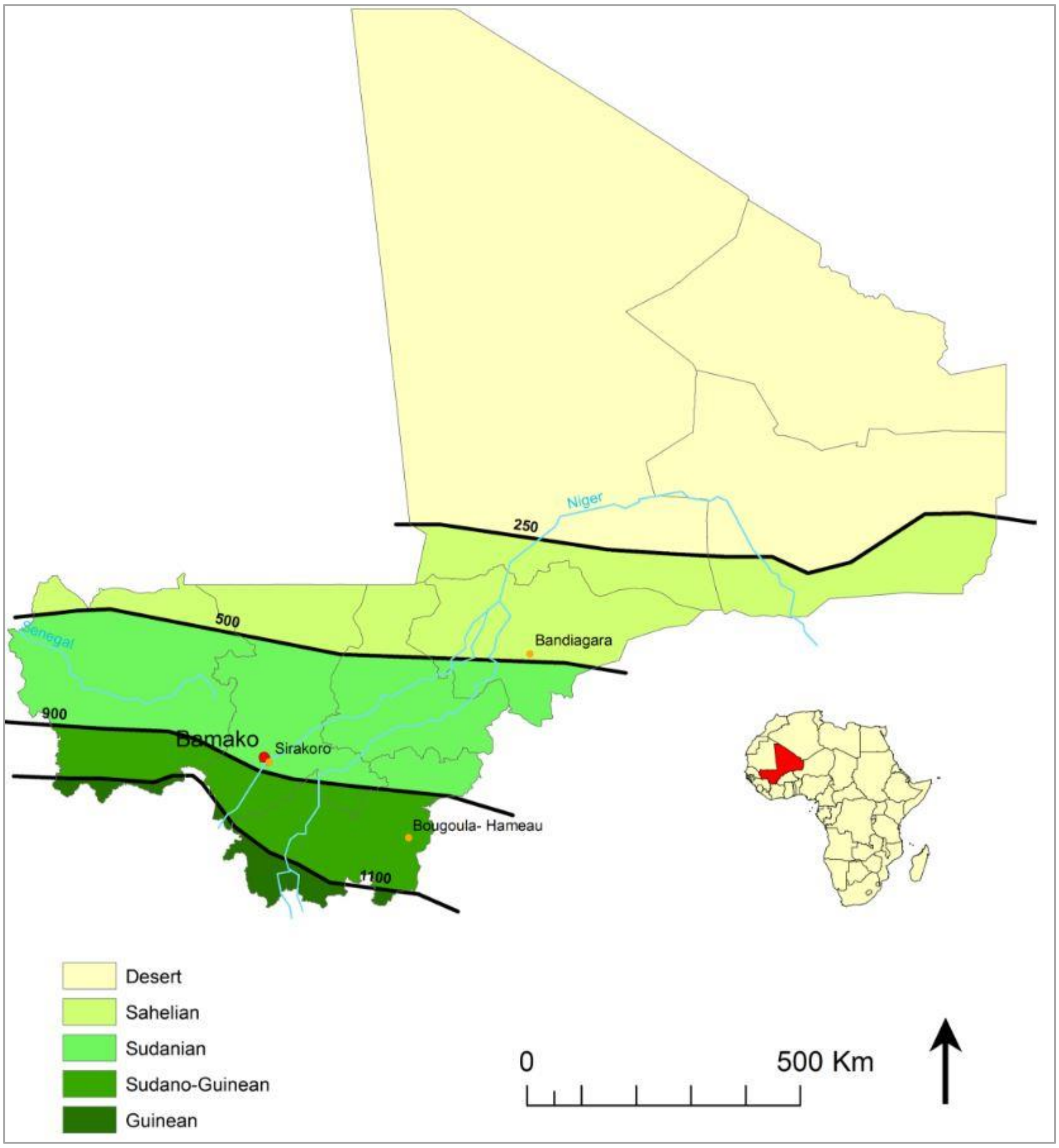


Figure 3.7 Map for three climatic zones of Mali (Coulibaly et al., 2016)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Climate Change Characteristics for Mali

4.1.1 Current Trend of Rainfall Characteristics for Bamako, Segou and Sikasso

The analysis of rainfall anomaly index shows the interannual variability in the 1960-2020 series for Bamako (Figure 4.1) Since 1968, there have been significant year of rainfall deficit with the year 1970, therefore the number of drought events occurred from years 1980 to 1990 and 2000 considered as year of great drought.

Our results are identical to those of Nicholson et al., (2018) who worked on precipitation on the African continent in the 19th and 21st centuries, more precisely the Sahel, these results showed a sharp drop in precipitation that occurred around 1968.

This evolutionary curve of rainfall accumulations from 1960 to 2020 shows a downward trend in accumulations in the 3 different regions of Mali then a very variable trend to normal from 2000 to 2007. However, from 1960 to 2020 there is a significant decrease in interannual rainfall with a downward trend in rainfall in these three regions of Mali Bamako, Ségou and Sikasso (Figure 4.1, Figure 4.4, Figure 4.6).

The calculation of the standardized index on rainfall from 1960 to 2020 of Bamako station shows a rainfall deficit which increases from 1970, 1972, 1980, 1883 to 1985. The year 1972 (average precipitation of 643mm) corresponds to the year from which there is a general downward trend in the time series of rainfall (Figure 4.1). A study on the Sahelian droughts showed the rainfall deficit for the whole of West Africa, precisely the ENSO events in the Sahel region from 1972, 76, 82, 83, 92 and 93 (Janicot et al., 1996).

The analysis of rainfall by the Mann Kendall and Homogeneity tests at the Bamako station shows in 1967 with an average precipitation of 1242 mm which is negative compared to the average. In addition, the first and second rupture has been observed in the period 1998 and 1994 with an average precipitation of 936 mm (Figure 4.2). The difference shows a drop in precipitation of 136mm after the break year. The trend analysis of the 1960-2020 series also shows a decrease in precipitation in the zone. Praveen et al., (2020) study on trend analysis and forecasting of rainfall changes in India using nonparametric and machine learning approaches showed the significant decrease in rainfall for India and that this decrease has been accentuated.

4.1.1.1 Trend of annual rainfall in Bamako from 1960-2020

The general trend of the 1960-2020 rainfall accumulation curve for Bamako shows a decrease in precipitation with a linear upward trend (Figure 4.3). But this trend is not significant because p-value (bilateral) = 0.38 which is higher than the alpha threshold level of significance = 0.05: according to the Mann-Kendall trend test.

4.1.1.2 Interannual variability of precipitation for Segou

Evolution of rainfall analysis for Ségou region shows a general drop in rainfall accumulations with an average decrease of 13mm from 1960 to 2020. The application of the Pettitt test detected a break from 1970 in the series of rainfall accumulations of Ségou (Figure 4.4). Our results are consistent with those of a study on climate variability case study in Burkina Faso which showed that rainfall in the region suffered a major break in 1970 using the Pettitt test (Tirogo et al., 2016). The periods with the most marked dry spells were: 1970 to 1974; 1980 to 1987; 2000 to 2006 and from 2012 to 2018.

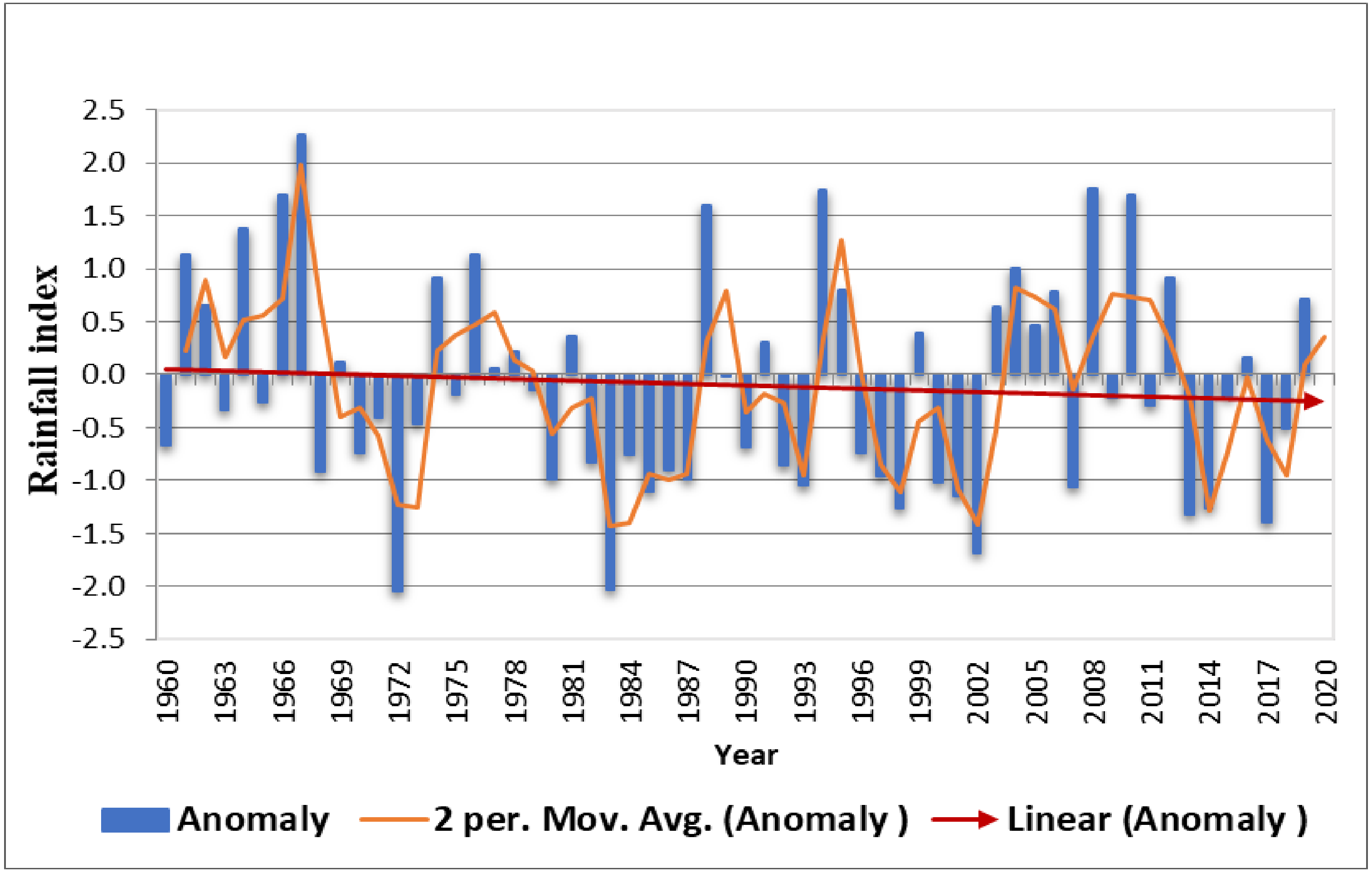


Figure 4.1 Interannual variability of rainfall for Bamako (orange line is moving average and red line is linear trend forecasting)

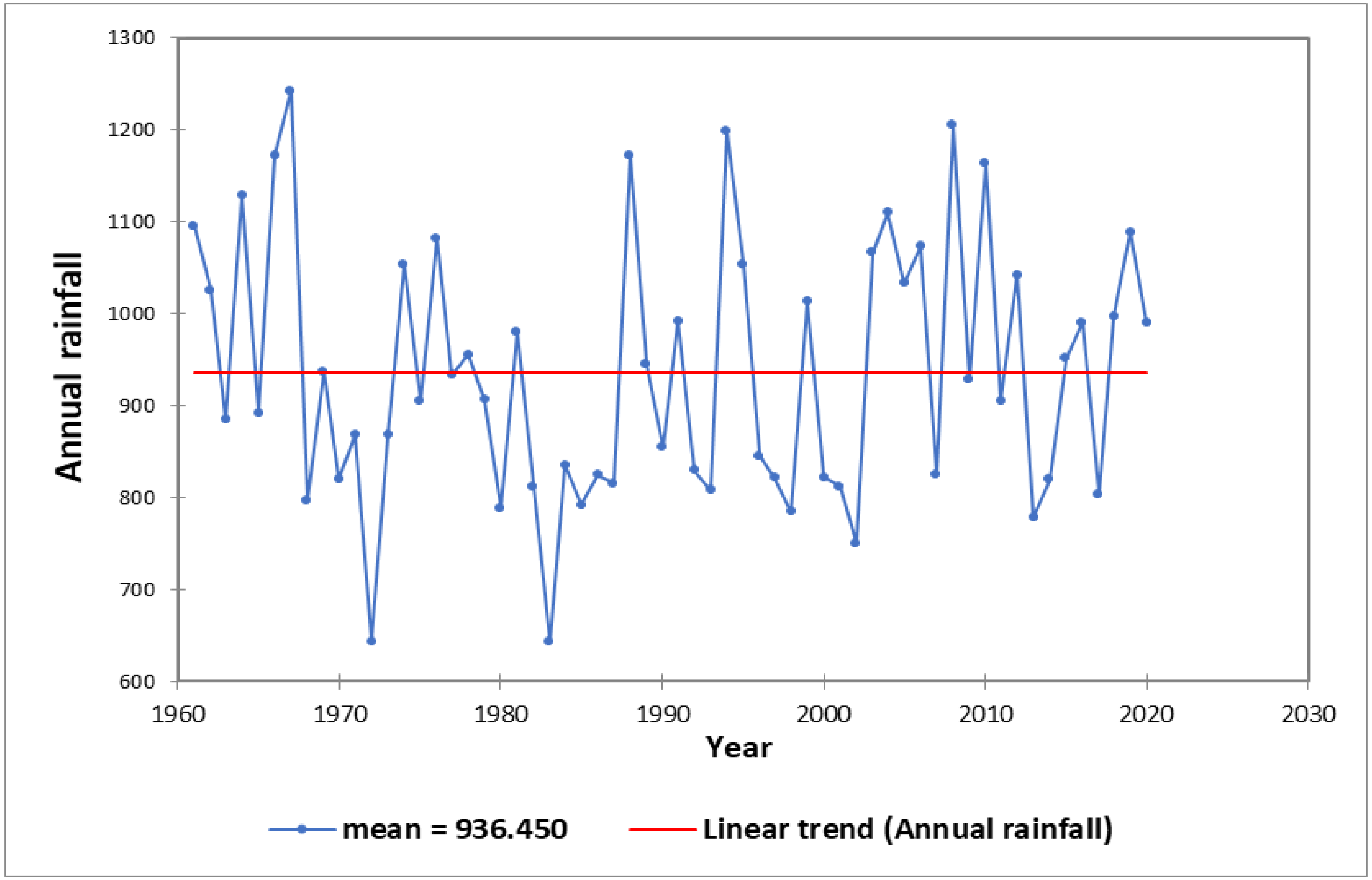


Figure 4.2 Annual rainfall of Homogeneity test trend test for Bamako (blue line is a mean in the series form 1960-2020 and red line is linear trend)

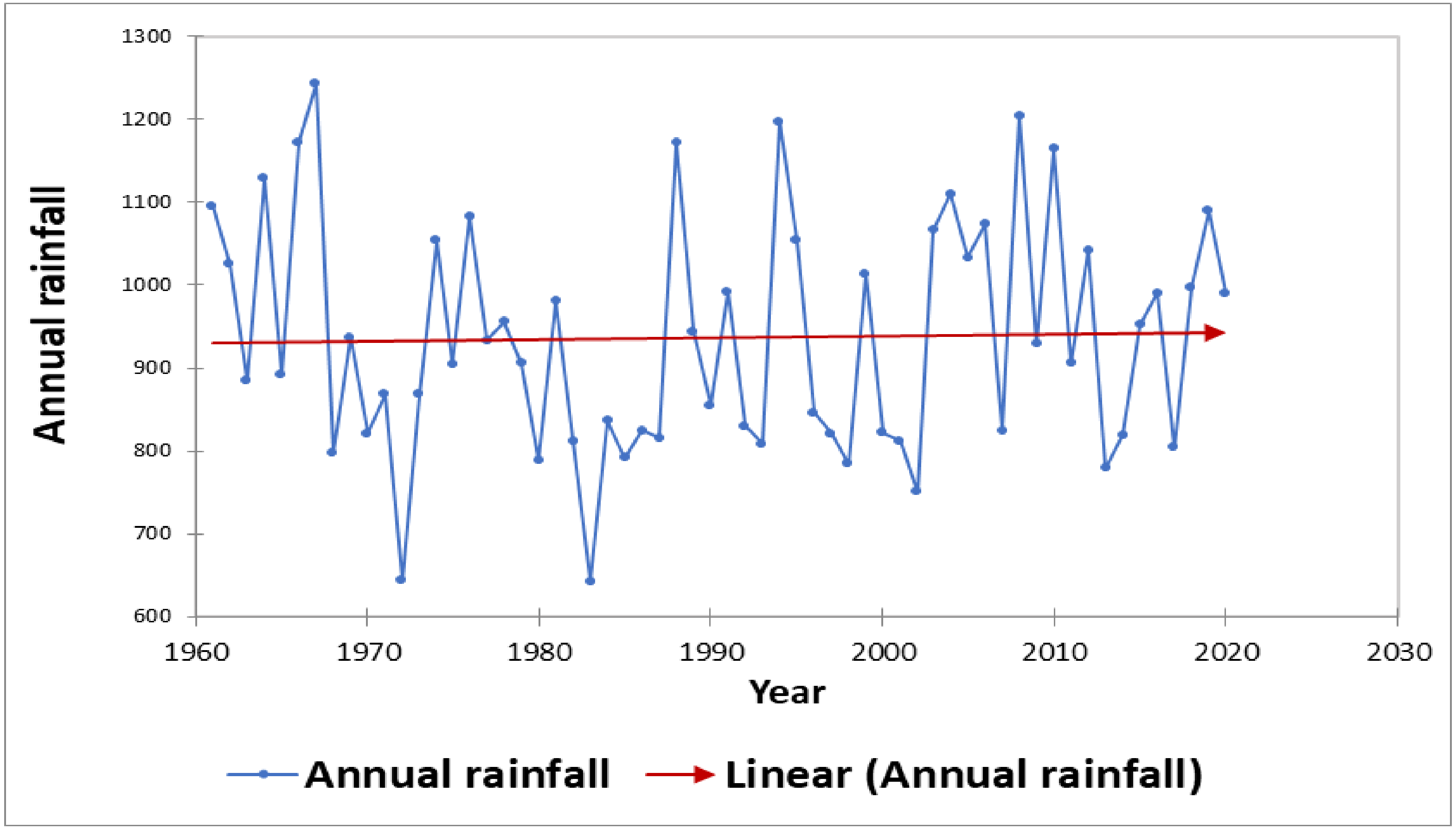


Figure 4.3 Interannual variability of Man-Kendal trend test for Bamako (orange line is moving average and red line is linear trend forecasting)

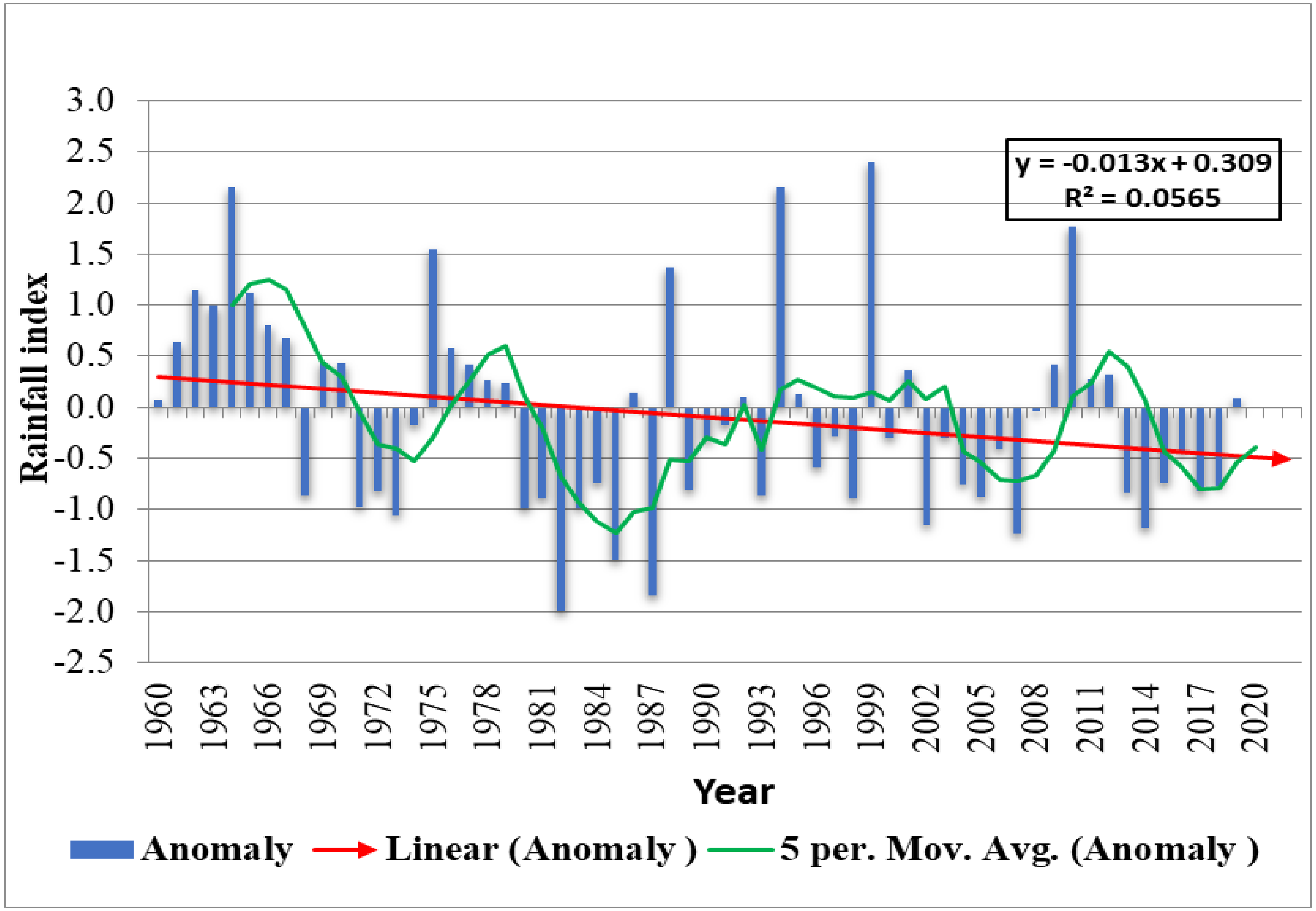


Figure 4.4 Interannual variability of rainfall for Segou (green line is moving average and red line is linear trend forecasting)

4.1.1.3 Trend analysis of rainfall for Segou from 1960-2020

The detection of breaks in the rainfall series of the Ségou region, according to Mann Kendall (Pettitt test) showed that there is no statically significant trend in the series. According to P-value=0.6586 (Figure 4.5(a)) and that of P-value=0.224 (Figure 4.5(b)) which shows that there is no rupture according to the Pettitt test. Indeed, on the basis of calculations of the two averages, it appears that between the series of 1960-1989 (i.e. 622 mm) and 1990-2020 (i.e. 635 mm), a drop of -13mm (i.e. an annual decrease of -638.2 mm) in the time series 1960-2020. In addition, Pettitt's test showed an abrupt change in the 1983 annual series (Figure 4.5 (b)). However the results of the present study are identical to a study carried out in the southwest from Iran which showed that the rainfall abrupt was in 1983 (Dhorde & Zarenistanak, 2013).

4.1.1.4 Precipitation anomaly of Sikasso from 1960 to 2020

Error! Reference source not found. for the Sikasso region indicates the p resence of dry period from 1965 which has been observed. However, the period 1968 to 1970 and 1975 to 1980 is wet in the time series of rainfall. There is an alternation of dry year between 1994. The results are similar to those studies conducted on changes in temperature and precipitation extremes over West and Central Africa which revealed that 1994 is considered as a dry period in Sikasso region (Lin et al., 2013; West, 2017).

The wettest month of the rainy season is August. However, the trend of annual cumulative rainfall is decreasing. This decrease is statistically significant according to the Man Kendall test at the 5% level (Figure 4.7 (a)). According detection of breaks in the 1960-2020 rainfall series on Sikasso, the Mann Kendall (Pettitt test) showed a break in the 1960-2020 series. The break years are 1989 and 2010 (Figure 4.7 (b)).

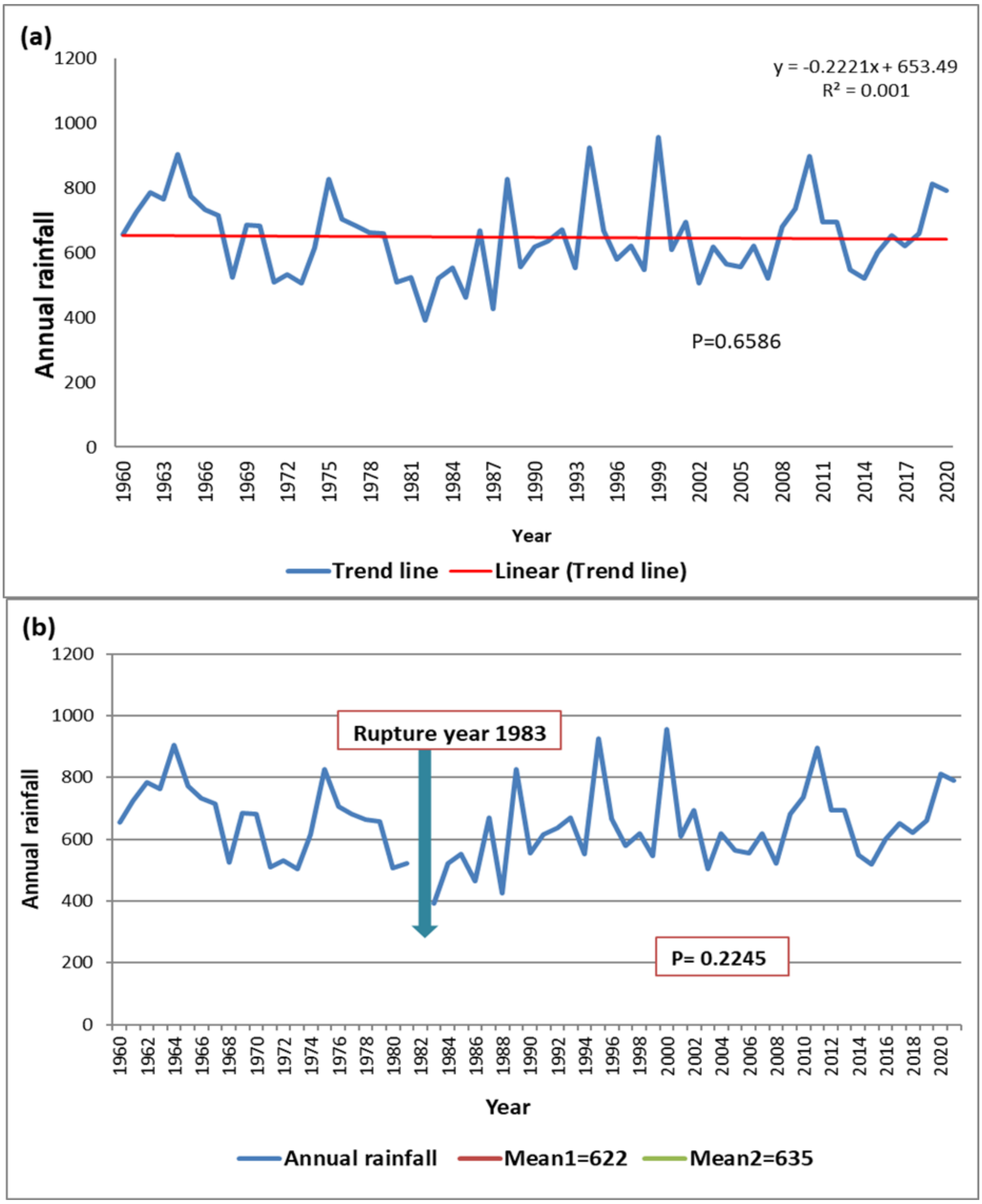


Figure 4.5. Trend analysis of annual rainfall (a) and the abrupt change in the trend (b) for Segou

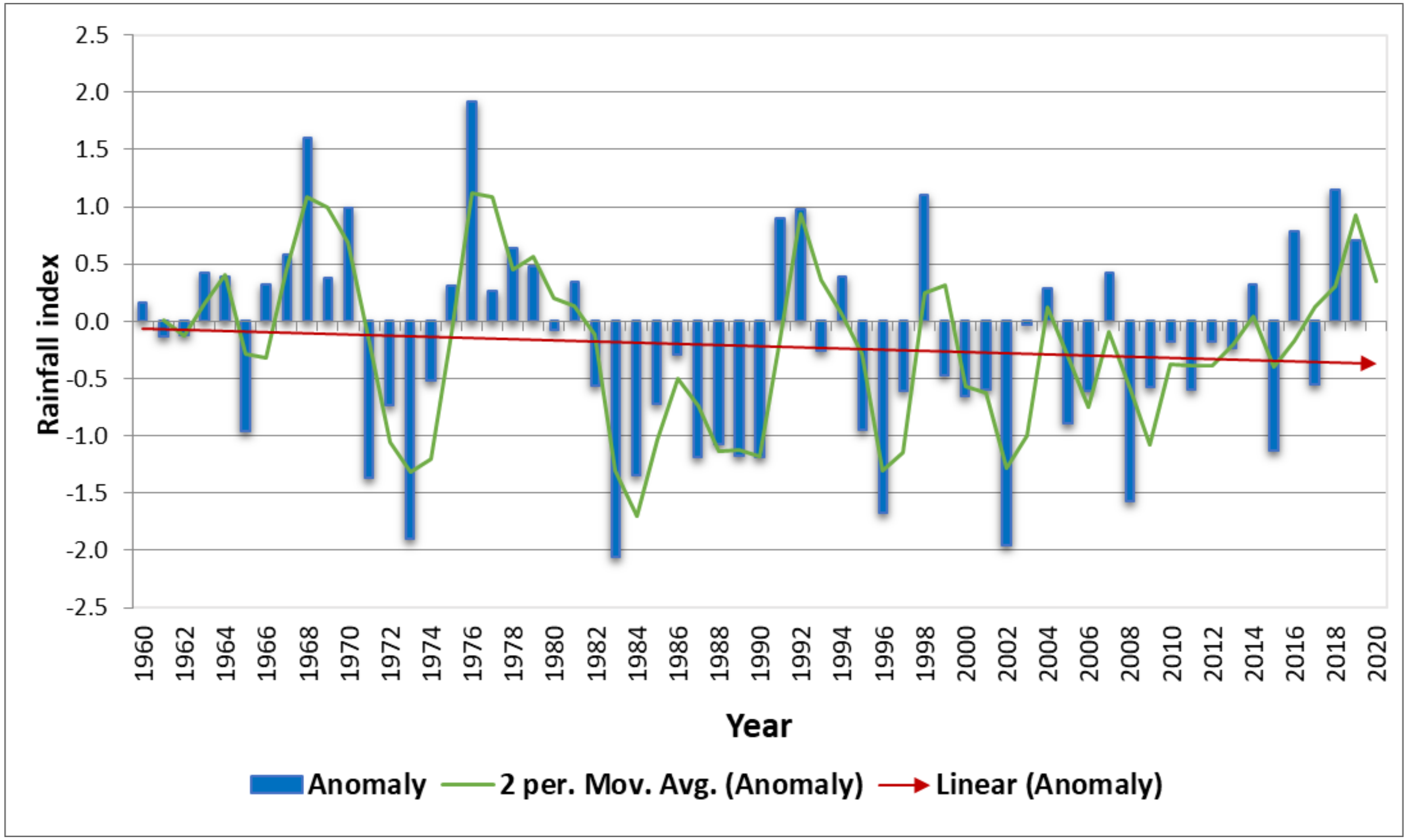


Figure 4.6 Interannual variability rainfall for Sikasso (green line is moving average and red line is linear trend)

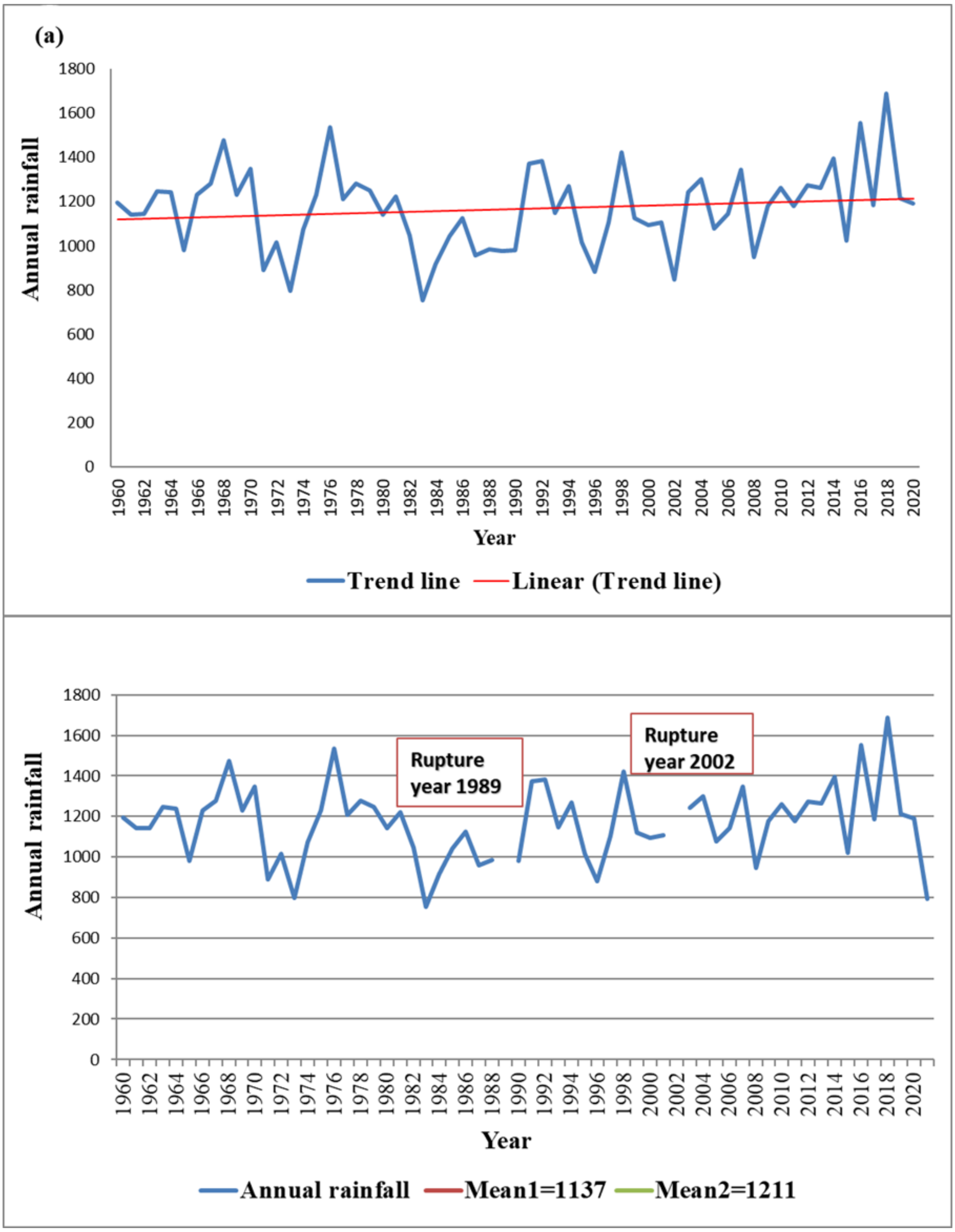


Figure 4.7. Trend analysis of annual rainfall (a) and the abrupt change in the trend (b) for Sikasso

4.1.1.5 Start and end date of the rainy season of Bamako in the period from 1960-2020

The results of the statistical analysis of rainfall data for a period from 1960 to 2020 show that the average date of the rainy season starts from May 28 and the average end date of the rainy season is October 6 in Bamako Figure 4.8 (a)).

The trend in the length of the rainy season in Bamako has been decreasing for the period 1960-2020 Figure 4.8 (b)). This reduction trend is reflected in the variability of rainfall reported by agropastoralists during the field surveys that were conducted.

4.1.1.6 Start and end date of rainy season of Segou region in the period from 1960-2020

The evolution of the climatic parameters of the rainy season in the region of Ségou (Figure 4.9 (a)) experiences a high inter-annual variability both for the start date and the end of the rainy season. The data shows an increasingly late arrival of the rainy season on June 16 for the 1960 to 2020 series. On the other hand, the end of the season is getting earlier and earlier with a date of September 23.

The length of the season shows a downward trend, which results in the reduction of the wet period. This tendency to reduce the length of the season is estimated at 7 days (Figure 4.9 (b)). These results confirm the perception of the agropastoralists surveyed who perceive that the start of the rainy season is late and the end is early.

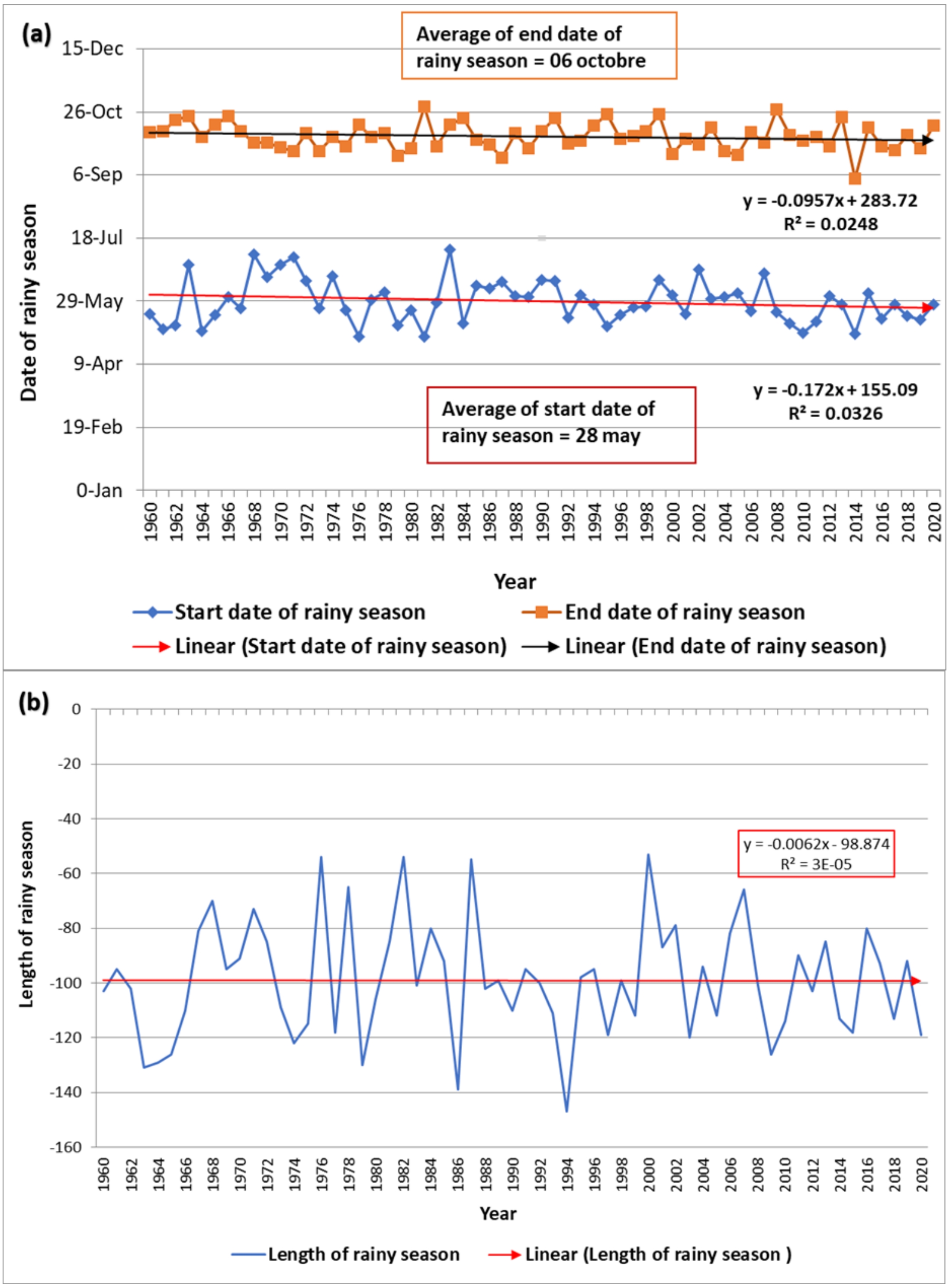


Figure 4.8. Trend of the start and end of the rainy season (a)and the length trend of the rainy season (b)for Bamako

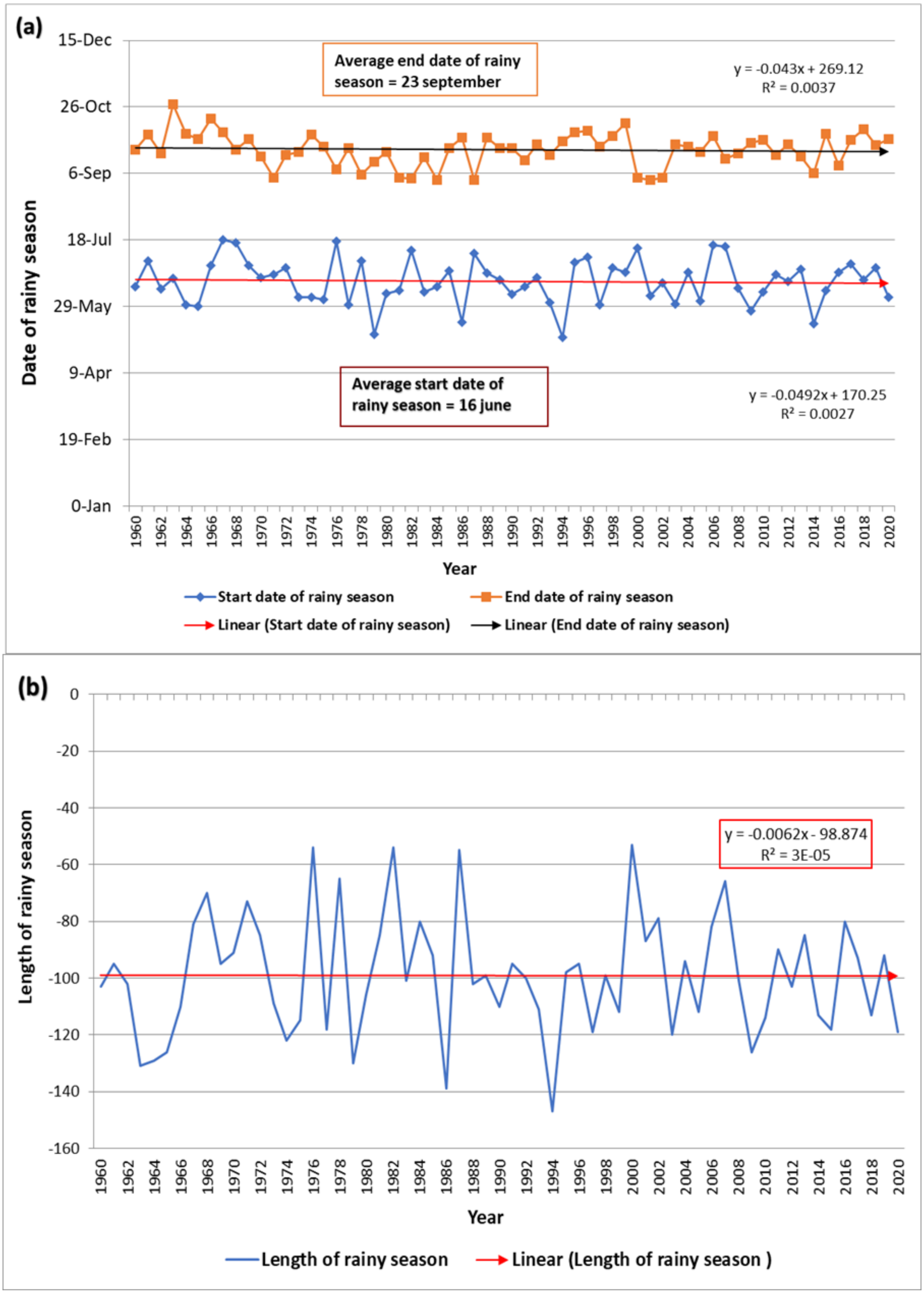


Figure 4.9. Trend of start and end of the rainy season (a), and the length trend of the rainy season (b) for Segou

4.1.1.7 Start and End date of rainy season of Sikasso region in the period from 1960-2020

The analysis of climatic parameters shows that the rainy season in the Sikasso region starts on average on May 20 and ends on October 14 (Figure 4.10 (a)). It is deduced that there is a longer duration of the rainy season in the region of Sikasso compared to Bamako and Segou.

The trend of the length of the rainy season in Sikasso is shows a reduction in the series of 1960-2020 (Figure 4.10 (b)) This decreasing trend results in increased rainfall variability. These results confirm the perception of agropastoralists concerning the length of the rainy season mentioned during the surveys that were carried out in the field.

4.1.2 Current Trend of Temperature Characteristics for Mali

4.1.2.1 Analysis of maximum and minimum temperatures for Bamako, Ségou and Sikasso

4.1.2.1.1 Temperatures for Bamako

The analysis of the maximum temperatures shows an anomaly of a general upward trend (Figure 4.11 (a)) for an average of 34.65°C in the time series of 1960-2020. According to the Mann-Kendall test, this trend is significant because the p-value = 0.03 which is lower than the threshold significance level alpha=0.05. The risk of rejecting the "no" significance of the trend is 0.03%. The average of the two ruptures in the series from 1960-1989 is estimated at 34.57°C and from 1990-2020 is at 34.72°C (increase of +0.15°C).

The analysis of minimum temperatures (Figure 4.11 (b)) shows that the trend is increasing with an average of 21.18°C in Bamako during the period 1960 to 2020 and this increase in minimum temperatures is in accordance with the perception of surveyed agropastoralists.

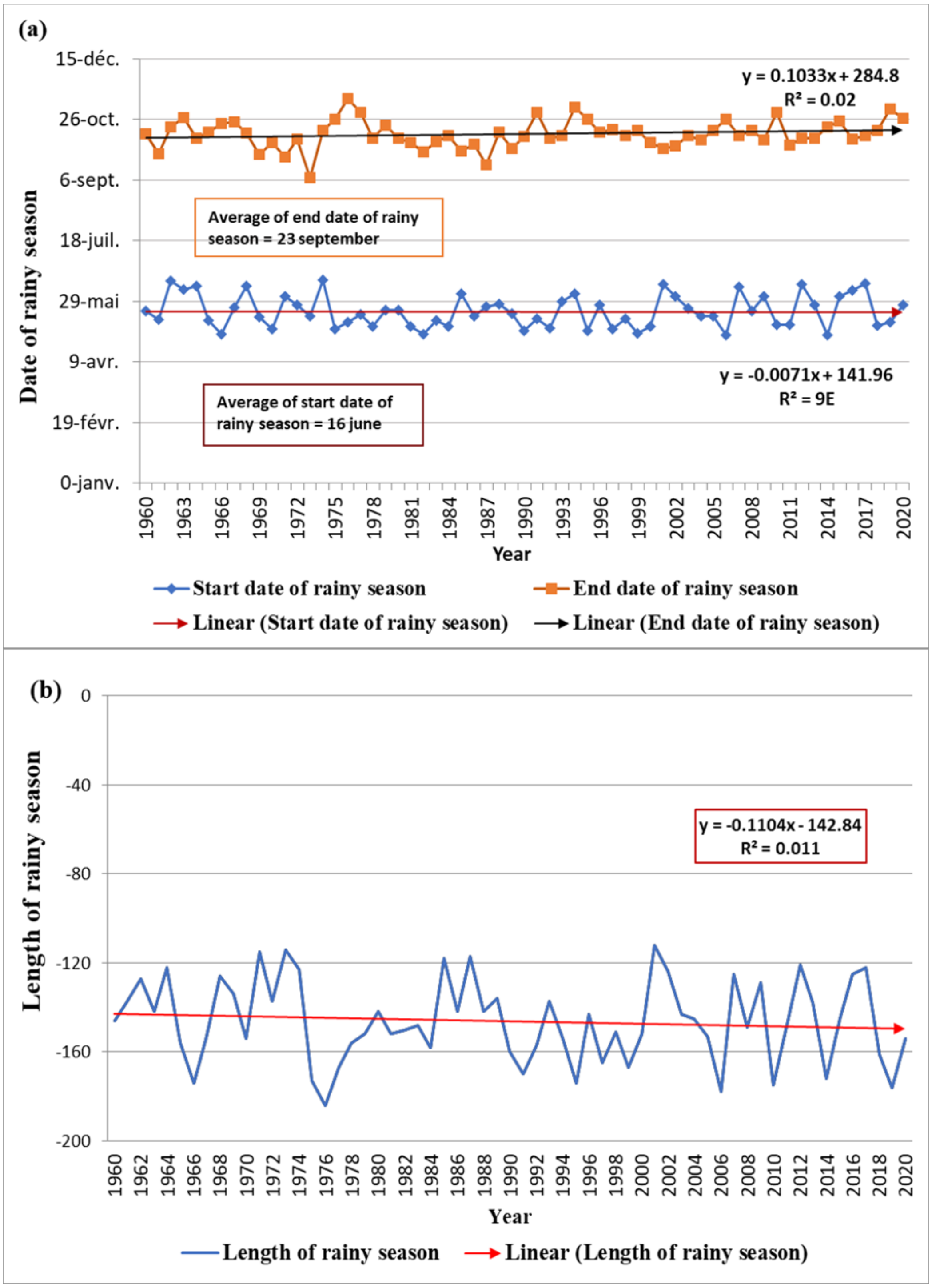


Figure 4.10. Trend of start and End of the rainy season (a), and the length trend of the rainy season (b) for Sikasso

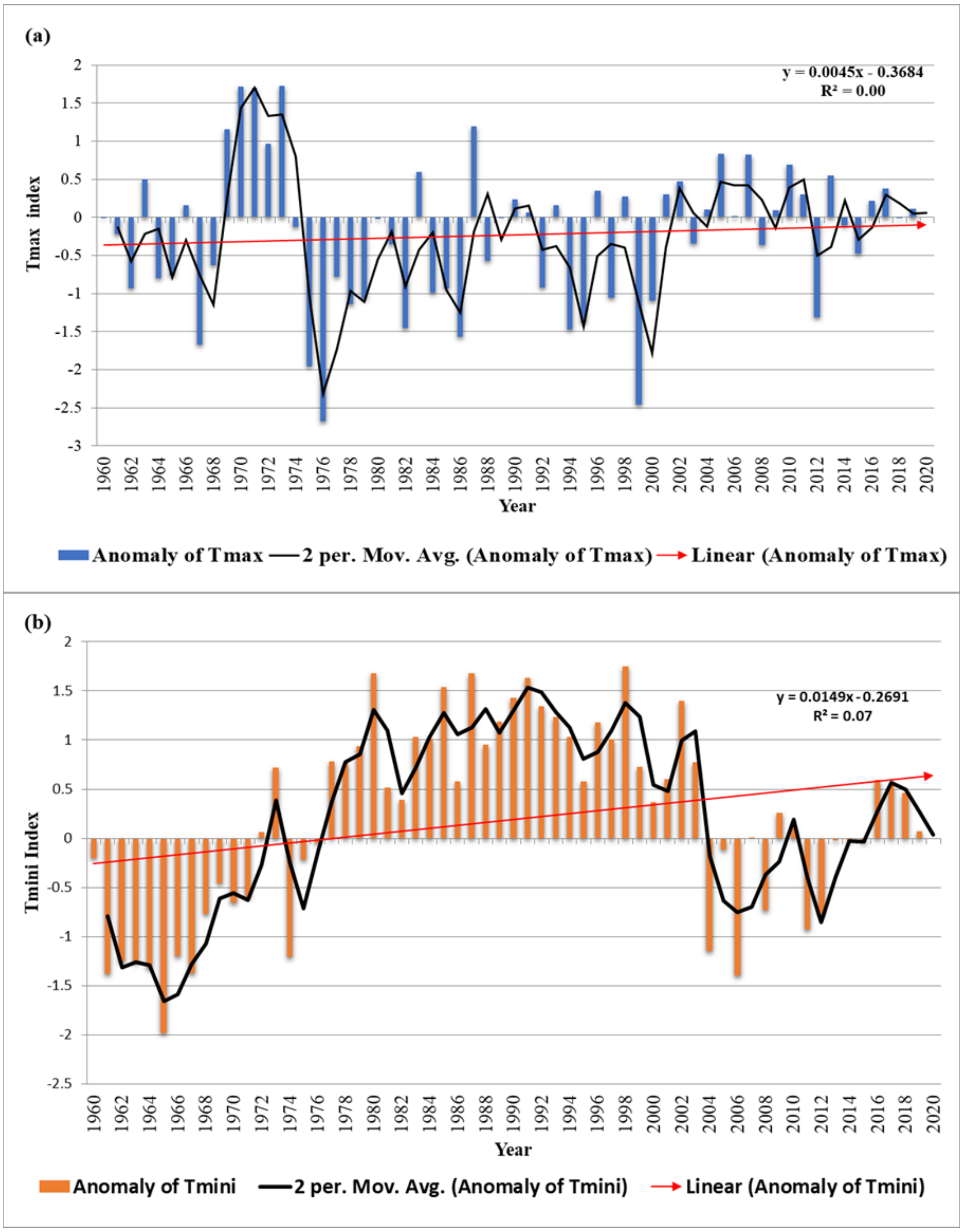


Figure 4.11. Anomaly trend of maximum (a)and minimum temperature (b) for Bamako from 1960-2020 (red line a, b is linear trend, green and black line is moving average)

4.1.2.1.2 Temperatures for Segou

The maximum temperature for the Segou region shows an increasing trend in the time series of 1960-2020 with an average of 36.23°C (Figure 4.12 (a)). This upward trend is 0. 51°C for the whole period (Table 4.1). These results of the evolution of the maximum temperature of the series considered are in agreement with the perception of the agro-pastoralists who declared an increase in temperature. Also, other studies have shown an upward trend in maximum temperatures in the Segou region (Touré et al., 2017; Diop and Barro, 2021).

Data from the analysis of minimum temperatures in the Ségou region showed an interannual change in temperatures recorded throughout the 1960-2020 series with an average of 22.67°C (Figure 4.12 (b)), Table 4.2). Ruptures were observed during the period 1960-1979 with an average of 22.48°C and from 1980-1999 with an average of 22.74°C (Table 4.2).

Table 4:1. Segou maximum temperatures

Ségou Station	**Year of ruptures**	**Mean**	**Average increase**
	1960-1989	35.96°C	+0.51 °C
	1990-2020	36.47°C	+0.75°C

Table 4:2. Ségou minimum temperatures rupture

	Ségou Station	
Year of ruptures	Mean	Average increase
1960-1979	22.48°C	+0.19
1980-1999	22.74°C	+0.30°C
2000-2020	22.77°C	+0.49°C

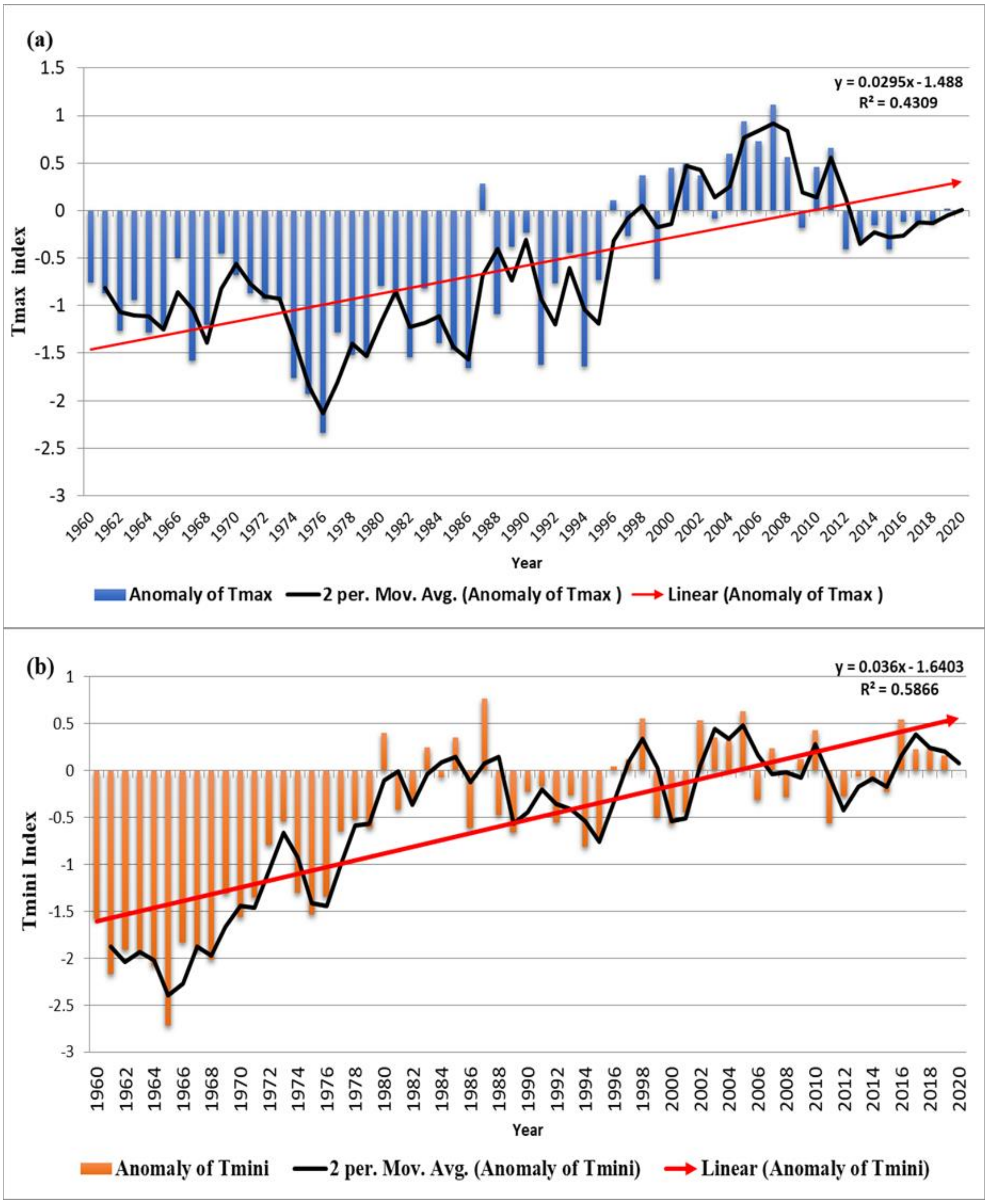


Figure 4.12. Anomaly trend of maximum (a) and minimum temperature (b) for Segou from 1960-2020 (red line a, b is linear trend, green and black line is moving average)

4.1.2.1.3 Temperatures in Sikasso

The evolution of minimum temperatures shows an upward trend of +0.58°C under two time series (1960-1989 and 1990-2020) for the period 1960-2020 (Figure 4.13 (a)). The average maximum temperature is 33.85°C. Since 1979, year of temperature increase have generally been recorded until 2010. The trend is statistically significant since p-value equal to 0.0001, therefore lower than the alpha threshold of 0.05 (Mann Kendall test) (Figure 4.13 (b)).

As for the annual average minimum temperature, the application of the Pettitt test has made it possible to highlight a significant break from 1982, thus dividing the series into two homogeneous sub-series. The average for the 1960-1989 series is 21.36°C against 21.94°C for the 1989-2020 series (Table 4.3). Therefore, similar results showed that the increase in the annual minimum temperature of +0.58°C of Sikasso station (B. Traore et al., 2013).

4.1.3 Climate projection for Mali under scenarios SSP24.5 and SSP58.5 of precipitation, temperature and solar radiation in the near future 2021-2050 and far future 2070-2100

4.1.3.1 Climate projection for Sikasso in the near future (2021-2050)

The average annual precipitation under the scenarios SSP2-4.5 and SSP5-8.5 for Sikasso during the periods 2021-2050 show an interannual variability of precipitation (Figure 4.14 (a, b)). Indeed, a slight increase in precipitation for the SSP5-8.5 scenario with 33 mm per decade, a statistically insignificant trend in the annual series (Table 4.4).

Table 4:3. Sikasso minimum temperature rupture

	Station de Sikasso	
Year of ruptures	Moyenne	Average increase
1960-1989	21.36°C	
1990-2020	21.94°C	+0.58°C

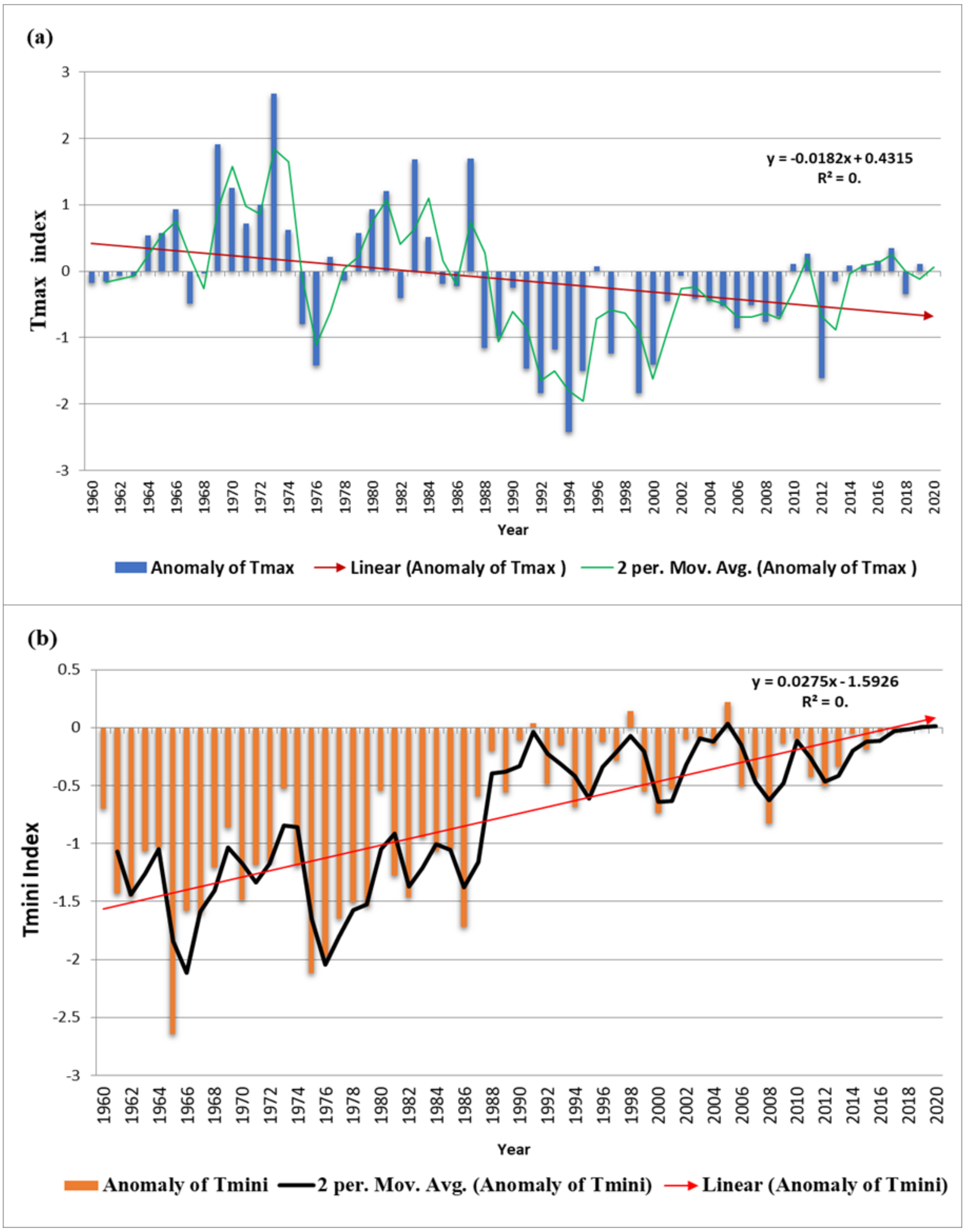


Figure 4.13. Anomaly trend of maximum (a) and minimum temperature (b)for Sikasso from 1960-2020 (red line a, b is linear trend, green and black line is moving average)

These results are similar to a recent study on precipitation projections with the CMP6 model under two scenarios SSP2-4.5 and SSP5-8.5 whose results of the trend analysis for annual precipitation for the Volta basin from the year 1985 to 2050 showed a statistically increasing trend in rainfall in the Sahel and savanna zones with SSP5-8.5 (Yue et al., 2021). Identical with a recent study under the SSP5-8.5 scenario, revealed that annual rainfall is expected to increase by 32.5% per decade in the Sahel (Dotse et al., 2023).

The annual average projection of solar radiation according to the scenarios (SSP2-4.5 and SSP5-8.5) in the Sikasso region showed a general downward trend for both scenarios. This downward trend is 0.58 W/m^2 per decade for the SSP2-4.5 scenario and 1.09 W/m^2/year/decade for the SSP5-8.5 scenario (Table 4.4, Figure 4.15 (a, b)).

Concerning the projection on average annual temperatures, this trend was noted significantly upwards (at 0.001 significance level) by 0.29°C per decade for the SSP2-4.5 scenario (Figure 4.16 (a, b)). According to the SSP5-8.5 scenario, the trend is significant (significant level of 0.001) with an increase of 1.23°C and 0.41°C per decade (Table 4.4).

This rising temperature trend could increase evapotranspiration, increase water and heat stress, which could lead to lower crop yields. Several studies have shown that solar radiation has a greater impact on crops with lower solar radiation intensities, which could lead to deterioration in agricultural productivity (Chen et al., 2013; Shi et al., 2008; Yang et al., 2019).

Table 4:4 Projection of precipitation, solar radiation and temperature for Sikasso region under scenarios SSP2-4.5 and SSP5-8.5 in the near future 2021-2050

Scenarios	Time series Sikasso region	Z-test	Signific.	Q	AC
SSP2-4.5 (2021-2050)	Precipitation (mm/ year)	0.00		-0.071	-0.71
	Solar radiation (W/m^2/year)	-1.57		-0.058	-0.58
	Temperature (°C)	4.39	***	0.029	0.29
SSP5-8.5 (2021-2050)	Precipitation (mm/ year)	0.87		3.300	33
	Solar radiation (W/m^2/ year)	-2.46	*	-0.109	-1.09
	Temperature (°C)	4.98	***	0.041	0.41

*** if trend at $\alpha = 0.001$ level of significance; ** if trend at $\alpha = 0.01$ level of significance

* if trend at $\alpha = 0.05$ level of significance; + if trend at $\alpha = 0.1$ level of significance

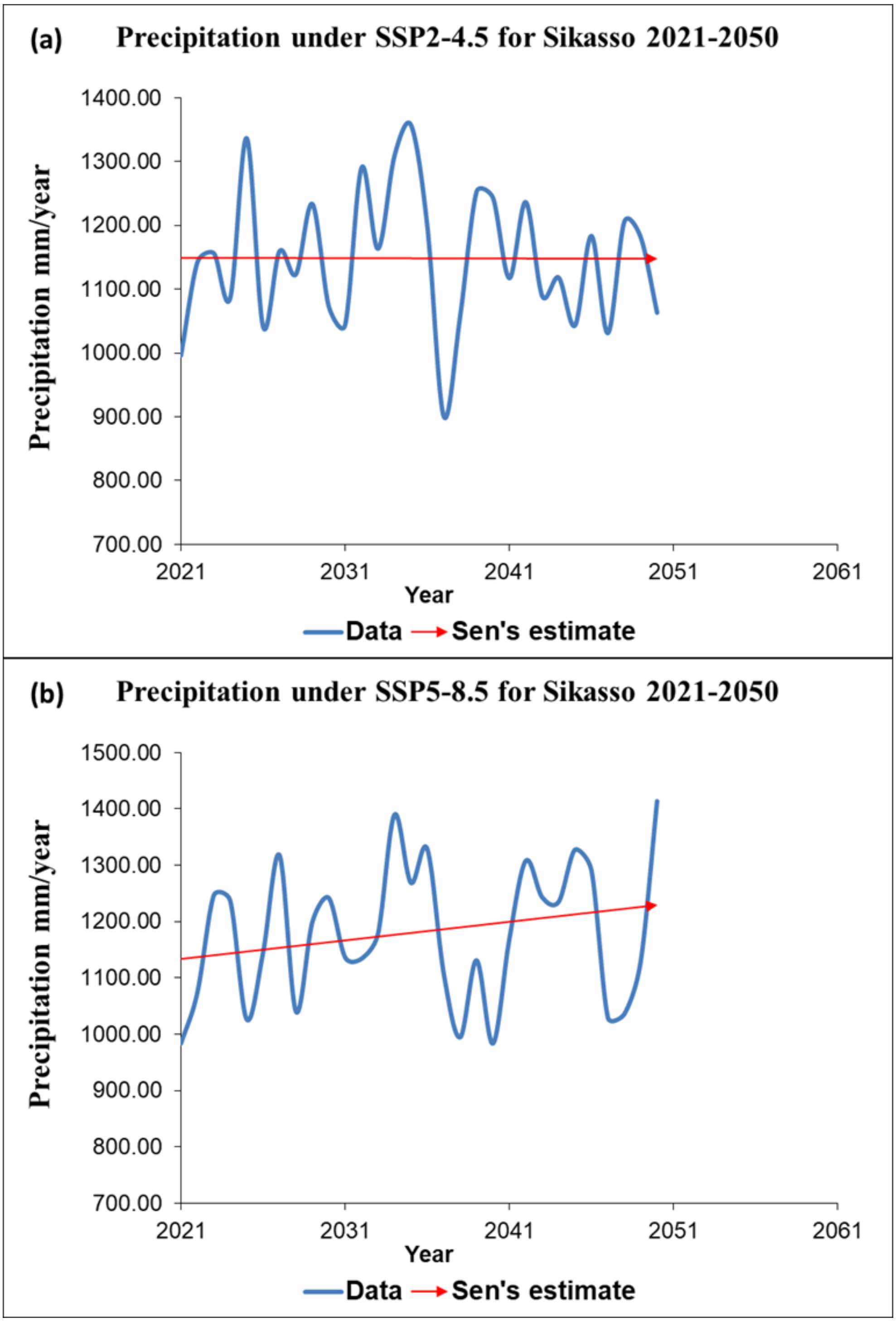


Figure 4.14. Precipitation under scenario SSP2-4.5 (a) and SSP5-8.5 (b) for Sikasso in the near future 2021-2050

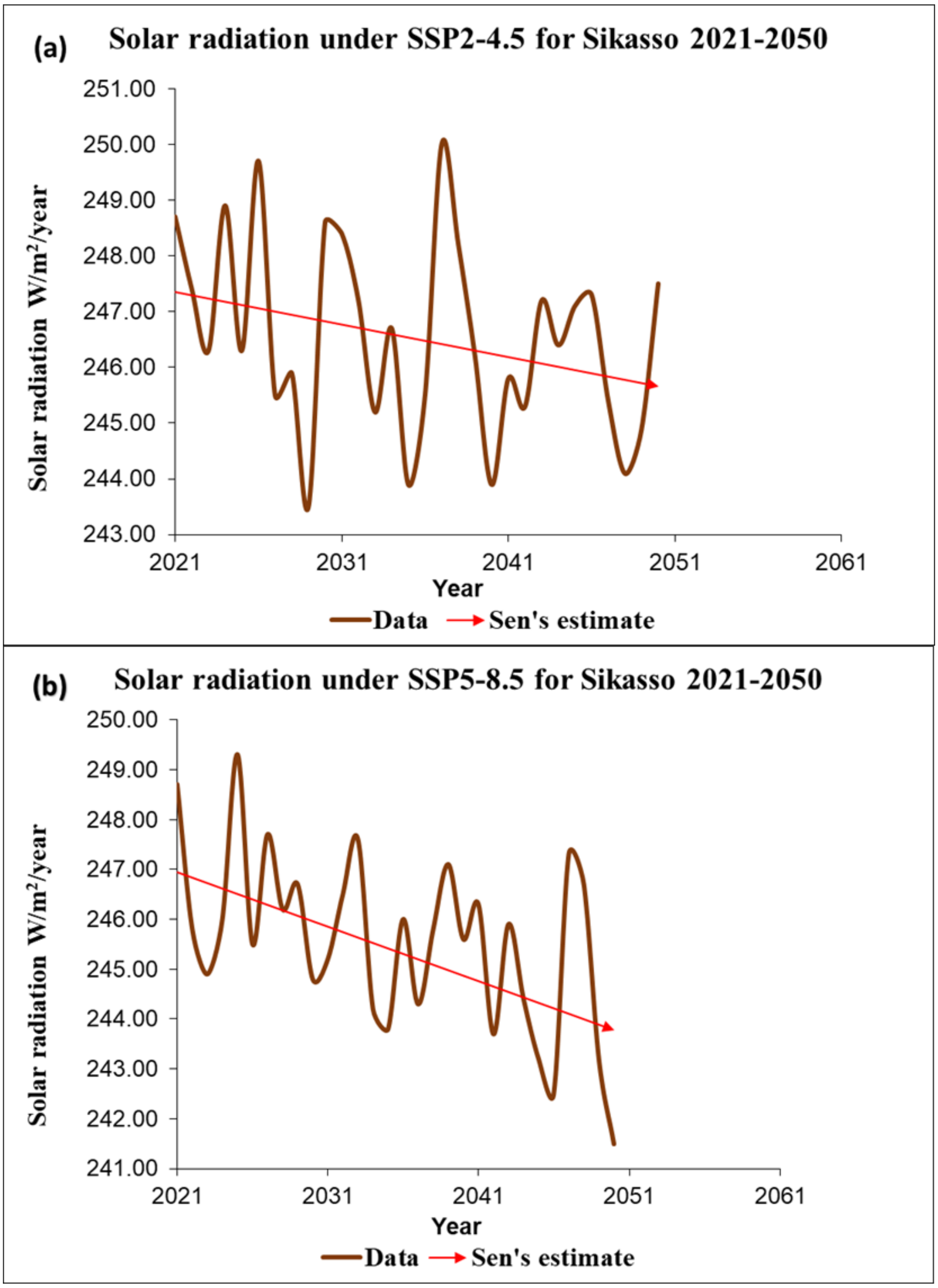


Figure 4.15. Solar radiation under scenario SSP2-4.5 (a) and SSP5-8.5 (b) for Sikasso in the near future 2021-2050

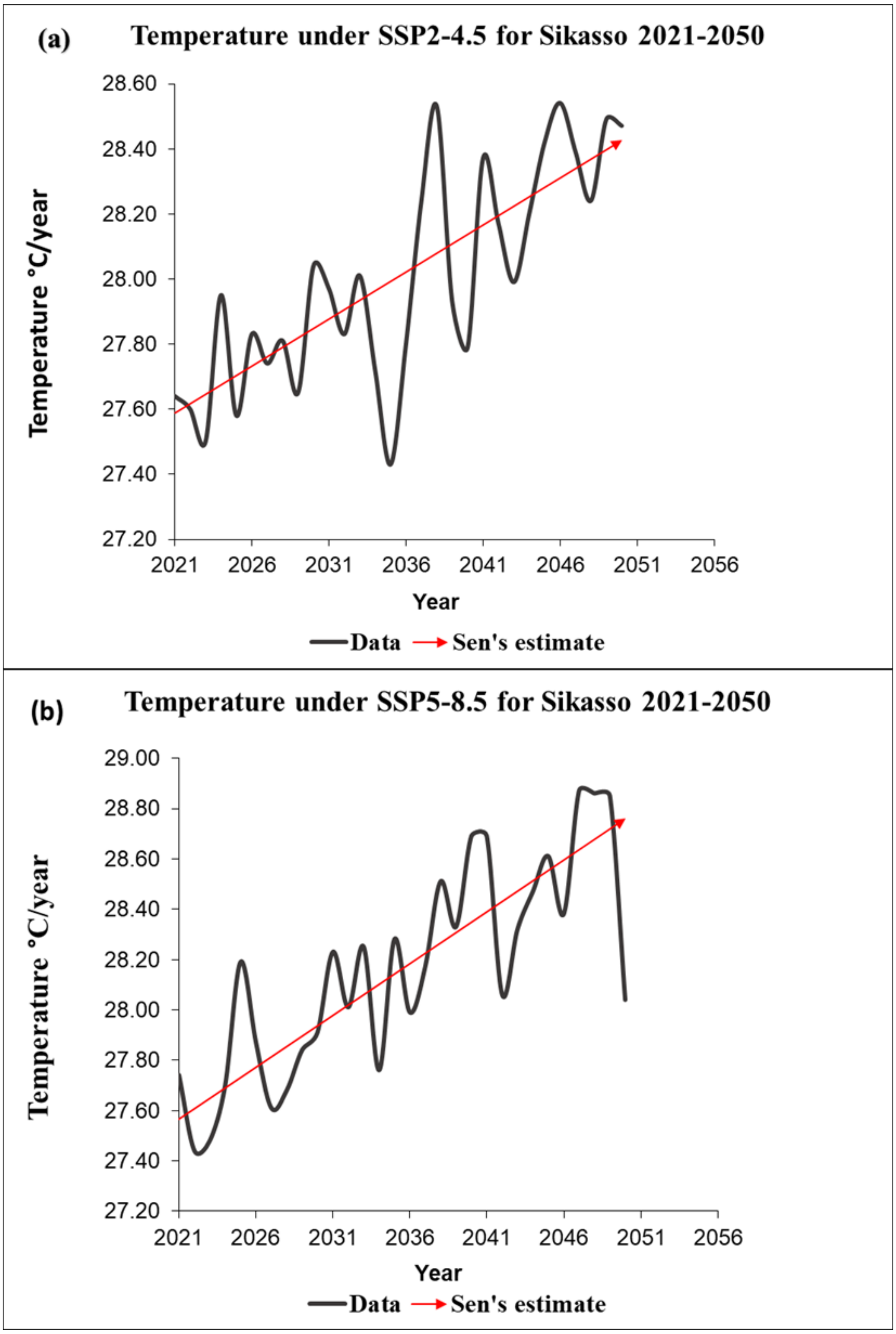


Figure 4.16. Temperature under scenario SSP2-4.5 (a) and SSP5-8.5 (b) for Sikasso in the near future 2021-2050

4.1.3.2 Climate Projection for Kolondieba in the near future (2021-2050)

The average annual precipitation for Kolondieba illustrates a variability with the climatic trend on the rainfall series of 2021-2050 on both scenarios (SSP2-4.5 and SSP5-8.5). A slight increase in rainfall was observed for the scenario SSP5-8.5 per decade in the Kolondieba area; therefore, this increasing trend is not significant (Table 4.5). Our results are consistent with a study on global changes in terrestrial monsoon precipitation in the CMIP6 projections, an uncertain increase of (5.75 ± 5.92%) in long-term precipitation was found with the SSP5-8.5 scenario (Yue et al., 2021).

The projection of solar radiation on the scenarios (SSP2-4.5 and SSP5-8.5) shows a slight, non-significant increase for both scenarios. This increase is 0.50 W/m^2/year/decade not significant for the SSP2-4.5 scenario and 0.86 W/m^2/decade for the SSP5-8.5 scenario at the significant level is 0.05 (Table 4.5). The temperature projection of the SSP 2-4.5 and SSP5-8.5 scenarios shows an upward trend with a significant level of (0.001). This upward trend is significant at 0.31°C per decade for the SSP2-4.5 scenario and 0.42°C per decade for the 2021-2050 series (Table 4.5).

Table 4:5. Projection of precipitation, solar radiation and temperature for Kolondieba under scenarios SSP24.5 and SSP5-8.5 in the near future 2021-2050

Scenarios	Time series of Kolondieba	Z-test	Signific.	Q	AC
SSP2-4.5 (2021-2050)	Precipitation (mm/ year)	-0.39		-0.960	-9.6
	Solar radiation (W/m^2/year)	-1.30		-0.050	-0.5
	Temperature (°C)	4.51	***	0.031	0.31
SSP5-8.5 (2021-2050)	Precipitation (mm/ year)	0.54		1.571	15.71
	Solar radiation (W/m^2/ year)	-2.04	*	-0.086	-0.86
	Temperature (°C)	5.14	***	0.042	0.42

*** if trend at $\alpha = 0.001$ level of significance; ** if trend at $\alpha = 0.01$ level of significance

* if trend at $\alpha = 0.05$ level of significance; + if trend at $\alpha = 0.1$ level of significance

4.1.3.3 Climate Projection for Bamako in the near future (2021-2050)

The average annual precipitation under the scenario (SSP2-4.5 and SSP5-8.5) illustrates an increased variability of precipitation in Bamako for the series of 2021-2050 (Figure 4.17 (a, b)). The results of the annual average projection of solar radiation show a general decrease for the series from 2021 to 2050 for the scenarios (SSP2-4.5 and SSP5-8.5) (Table 4.6, Figure 4.18(a, b)). This decrease is 0.50 W/m^2/year per decade at a significant level of ($\alpha = 0.1$) for the SSP2-4.5 scenario the significant level is ($\alpha = 0.05$) with a decrease of 0.10 W/m^2/year per decade for the SSP5-8.5 scenario (Table 4.6, Figure 4.18(a, b)). Studies have shown a downward trend in rainfall in Africa for both scenarios (SSP2-4.5 and SSP5-8.5) and similar to the Sahara Desert in Africa which gets very low average annual rainfall (Almazroui et al., 2020).

An upward trend has been noted in projected average annual temperatures, this trend is significantly upward (0.001 significant) of 0.32°C per decade for the SSP2-4.5 scenario (Table 4.6, Figure 4.19 (a)). According to the SSP5-8.5 scenario the trend is 0.43 °C per decade at a significant level of (0.001 significant) (Table 4.6, Figure 4.19(b)). So an increase in average temperature at 1.5 ◦C and 2 ◦C (Rogelj et al., 2018). Our results are similar to previous studies which found that extreme climate change and this increase in average temperature was observed in several sub-regions in West Africa, particularly in the Sahel (Diedhiou et al., 2018; Sylla et al., 2018).

Table 4:6. Projection of precipitation, solar radiation and temperature for Bamako under scenarios SSP24.5 and SSP5-8.5 in the near future 2021-2050

Scenarios	Time series of Bamako	Z-test	Signific.	Q	AV
SSP2-4.5 (2021-2050)	Precipitation (mm/ year)	-0.23		-0.381	-3.81
	Solar radiation (W/m^2/year)	-1.84	+	-0.059	-0.59
	Temperature (°C)	4.52	***	0.032	0.32
SSP5-8.5 (2021-2050)	Precipitation (mm/ year)	0.62		1.632	16.32
	Solar radiation (W/m^2/ year)	-2.13	*	-0.100	-1
	Temperature (°C)	5.09	***	0.043	0.43

*** if trend at $\alpha = 0.001$ level of significance; ** if trend at $\alpha = 0.01$ level of significance

* if trend at $\alpha = 0.05$ level of significance; + if trend at $\alpha = 0.1$ level of significance

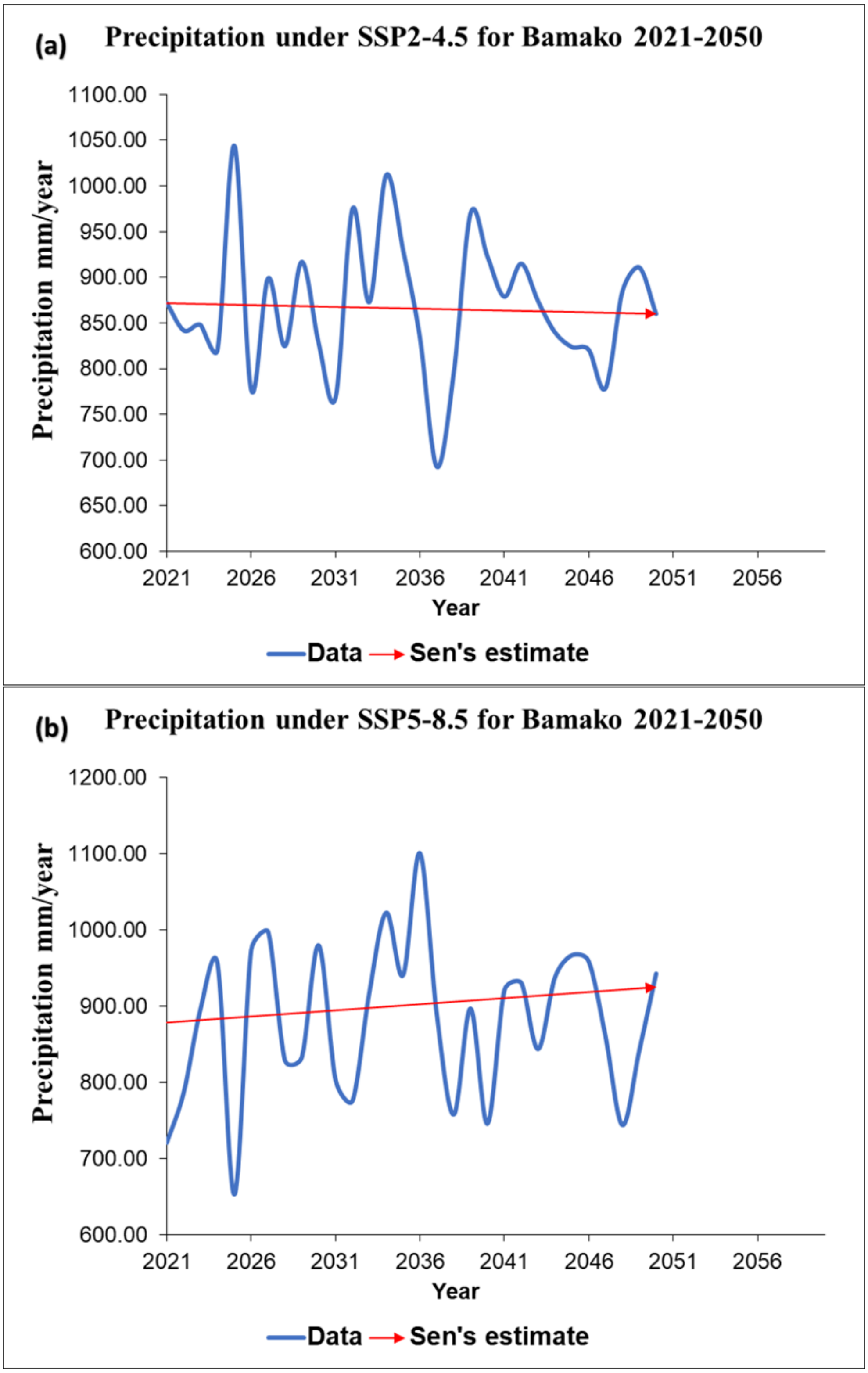


Figure 4.17. Precipitation under scenario SSP2-4.5 (a) and SSP5-8.5 (b) for Bamako in the near future 2021-2050

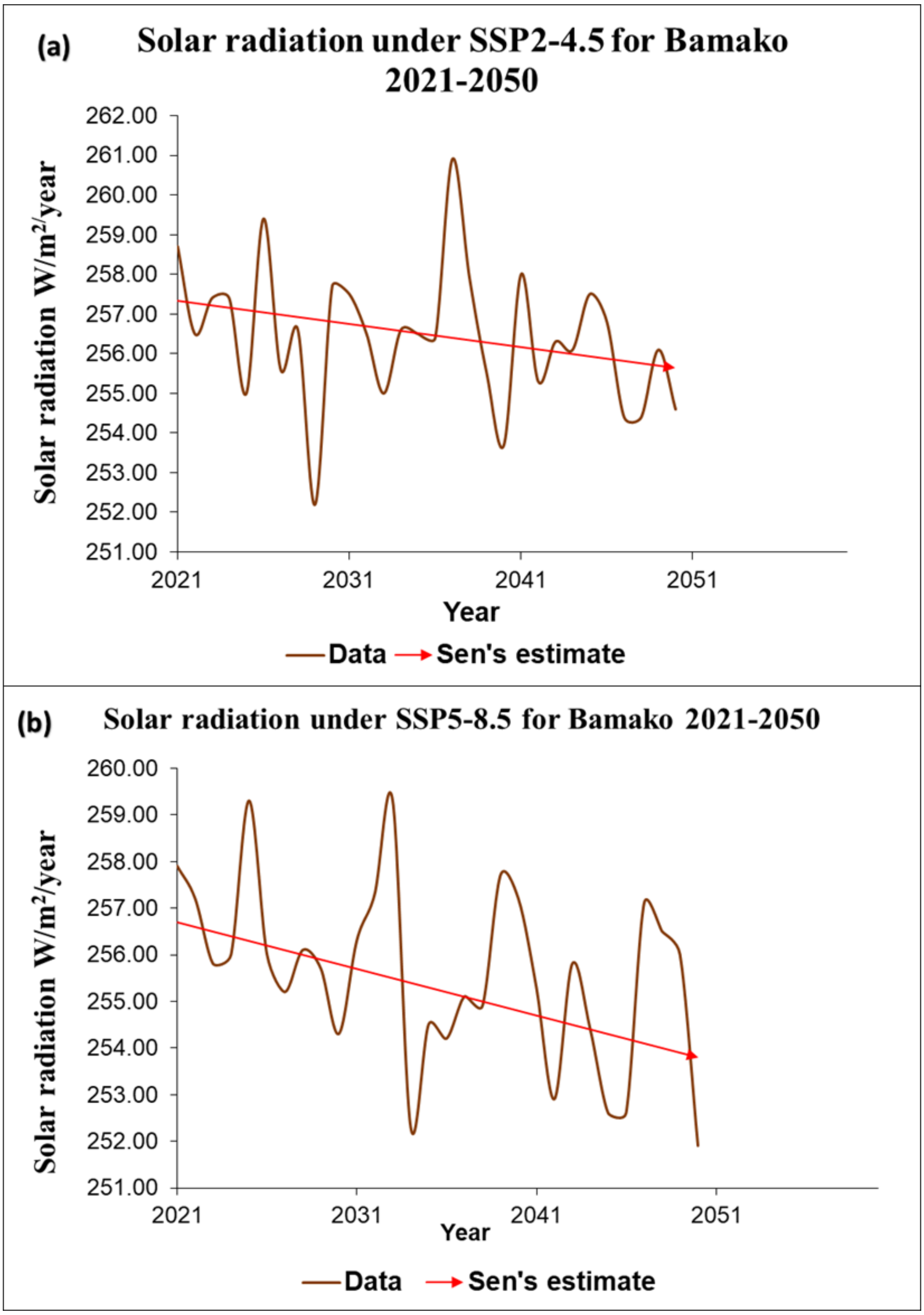


Figure 4.18. Solar radiation under scenario SSP2-4.5 (a) and SSP5-8.5 (b) for Bamako in the near future 2021-2050

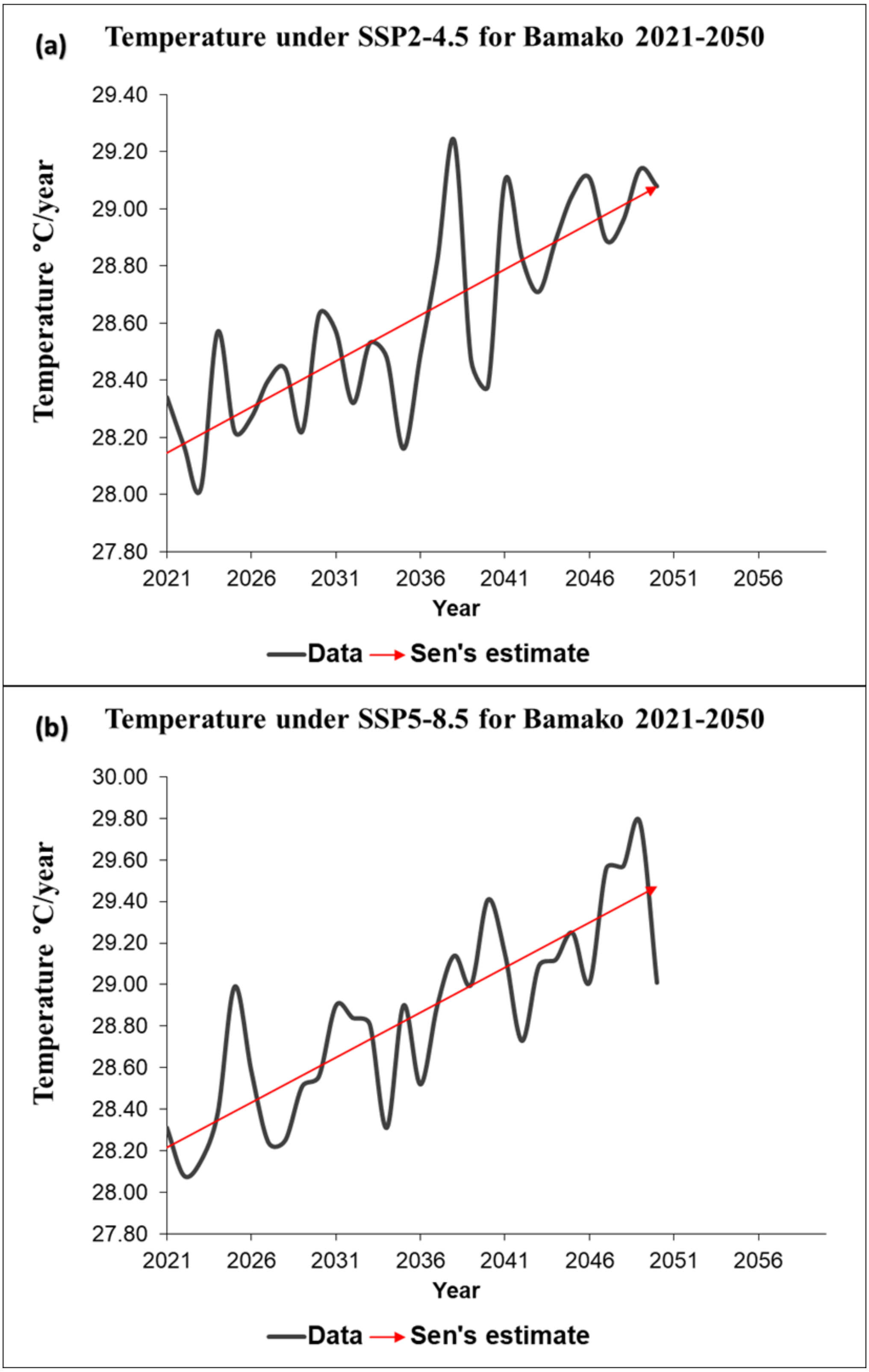


Figure 4.19. Temperature under scenario SSP2-4.5 (a) and SSP5-8.5 (b) for Bamako in the near future 2021-2050

4.1.3.4 Climate Projection for Segou under SSP24.5 and SSP5-8.5 Scenarios in the near future 2021-2050

The average annual precipitation of Ségou under the scenario SSP2-4.5 and SSP5-8.5 illustrates a decrease trend in precipitation for the series of 2021-2050 (Figure 4.20 (a, b)). Indeed, this trend is 2.21mm/year per decade for the SSP2-4.5 scenario and for the SSP5-8.5 scenario 1.17mm/year per decade (Table 4:7). Our results are consistent with previous studies that have found that mean annual rainfall has decreased in Sahelian regions. Rainfall observed for Africa also shows strong seasonal variability (Lebel et al., 2003; Lebel and Ali, 2009).

The annual average projection of solar radiation showed an increase with SSP2-4.5 and decrease for SSP5-8.5 scenario. This upward trend is 0.45 W/m2/year per decade for the SSP2-4.5 scenario and downward trend is 0.10 W/m2/year per decade, the trend is significant (at 0.01 significance level) for the scenario SSP5-8.5 (Table 4:7, Figure 4.21(a, b)).

The projection of annual average temperatures shows an increase trend in temperatures for the two scenarios (SSP2-4.5 and SSP5-8.5) (Figure 4.22 (a, b)). This trend is significantly upward (at 0.01 significance level) by 0.16°C per decade for the SSP2-4.5 scenario. According to the SSP5-8.5 scenario, the trend is significant (significant level of 0.001) with 0.44°C per decade (Table 4*:7*, Figure 4.22 (a, b)). Our results are consistent with those of previous studies in Iran on trend changes in annual mean temperature and precipitation in showed an increase in long-term trends in temperature and also a decrease in mean annual rainfall in future periods (12 to 17%) (Sharafi and Mir Karim, 2020).

Table 4:7. Projection of precipitation, solar radiation and temperature for Segou under scenarios SSP24.5 and SSP5-8.5 in the near future 2021-2050

Scenarios	Time series of Segou	Z-test	Signific.	Q	AC
SSP2-4.5 (2021-2050)	Precipitation (mm/year)	0.16		0.221	2.21
	Solar radiation (W/m^2/year)	1.09		0.045	0.45
	Temperature (°C)	3.23	**	0.016	0.16
SSP5-8.5 (2021-2050)	Precipitation (mm/year)	0.04		0.117	1.17
	Solar radiation (W/m^2/year)	-2.68	**	-0.100	-1
	Temperature (°C)	5.14	***	0.044	0.44

*** if trend at $\alpha = 0.001$ level of significance, ** if trend at $\alpha = 0.01$ level of significance

* if trend at $\alpha = 0.05$ level of significance, + if trend at $\alpha = 0.1$ level of significance

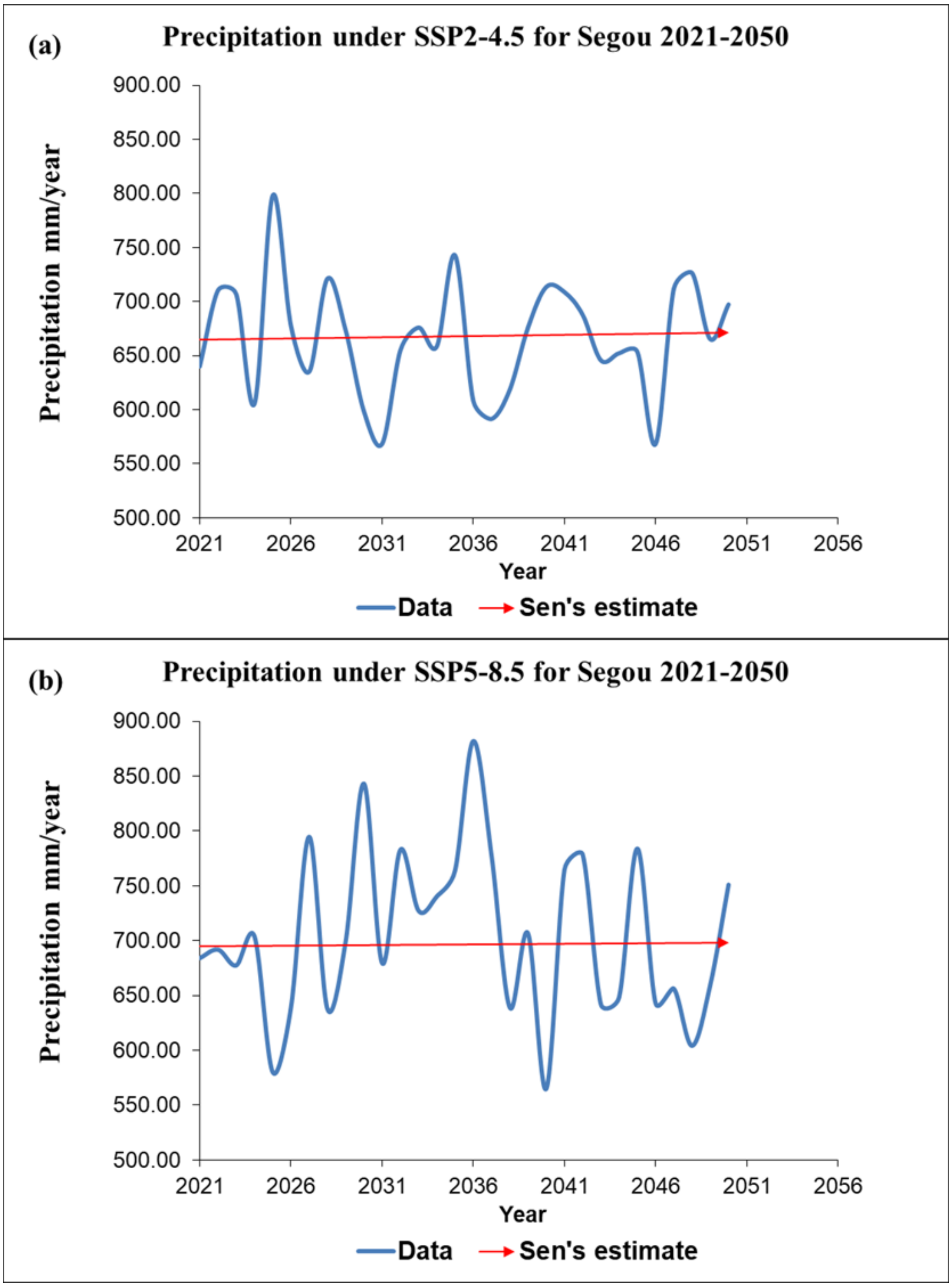


Figure 4.20. Precipitation under scenario SSP2-4.5 (a) and SSP5-8.5(b) for Segou in the near future 2021-2050

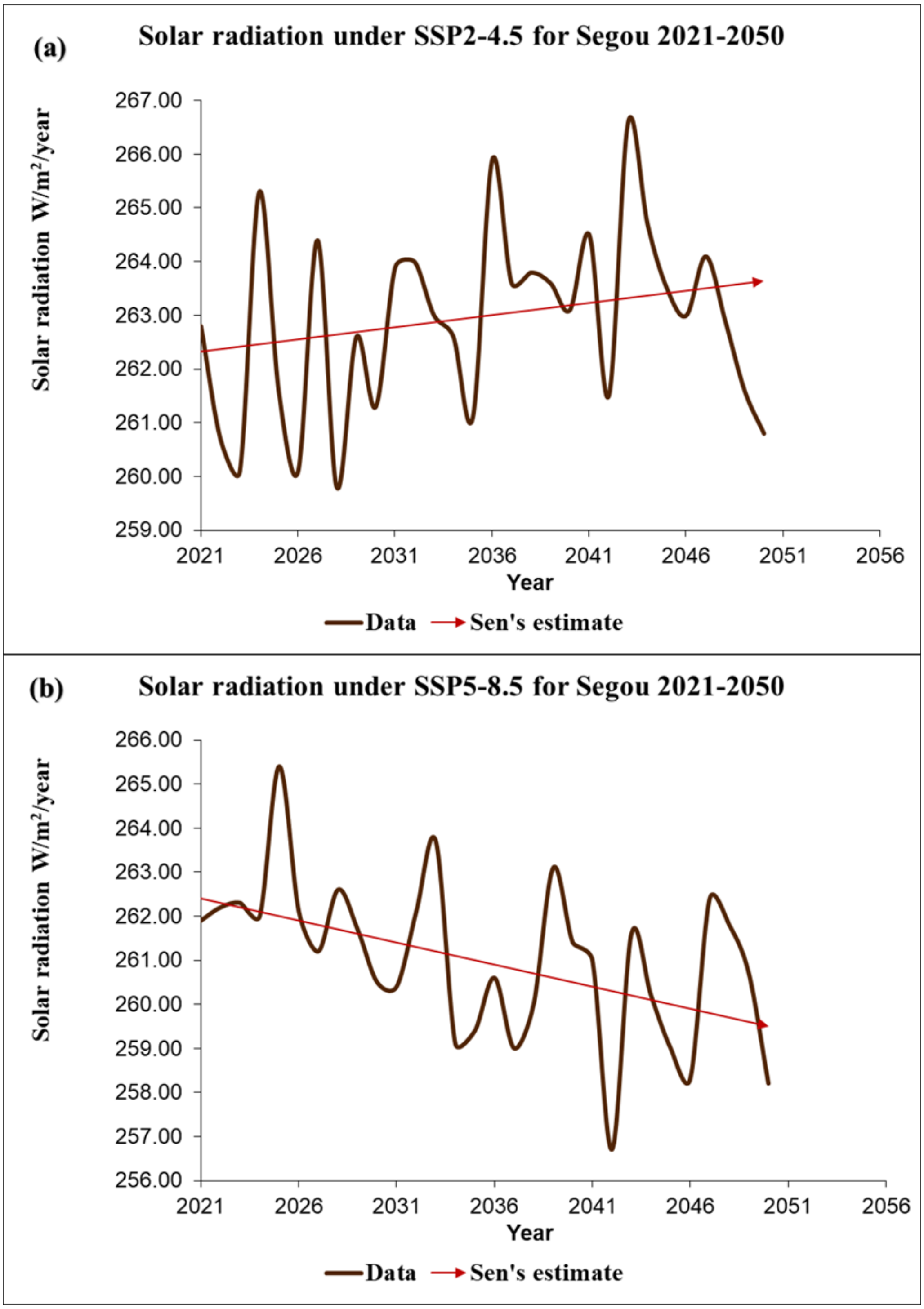


Figure 4.21. Solar radiation under scenario SSP2-4.5 (a) and SSP5-8.5(b) for Segou in the near future 2021-2050

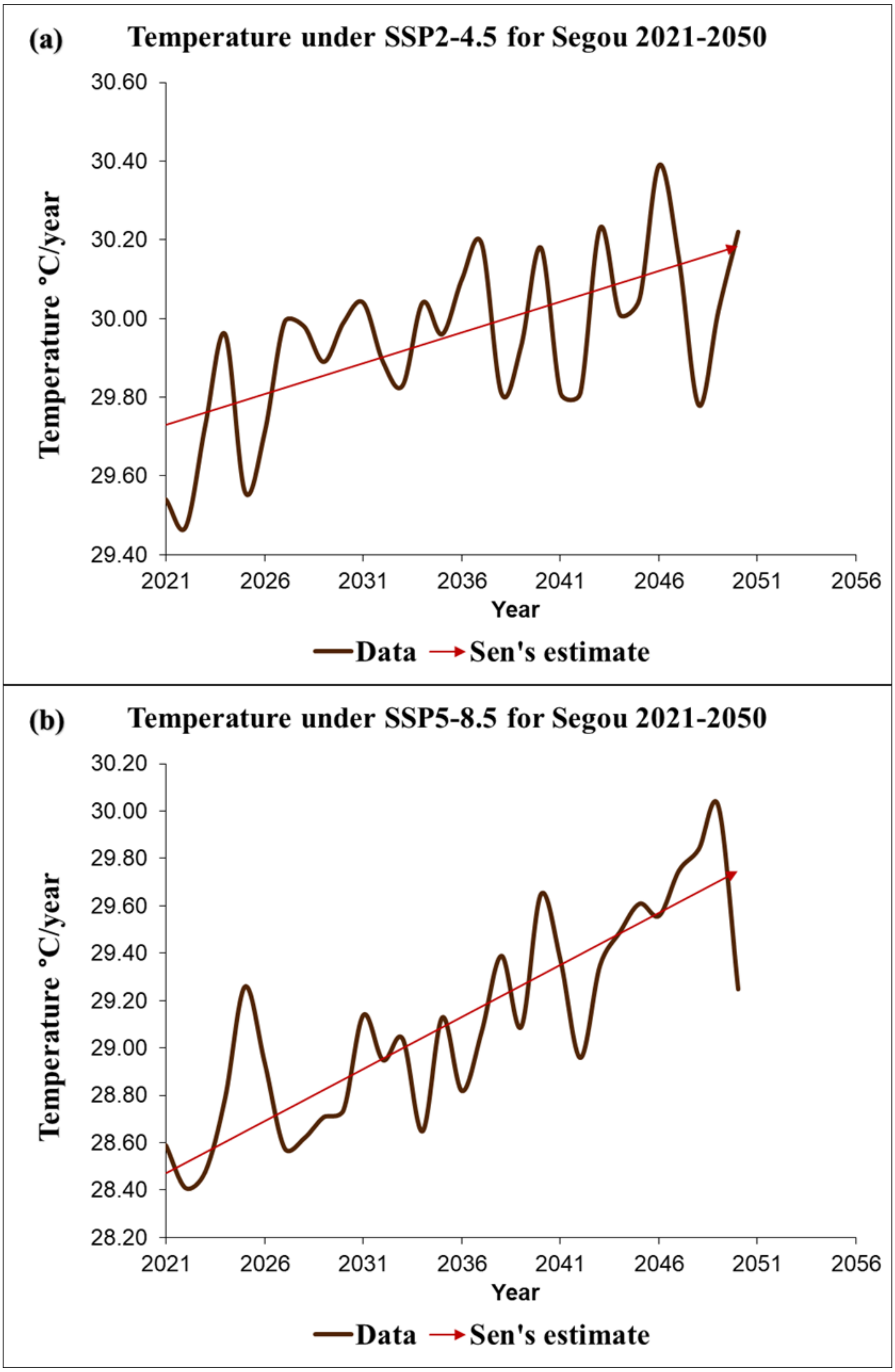


Figure 4.22. Temperature under scenario SSP2-4.5 (a)and SSP5-8.5 (b) for Segou in the near future 2021-2050

4.1.4 Climate projection for Sikasso, Kolondieba in the far future 2070-2100

The results of the projection of average annual precipitation in the region of Sikasso and Kolondieba under the scenarios SSP2-4.5 and SSP5-8.5, an interannual variability was observed on the series of 2070-2100. Indeed, a downward trend in the annual averages of solar radiation for the scenarios SSP2-4.5 and SSP5-8.5 (Figure 4.23(a, b, c, d)). This downward trend is 0.79W/m2/year per decade for the SSP2-4.5 scenario in the Sikasso region statistically significant at the level (0.05 significant) as well as in the Kolondieba zone with a trend of 0.69W/m2/year per decade (Table 4:8). According to the SSP5-8.5 scenario, the trend in the Sikasso region is 0.33 W/m2/year per decade, with 0.67 in Kolondieba at the significant level (0.1 significant) (Table 4:8, Figure 4.24 (a, b, c, d).

According to the projection of the annual average temperatures show an increasing trend in temperatures for the two scenarios SSP2-4.5 and SSP5-8.5. This trend is 0.45 °C per decade (statistically significant) on the rise (00.01 significant). In Sikasso and Kolondieba the rise is 0.46 °C per decade according to scenario SSP5-8.5 (Table 4:8, Figure 4.25 (a, b, c, d)). The interannual variability of rainfall, the drop in solar radiation and the rise in temperature are climatic phenomena that accentuate drought and could lead to a drop in the yields of agricultural production.

Table 4:8 Climate projection for Sikasso, Kolondieba under scenarios SSP24.5 and SSP58.5 of precipitation temperature and solar radiation in the far future 2070-2100

Scenarios	**Time series of Sikasso**	**Z-test**	**Signific.**	**Q**	**AC**
SSP2-4.5 (2070-2100)	Precipitation (mm/ year)	0.63		1.333	13.33
	Solar radiation (W/m^2/year)	2.25	*	0.079	0.79
	Temperature (°C)	2.72	**	0.013	0.13
SSP5-8.5 (2070-2100)	Precipitation (mm/ year)	0.36		1.471	14.71
	Solar radiation (W/m^2/ year)	0.88		0.033	0.33
	Temperature (°C)	5.85	***	0.045	0.45
Scenarios	**Time series of Kolondieba**	**Z-test**	**Signific.**	**Q**	**AC**
SSP2-4.5 (2070-2100)	Precipitation (mm/ year)	0.39		0.556	5.56
	Solar radiation (W/m^2/year)	2.19	*	0.069	0.69
	Temperature (°C)	2.77	**	0.014	0.14
SSP5-8.5 (2070-2100)	Precipitation (mm/ year)	0.77		2.000	20
	Solar radiation (W/m^2/ year)	1.77	+	0.067	0.67
	Temperature (°C/)	5.93	***	0.046	0.46

*** if trend at α = 0.001 level of significance; ** if trend at α = 0.01 level of significance

* if trend at α = 0.05 level of significance; + if trend at α = 0.1 level of significance

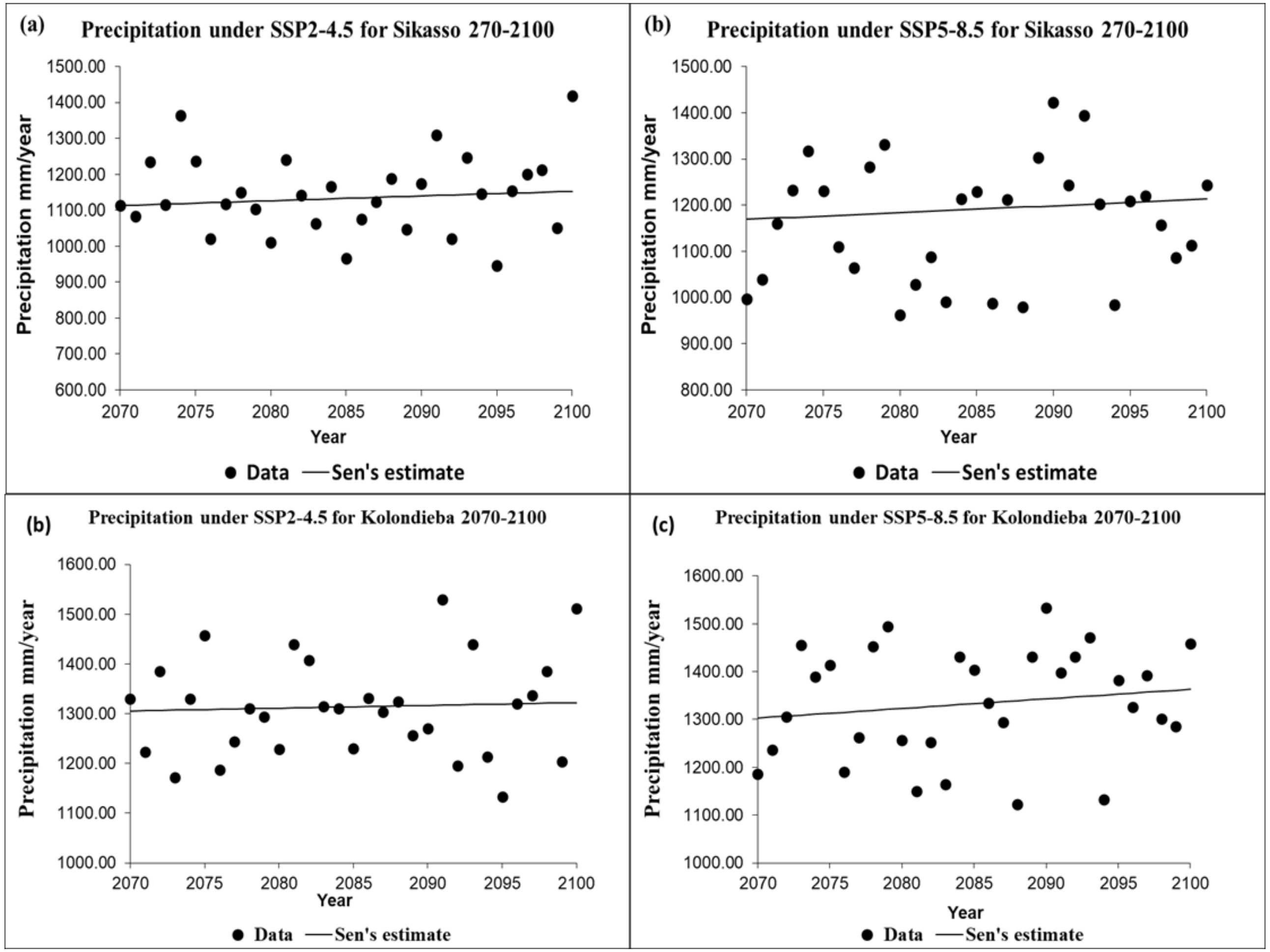


Figure 4.23 Precipitation under scenarios SSP24.5(a) and SSP58.5 (b) for Sikasso and Kolondieba (c, d) in the far future 2070-2100

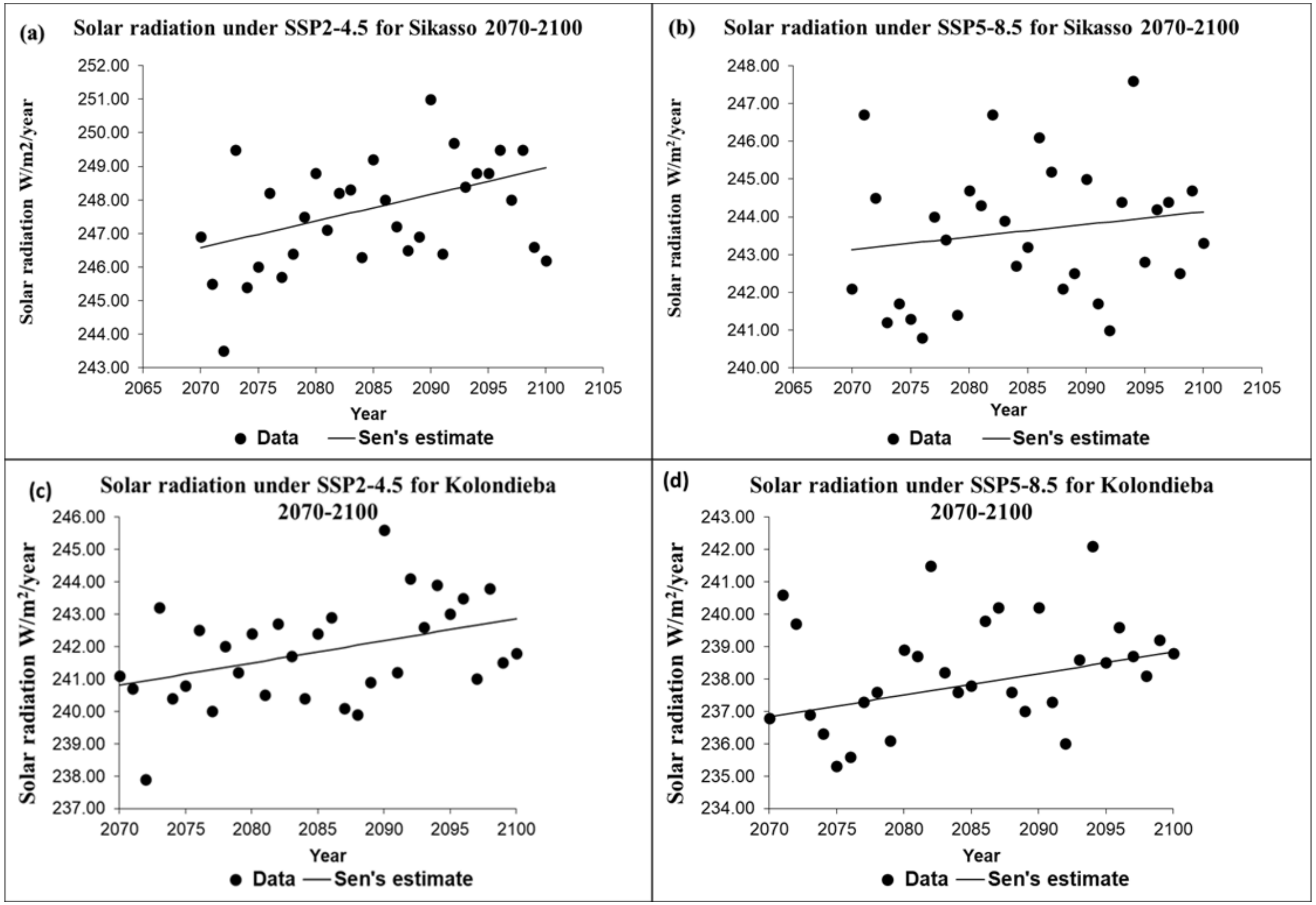


Figure 4.24 Solar radiation under scenarios SSP24.5(a) and SSP58.5 (b) for Sikasso and Kolondieba (c, d) in the far future 2070-2100

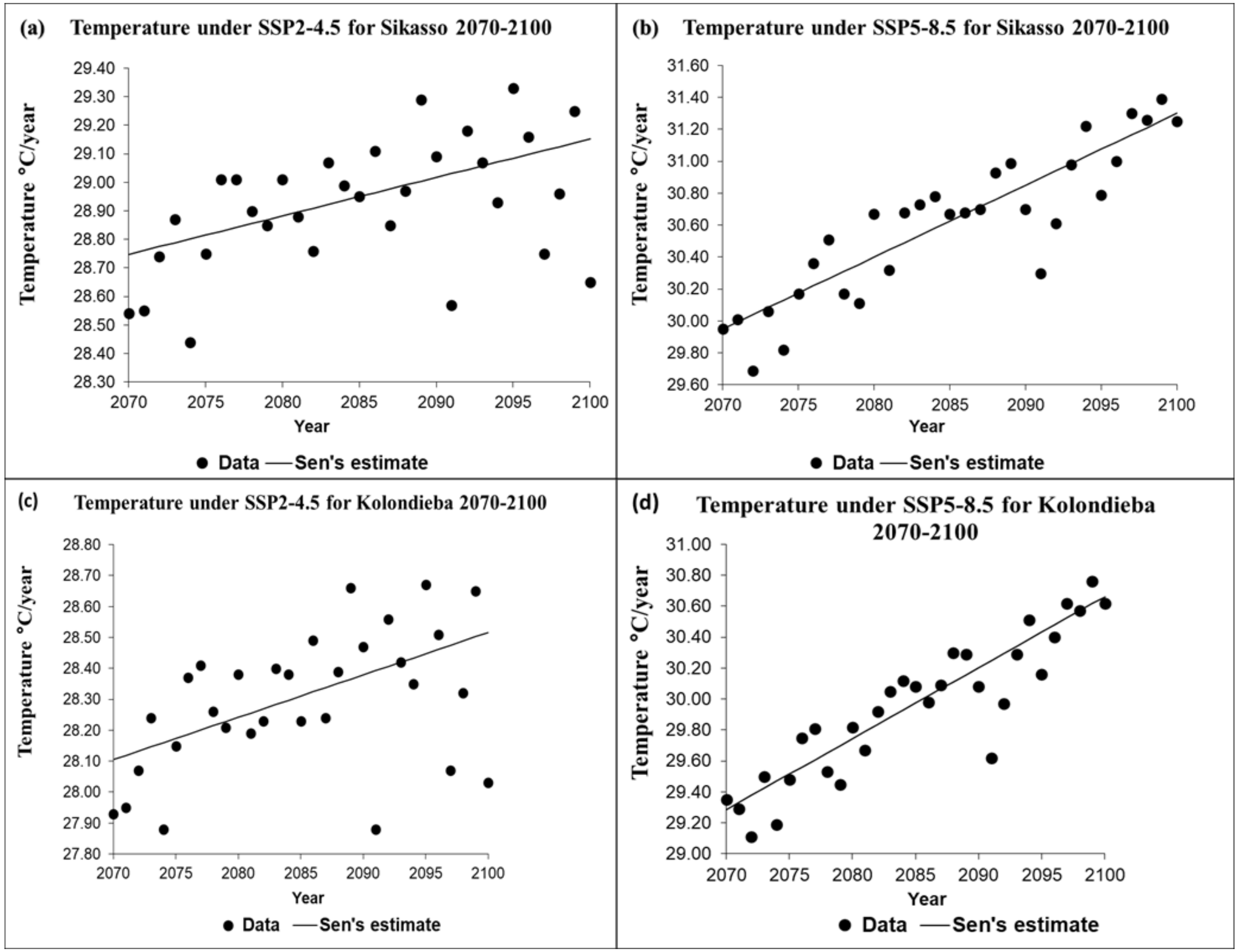


Figure 4.25 Temperature under scenarios SSP24.5(a) and SSP58.5 (b) for Sikasso and Kolondieba (c, d) in the far future 2070-2100

4.1.5 Climate projection for Segou, Niono and Bamako in the far future 2070-2100

Average annual rainfall shows a general downward trend in the region of Ségou, Niono and Bamako district for the scenario SSP2-4.5 and SSP5-8.5 (Figure 4.26 (a, b, c, d)). Indeed, inter-annual variability of precipitation has been noted during the future period 2070-2100. However, a downward trend in annual average solar radiation was observed for both scenarios SSP2-4.5 and SSP5-8.5 (Table 4:9, Figure 4.27 (a, b, c, d)).

The average temperature for the period 2070-2100 shows a general decrease trend in temperatures in these three localities (Ségou, Niono and Bamako) Figure 4.28(a, b, c, d) Figure 4.31 (a, b)).

According to the SSP2-4.5 scenario, this upward trend is significant (0.01 significant level) of 0.13°C per decade in the region of Ségou and the district of Bamako and 0.15°C per decade and Niono (Table 4:9). On the other hand, for the SSP5-8.5 scenario, the upward trend is higher at the significant level of 0.001 for the three localities. This upward trend is 0.51°C per decade in Ségou as well as in Bamako and 0.55°C per decade at Niono (Table 4:9) for the future period 2070-2100. As a result, our results are similar to studies made on the future projection of annual average precipitation and temperature with these two different scenarios (SSP1-2.6, SSP2.4.5 and SSP5-8.5), which showed that the temperature will increase throughout 21st century (Ayugi et al., 2021; Iyakaremye et al., 2021).

Table 4:9 Climate projection for Segou, Niono and Bamako under scenarios SSP24.5 and SSP58.5 of precipitation temperature and solar radiation in the far future 2070-2100

Scenarios	Time series of Segou	Z-test	Signific.	Q	AC
SSP2-4.5 (2070-2100)	Precipitation (mm/ year)	0.66		0.829	8.29
	Solar radiation (W/m^2/year)	0.95		0.036	0.36
	Temperature (°C)	2.74	**	0.013	0.13
SSP5-8.5 (2070-2100)	Precipitation mm/ year	0.03		0.085	0.85
	Solar radiation (W/m^2/ year)	0.00		0.000	0
	Temperature (°C)	5.78	***	0.051	0.51
Scenarios	**Time series of Niono**	**Z-test**	**Signific.**	**Q**	**AC**
SSP2-4.5 (2070-2100)	Precipitation (mm/ year)	0.37		0.961	9.61
	Solar radiation (W/m^2/year)	1.38		0.053	0.53
	Temperature (°C)	3.06	**	0.015	0.15
SSP5-8.5 (2070-2100)	Precipitation (mm/ year)	-0.34		-0.393	-3.93
	Solar radiation (W/m^2/year)	0.00		0.000	0
	Temperature (°C)	5.88	***	0.055	0.55
Scenarios	**Time series of Bamako**	**Z-test**	**Signific.**	**Q**	**AC**
SSP2-4.5 (2070-2100)	Precipitation (mm/ year)	1.16		2.381	23.81
	Solar radiation (W/m^2/year)	1.24		0.040	0.4
	Temperature (°C)	2.54	*	0.013	0.13
SSP5-8.5 (2070-2100)	Precipitation (mm/ year)	0.59		1.308	13.08
	Solar radiation (W/m^2/year)	0.39		0.014	0.14
	Temperature (°C)	5.71	***	0.051	0.51

*** if trend at $\alpha = 0.001$ level of significance; ** if trend at $\alpha = 0.01$ level of significance

* if trend at $\alpha = 0.05$ level of significance; + if trend at $\alpha = 0.1$ level of significance

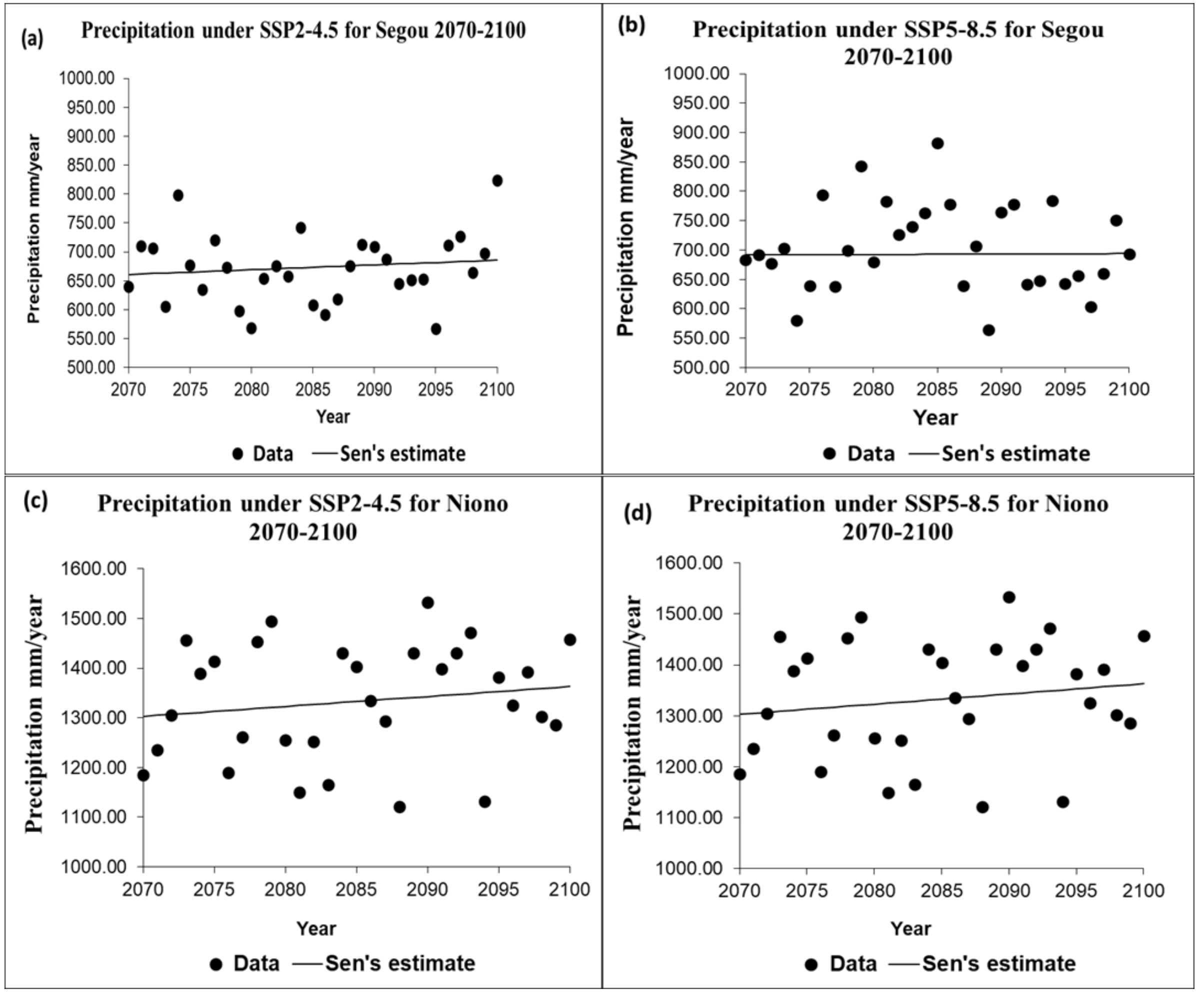


Figure 4.26 Precipitation under scenarios SSP24.5(a) and SSP58.5(b) for Segou and Niono (c, d) in the far future 2070-2100

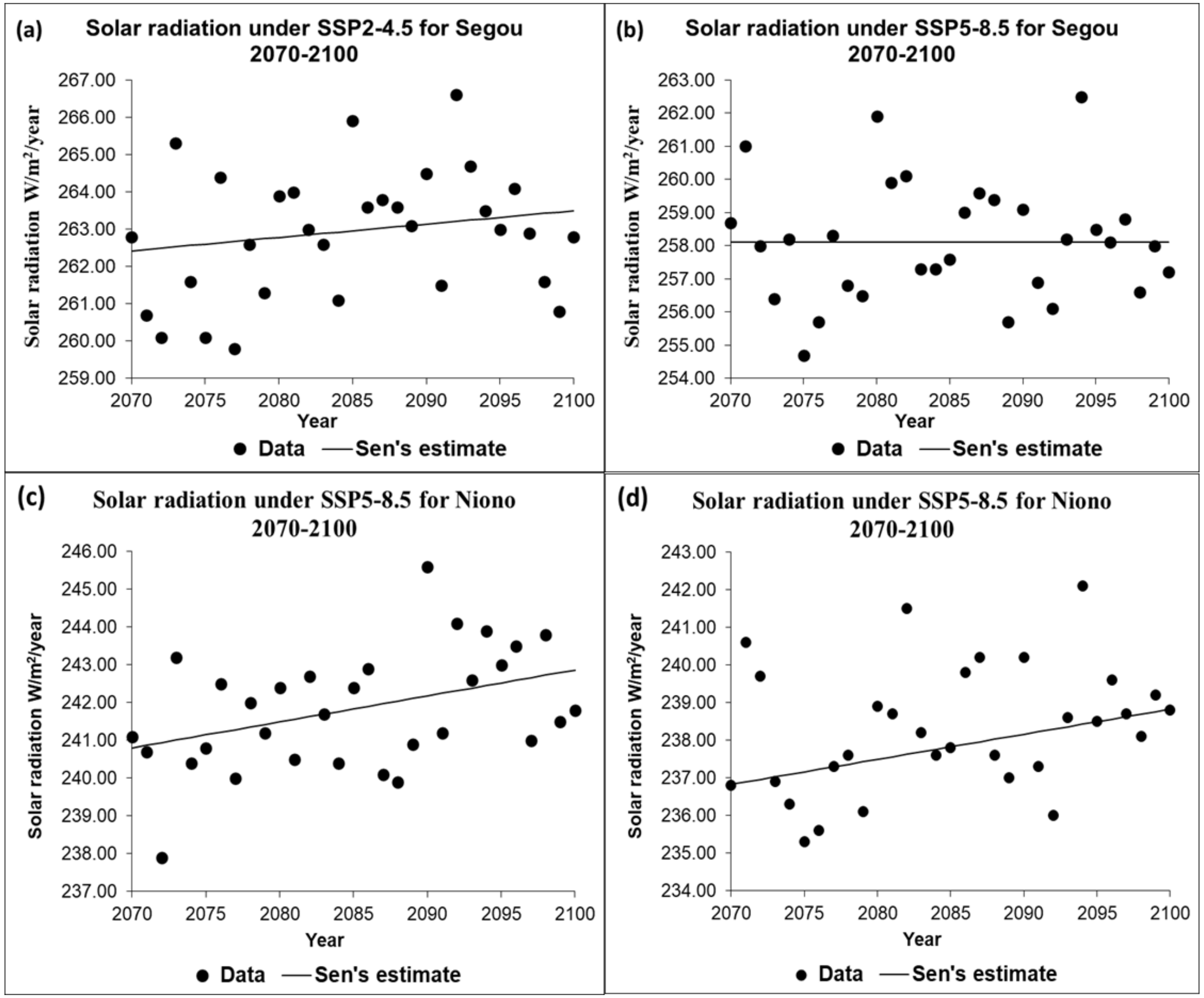


Figure 4.27 Solar radiation under scenarios SSP24.5(a) and SSP58.5(b) for Segou and Niono (c, d) in the far future 2070-2100

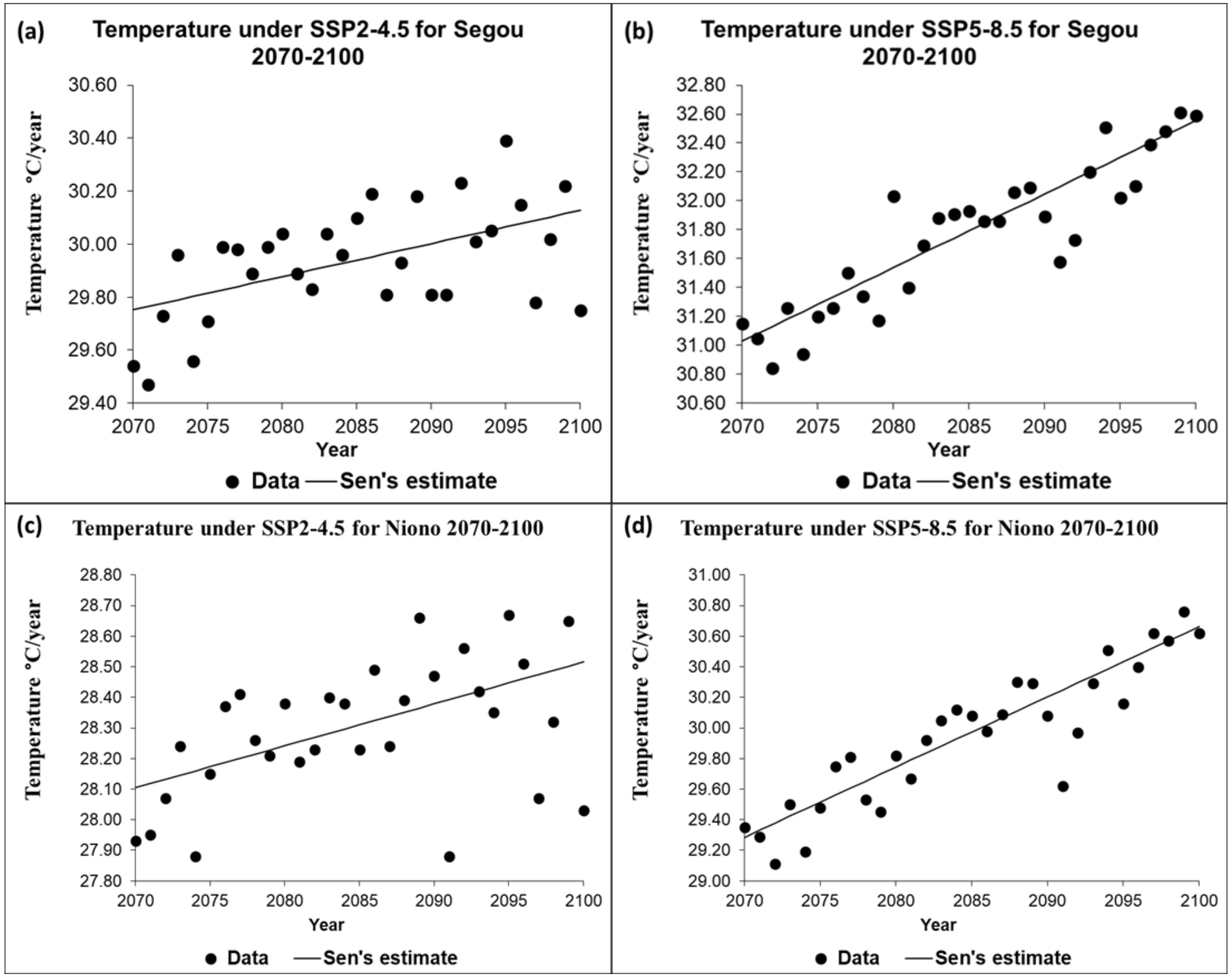


Figure 4.28 Temperature under scenarios SSP24.5(a) and SSP58.5(b) for Segou and Niono (c, d) in the far future 2070-2100

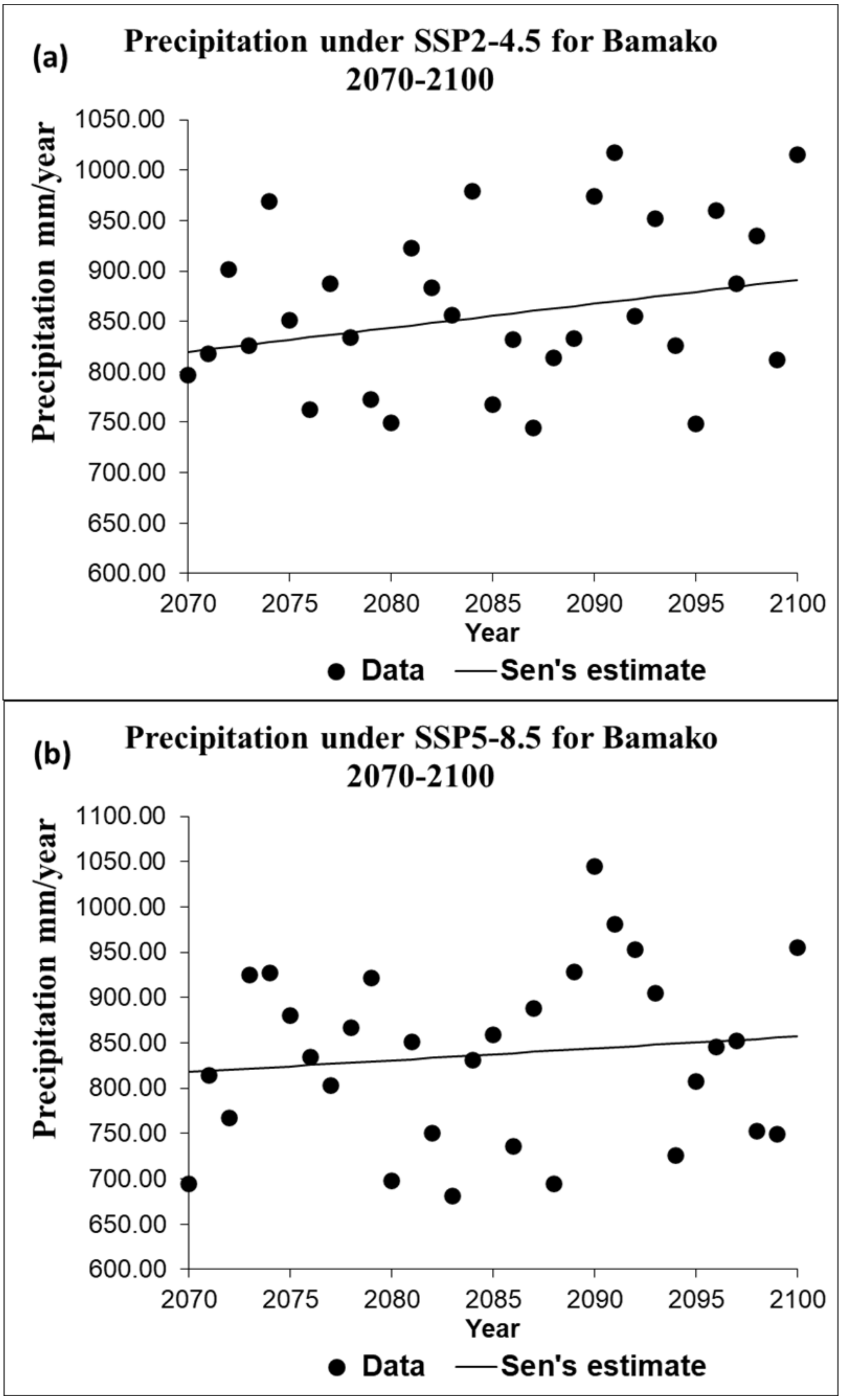


Figure 4.29. Precipitation under SSP24.5(a) and SSP58.5(b) scenarios for Bamako in the far future 2070-2100

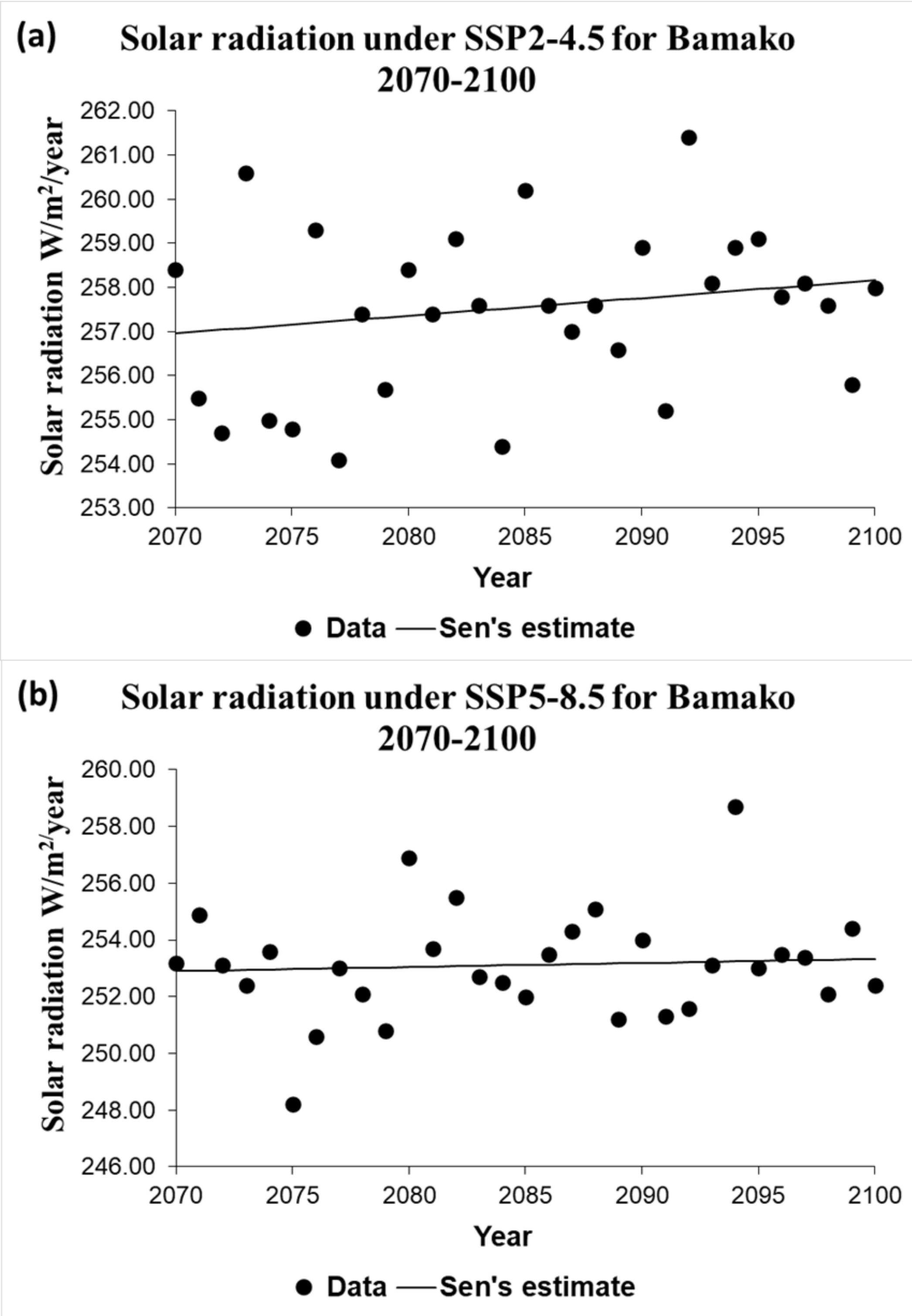


Figure 4.30. Solar radiation under scenarios SSP24.5(a) and SSP58.5(b) for Bamako in the far future 2070-2100

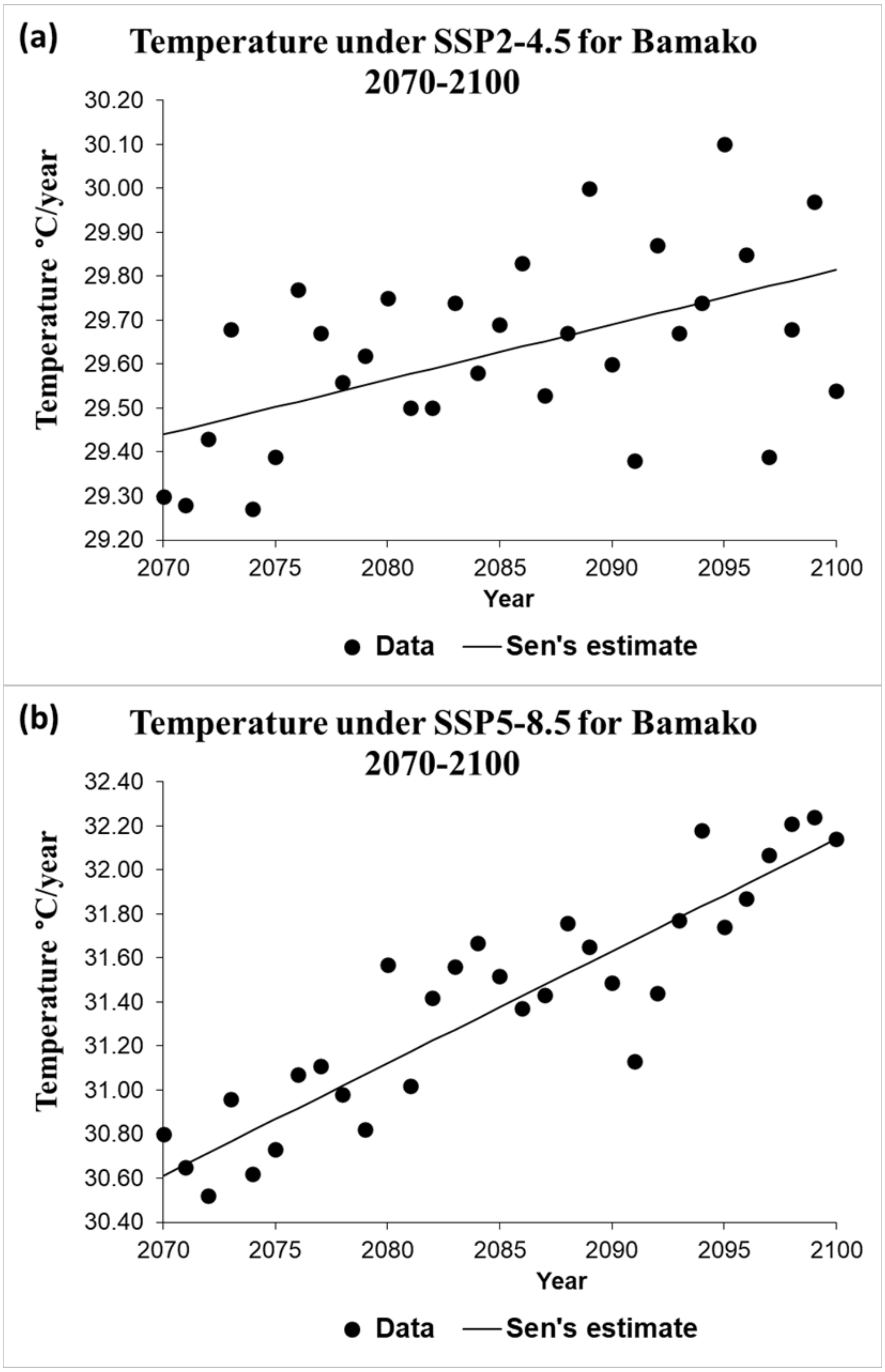


Figure 4.31. Temperature under scenarios SSP24.5(a) and SSP58.5(b) for Bamako in the far future 2070-2100

4.2 Climate Impacts on crop yields (Sorghum and Groundnut)

4.2.1 Experiments on Sorghum

- ✓ **Panicle yield**

The analysis of variance indicates significant differences between the genotypes. Indeed, the DT-15 genotype recorded the best panicle yield with 3678kg/ha followed respectively by Tiandougou-Coura, Soubatimi and KIT19 which are statistically equal. The CSM63E genotype gave the lowest yield with 1043kg/ha and CSM388 with 1998kg/ha (Table 4:10).

- ✓ **Grain yield**

It appears from the statistical analysis of the grain yield that a highly significant difference exists between the genotypes. The best performance (2367kg/ha) was found in the DT-15 genotype followed by Soubatimi (2250kg/ha) and Tiandougou-Coura (1733kg/ha) (Table 4:10). Low yield has been observed to CSM388 with 933kg/ha and KIT19 (750 kg/ha). The lowest yield was recorded by CSM63E (233kg/ha) (Table 4:10), this low yield is explained by the earliness of CSM63E which started its flowering well before the other genotypes and thus exposed to incessant bird attacks.

- ✓ **Fresh straw yield**

The result of the statistical analysis showed no significant difference between the genotypes. However, arithmetically CSM63E provided the best fresh straw yield (17925kg/ha) and KIT19 lowest yield (13028kg/ha) (Table 4:10).

- ✓ **Dry straw yield**

Statistical analysis of dry straw yield indicates that a statistical difference exists between the genotypes. With an average of 8587kg/ha and a coefficient of variation of 16.8%, the greatest weight was found in Tiandougou-Coura (9885 kg/ha) followed by CSM388 (9490 kg/ha). The lowest yield was noticed in KIT19 (7063 kg/ha) (Table 4:10).

- ✓ **Weight 1000 grain**

The analysis of variance shows a highly significant difference between the genotypes. Indeed, the weights vary from 17.50 to 27.75g with an average of 20.71g and a coefficient of variation of 9.7%, the genotypes CSM388 and CSM63E gave the highest 1000 grain weights (27.75 and 21.75). The lowest weight was found in Tiandougou-Coura, KIT19, Soubatimi and DT-15 (Table 4:10).

Table 4:10. Sorghum yield

Genotype	**Sorghum yield kg/ha**				
	Panicle	**Grain**	**Fresh straw**	**Dry straw**	**Weight 1000 Grain (g)**
CSM63E	1043	233	17925	7180	21.75
CSM388	1998	933	14912	9490	27.75
KIT19	2706	750	13028	7063	19.50
Soubatimi	2895	2250	14514	9282	19.25
Tiandougou Coura	3188	1733	16465	9885	17.50
DT-15	3678	2367	13975	8620	18.50
MG	2585	1607	15137	8587	20.71
Probability	**0.005**	**<.001**	**0.278**	**0.055**	**<.001**
Meaning	**S**	**HS**	**NS**	**S**	**HS**
CV %	**31.5**	**44.2**	**19.8**	**16.8**	**9.7**

NB:CV= coefficient of variation, MG= general mean, S= significant, HS= highly significant, NS= not significant

The results of this study lead to the conclusion that with regard to the conditions of establishment of the trial, the DT-15 genotype and Soubatimi gave the highest grain yields. However, the best 1000 grain weight has been observed with CSM388

4.3 Experiments on Groundnut

- ✓ **Groundnut yield**

The analysis revealed no statistical difference between the two genotypes with a coefficient of variation of 10.2% and an average of 770 kg/ha, the ICVG 26024 variety gave the best pod yield (776 kg/ha) and Fleur 11 the lowest (764 kg/ha) (Table 4:11).

- ✓ **Kernel yield**

The grain yield analysis of variance did not reveal any statistically significant difference between the two varieties. With a coefficient of variation of 9.9% and an average of 106.7 kg/ha, the variety Fleur 11 gave a weight of 106.9 kg/ha and ICVG 26024 106.5 kg/ha (Table 4:11).

- ✓ **Fresh and dry straw yield**

It emerges from the analysis of variance that no statistically significant difference exists between the genotypes. However, arithmetically ICVG 26024 gave fresh (3952 kg/ha) and dry (2311 kg/ha) tops better than Fleur 11 (3855 kg/ha) and (2249 kg/ha) (Table 4:11).

- ✓ **Weight 1000 kernels**

Statistical analysis of 1000 grain weight did not reveal any significant difference between the two genotypes.

It appears from the results of the experiments that the two varieties of recorded lower yields compared to their estimated potential, for example for Fleur 11 at 1300-1400 kg/ha pod weight and 500 to 550kg/ha 1000 kernels weight (Bhati et al., 2017).

Table 4:11. Groundnut yield

Genotype	Groundnut yield kg/ha				
	Pod	**Kernels**	**Fresh leaf**	**Dry leaf**	**Weight 1000 kernels (g)**
CGLI 26024	776	106.5	3952	2315	270.0
Fleur 11	764	106.9	3855	2249	286.7
GM	770	106.7	3903	2282	278.3
Probability	0.868	0.970	0.765	0.386	0.300
Meaning	NS	NS	NS	NS	NS
CV %	10.2	9.9	8.9	12.6	5.3

NB:GM= general mean, CV= coefficient of variation

These poor results are due to the experimental approach adopted in our research which was based on organic production without the addition of chemical fertilizers and organic manure. To this is added a pocket of drought observed between August and September 2021 with 23 dry days without rain, or 38% of non-rainy days for the period.

4.2.2 Laboratory soil analysis of eleven samples taken from plots of different varieties of sorghum and groundnut

The results of soil analysis of different of sorghum and groundnut plots shows a predominantly sandy-loamy and loamy sand texture. The soils of this poor agricultural area are in reference to the selected indicators and their tolerance thresholds (Table 4:12, Table 4:13). These soils, like most soils in tropical countries, are characterized by their poverty due to the preponderance of the sandy texture, the very low amount of clay and low nutrient status organic matter. They are very vulnerable to water erosion. Their nutrient retention capacity is low. Due to their physico-chemical properties, these soils are better suited to market gardening and dry farming while correcting the problems of low continual fertility.

The management of the fertility of these soils would therefore be greatly improved by additional annual inputs of 5 to 10 t/ha of organic matter, PROFEBA enriched mixed with agricultural lime to reduce acidity. In mineral fertilization according to the means of the producer, we can recommend the application 50kg of DAP 46% of Phosphorus (P) and 18% of Nitrogen (N) (Diammonium Phosphate) NPK organic compound fertilizer 16N-26P-12K (100 kg/ha of Diammonium phosphate and 50 to 100 kg of fractionated urea on cereals (millet, sorghum) or the practice of the seed soaking technique coupled with the micro-dosing of fertilizers to reduce the time, the difficulty of the work and the production costs.

Table 4:12. Results of laboratory soil analysis of eight samples taken from plots of different varieties of sorghum

Laboratory number	1	2	3	4	5	6	7	8
Applicant specification	Sorghum S1R1 08/09/21	Sorghum S1R2 08/09/21	Sorghum S1R3 08/09/21	Sorghum S1R4 08/09/21	Sorghum S2R1 08/09/21	Sorghum S2R2 08/09/21	Sorghum S2R3 08/09/21	Sorghum S2R4 08/09/21
pH (Water)	5.95	5.98	5.90	5.93	5.85	5.85	5.86	5.81
pH (KCl)	5.41	5.36	5.35	5.28	5.26	5.25	5.24	5.21
Electrical conductivity (EC) (dS/m)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Organic carbon% VS (v/v)	0.21	0.28	0.26	0.23	0.20	0.21	0.47	0.21
total nitrogen% NOT (w/w)	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Available phosphorus (ppm P)	14.77	18.62	15.61	15.82	13.44	14.49	15.19	13.92
CEC ammon. acetate (meq/100g)	2.04	2.04	1.80	1.20	1.20	1.04	1.20	1.10
Ca exchangeable (meq/100g)	1.09	1.09	0.89	0.59	0.59	0.50	0.59	0.50
Mg exchangeable (meq/100g)	0.55	0.55	0.43	0.30	0.30	0.26	0.30	0.30
K exchangeable (meq/100g)	0.25	0.25	0.23	0.20	0.20	0.16	0.20	0.20
Na exchangeable (meq/100g)	0.15	0.15	0.15	0.1	0.1	0.08	0.1	0.1
Sand %>0.05mm	49	84	44	73	78	52	81	64
Fine silt % 0.05-0.002mm	48	14	42	25	20	46	14	34
clay %<0.002mm	3	2	4	2	2	2	3	2
Textural Class	LS	SL	LS	LS	SL	LS	SL	LS

NB:LS= Loamy Sand, SL= Sandy Loam

Table 4:13. Results of laboratory soil analysis of trois samples taken from plots of different varieties groundnut

Laboratory number	1	2	3
Applicant specification	Groundnut R1	Groundnut R2	Groundnut R3
	08/09/2021	08/09/2021	08/09/2021
Applicant specification			
pH (Water)	5.85	5.86	5.83
pH (KCl)	5.15	5.22	5.22
Electrical conductivity (EC) (dS/m)	0.02	0.02	0.02
Organic carbon (% C w/w)	0.20	0.27	0.26
Total nitrogen (% N w/w)	0.01	0.01	0.01
Available phosphorus (ppm P)	11.90	12.18	11.97
CEC acetate of Ammon (meq/100g)	1.38	1.40	1.40
Ca exchangeable (meq/100g)	0.69	0.69	0.69
Mg exchangeable (meq/100g)	0.34	0.34	0.34
K exchangeable (meq/100g)	0.20	0.20	0.20
Na Sodium exchangeable (meq/100g)	0.1	0.1	0.1
Sand %> 0.05mm	70	55	25
Fine silt % 0.05-0.002mm	26	41	68
Clay % < 0.002mm	3	4	7
Textural Class	LS	LS	FS

NB: SL= Loamy sand, FS= Fine Silt

4.4 DSSAT Model Simulation on Sorghum

4.2.3 DSSAT Sensitivity analysis

Main objective of the sensitivity analysis is to find the most important genetic coefficients. The following steps were applied:

Setup a correct standard run for the field experiment for one of the varieties (with correct weather data, soil data, management data…). In this case we will use CSM355 because the genetic parameters have been determined by the previous investigators (Table 4:15). Note the important simulation crop growth results (from the DSSAT results file for view.out), and results in EXCEL file (Table 4:14). The ECO# in the CUL file refers to IB0002 in the ECO file! Calculate the new coefficients (10% smaller, i.e. multiply by 0.9). Very important: the number of decimals may not change!

- Modify the first coefficient in the CUL file (P1): Change 400.0 against 360.0 (i.e. 10% smaller), save the CUL file, and run the simulation (Table 4:16). Very important: the number of decimals may not change! Position of the number may not change!
- Note down the important simulation crop growth results (from file forview.out), note results in EXCEL file).
- Change the modified coefficient back to its original value (360 back to 400). Modifiy the next coefficient (i.e. P2): Change 252.0 against 226.8 (i.e. 10% smaller), save the CUL file, and run the simulation. Very important: the number of decimals may not change! Position of the number may not change! (Table 4:16).

Table 4:10 Simulation on crop growth and development of different parameters

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@	VARIABLE	SIMULATED
	--------	---------
	Panicle Initiation day (dap)	53
	Anthesis day (dap)	89
	Physiological maturity day (dap)	116
	Yield at harvest maturity (kg [dm]/ha)	1452
	Number at maturity (no/m2)	24446
	Unit wt at maturity (g [dm]/unit)	0.0059
	Number at maturity (no/unit)	2746.7
	Tops weight at maturity (kg [dm]/ha)	10790
	By-product produced (stalk) at maturity (kg[dm]/ha	9338
	Leaf area index, maximum	2.88
	Harvest index at maturity	0.135

Note down the genetic coefficients for this variety from the CUL and the ECO file (in EXCEL file):

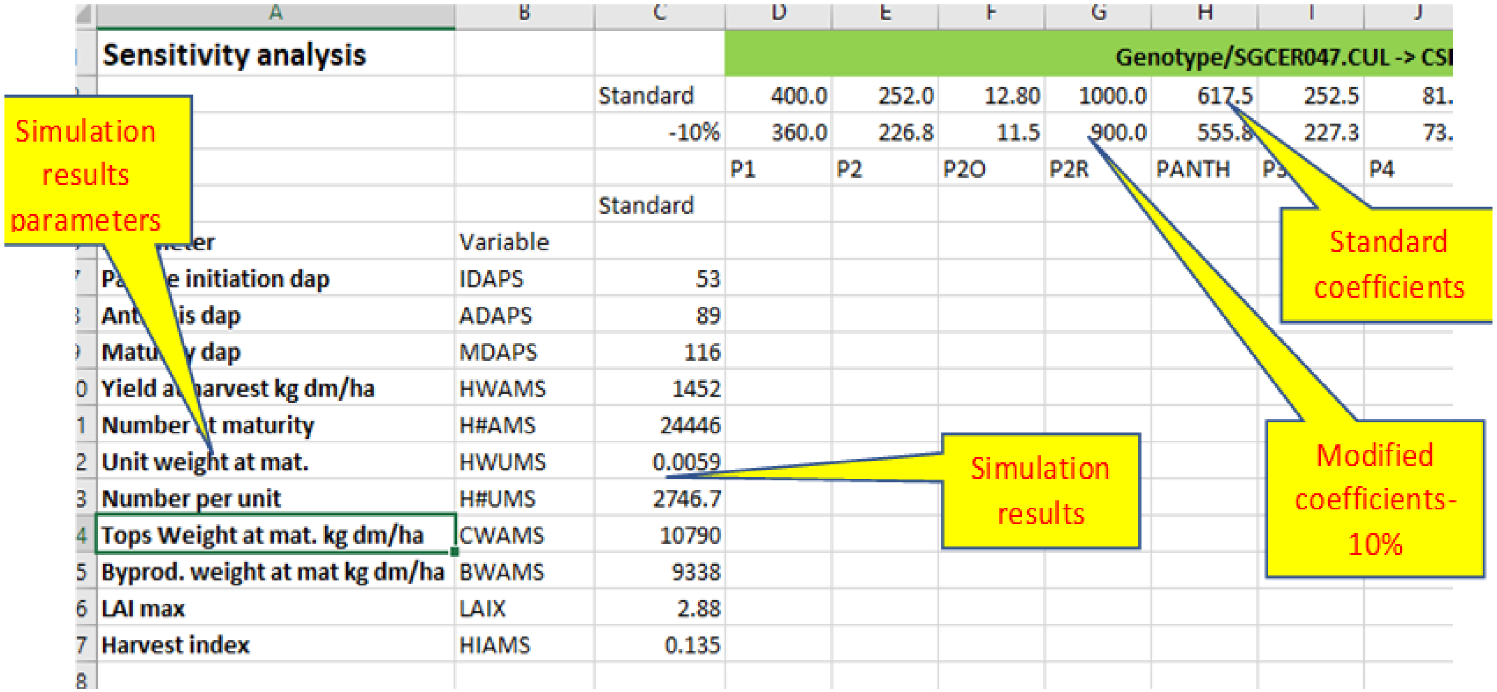
Table 4:11 Sensitivity analysis genetic coefficients of CSM335

```
SGCER047.CUL - Editor
Datei  Bearbeiten  Format  Ansicht  ?
@VAR#  VAR-NAME........ EXPNO   ECO#    P1    P2   P20   P2R PANTH    P3    P4    P5 PHINT    G1    G2 PBASE  PSAT
!                                  1     2     3     4     5     6     7     8     9    10    11    12    13    14
IB0056 CSM335                . IB0002 400.0 252.0 12.801000.0 617.5 252.5  81.5 400.0 60.00  10.0   3.0
```

```
SGCER047.ECO - Editor
Datei  Bearbeiten  Format  Ansicht  ?

@ECO#  ECONAME.........  TBASE  TOPT  ROPT  GDDE   RUE  KCAN  STPC  RTPC TILFC  PLAM
!                            1     2     3     4     5     6     7     8     9    10
IB0002 West Africa        11.0  34.0  34.0   6.0   3.8  0.85 3.000 0.200   1.0 6000.
```

Table 4:12. Simulation of sensitivity analysis on different parameters (yield harvest, maturity dap tops weight, …)



A	B	C	D	E	F	G	H	I	J
Sensitivity analysis			Genotype/SGCER047.CUL -> CSI						
		Standard	400.0	252.0	12.80	1000.0	617.5	252.5	81.
		-10%	360.0	226.8	11.5	900.0	555.8	227.3	73.
			P1	P2	P2O	P2R	PANTH	P3	P4
		Standard							
…er	Variable								
Pa… e initiation dap	IDAPS	53							
Ant… is dap	ADAPS	89							
Matu… y dap	MDAPS	116							
Yield a… harvest kg dm/ha	HWAMS	1452							
Number … t maturity	H#AMS	24446							
Unit weight at mat.	HWUMS	0.0059							
Number per unit	H#UMS	2746.7							
Tops Weight at mat. kg dm/ha	CWAMS	10790							
Byprod. weight at mat kg dm/ha	BWAMS	9338							
LAI max	LAIX	2.88							
Harvest index	HIAMS	0.135							

- Note down the important simulation crop growth results (from file for view.out), note results in EXCEL file).

Continue this procedure until all coefficients in CUL file and in ECO file have been modified one at a time!

At the end, calculate the relative impact of the different coefficients on the simulated results as

$$\mathbf{sensitivity} = \frac{(\mathbf{standard - modifiedresult})}{\mathbf{standard}} \cdot \mathbf{100} \qquad \textbf{Equation 4 1}$$

4.3.1 Sensitivity analysis of CSM63E

Sensitivity analysis was done for the cultivar CSM63E, the only Sorghum cultivar from the experiment which was available in DSSAT (Table 4:17).

4.3.1.1 Data used for calibration

Calibration was done based on the following input data from the field experiment. In the first step, the anthesis and maturity dates has been calibrated (Table 4.19).

The sowing date is day 198. Therefore, the Anthesis dates are days 285, 263, 280, 288, 278, 285 (which is 87, 65, 82, 90, 80, 87 anthesis days after planting dap). The maturity days are 315, 294, 315, 315, 315, 315 (which is 117, 96 maturity days after planting dap). In the second step, the tops weight (above ground biomass) has been calibrated, and in the last step the grain yield (Table 4:20). As the grain yield for the variety CSM63E is not reliable due to bird's damage, The straw dry matter yield was used to calibrate the variety CSM63E.

Table 4:13. Simulation of sensitivity analysis on different parameters (yield harvest, maturity dap tops weight)

Sensitivity analysis													
CSM63E		Standard											
		-10%											
			P1	P2	P2O	P2R	PANTH	P3	P4	P5	PHINT	G1	G2
		Standard											
Parameter	Variable												
Panicle initiation dap	IDAPS	31	+s1	s0	-s4	s0	s0	s0	s0	s0	s0	s0	s0
Anthesis dap	ADAPS	69	+s0	s0	-s4	s0	+s0	s0	s0	s0	s0	s0	s0
Maturity dap	MDAPS	99	+s0	s0	-s2	s0	+s0	s0	s0	+s0	s0	s0	s0
Yield at harvest kg dm/ha	HWAMS	2018	-s0	s0	+s3	s0	-s0	-s0	-s0	+s0	+s0	+s0	+s0
Number at maturity	H#AMS	26265	+s3	s0	+s1	s0	+s1	+s0	s0	+s0	-s1	+s0	s0
Unit weight at mat.	HWUMS	0.0077	-s4	s0	+s2	s0	-s1	-s0	s0	+s0	+s1	-s0	+s1
Number per unit	H#UMS	2951.1	+s3	s0	+s1	s0	+s1	+s0	s0	+s0	-s1	+s0	s0
Tops Weight at mat. kg dm/ha	CWAMS	10052	+s2	s0	-s1	s0	+s1	-s0	-s0	+s0	-s1	+s0	+s0
Byprod. weight at mat kg dm/ha	BWAMS	8035	+s2	s0	-s2	s0	+s2	+s0	-s0	+s0	-s1	+s0	-s0
LAI max	LAIX	2.57	+s4	s0	-s3	s0	+s3	-s0	s0	s0	-s2	+s1	s0
Harvest index	HIAMS	0.201	-s3	s0	+s4	s0	-s2	-s0	s0	+s0	+s1	-s0	+s1
	s0	< abs 5%											
	s1	abs 5 to abs 10%											
	s2	abs 10 to abs 15 %											
	s3	abs 15 to abs 20 %											
	s4	> abs 20%											

Most important coefficients in CUL file for

● Anthesis day: P2O; ● Maturity day: P2O; ● Yield: P2O,

● Tops weight: P1,P2O,PANTH,PHINT; ● Straw weight: P1, P2O, PANTH, PHINT

Table 4:14 Simulation of sensitivity analysis on different parameters (anthesis and maturity day after planting)

Sensitivity analysis												
CSM63E		Standard										
		-10%										
			TBASE	TOPT	ROPT	GDDE	RUE	KCAN	STPC	RTPC	TILFC	PLAM
		Standard										
Parameter	Variable											
Panicle initiation dap	IDAPS	31	+s0	-s0	s0	s0	s0	s0	s0	s0	s0	s0
Anthesis dap	ADAPS	69	+s0	-s0	-s0	s0	s0	s0	s0	s0	s0	s0
Maturity dap	MDAPS	99	+s1	-s0	-s0	s0	s0	s0	s0	s0	s0	s0
Yield at harvest kg dm/ha	HWAMS	2018	-s2	+s0	+s0	s0	+s1	-s0	-s0	-s0	s0	+s0
Number at maturity	H#AMS	26265	+s0	-s0	-s0	-s0	+s3	s0	-s0	-s0	s0	+s0
Unit weight at mat.	HWUMS	0.0077	-s2	+s0	+s0	+s0	-s2	s0	+s0	+s0	s0	-s0
Number per unit	H#UMS	2951.1	+s0	-s0	-s0	-s0	+s3	s0	-s0	-s0	s0	+s0
Tops Weight at mat. kg dm/ha	CWAMS	10052	+s0	-s0	-s0	-s0	+s3	-s0	-s0	-s0	s0	+s0
Byprod. weight at mat kg dm/ha	BWAMS	8035	+s1	-s0	-s0	-s0	+s3	-s0	-s0	-s0	s0	+s0
LAI max	LAIX	2.57	+s1	-s2	s0	-s0	+s3	s0	-s3	-s0	s0	+s1
Harvest index	HIAMS	0.201	-s3	+s0	+s0	+s0	-s2	-s0	+s0	+s0	s0	-s0
	s0	< abs 5%										
	s1	abs 5 to abs 10%										
	s2	abs 10 to abs 15 %										
	s3	abs 15 to abs 20 %										
	s4	> abs 20%										

Most important coefficients in ECO file for

- Anthesis day: --
- Maturity day: TBASE
- Yield: TBASE,RUE
- Tops weight: RUE
- Straw weight: TBASE, RUE

Table 4:15. Crop growth on different of variety of sorghum (sowing and anthesis date, anthesis days after planting, maturity date and maturity days after planting)

Dates					
Variety	Sowing date	Anthesis date	Anthesis dap	Maturity date	Maturity dap
CSM388	17.07.2021	12.10.2021	87	11.11.2021	117
CSM63E	17.07.2021	20.09.2021	65	21.10.2021	96
DT-15	17.07.2021	07.10.2021	82	11.11.2021	117
KIT19	17.07.2021	15.10.2021	90	11.11.2021	117
Soubatimi	17.07.2021	05.10.2021	80	11.11.2021	117
TiandougouCoura	17.07.2021	12.10.2021	87	11.11.2021	117

Table 4:16. Crop yield on different of variety of sorghum

Yield Summary								
Variety	Grain DM	Grain DM SD	Straw DM	Straw DM SD	Tops DM	Tops DM SD	1000 grain DM	1000 grain DM SD
CSM388	848	492.4	9490	1400.0	11488	1497.3	25.2	1.18
CSM63E	212	67.8	7180	2429.2	8223	2488.6	19.8	0.99
DT-15	2152	546.3	8620	301.6	12298	851.2	16.8	1.02
KIT19	682	279.0	7063	1639.9	10744	1342.5	17.7	1.98
Soubatimi	2303	261.8	9282	677.5	13365	91.7	17.5	2.07
TiandougouCoura	2020	103.0	9885	1298.4	13926	1292.6	15.9	2.45

4.3.1.2 Data file preparation

Adding cultivars to CUL and ECO files (in DSSAT/Genotype)

In a first step, the cultivars to be calibrated were added to the CUL file **SGCER047.CUL** The coefficients for CSM63E were copied and called CSM63E_A to make it different to the original values (Table 4:21).

The IB numbers were added from IB0060 to IB0065; the ECO-file numbers were added from IB0003 to IB0008 (to make the ECO parameters also possible to calibrate).

The ECO-file **SGCER047.ECO** was also edited to include the ECO parameters IB0003 to IB0008. For CSM63E (ECI IB0003), the data from IB0001(GENERIC) were copied. For the other (West African) varieties, the ECO parameters from IB0002 (West African) were copied (Table 4:22).

4.3.1.3 Preparing files with the results data (in DSSAT/Sorghum)

The calibration program needs to know the measured values to adjust the coefficients so that measured and simulated values match closely. Therefore, files for the measured values must be prepared (Table 4:23). Simulation files for the 6 different cultivars were prepared as S-Sotuba; CAL-Calibration; 21-year 2021; 1…6 numbers. All simulations are the same, except that the varieties in the simulation file are different. **SGA-Files** (with measured data) (Table 4:24). Each simulation files needs an SGA file with the measured results (Table 4:25). The files contain the following results:

Table 4:17. Calibration of six varieties of Sorghum

```
IB0059 TS15401          . IB0002 500.0 300.0 12.801800.0 640.5 300.5  81.5 350.0 55.00   0.5   2.0

!Calibration Assa
IB0060 CSM63E_A         . IB0003 300.0 102.0 12.80 100.0 647.5 142.5  61.5 450.0 55.00  16.0   3.0
IB0061 CSM388           . IB0004 413.0 102.0 13.60  40.0 617.5 152.5  81.5 640.0 49.00   3.0   6.5
IB0062 DT-15            . IB0005 413.0 102.0 13.60  40.0 617.5 152.5  81.5 640.0 49.00   3.0   6.5
IB0063 KIT19            . IB0006 413.0 102.0 13.60  40.0 617.5 152.5  81.5 640.0 49.00   3.0   6.5
IB0064 Soubatimi        . IB0007 413.0 102.0 13.60  40.0 617.5 152.5  81.5 640.0 49.00   3.0   6.5
IB0065 TiandougouC      . IB0008 413.0 102.0 13.60  40.0 617.5 152.5  81.5 640.0 49.00   3.0   6.5
```

Table 4:18 Genetic coefficients for the variety “West African”

```
! PLAM    Plant leaf area maximum (initial leaf area)
!
@ECO#  ECONAME.........  TBASE  TOPT  ROPT  GDDE   RUE  KCAN  STPC  RTPC TILFC  PLAM
!                            1     2     3     4     5     6     7     8     9    10
IB0001 GENERIC             8.0  34.0  34.0   6.0   3.2  0.85 0.100 0.250   0.0 6000.
IB0002 West Africa        11.0  34.0  34.0   6.0   3.8  0.85 3.000 0.200   1.0 6000.
DFAULT DEFAULT             8.0  34.0  34.0   6.0   3.2  0.85 0.100 0.250   1.0 6000.
IB0003 West Africa         8.0  34.0  34.0   6.0   3.2  0.85 0.100 0.250   0.0 6000.
IB0004 West Africa        11.0  34.0  34.0   6.0   3.8  0.85 3.000 0.200   1.0 6000.
IB0005 West Africa        11.0  34.0  34.0   6.0   3.8  0.85 3.000 0.200   1.0 6000.
IB0006 West Africa        11.0  34.0  34.0   6.0   3.8  0.85 3.000 0.200   1.0 6000.
IB0007 West Africa        11.0  34.0  34.0   6.0   3.8  0.85 3.000 0.200   1.0 6000.
IB0008 West Africa        11.0  34.0  34.0   6.0   3.8  0.85 3.000 0.200   1.0 6000.
```

Table 4:19. Simulation files for the 6 different cultivars

☐	4	ITSA1415.SGX	SORGHUM PHOSPHORUS TRIALS IN MALI	15:24:22, Fri, 1 Mar 2019
☐	5	SCAL2101.SGX	SOTUBA SORGHUM CALIBRATION CSM388	16:23:33, Mon, 11 Apr 2022
☐	6	SCAL2102.SGX	SOTUBA SORGHUM CALIBRATION CSM63E_A	16:29:37, Mon, 11 Apr 2022
☐	7	SCAL2103.SGX	SOTUBA SORGHUM CALIBRATION DT-15	16:28:15, Mon, 11 Apr 2022
☐	8	SCAL2104.SGX	SOTUBA SORGHUM CALIBRATION KIT19	16:25:33, Mon, 11 Apr 2022
☐	9	SCAL2105.SGX	SOTUBA SORGHUM CALIBRATION SOUBATIMI	16:26:15, Mon, 11 Apr 2022
☐	10	SCAL2106.SGX	SOTUBA SORGHUM CALIBRATION TIANDOUGOUCOURA	16:27:07, Mon, 11 Apr 2022
☐	11	SOTU2101.SGX	ASSA (SOTUBA SORGHUM - STANDARD)	13:26:35, Sat, 9 Apr 2022

Table 4;20. Simulations file of six different varieties

ITSA1415.SGA	3/1/2019 2:24 PM	SGA-Datei	1 KB
SCAL2101.SGA	4/11/2022 4:48 PM	SGA-Datei	1 KB
SCAL2102.SGA	4/11/2022 4:48 PM	SGA-Datei	1 KB
SCAL2103.SGA	4/11/2022 4:48 PM	SGA-Datei	1 KB
SCAL2104.SGA	4/11/2022 4:48 PM	SGA-Datei	1 KB
SCAL2105.SGA	4/11/2022 4:48 PM	SGA-Datei	1 KB
SCAL2106.SGA	4/11/2022 4:48 PM	SGA-Datei	1 KB

Table4:21. SGA file with the measured results on (anthesis date, maturity date, tops weight at maturity, harvested yield at maturity, unit weight at maturity)

@TRNO	ADAT	MDAT	CWAM	HWAH	HWUM
1	21285	21315	11488	848	0.025

- @TRNO: treatment number, always 1
- ADAT: Anthesis date, MDAT: Maturity date, CWAM: Tops weight at maturity, HWAM: Harvested Yield at maturity, HWUM: Unit weight at maturity

4.3.2 The difference between simulated and measured anthesis time

According to the results of simulation of sorghum crops on the number of days of anthesis after sowing, it emerged that the average duration of anthesis is 70 days for the 5 varieties (CSM388, DT15, KIT19, Soubatimi and Tiandougou-coura) and 61 days for the CSM63E, with a difference of 9 days on the other hand to the other varieties (Table 4:26). The results are similar to those of a study which confirmed that the average flowering time for the CSM63E variety is 62 days (Soumaré et al., 2005). The CSM63E variety is considered the earliest variety unlike others such as CSM388, DT15, KIT19, Soubatimi and Tiandougou-coura. Several studies have also shown that CSM63E is a very early variety in Mali (Akinseye et al., 2017; ICRISAT, 2020; Diallo et al., 2022).

The simulation analysis on the average duration of the anthesis cycle measured shows a difference in statistical variance between the 6 different varieties, indeed in the variety CSM63E is (65 days), Subatimi (80 DS), DT15 (82 DS), Tiandougoucoura (87 DS), CSM388 (87 DS) and KIT19 (90 DS) (Table 4:26). The difference between the simulated and measured anthesis time varies from (-4, -10, -12, -17, -20) by order of the varieties (CSM63E, Soubatimi, DT15, Tiandougoucoura, CSM388 and KIT19) (Table 4:26).

Compared to the simulated physiological maturity time of the 6 different varieties, it appears that the average duration is 112 days for the 5 varieties (such as CSM388, DT15, KIT19, Soubatimi and Tiandougoucoura) including (86DS) for CSM63E (Table 4:26). with a difference of 5 days contrary to the maturity time measured.

4.5 Simulation results after calibration

Running the model now with the 6 different varieties give the following result, which can be seen in the file evaluate.out (Table 4:27).

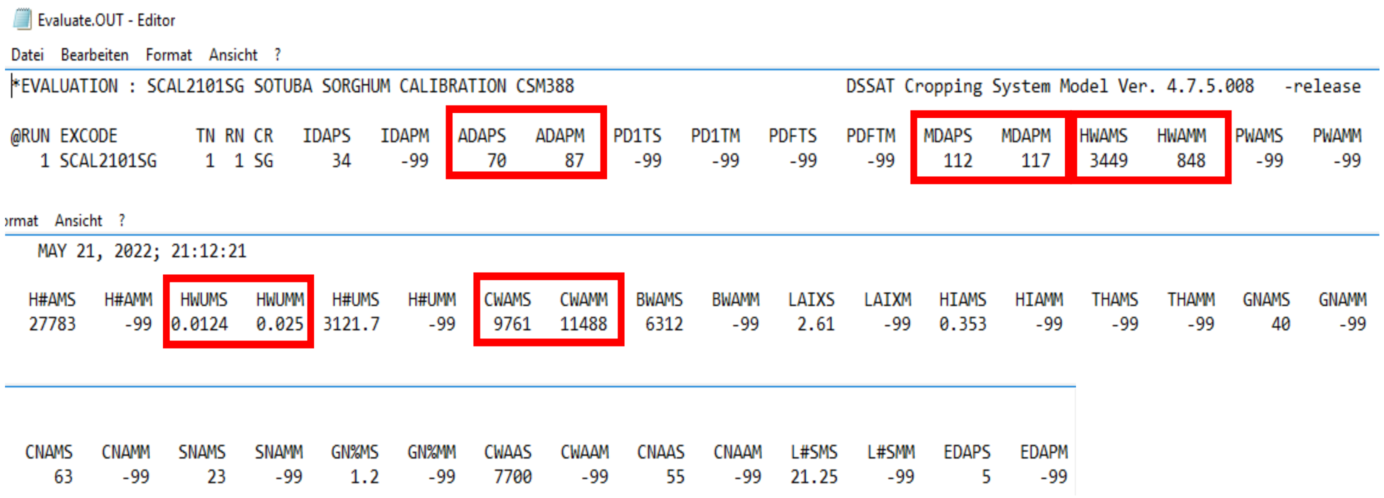
Table 4:22. Simulated (without calibration) and measured results of 6 different cultivars of sorghum on Growth Stages (Anthesis and Maturity days after planting)

Variety	**ADAPS**	**ADAPM**	**MDATS**	**MDATM**
CSM388	70	87	112	117
CSM63E_A	61	65	86	96
DT15	70	82	112	117
KIT19	70	90	112	117
Subbatimi	70	80	112	117
Tiandougoucoura	70	87	112	117

ADAP: Anthesis days after planting; **MDAT:** Maturity days after planting;

S: simulated; **M:** measured

Table 4:23 Calibration of CSM388 genotype on simulated and measured (ADAP, MDAT, CWAM, HWAM, HWUM)



Evaluate.OUT - Editor

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*EVALUATION : SCAL2101SG SOTUBA SORGHUM CALIBRATION CSM388 DSSAT Cropping System Model Ver. 4.7.5.008 -release

@RUN	EXCODE	TN	RN	CR	IDAPS	IDAPM	ADAPS	ADAPM	PD1TS	PD1TM	PDFTS	PDFTM	MDAPS	MDAPM	HWAMS	HWAMM	PWAMS	PWAMM
1	SCAL2101SG	1	1	SG	34	-99	70	87	-99	-99	-99	-99	112	117	3449	848	-99	-99

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H#AMS	H#AMM	HWUMS	HWUMM	H#UMS	H#UMM	CWAMS	CWAMM	BWAMS	BWAMM	LAIXS	LAIXM	HIAMS	HIAMM	THAMS	THAMM	GNAMS	GNAMM
27783	-99	0.0124	0.025	3121.7	-99	9761	11488	6312	-99	2.61	-99	0.353	-99	-99	-99	40	-99

CNAMS	CNAMM	SNAMS	SNAMM	GN%MS	GN%MM	CWAAS	CWAAM	CNAAS	CNAAM	L#SMS	L#SMM	EDAPS	EDAPM
63	-99	23	-99	1.2	-99	7700	-99	55	-99	21.25	-99	5	-99

ADAP: Anthesis days after planting; **MDAT**: Maturity days after planting; **CWAM**: Tops weight at maturity; **HWAM**: Harvested weight at maturity; **HWUM**: Harvest weight per unit at maturity (one grain); **S**: simulated; **M**: measured (Example for the variety CSM388)

4.3.3 Simulation on tops weight at maturity

According to the result of the analysis on tops weight at maturity simulated showed no difference between the genotypes of 5 varieties, with an average of 9761 kg/ha. However, CSM63E gave the best performance (10141kg/ha) compared to varieties that have low yield.

4.3.4 Simulation on harvested weight at maturity

Grain yield simulation analysis showed no existing difference between the genotypes of the 5 varieties (CSM388, DT15, KIT19, Soubatimi and Tiandougoucoura) which gave a statistically identical higher yield of 3449kg/ha with the lowest yield recorded in CSM63E (1894kg/ha) see Table 4:28. However, the grain yield of the CSM63E variety measured was low due to bird damage. The straw dry matter yield was used to calibrate the CSM63E variety.

The varieties CSM388, DT15, KIT19, Soubatimi and Tiandougou-coura gave the same simulated results because of the use of same genetic parameters. However, there are large differences between the measured and simulated values. Indeed, this low yield is explained by three main factors which are: caterpillar attack, birds constitute a major risk for sorghum crops; strong winds causing very intense evapotranspiration; dry spells or insufficient and poor distribution of rainfall.

4.3.5 Harvest weight per unit at maturity (one grain)

According to the simulation results on the 1000 grain weight, it gave identical values for the 5 different varieties (CSM388, DT15, KIT19, Soubatimi and Tiandougou-coura) who gave the highest 1000 grain weights with a coefficient of variation of 18% and 9% for CSM63E (Table 4:28). Nevertheless, these differences between the measured and simulated values are significant because the low measured yield is explained by a number of factors to which the crops are exposed such as caterpillar attacks, birds, high winds and drought.

4.3.6 Simulation of tops weight and grain weight

According to the results of the simulation with the DSSAT model on crops yield, variety 1, 3, 4, 5, and 6 give the same simulated results, because they use the same genetic parameters. However, there are large differences between the measured and simulated values. Although all the parameters were the same, the climatic factor created the difference that made the performance at the station for my research lower compared to the simulation.

According to the simulation results on the weight of the tops at simulated maturity shows a low yield of 9761kg/ha for the genotype of CSM388, with a higher grain weight of 3449kg/ha with a coefficient of variance of 18.2% compared to the measured yield (Figure 4.32(a)). This Figure 4.32(b) illustrate simulated tops weight, and shows a higher yield of 10141kg/ha for the CSM63E variety compared to the measured values which gave low yield of 212kg/ha. However, CSM63E gave the best performance on grain weight (1894kg/ha) with a coefficient of variation of 9.1% compared to measured values (Figure 4.32(b)).

Simulation analysis on tops weight gave a low yield of 9761 kg/ha. Indeed, it indicates a better grain yield (3449 kg/ha) for the DT-15 genotype, with a coefficient of variation of 18.2% (Figure 4.33(a)). According to the results of the simulation on the tops weight, this also gives a low yield of (9761 kg/ha) but highest yield compared to the measured values for the KIT19 variety with a higher grain weight yield plus a coefficient change of 18.2% (Figure 4.33(b)).

Table 4:24. Simulated and measured results of 6 different cultivars of sorghum (Tops weight at maturity, harvested weight at maturity, weight per unit at maturity (one grain)

Variety	CWAMS	CWAMM	HWAMS	HWAM	HWUMS	HWUM
CSM388	9761	11488	3449	848	0.0124	0.0252
CSM63E_A	10141	8223	1894	212	0.0062	0.0198
DT15	9761	12298	3449	2152	0.0124	0.0168
KIT19	9761	10744	3449	682	0.0124	0.0177
Subbatimi	9761	13365	3449	2303	0.0124	0.0175
Tiandougoucoura	9761	13926	3449	2020	0.0124	0.0159

CWAM: Tops weight at maturity; **HWAM:** Harvested weight at maturity; **HWUM:** Harvest weight per unit at maturity (one grain); **S:** simulated; **M:** measured

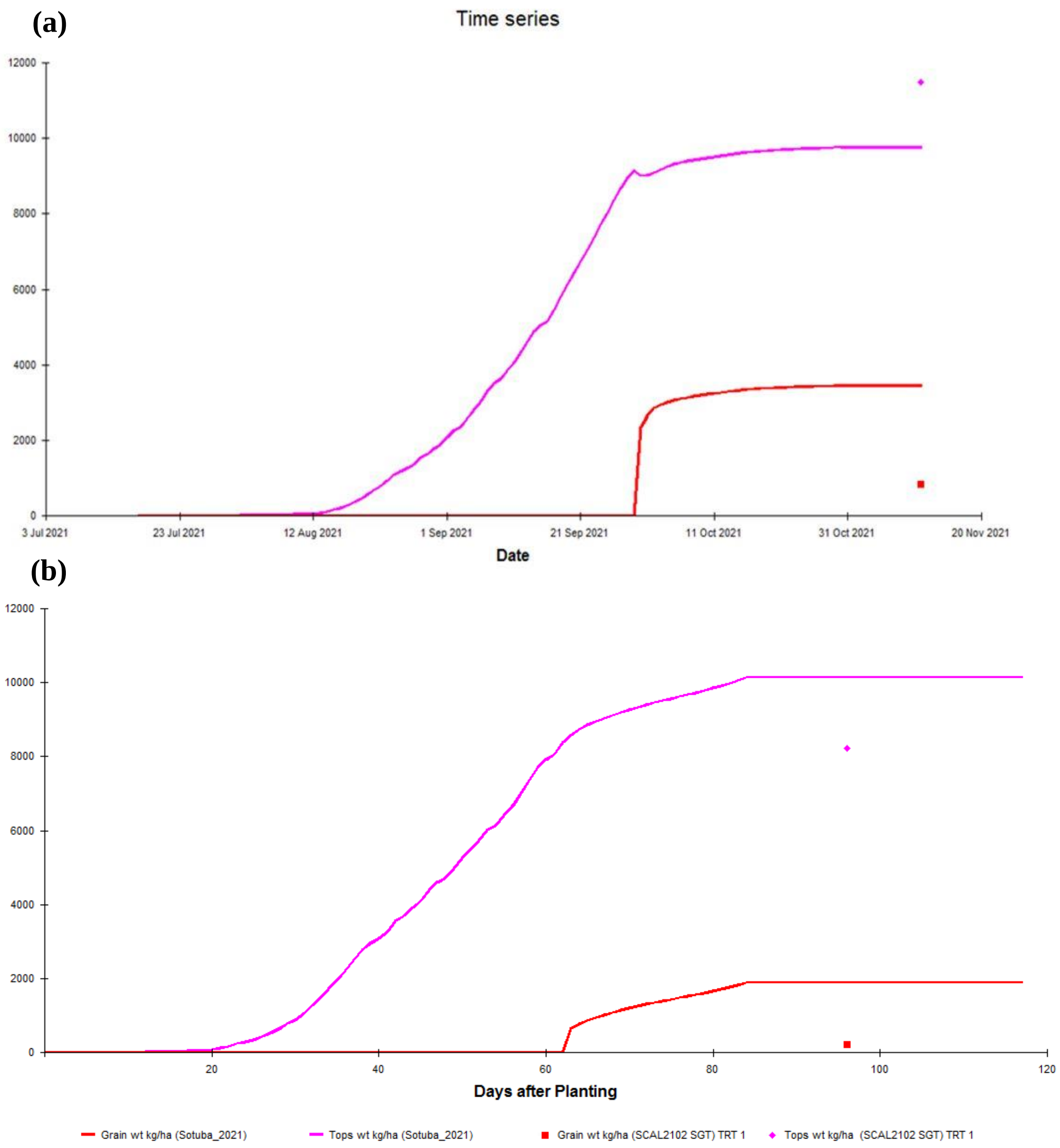


Figure 4.32. Simulated and measured tops weight and grain weight, (a) CSM63E_A, (b) CSM388

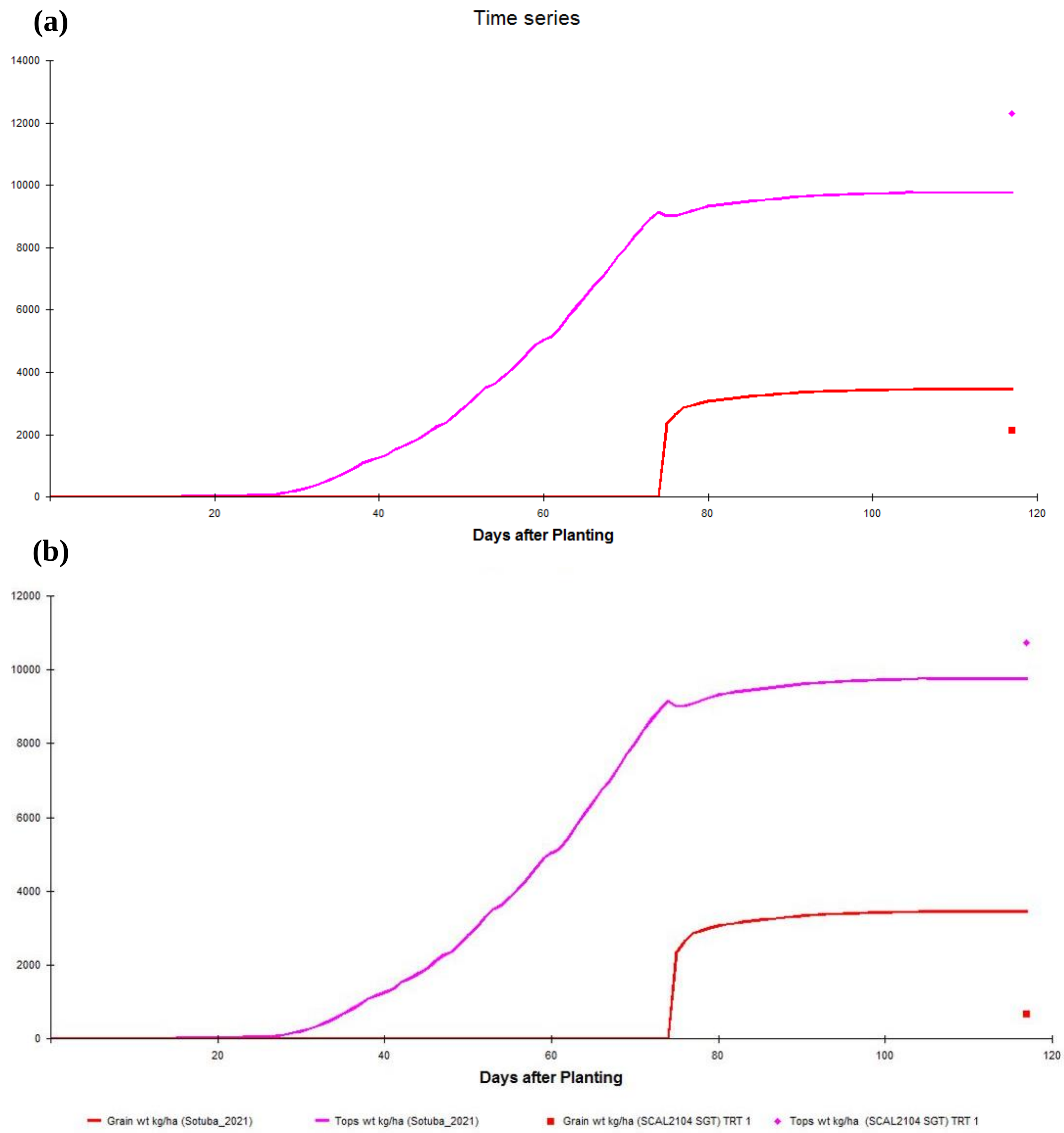


Figure 4.33. Simulated and measured tops weight and grain weight, (a) DT-15, (b) KIT19

According to the simulation results, there is a low yield of Tiandougou-coura genotype with an average of 9761 kg/ha, highest yield compared to the measured value. However, a higher grain yield of 3449 kg/ha was recorded, with a coefficient of variation of 18.2% (Figure 4.34(a)). A low yield was recorded for Tiandougou-coura with an average of 9761 kg/ha, higher yield compared to the measured value. However, a higher grain yield of 3449 kg/ha was recorded, with a coefficient of variation of 18.2% (Figure 4.34(b)).

4.3.7 Simulation with Calibration

Calibration Step 1 (ADAP and MDAP)

In a first step the dates of anthesis and maturity will be calibrated (Example Tiandougoucoura) (Table 4:29).

In Genotype coefficient calculator: edit rules files for Sorghum (Figure 4.35):

Program will vary ADAP by modifying P1 and P2O

Program will vary MDAP by modifying P5

Simulated results from calibration of Tiandougoucoura genotype on tops weight at maturity gave higher yield of 9837kg/ha compared to simulation value without calibration it has been recorded 9761kg/ha (Table 4.31).

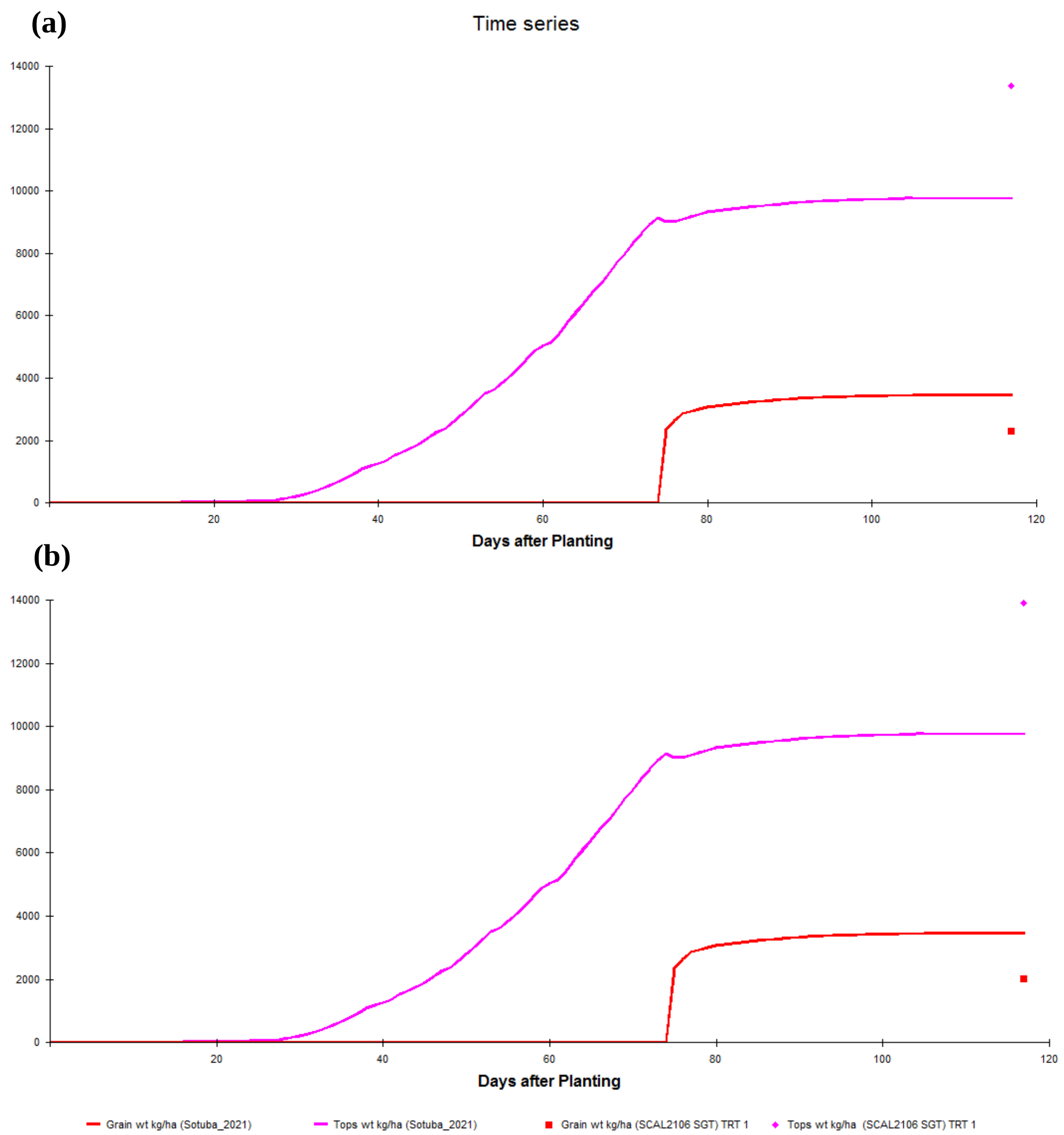


Figure 4.34. Simulated and measured tops weight and grain weight (a) Soubatimi, (b) Tiandougoucoura

Table 4:25. Simulation with calibration on Tiandougoucoura of (ADAP and MDAP)

Variety	***ADAPS***	***ADAPM***	***MDATS***	***MDATM***	***CWAMS***	***CWAMM***	***HWAMS***	***HWAMM***	***HWUMS***	***HWUMM***
before calibration	70	87	112	117	9761	13926	3449	2020	0.0124	0.0159

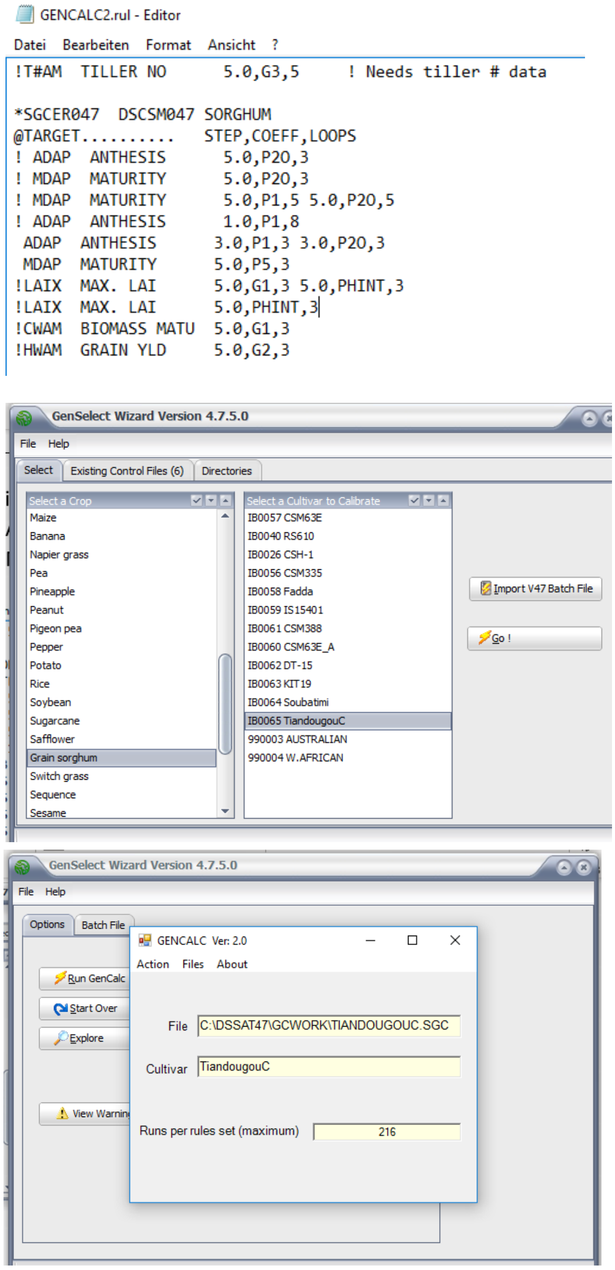


Figure 4.35 Run Gencalc: (Action->Run)

Results: Files->Model output->Evaluate->Final run

Table 4:26. After first calibration step (Example Tiandougoucoura)

Variety	*ADAPS*	*ADAPM*	*MDATS*	*MDATM*	*CWAMS*	*CWAMM*	*HWAMS*	*HWAMM*	*HWUMS*	*HWUMM*
before calibration	70	87	112	117	9761	13926	3449	2020	0.0124	0.0159
after 1. step	74		117		9837		3258		0.0114	

Update CUL file:

Files->Coefficients->Main CUL file-> Automatically insert run results

CUL file for Sorghum:

Calibration results of six varieties on tops weight at maturity of sorghum specifically CSM388, CSM63E_A, DT15, KIT19, Soubatimi and Tiandougoucoura, it has been provided similar value for the 5 genotypes which is CSM388, DT15, KIT19, Soubatimi and Tiandougoucoura (Table 4.32).

Parameters P1 and P2O have been modified!

Next step: Calibration of CWAM and HWAM:

In Genotype coefficient calculator: edit rules files for Sorghum:

Program will vary CWAM (Biomass at maturity) by modifying G1

Program will vary HWAM (Harvest weight at maturity) by modifying G2 (Table 4.33).

Run Gencalc: (Action->Run)

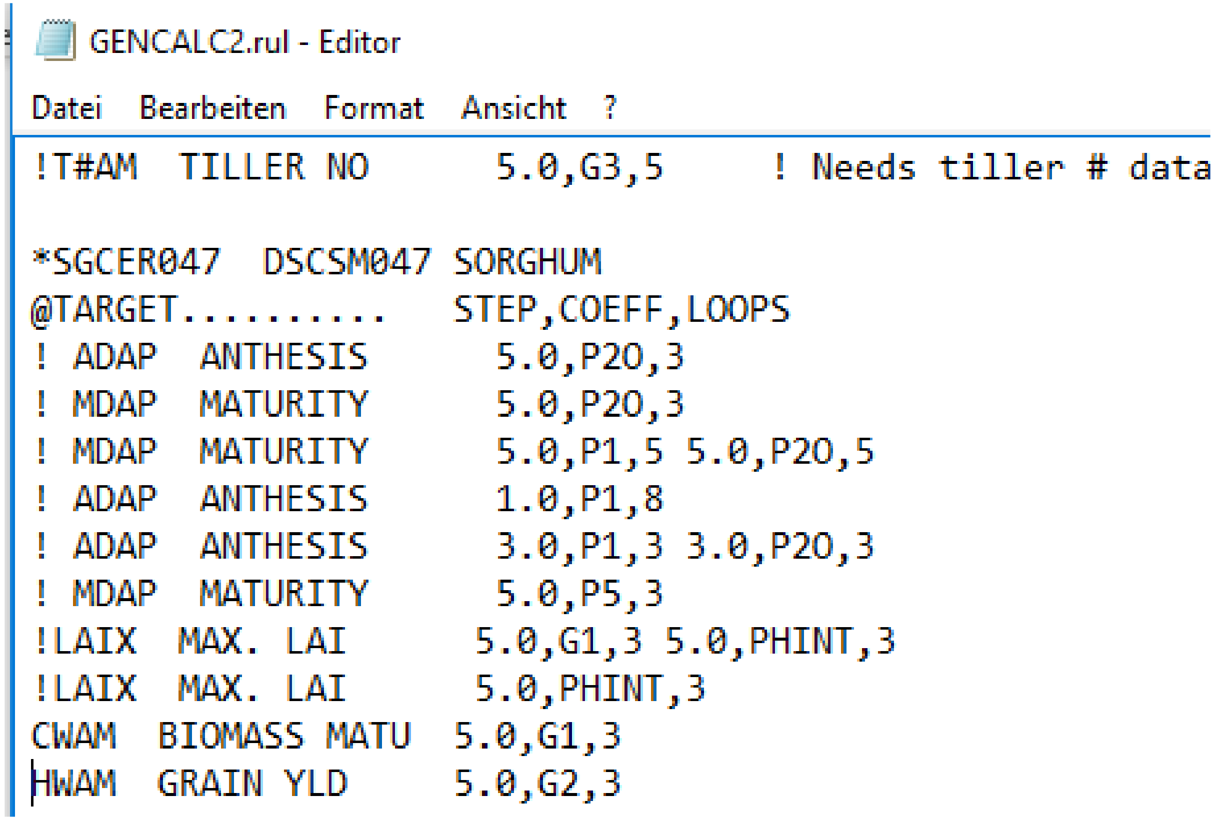
Results: Files->Model output->Evaluate->Final run

According to the calibration results on grain yield, it has been noted higher yield at Tiandougou-coura with an average of 10564 kg/ha compared to measured value. However, a low tops weight at maturity with 2198 kg/ha as recorded (Table 4.34).

Table 4:27. Second step of calibration of Tiandougoucoura genotype

```
!Calibration Assa
IB0060 CSM63E_A          . IB0003 300.0 102.0 12.80 100.0 647.5 142.5  61.5 450.0 55.00  16.0   3.0
IB0061 CSM388            . IB0004 413.0 102.0 13.60  40.0 617.5 152.5  81.5 640.0 49.00   3.0   6.5
IB0062 DT-15             . IB0005 413.0 102.0 13.60  40.0 617.5 152.5  81.5 640.0 49.00   3.0   6.5
IB0063 KIT19             . IB0006 413.0 102.0 13.60  40.0 617.5 152.5  81.5 640.0 49.00   3.0   6.5
IB0064 Soubatimi         . IB0007 413.0 102.0 13.60  40.0 617.5 152.5  81.5 640.0 49.00   3.0   6.5
IB0065 TiandougouC     1,1 IB0008 394.8 102.0 12.10  40.0 617.5 152.5  81.5 672.0 49.00   3.0   6.5
!B0065 TiandougouC       . IB0008 413.0 102.0 13.60  40.0 617.5 152.5  81.5 640.0 49.00   3.0   6.5
```

Table 4:28. Calibration of CWAM-Biomass and HWAM-Grain Yield



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```
!T#AM  TILLER NO      5.0,G3,5     ! Needs tiller # data

*SGCER047  DSCSM047 SORGHUM
@TARGET..........   STEP,COEFF,LOOPS
! ADAP  ANTHESIS      5.0,P20,3
! MDAP  MATURITY      5.0,P20,3
! MDAP  MATURITY      5.0,P1,5 5.0,P20,5
! ADAP  ANTHESIS      1.0,P1,8
! ADAP  ANTHESIS      3.0,P1,3 3.0,P20,3
! MDAP  MATURITY      5.0,P5,3
!LAIX  MAX. LAI      5.0,G1,3 5.0,PHINT,3
!LAIX  MAX. LAI      5.0,PHINT,3
CWAM  BIOMASS MATU  5.0,G1,3
HWAM  GRAIN YLD     5.0,G2,3
```

Table 4:29. After second calibration step (Example Tiandougoucoura)

Variety	ADAPS	ADAPM	MDATS	MDATM	CWAMS	CWAMM	HWAMS	HWAMM	HWUMS	HWUMM
before calibration	70	87	112	117	9761	13926	3449	2020	0.0124	0.0159
after 1. step	74		117		9837		3258		0.0114	
after 2. step	74		117		10564		2198		0.0077	

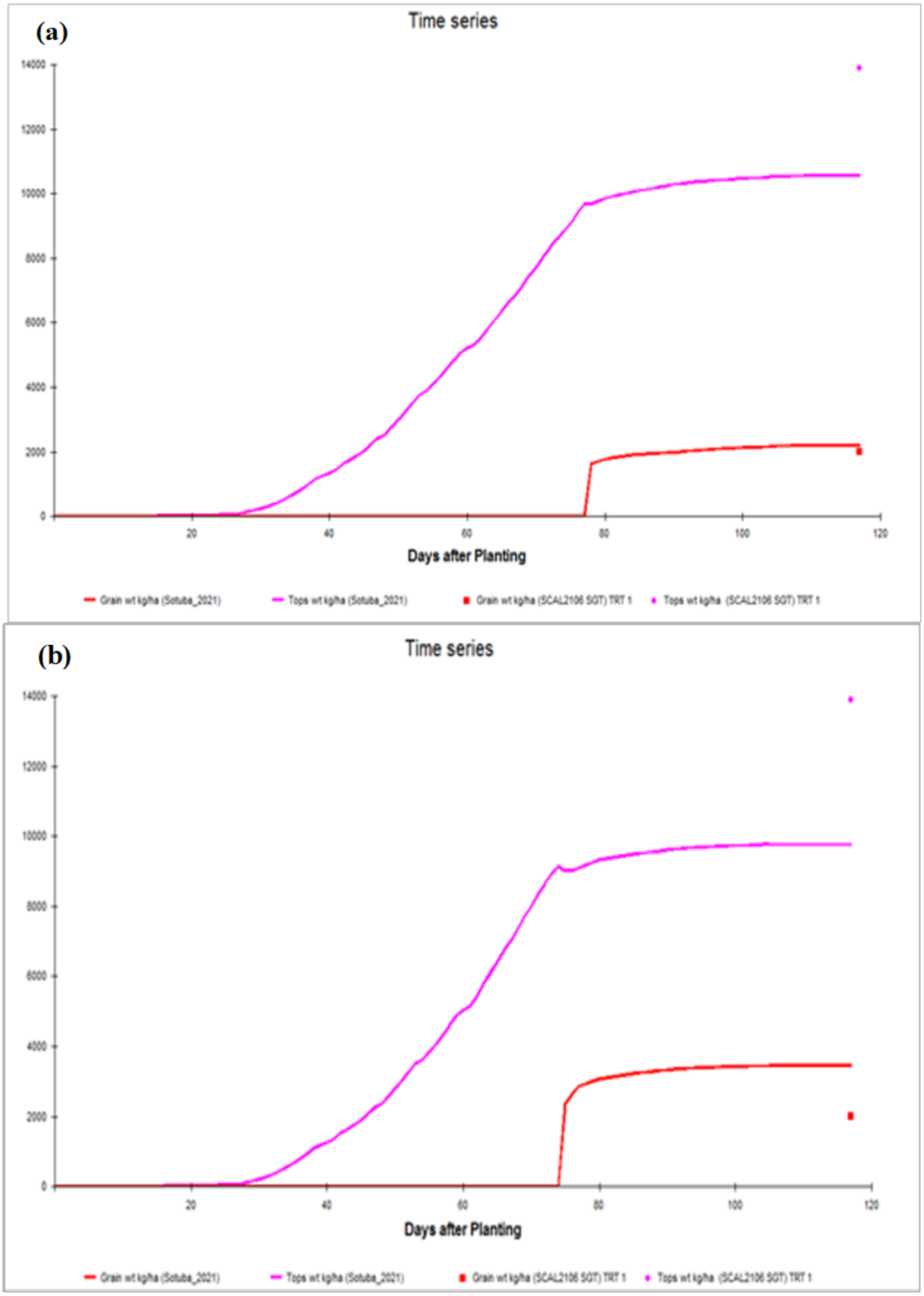

Figure 4.36. A: after calibration (simulated yield is better, simulated biomass slightly better), b: before calibration

The results from the experimentation conducted on groundnut varieties are low, so this low yield did not allow calibration and simulation on groundnut to be carried out. In view of the results of various experiments with sorghum and groundnuts, the impact of the climate was felt on the yields of the varieties studied. This is how the drop in rainfall during the dry periods during the experiment was observed with the attacks of crops pests (rodents, birds, insects and wildlife) and climatic hazards the yields of the crops experienced a drop at the level of the varieties (CSM63E, KIT19, Tiandougoucoura and CSM388) and also the two varieties of groundnut which gave a lowest yield with an average of 106.9 kg/ha for Fleur 11 and ICVG 26024 of 106.5 kg/ha. These decreases are due to the factors mentioned above.

4.3.8 Spatial Simulation of Future Climate Projection of Crop Yield for the Different Localities of Kayes Regions in Mali

Spatial simulation of future climate projection on crop yield was conducted with DSSAT model for Kayes regions in Mali from 2015-2099. The technique to use DSSAT as a spatial model was evaluated. Regional soil and climate data were prepared and simulations for different localities of Kayes regions in Mali have been established.

Results from projection of crop yields in the Kayes region from 2015-2099 show a highest yield in the locality of Bafoulabe with an average of 2792 -3497 kg dry matter/ha compared to the other localities followed by Kita which gave 2200-2457 kg dry matter/ha, Diema 909-1330 kg/ha, then a drop in return (low yield) was found in the Kenieba area of 248-569 kg/ha, Kayes gave 559-909 kg/ha and Yelimané with an average of 100-248 kg/ha (Figure 4.37).

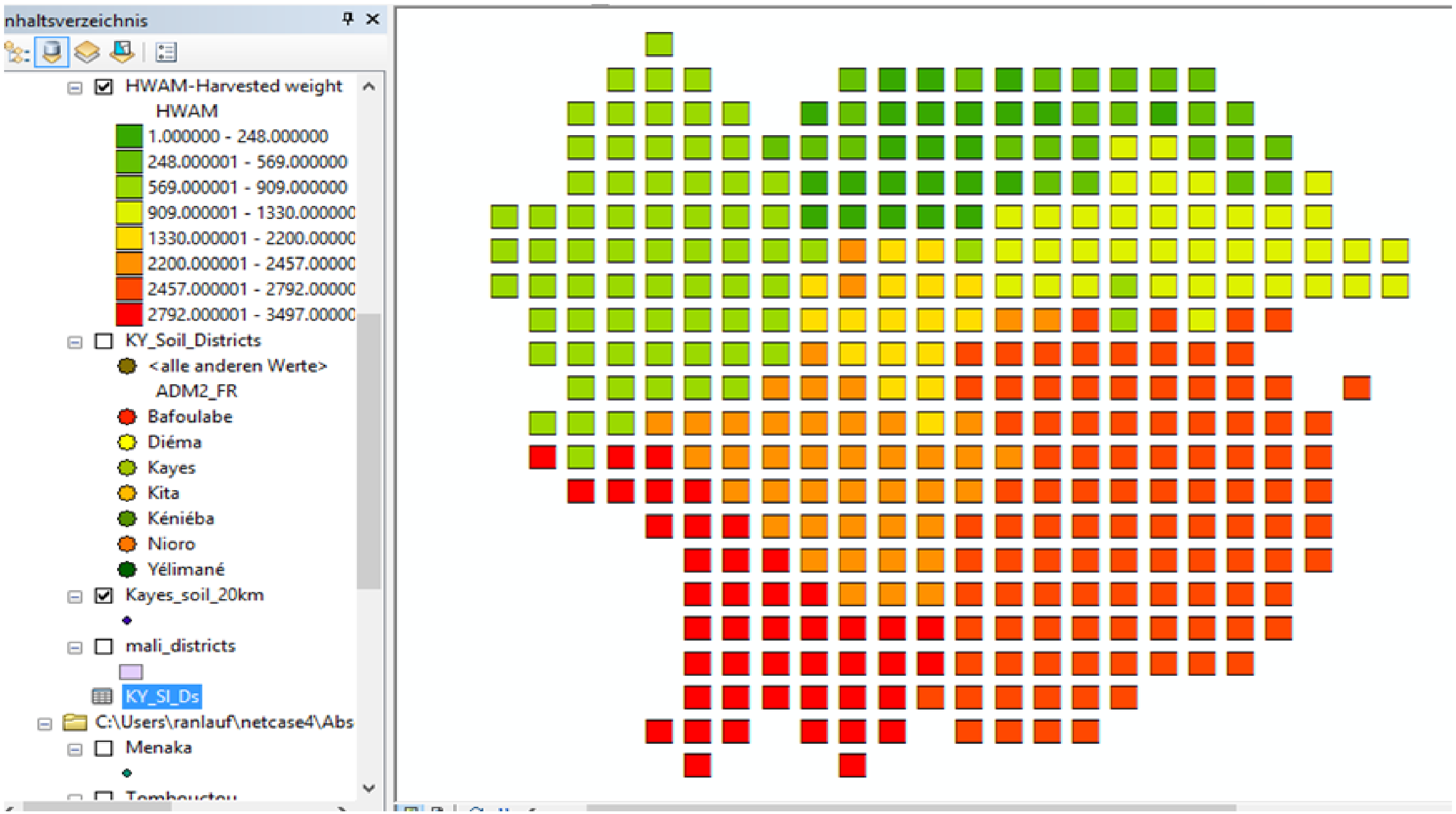

Figure 4.37 Spatial simulation of future climate projection on harvested weight at maturity in Kayes region

4.6 Vulnerability of agropastoralists to the impacts of climate change

The survey involved 355 people, 39% of whom were women and 61% of men, in 33 villages in 22 communes in 14 circles and 10 regions of Mali (ie 52% fodder rate for the regions of Mali).

The surveys carried out showed that 88% are married persons of which 63% are polygamists; 11% are divorced or widowed/widowed and 2% are single (never married). As for the education of agropastoralists, 26% have no level of education, 23% have attended Arabic school, 11% are literate in local languages, and only 19% have reached the higher level.

4.3.9 Impacts of climate change on production sectors

4.3.9.1 Perception of agropastoralists on climate variability of the seasons

The analysis of information collected from agropastoralists on the perception of climate variability shows an increased variability of the start date of the rainy season in the last 30 year compared to that of now. About 55% of respondents said that the rainy season began in May for the past 30 year (Figure 4.38a), while currently it begins in July according to 51% of respondents (Figure 4.38(b)).

According to the results of the analyses of the surveys of agropastoralists, it appears that the rainy season could last up to five (05) months in the southern regions of Mali (9%) during the last 30 year and four (04) months mentioned by 58% of the surveys (Figure 4.39(c)). Nowadays, the same people said that the duration is shortened to three months (03) according to 55% of people (Figure 4.39 (b)).

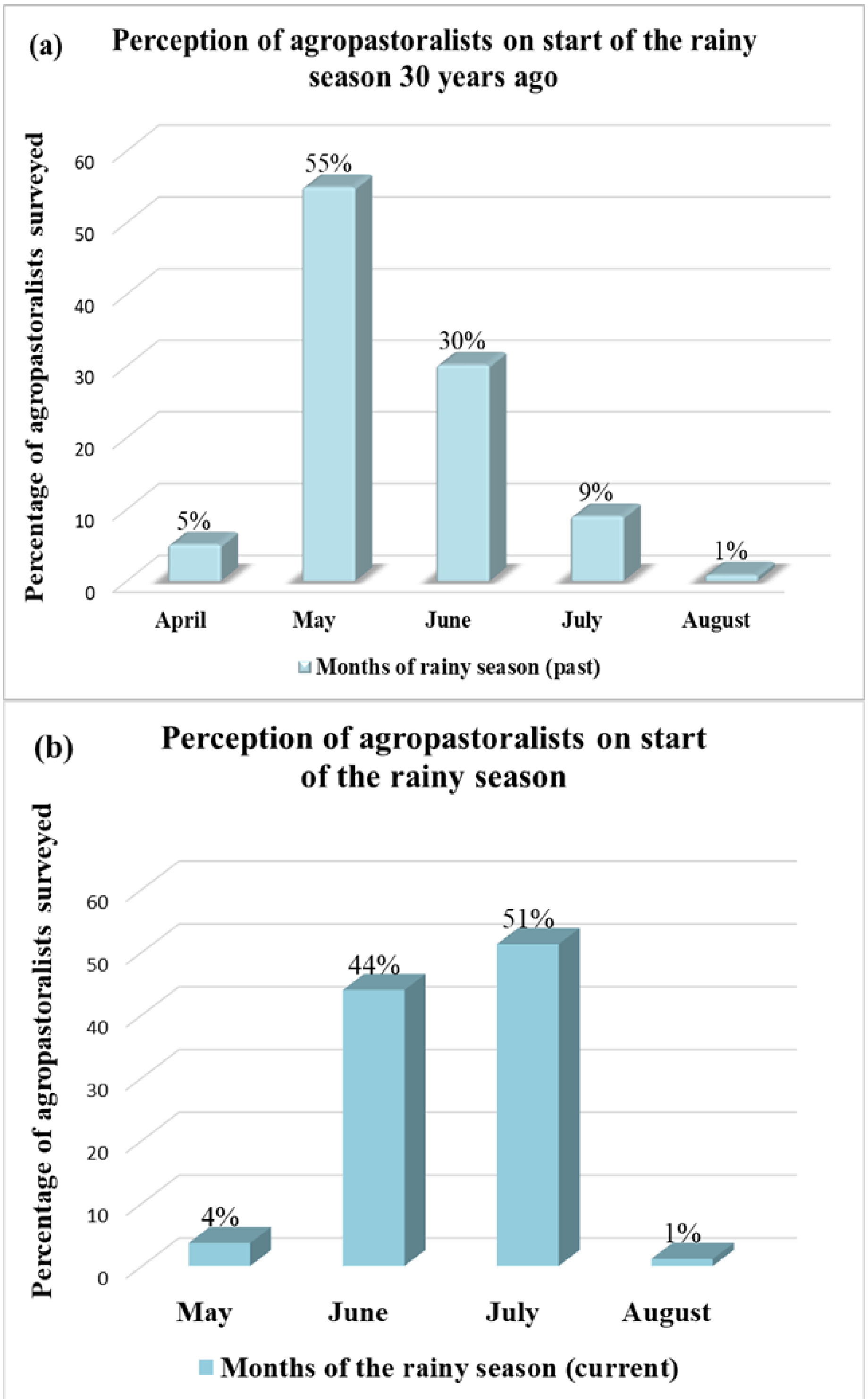

Figure 4.38. (past)Trend months of rainy seasons (a) and current (b)

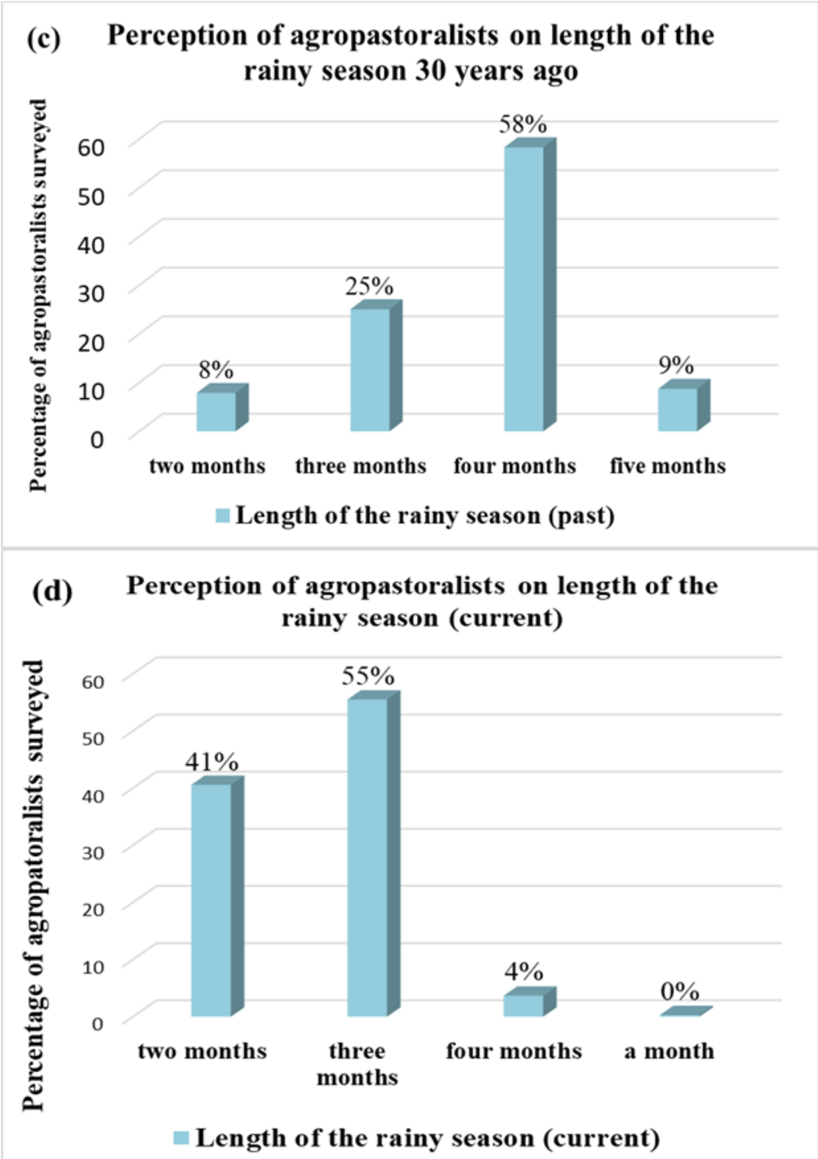

Figure 4.39. (past) Trend length of rainy seasons (c) and current (d)

4.3.9.2 Perception of agropastoralists on natural resources: water points, soil condition, vegetation and biodiversity

The result of the analysis of the surveys of agro-pastoralists revealed that 90% of those who responded declared that the current state of the main water points are temporary and decreasing in quantity (91%) (Figure 4.40 (a)). Agropastoralists (81%) indicated that water points such as wells and ponds are drying up earlier now than in the last thirty (30) years.

Water and wind erosion, according to 67% of agropastoralists surveyed, have negatively affected the current state of the soil than in the past. As for soil fertility, 71% of agropastoralists said that the soils were more fertile before compared to the current one (Figure 4.40(b)).

Surveys of agropastoralists on vegetation revealed a rate of 88% who declared that the current vegetation is less dense than compared to the last thirty (30) years. This Figure 4.41(a) show that 65% affirmed that the current biodiversity is very degraded with the disappearance of plant species expressed by 59% of those surveyed. These species in scientific name are among others: Salvadora persica, Boscia senegalensis, Faidherbia albida, Adansonia digitata, Grewia tenax, Maerua crassifolia, Maerua senegalensis, Tamarindus indica, Ziziphus, Khaya senegalensis, Vitellaria paradoxa. The varieties and species in local languages and scientific name in bracket are: Balanza (Faidherbia albida), N'toro (Laggera alata), Doubalén (Canarium schweinfurthii), N'djoun (Mitragyna inermis), Bànà, N'gaba, Néré (Parkia biglobosa), Bôjiri, N'galajiri, Boina, Saboye, Dani, Guele, Sama-nère (Entada Africana), Ntongue, Sindia, Koronifi (Vitex doniana), Zamba, Sounsou (Annona senegalensis), N'gueni.

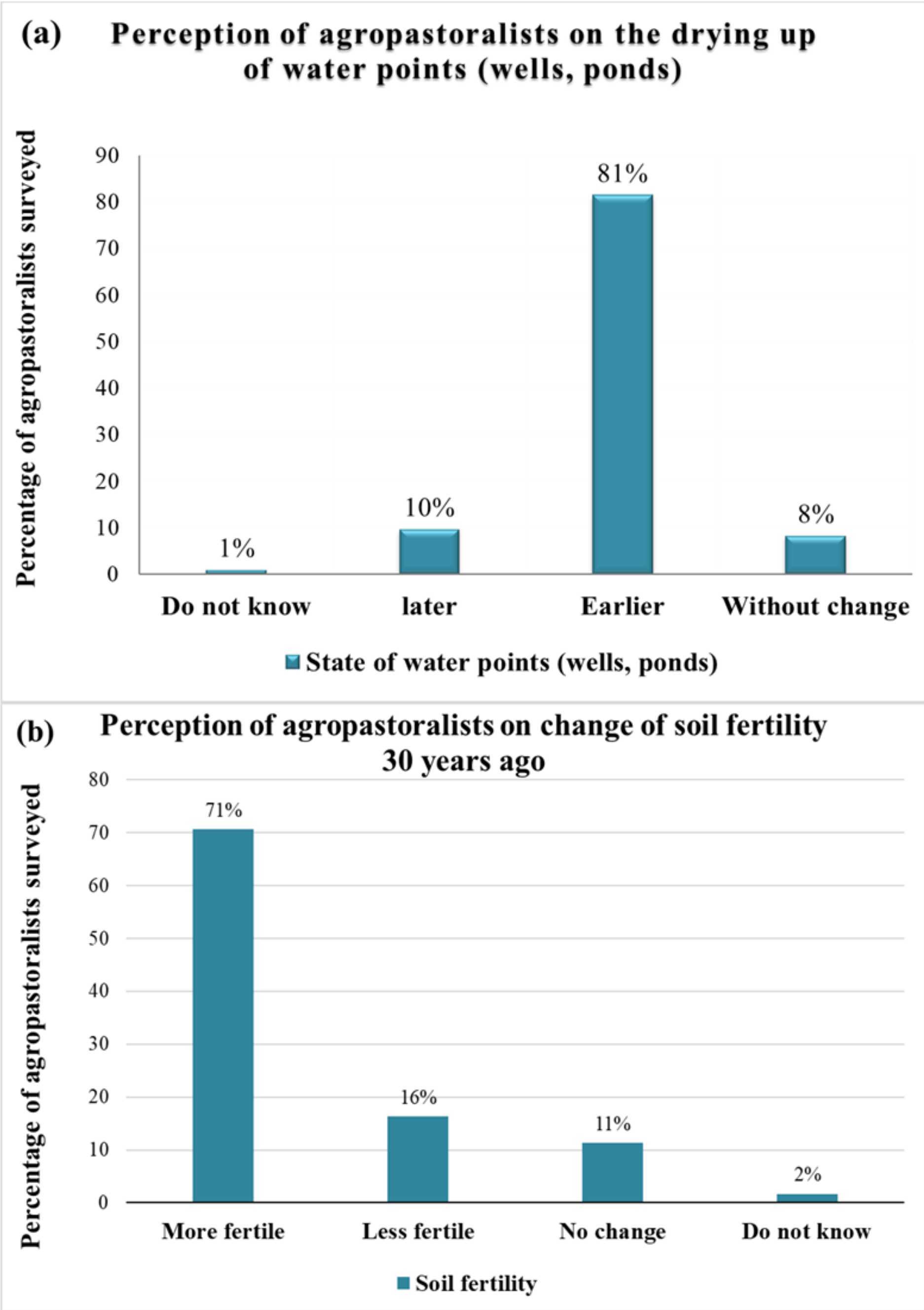

Figure 4.40. Perception of agropastoralists on drying up of water points (wells, ponds) (a) and soil fertility (b)

The results of the surveys revealed that 61% of agro-pastoralists were victims of at least one climate-related disaster and which caused several damages (Figure 4.41 (b)), in particular: loss of crops (44%); loss of fields (26%), loss of animals (12%), insufficient pasture (5%), farmer-herder conflicts (4%) (Figure 4.42). These various damages suffered by agro-pastoralists have been caused by flooding, drought, locusts, erosion, wandering animals, low rainfall, insufficient water available for agriculture and for breeding.

4.3.9.3 Impacts of climate change on cropping systems, soil fertility and socio-economic and natural resources

Analyses of the results of exchanges carried out with agropastoralists in the field compared to the impacts of climate change on agricultural activities highlighted: an increase temperature, a change in precipitation patterns, an intensification of extreme events such as drought, low rainfall (51%), the strong heat (25%), strong winds. 82% of agropastoralists surveyed said that the current sowing date is later than in the past.

Agropastoralists have announced that these climatic factors are challenges they face. Figure 4.42 illustrated that climate change has led agro-pastoralists to modify farming and livestock practices: the abandonment of species or varieties cultivated (85%) in the past (e.g. Fonio, Sorghum varieties Seguetana, Henriho, Babatassi, Wereno, Thiozounou; Bambara groundnut were abandoned because of their long cycle) to adopt new species (e.g. Rice-Nerika, Sorghum-Fuladieba, CSM585, Soubatimi and Tiandougoucoura) or early varieties adapted as well as new practices (see chapter adoption strategies). According to 57% of the agro-pastoralists who responded during the surveys, certain varieties of abandoned crops have a long cycle, less resistant (15%) with low yield (14%).

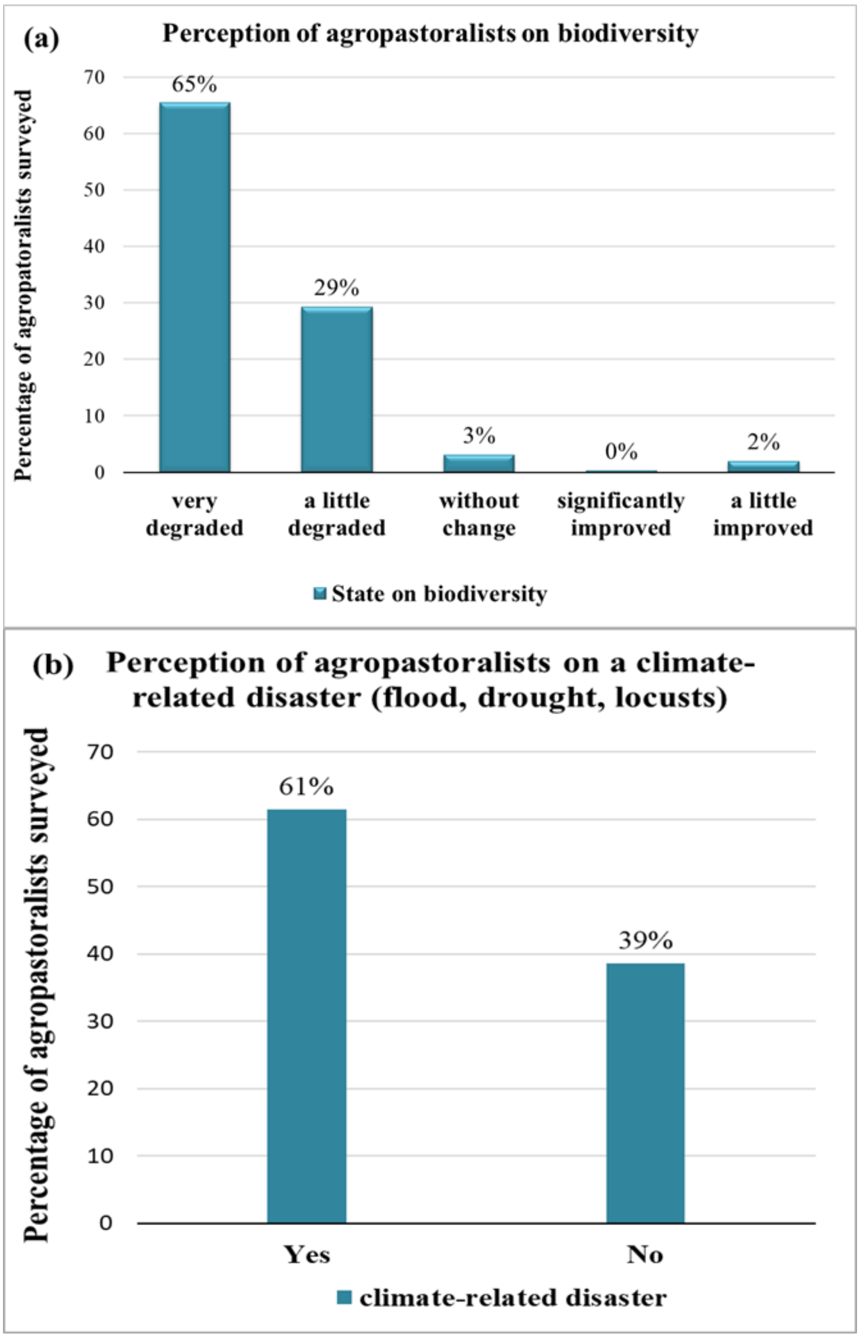

Figure 4.41. Perception of agropastoralists on state of biodiversity (a) and (b) climate related disaster

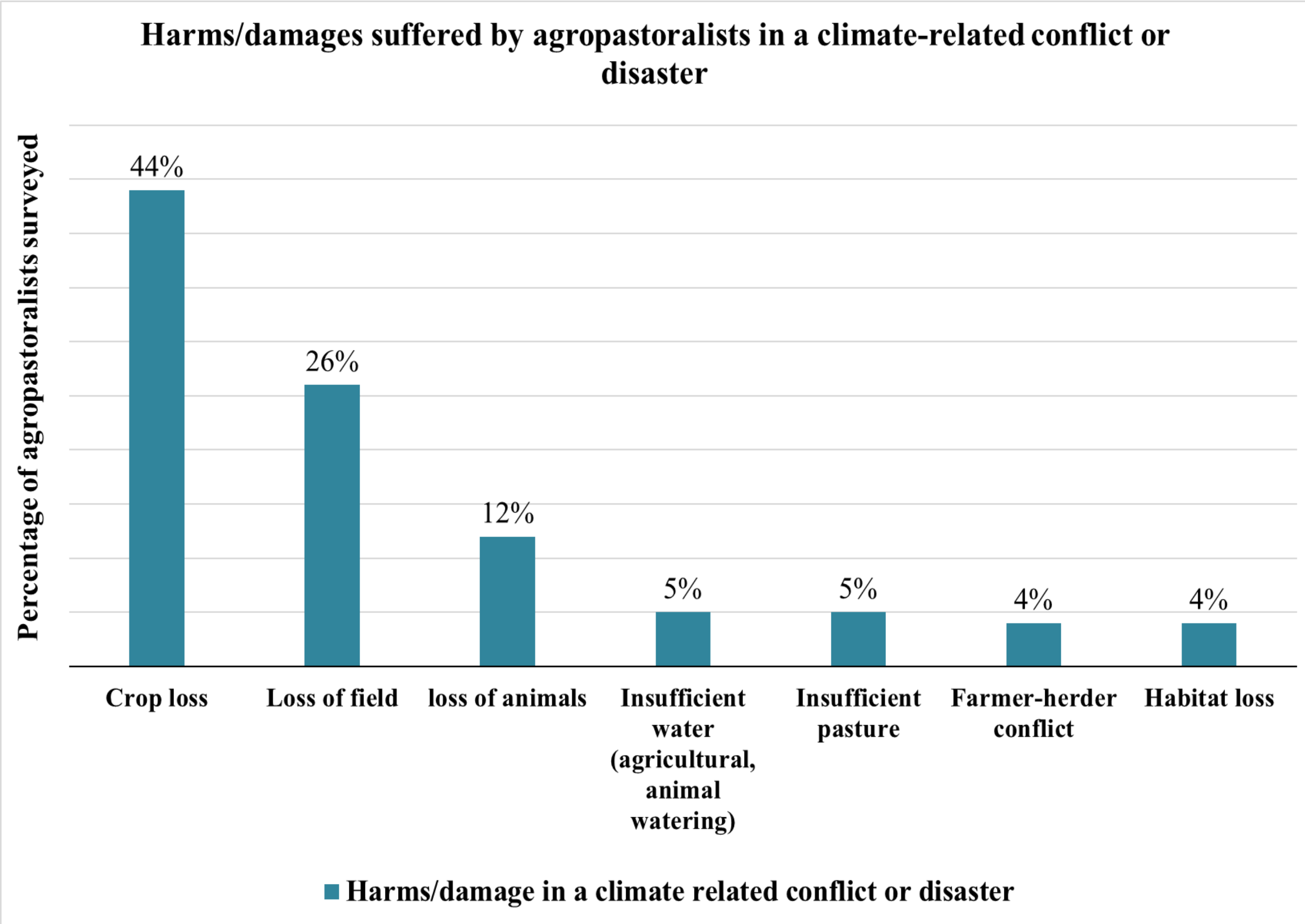

Figure 4.42 Perception of agropastoralists on climate related conflict or disaster

The most practical cropping methods declared in the areas surveyed are: pure cropping (36%), intercropping (24%), irrigated cropping (22%), crop rotation (12%) and flood recession cropping (6%). The most efficient crops (most profitable) in the current context of climate variability and change, 33% of agropastoralists indicated combined crop, 25% for irrigated crops, 22% for pure crops, 14% for crop rotation and 7% for flood recession crops. The management of soil fertility from the contribution of mineral fertilizers such as NPK, urea, phosphate, the contribution of organic matter (compost, animal waste, mulching, agroforestry) was declared by 60% of the agropastoralists surveyed.

With regard to techniques on the management of weeds and crop pests, 73% of the agropastoralists surveyed declared that they used phytosanitary products (herbicides, insecticides, fungicide). Some have used certified seeds, botanical extracts (leaves, neem seeds etc.), crop associations, crop rotation, fallowing, slash and burn and integrated pest management (natural enemies).

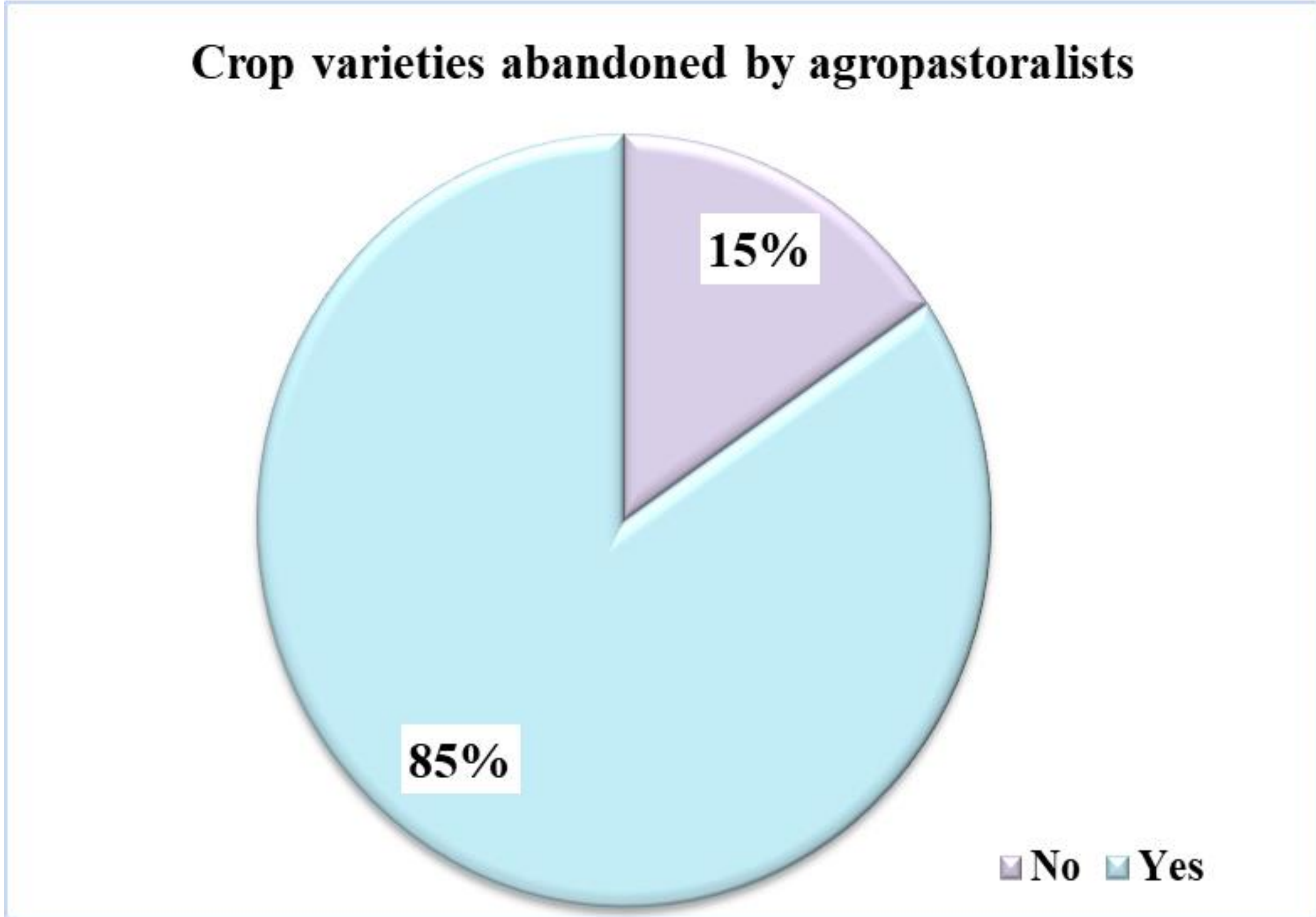

Figure 4.43 Perception of agropastoralists on crop varieties abandoned by agropastoralists

4.3.9.4 Access of agropastoralists to climate information and use.

The surveys carried out among the targets (91%) revealed that access to agro-meteorological information has helped farmers to better adapt to weather conditions, which has reduced climatic risks in agro-pastoral production (Figure 4.44 (a)). Agropastoralists had access to information on:

- seasonal forecasting has enabled better planning of agro-pastoral activities in time and space and decision-making;
- the location of pastures, water points, harvest periods, etc.

Nearly all 97% testified that climate information is useful and real on agricultural and livestock practices. About 68% of agropastoralists said the quality of information is good (Figure 4.44(b)). Access to information according to agropastoralists is through the following channels: radio (52%), television (29%), projects and non-gornmental organizations (10%), agents of State technical services (6%) and resource persons (3%).

4.3.9.5 Adaptation strategies practiced by agro-pastoralists in the face of climate change

It emerged during field surveys that in the face of climate variability, 85% of agro-pastoralists have adopted and practice new techniques:

- in agriculture, these are: the use of new varieties of adapted early seeds, the use of organic manure (41%) or the spreading of household waste, chemical fertilizer (15%) (Urea 46%, Nitrogen 17%, Phosphorus 17%, and Potassium 17%), ridging (22%), ploughing (12%), cover plant (11%), Zai (7%), half-moon ploughing (5%) and tree planting (5%) (Figure 4.45 (a)), stone cordon for the fight against water erosion (13%), crop rotation, crop diversity, flood recession cropping,

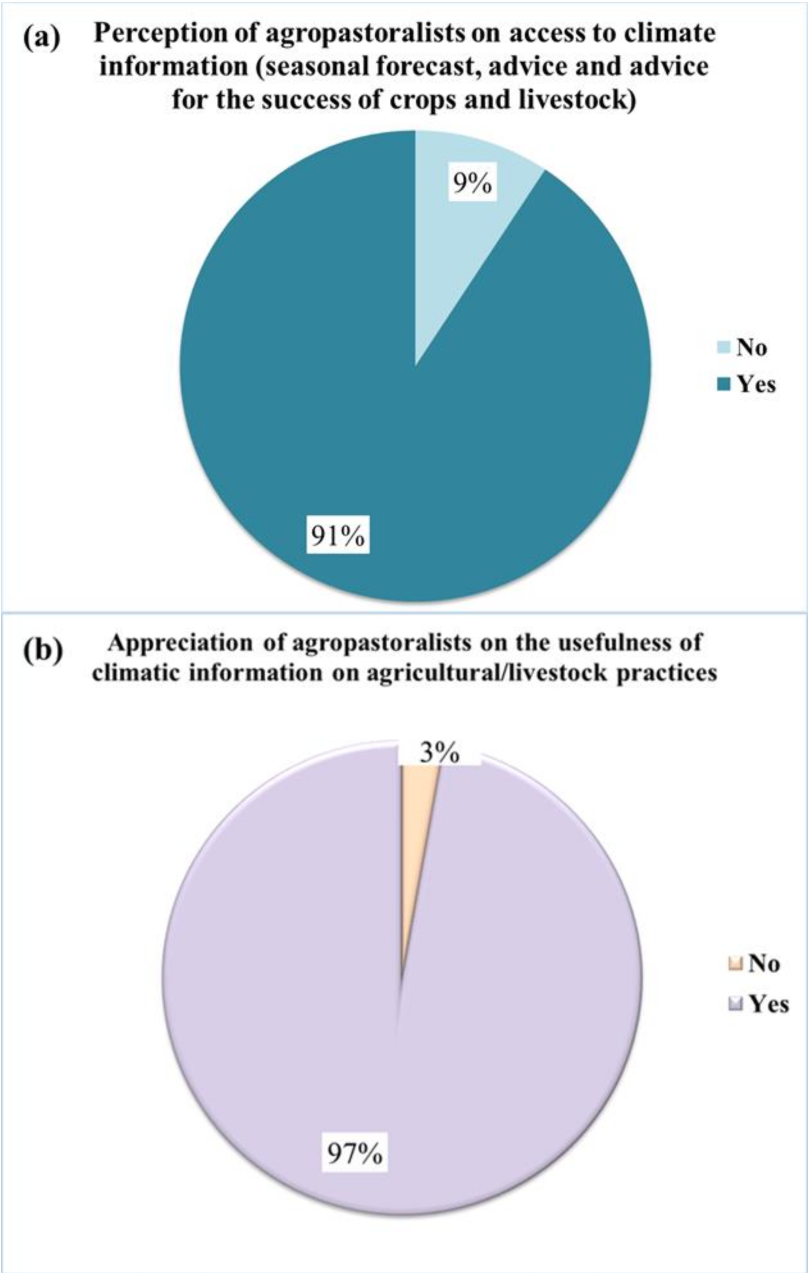

Figure 4.44. Perception of agropastoralists on access to climate information(a) and Appreciation of agropastoralists on the usefulness of climatic information (b)

rainwater harvesting. The effects of climate change led 72% of the people surveyed to re-sow their fields. In order to cope with the effects of runoff and strong winds on crops, 39% of agropastoralists surveyed said they had adopted tree planting (windbreak).

- in breeding, it is: the cultivation of fodder cowpea for animals, the sowing of pastures, the cultivation of forestry cultivation in ponds (Echinochloa stagnina) and lowlands for fodder, the storage of straw, the creation of livestock feed banks, cattle and sheep fattening. Agropastoralists have taken steps with various technical and financial partners to help them in the development of pastoral spaces (drilling of pastoral boreholes, materialization of pastoral tracks), the construction of livestock feed storage warehouses, animal health support.

Agropastoralists said they used other types of strategies during periods of household food deficit but also during livestock fodder deficit in order to support:

- the strategies adopted and mentioned in relation to the food deficit in households were: market gardening (47%), the sale of animals (31%), petty trade (11%), external transfer (6%), exodus (3%), loan or debt (1%), temporary labour, village solidarity and aid from projects or NGOs (Figure 4.45(b)).
- the strategies adopted and mentioned in relation to the fodder deficit of livestock focused on: the sale of animals/destocking (53%), loan or debt (27%), transhumance (13%), aid from projects and NGOs (5%) and the reduction of the food ration (1%).

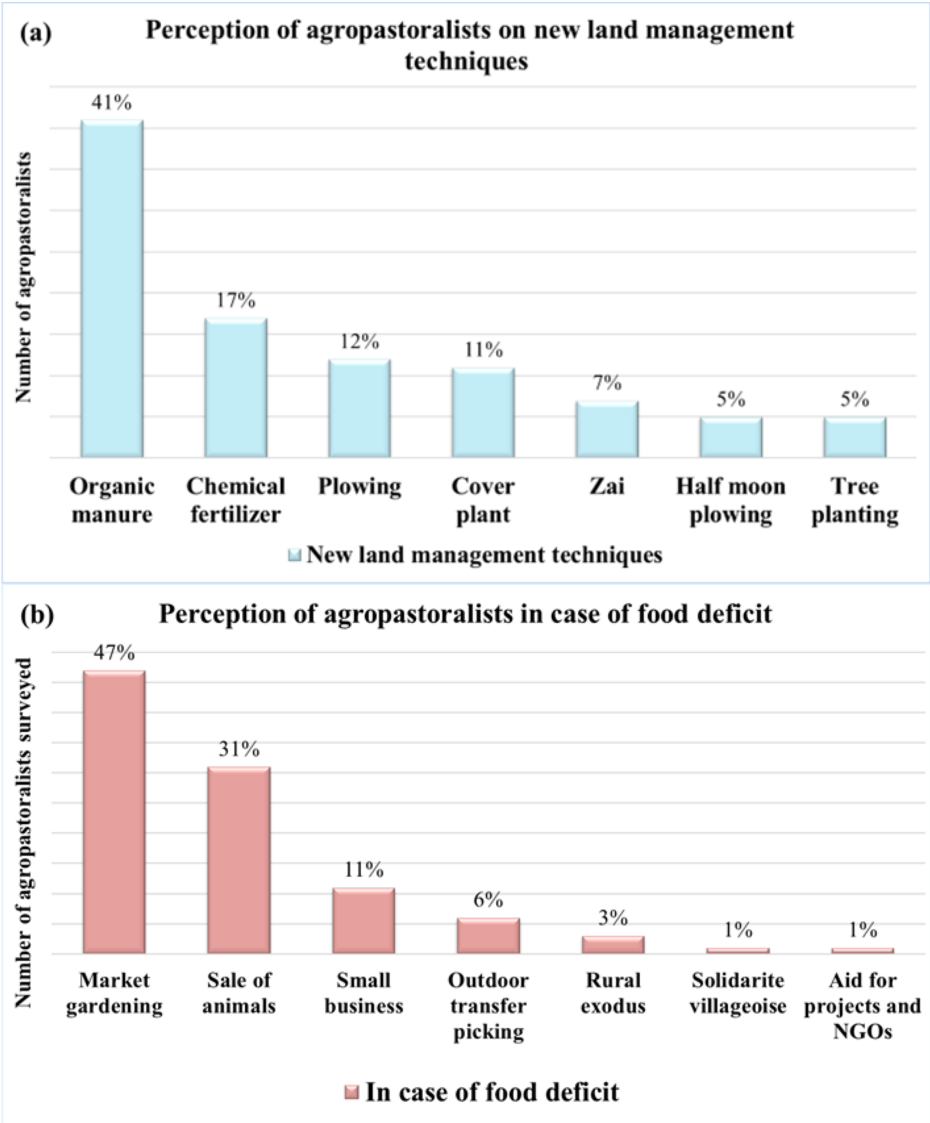

Figure 4.45. Perception of agropastoralists on new land management techniques (a) and in case of food deficit (b)

4.3.9.6 Proposals for improving the production system of agro-pastoralists in the face of climate change involving more agro-pastoralists in the control and improvement of their production system in their environment

The main climate challenges identified during the research work were:

- droughts, floods, strong winds, strong temperature variations (AEDD, 2010) which have impacted on agricultural and livestock activities.
- A large part of the population is vulnerable to climatic problems and women in rural areas;
- Conflicts between farmers and herders;
- A change in agricultural and livestock practices;
- Massive migratory flows from rural areas to town;
- - Women are more in the majority in Mali, the involvement of this layer is important for activities in the context of climate change in agriculture and livestock;
- Added to this is their status as mothers (women) and responsible for the well-being of the family, which accentuates their vulnerability.

This is what justifies the present proposals for improving the production system of agro-pastoralists in the face of climate change.

Table 4*:34* illustrate prioritization of adaptation strategies options, in the total of 14 adaptation options were selected. However, the option 1 has to be implemented to strengthen the resilience of agropastoralists in Mali which is mulching, use of organic manure and conservation of crop residues for restoration of soil fertility, ANR (Assisted natural regeneration).

Table 4:34. Prioritization of adaptation options

Adaptation options	**Cost**	**Facility**	**Efficiency**	**Speed**	**Ability**	**Sum**	**Rank**
Mulching, use of organic manure, and conservation of crop residues for restoration of soil fertility, ANR	2	3	3	3	3	14	1st
Use of early varieties, adoption of new species or varieties, sowing of early or drought-resistant varieties, agroforestry	3	2	3	1	3	12	3rd
Use heat resistant species/varieties adjust plant population densities	3	2	3	2	3	13	2nd
Popularize and institutionalize the agro-pastoral school field approaches (CEAP) and or the resilience funds for the accompaniment and support of agro-pastoralists, the integration of the CEAP approach into university curricula	3	2	2	1	3	11	5th
Improve the efficiency of water use, improvement of natural	3	2	2	2	3	12	4th

resource management rules							
Develop production, agricultural processing, livestock and fish farming infrastructures, infrastructures for the collection, control and recovery of runoff water (retention basin, ponds), water collection techniques and equipment for agro-pastoralists	3	1	2	1	3	10	6th
Maintain soil cover to reduce water and wind erosion, reforestation	3	1	2	1	2	9	7th
Raising awareness on gender and the impacts of climate change	1	2	2	2	1	8	8th

4.3.9.7 Brief description of proposed approaches

- **Farmer Field School (CEP) or Agro-Pastoral Field School (CEAP)**

The Farmers' Field School (CEP) or Agro-pastoral Field School (CEAP) which brings together 20 to 25 producers, is a meeting and training framework for a group of producers, a school "without walls", which takes place in a field, on the site of breeding (fattening) throughout a cropping season or the cycle of breeding activity. It is a place for exchanging experiences and knowledge where producers who share the same interests, research, discuss and make decisions on the management of their experimentation (fields, animals) based on their real situation.

The field school for producers gives producers the opportunity to learn by doing, by being involved in experimentation, discussions and decision-making (experiential learning);

equips producers with tools to analyse their practices and identify solutions to their problems;

The CEP and CEAP values the producer's expertise and puts it at the centre of all the stages of the training: the diagnosis of the problems, the identification and experimentation of the best solutions, the evaluation of the results obtained, and the post-CEP actions.

- **Resilience Fund (CdR)**

The Caisses de Résilience (CdR) approach is centered on agro-pastoral communities, made up of men and women (groups of 20-30 members) that connects and integrates productive, financial and social activities. This approach promotes the empowerment and commitment of communities in the application of good agricultural, nutritional, environmental, economic and social practices thanks to a system of conditionality which makes it possible to achieve long-term objectives through activities with short-term impacts. The Resilience Funds apply particularly well to women's associations, allowing them a certain form of empowerment as well as recognition within the community for both their economic and social roles.

For all, the approach enables communities to fully exploit their existing capacities and have different options (productive, financial and social) to better anticipate, react to and adapt to risks and crises related to rural living conditions.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

At the end of this doctoral research, the results of the field research have made it possible to achieve the three research objectives. These results were acquired by experimental practical work in the field, in the laboratory in Mali but also in Germany through interactions with the various supervisors at the level of FUTA, Mali and Germany. The analysis carried out on the three objectives gave results which are available to the scientific and rural world.

For objective 1, which is to examine the impact of climate change on agro-pastoral activities in Mali, the research work led to the following conclusions:

The analysis of rainfall accumulations shows the interannual variability in the 1960-2020 series and a downward trend of (13mm) with rainfall variability in the 1960-2020 series in the different regions (Ségou, Sikasso and Bamako district) of Mali. Indeed, these climatic disturbances generally translate into late beginnings and early ends of the rainy season, shortening of the rainy seasons in recent decades and frequent drought year have been observed since the1968. There were significant rainfall deficits with the year 1970, 1976, 1980 until the year 1990 and 2000 considered as year of great drought in the different regions of Mali.

However, it indicates an upward trend in temperatures in the three regions of Mali with an average (36°C) with an increase of (0.40°C) for the 1960-2020 series.

The climatic projection of average annual precipitation in the different regions of Mali (Sikasso, Kolondieba, Ségou, Niono and Bamako) during the period 2021 to 2050 and 2070 to 2100 under the scenarios (SSP2-4.5 and SSP5-8.5) highlights according to the studies, a general downward trend observed as well as inter-annual variability.

As a result, the mean annual temperatures under scenarios SSP4.5 and SSP8.5 showed an increasing temperature trend which is statistically significant for both scenarios (SSP4.5 and SSP5-8.5). This upward trend is higher and significant at the level of (0.001 significant) for the SSP5-8.5 scenario.

According to the scenario SSP2-4.5 for the period 2021-2050, the average annual increase in temperature is 0.13°C in the three localities (Ségou, Sikasso and Bamako) and 0.15°C in Niono. Compared to the scenario SSP5-8.5 the temperature increase trend is 0.44°C in Ségou, 0.41°C in Sikasso 0.43°C in Bamako and 0.42°C in Kolondieba. The scenario SSP2-4.5 for the period 2070-2100 the upward trend in annual average temperatures is 0.16°C in Ségou, 0.29°C in Sikasso, 0.32°C in Bamako and 0.31 °C in Kolondieba. On the other hand, for the scenario SSP5-8.5 the upward trend is 0.51°C in Ségou, 0.45°C in Sikasso, 0.43°C in Bamako, 0.51°C, 0.46°C in Kolondieba and 0.55°C in Niono.

For objective 2, which is to evaluate the potential impacts of climate change on crop yields (sorghum and groundnut) in Mali; The research led to the following conclusions:

Experimental trials focused on six varieties of sorghum (CSM63E, CSM388, DT-15, KIT19, Tiandougou-Coura and Soubatimi) and two varieties of groundnut (ALLASSON Fleur 11 and ICVG 26024) for the period of 2021. The field research studies have led to the conclusion that with respect to sowing date and trial planting conditions, the DT-15 genotype and sobatimi gave the best grain yields, however the best 1000 grain weight was observed at CSM388.

Both groundnut varieties recorded low yields compared to their estimated potential, for example for Fleur 11 at 1300-1400 pod weight and 500-550 1000 grain weight. A coefficient of variation of 10.2% and an average of 770 kg/ha, the ICVG 26024 variety gave the best pod yield (776 kg/ha) and the lowest Fleur 11 (764 kg/ha). This drop in yield can be explained through the experimental approach adopted in the research, which was based on organic production without the addition of chemical fertilizers and organic manure. Added to this is a pocket of drought observed between August and September 2021 with 23 dry days of rain, (i.e. 38%) of non-rainy days for the period.

According to the yield of the simulated crops, it indicates a low yield with an average (9761Kg/ha) and 17% for the 5 varieties (CSM388, DT15, KIT19, Soubatimi and Tiandougou-coura). On the other hand, the CSM63E gave a better yield of (10141kg/ha) and (17%). It appears from the statistical analysis of grain yield (1000grains) a higher yield of (3449kg/ha) found for the genotype of 5 varieties (CSM388, DT15, KIT19, Soubatimi and Tiandougou-coura) with 18% unlike CSM63E which has the lowest yield (1694kg/ha) with 10%.

For objective 3, which is to assess the vulnerability of agro-pastoralists to climate change, the research work has led to the following conclusions

It became clear that agropastoralists in Mali perceive climate changes in precipitation, temperature and high wind patterns and the impact of these on their activities. Agriculture and livestock, the main activities of agropastoralists, are experiencing an unprecedented crisis. It emerges from the impacts of climate change on agricultural activities: a rise in temperatures, a change in precipitation patterns, an intensification of extreme events such as drought, low rainfall (51%), high heat (25%), strong winds, 82% of agropastoralists surveyed said that the current sowing date is later than in the past.

Production and income from agricultural activity are significantly down compared to previous year. Pasture surfaces are reduced because they are threatened by soil erosion. Water resources dry up quickly and undergo the phenomenon of silting up and the water tables deepen. The natural vegetation is degraded, some very rich plant species eaten by animals have completely disappeared because they can no longer adapt to these current climatic conditions.

Faced with the effects of climate change, agropastoralists have developed adaptation strategies to guard against climatic hazards and manage their livestock capital. Adaptation strategies relating to the improvement of agricultural production, the management of water resources and vegetation have been proposed. These include the use of organic manure, and the conservation of crop residues for the restoration of soil fertility, mulching, use of early varieties, adoption of new species or varieties, sowing of early varieties or resistant to drought, agroforestry, maintaining soil for to reduce water and wind erosion, reforestation.

5.2 Recommendations

At the end of this study, some recommendations were proposed to development institutions. These recommendations go particularly to: Ministries of Agriculture and Environment.

(i) Raising awareness on gender and the impacts of climate change

(ii) Develop production, agricultural processing, livestock and fish farming infrastructures, infrastructures for the collection, control and recovery of runoff water (retention basin, ponds), water collection techniques and equipment for agro-pastoralists;

(iii) Improve water use efficiency, improvement of natural resource management rules;

(iv) Use heat resistant species/varieties adjust plant population densities;

(v) Popularize and institutionalize the agro-pastoral school field approaches (CEAP) and or the resilience funds for the accompaniment and support of agro-pastoralists, the integration of the CEAP approach in university curricula;

(vi) Build social infrastructure in the area and further involve decision-makers, research structures, producer organizations and NGOs in studies of vulnerability and adaptation to climate variability and change;

(vii) Support agriculture adapted to climate variations and change and strengthen the capacity of vulnerable communities to adapt to climate change;

(viii) Encourage conservation agriculture which could help cope with climate fluctuations;

(ix) Provide subsidies (credits, inputs, etc.) to rural communities and allow better access to regional markets and trade capacity building, then involve vulnerable agricultural populations.

Contribution to Knowledge

The results of this work will make it possible to contribute, on the one hand, to enriching the scientific work of researchers and, on the other hand, to lay the foundations for improving the production system of agro-pastoralists in the face of climate change through research proposals, - actions involving more agro-pastoralists in the control and improvement of their production system in their environment.

- Improve understanding of the impact of climate change on agro-pastoralists in West Africa in general and in Mali in particular;
- Provide a scientific and technical contribution that has made it possible to better understand and take into account climate risk when developing adaptation measures planned for agro-pastoralists,

- The research work made it possible to determine the genetic coefficients of four varieties of sorghum whose genetic coefficients were not known in the research activities with the Dssat: DT-15, KIT19, Soubatimi and TiandougouCoura. These coefficients were determined from experimental work that was carried out in the field during the 2021 agricultural campaign at the Sotuba agronomic research center.

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Appendices

Individual survey form

Perception, Impacts and Adaptation Strategies to Climate Change in Mali

Hello my name is ______, as part of the preparation of a doctoral thesis, we are conducting a survey. For this, you have been chosen, your opinion counts enormously for the success of this thesis and the information you were going to give will remain confidential.

Table 5.0:1. Questionnaire for Agropastoralists

Division 00: Identification

Q01	Region	1.Kayes 2. Koulikoro 3. Segou 4. Sikasso 5.Mopti 6. Gao	7. Timbuktu 8. Kidal 9. Menaka 10.Taoudeni 11.Bamako	/…………. /
Q02	Cercle	1.Kayes 2.Kita 3. Koulikoro 4. Banamba 5. Segou 6.Niono 7. Sikasso 8.Bougouni	9.Mopti 10. Bandiagara 11. Gao 12.Timbuktu 13. Kidal 14. Menaka 15.Taoudeni 16. Bamako	/…………. /
Q03	Commune	-		/…………... /
Q04	Village	-		/…………/
Q05	Agroecological zone ?	1= Agricultural zone, 2=Agro-pastoral zone, 3=Pastoral zone		/………..…/
Q06	Investigator's first and last name	/…………/		
Q07	Investigator phone number	/…………/		

Division 01: General information on the respondent

Q11	Respondent's surname and first name	/…………/	
Q12	What is your age?	/…………/year	
Q13	Sex?	1=man 2=female	/…………/
Q14	Are you married?	1- Yes 2- No	/…………/
Q15	If yes, what is your marital status?	1= married monogamous; 2= married polygamist; 3= single; 4= divorced (d); 5= widower	/…………/
Q16	What is your ethnicity?	1=Bambara; 2= Fulani; 3= Sarakole; 4= Moorish; 5= Malinke; 6= Khassonke; 7= Tamasheq; 8=Dogon; 9=Bozo 10=Other (specify)	/…………/
Q17	What is your level of education?	1= None; 2=Literate; 3=Quranic; 4=Primary; 5=Secondary; 6=Superior	/…………/
Q18	What are your 3 main activities?	1=Agriculture; 2=Livestock; 3=Trade; 4=Market gardening; 5=Hunting; 6=fishing; 7=Lumberjack; 8= Unoccupied; 9 =Other (specify):	/…………/ /…………/

Section 02: PERCEPTION OF AGRO-PASTORISTS AND CLIMATE VARIABILITY AND CHANGE

Q21	What month does the rainy season begin in the last 30 year?	1 = April; 2= May; 3= June; 4= July; 5= Other (specify)	/…………/
Q21. a	Which lunar month / Traditional name of the month corresponding to the beginning of the rainy season before the last 30 year?	1=Name of the lunar month corresponds: 2= Don't know	/…………/

Q22	What month does the rainy season start now?	1 = April; 2= May; 3= June; 4= July; 5= Other (specify)	/………../
Q22. a	Which lunar month/Traditional name of the month corresponding to the beginning of the rainy season now?	1=Name of the lunar month corresponds: 2= Don't know	/………../
Q23	Before the last 30 year, how long was the rainy season in the area?	1= One month; 2=two months; 3= three months; 4= four months; 5= five months; 6=six months; 7=Other (specify)	/………../
Q24	Currently, how long is the rainy season in the area?	1=One month; 2=two months; 3= three months; 4= four months; 5=five months; 6=six months; 7=Other (specify)	/………../
Q25	Before the last 30 year, how were the dry sequences?	1= unchanged; 2=longer; 3=shorter; 4=more frequent; 5=less frequent; 6=Other (specify)	/………../
Q26	Currently how are the dry sequences compared to the last 30 year?	1= unchanged; 2=longer; 3=shorter; 4=more frequent; 5=less frequent; 6=Other (specify)	/………../
Q27	Before the last 30 year, how were the winds during the rainy season compared to now?	1= unchanged; 2= more violent; 3= less violent 4=dustier; 5=less dusty; 6= other (to be specified)	/………../
Q28	How do you assess the recent heavy rain events compared to the period before the last 30 year?	1=no change; 2=more frequent; 3=less frequent; 4=other (to be specified)	/………../
Q29	Currently, how do you assess the temperatures during the day,	1= unchanged; 2= warmer; 3= cooler; 4= other (specify)	/………../

	compared to the period before the last 30 year?		
Q2.10	Currently, how do you assess the temperatures during the night, compared to the period before the last 30 year?	1=no change; 2=warmer; 3= cooler; 4=other (specify)	/…………/
Q2.11	Compared to the period before the last 30 year, how do you assess the current levels of waterways (rivers, lakes, etc.)?	1= unchanged; 2=increasing; 3= decreasing; 4= other (specify)	/…………/
Q2.12	Compared to the period before the last 30 year, how do you assess the state of the plant cfor (trees, grasses, pastures, etc.)?	1= unchanged; 2=increasing; 3= decreasing; 4= other (specify)	/…………/

Division 03: IMPACTS OF CLIMATE CHANGE ON PRODUCTION SECTORS

HAS.	Impact on water resources and soil		
Q31	Are your main water points?	1=Perennial; 2=Temporary; 3= Other (specify)	/…………/
Q32	Do you observe a decrease in the levels and number of your main water points compared to the past?	1.Yes 2. No	/…………/
Q33	If yes, what do you think are the causes of the decrease in watercourses?	1=heat; 2=Wind; 3= Forfishing; 4=silting; 5=decrease in rainfall; 6=Other (specify)	/…………/ /…………/
Q34	If No, what are the causes of the non-decrease of these rivers?	1= sufficient rainfall; 2= drop in temperature; 3= Under exploitation; 4= sand removal; 5= Other (specify)	/…………/ /…………/

Q35	Compared to the past, have water points (wells, ponds) dried up earlier or later?	1=Earlier; 2=Later; 3=No change; 4= Don't know	/…………/
Q36	If early drying up of water points, how many year ago did you start noticing this?	/…………/ Number of year	
Q37	Compared to the past, are the soils more and more or less and less affected by erosion (water and/or wind)?	1=increasingly; 2= less and less; 3=no change; 4=other (specify) 5= Don't know	/…………/
Q38	In the past, how was the level of soil fertility compared to now?	1=More fertile; 2=Less fertile; 3=No change; 4=other (specify) 5= Don't know	/…………/
B	**Impact on vegetation**		
Q39	How is the current state of vegetation compared to the past?	1= unchanged; 2=more dense; 3=Less dense; 4=Other (specify)	/…………/
Q3.10	How do you see current plant biodiversity, compared to the past?	1= unchanged; 2=very degraded; 3= somewhat degraded; 4= somewhat improved; 5= markedly improved; 6= Other (specify)	/…………/
Q3.11	Compared to the past, have you noticed the disappearance of plant species due to climate change?	1=Yes 2=No 3= Don't know	/…………/
Q3.12	If Yes, give examples of extinct species (do not make the answer mandatory)	-	/…………/ /…………/
vs.	**Impacts on cropping systems**		
Q3.13	Compared to the past, how are climate variability and change	1= unchanged; 2=Low rainfall; 3= good rainfall; 4= strong heat;	/…………/ /…………/

	affecting your agricultural activities?	5= severe cold; 6=drop in production; 7= abandonment of species or varieties cultivated in the past; 8= adoption of new species or varieties; 9= strong winds; 10=Other (specify)	
Q3.14	What were the main crops you grew in the past (in order of importance)?	1=Mil; 2=Maize; 3=Sorghum; 4= Cassava; 5=Peanut; 6=Cotton; 7=Rice; 8=wheat; 9=Sweet potato; 10 =Other (specify)	/…………/ /…………/
Q3.15	What are the main crops you currently grow (in order of importance)?	1=Mil; 2=Maize; 3=Sorghum; 4= Cassava; 5=Peanut; 6=Cotton; 7=Rice; 8=wheat; 9=Sweet potato; 10 =Other (specify)	/…………/ /…………/
Q3.16	Have you dropped crop varieties?	1=Yes 2=No	/…………/
Q3.17	If abandonment of certain cultures, what are the reasons?	1=Long Cycle; 2=Lowly resistant to drought; 3=Poor yields; 4= low heat resistance; 5= Not very resistant to winds; 6=Lowly resistant to flooding; 7=Other (specify)	/…………/ /…………/
Q3.18	What are the most common cropping methods in your area (in order of importance)?	1 = Pure culture; 2= associated crops; 3=Crop rotation; 4= irrigated crops; 5= Flood recession crops; 6=Other (specify)	/…………/ /…………/
Q3.19	What are the most efficient (most profitable) modes in the current context of climate variability and change (in order of importance)?	1 = Pure culture; 2= associated crops; 3=Crop rotation; 4= irrigated crops; 5= Flood recession crops; 6=Other (specify)	/…………/ /…………/

Q3.20	How do the current sowing dates compare to those of the past?	1= unchanged; 2= earlier; 3= later; 4=Other (specify)	/………../
Q3.21	How do you assess the current practice of resowing in your fields, compared to the past?	1= unchanged; 2= more frequent; 3= less frequent; 4= other (specify)	
D.	**Impact on socio-economic resources**		
Q32.2	Have you ever been the victim of a conflict or climate-related disaster (flood, drought, locusts) in the last 30 year?	1= Yes 2= No	/………../
Q3.23	If yes, what harm/damage have you suffered as a result of conflict or climate-related disaster (flood, drought, locusts) for the past 30 year?	1=field loss, 2=crop loss; 3=Habitat loss; 4= loss of animals; 5= Insufficient pasture; 6=Insufficient water (agricultural, animal watering); 7=Farmer-herder conflict 8=Other (specify)	/………../ /………../
Q3.24	Did you receive social assistance?	1= Yes 2= No	/………../
Q3.25	What are the impacts of this assistance on your socio-economic activities?	1=no impact; 2=increased income; 3=improved living conditions; 4=increased production; 5= other (specify)	/………../ /………../

Division 04: COPING STRATEGIES

E.	**Technical adaptation strategies of agro-pastoralists**		
Q41	Are you adopting new land management techniques in the face of climate variability and change?	1=Yes 2=No	/………../

Q42	If Yes, what new land management techniques are you currently using in the face of climate variability and change?	1= Zai; 2=half-moon, 3=bench; 4=cfor crop; 5= organic manure; 6=chemical fertilizer; 7=tree planting; 8=tillage; 9=scraping; 10=other (specify)	/…………/ /…………/
Q43	What techniques do you use to prevent the effects of runoff and strong winds on crops?	1= windbreak (tree, fence); 2= ridging; 3= partitioning; 4=straightening of plants 5=water channelling; 6=laying or spreading garbage; 7=Stone rim, 8=Other (to be specified)	/…………/ /…………/
Q44	What are you doing to reduce the effects of high temperatures on crops and animals?	1=mulching; 2=irrigation; 3=early sowing; 4=late sowing; 5=shading; 6=multiplication of water points: 7=tree planting; 8=Other (specify)	/…………/ /…………/
Q45	What do you do to reduce the effects of dry spells on crops and animals during the rainy season?	1= Reseeded; 2=sowing of early or resistant varieties; 3=dry sowing; 4=rainwater harvesting techniques; 5=irrigation; 6=plantation of fodder grasses; 7=straw storage; 8=livestock feed banks; 9=Other (specify)	/…………/ /…………/
Q46	What are the most adopted adaptation practices in Agriculture in your area? (Name 3 main techniques)	/…………/ /…………/	
Q47	What are the most adopted adaptation practices in livestock farming in your area? (Name 3 main techniques)	/…………/ /…………/	

Q48	In the event of a food deficit, what do you do to be able to support your household?	1= market gardening; 2=external transfer; 3=exodus; 4=sale of animals; 5=family displacement; 6=sale of agricultural equipment; 7=belly of material goods of the household; 8=petty trade; 9=Cereal Bank; 10=Loan or debt; 11=temporary labour; 12=state aid; 13=help from projects and NGOs; 14=village solidarity; 15=begging; 16=Decrease in food ration; 17=Decrease in the number of meals; 18=other (specify)	/…………/ /…………/
Q49	In the event of a fodder deficit, what do you do to be able to support your livestock?	1=sale of animals/destocking; 2=transhumance; 3=Loan or debt; 4=aid from projects and NGOs; 5=Decrease in food ration; 6=other (specify)	/…………/ /…………/
f.	**Fertility renewal**		
Q4.10	How do you manage the fertility of your soils?	1=Input of mineral fertilizers (NPK, urea, phosphate etc.) 2=Input of organic matter (compost, animal waste, mulch, agroforestry etc.); 3 = Burial of crop residues (tillage at the end of the cycle); 4=Fallow; 5=Crop rotations; 6=Crop associations; 7=Other (specify)	/…………/ /…………/
Q4.11	How do you manage weeds and pests in your crops?	1=Phytosanitary products (herbicide, insecticide, fungicide	/…………/ /…………/

		etc.); 2=Botanical extracts (leaves, neem seeds etc); 3=Crop associations; 4=Crop rotations; 5=Fallow; 6=Use of certified seeds; 7=Integrated pest management (natural enemies); 8=Fire (burn)	
Q4.12	Do you have access to climate information (seasonal forecast, advice and advice for the success of crops and livestock)?	1=Yes 2=No	/…………/
Q4.13	If yes, from whom or by what means?	1=state employee; 2=Project and NGO; 3=Radio; 4= television; 5=Resource people; 6 other (to be specified)	/…………/ /…………/
Q4.14	If yes, is climate information really useful to you for your agricultural/livestock practices?	1=Yes 2=No	/…………/
Q4.1That	Do you think of the quality of the meteorological information received by these means?	1. Good 2. Medium 3. Bad	

Division 05: MAIN DIFFICULTIES ENCOUNTERED

Q51	What are the 3 or 4 main difficulties encountered today by agropastoralists?	/…………/ /…………/
Q52	How do agropastoralists deal with each problem, especially the poorest?	/…………/ /…………/

Thank you, Mr/Mrs, for taking your time to answer me.

Table 5.0:2. Technical sheet of the 6 varieties of sorghum

Variety	Maturity days after planting	Photosensitivity	Isohyet	Plant height	Panicle type	Seed color	Grain yield	Susceptibility to Striga
Jakumbé CSM63-E	100	non photosensible	400- 600mm	210 cm	lâche	white	2 t/ha	sensible
Soubatimi	110	slightly	800- 1000mm	260 cm	semi-compact	straw yellow	2,5 t/ha	tolerant
DT-15	115	non photosensible	600- 1000mm	300 cm	mean	white	2 t/ha	little sensitive
Tiandougou-Coura	120	sensible	800-1000 mm	180 à 200 cm	semi-compact	whitish	2,5 t/ha	tolerant
CSM-388	125	photosensible	800- 1000mm	370 cm	loose	white	2.5 t/ha	resistant
Tagué (09-KI-F5T-19)	127	photosensible	800- 1000mm	340 cm	Pyramidale	white	2.5 t/ha	sensible

Table 2. Cultivation technique of the 6 varieties of sorghum

Variety	Seed Treatment	Sowing Period	Seeding Spacings	Plants Weeding	Fertilization	Plot Maintenance
CSM63-E	Treat the seeds with Apron star at a dose of 10g for 4 kg of seeds	Sow between July 1 and 15	0.75 m between sowing lines and 0.50 m between seed holes	Thin out 2 to 3 seedlings/hill between the 15th and 20th day after sowing	100 kg/ha of ammonium phosphate at sowing, i.e. 5 kg for 100m2 and 50 kg/ha of urea at bolting, i.e. 0.5 kg per 100m2	Weed on the 15th and 30th days after sowing Followed by ridging on the 45th day after sowing
Soubatimi	Treat the seeds with Apron star at a dose of 10g for 4 kg of seeds	Sow between July 1 and 30	0.75 m between sowing lines and 0.50 m between seed holes	Thin out 2 to 3 seedlings/hill between the 15th and 20th day after sowing	100 kg/ha of ammonium phosphate at sowing, i.e. 5 kg for 100m2 and 50 kg/ha of urea at bolting, i.e. 0.5 kg per 100m2.	Weed on the 15th and 30th days after sowing Followed by ridging on the 45th day after sowing
DT-15	Treat the seeds with Apron star at a dose of 10g for 4 kg of seeds	Sow between July 1 and 15	0.75 m between sowing lines and 0.50 m between seed holes	Thin out 2 to 3 seedlings/hill between the 15th and 20th day after sowing	100 kg/ha of ammonium phosphate at sowing, i.e. 5 kg for 100m2	Weed on the 15th and 30th days after sowing Followed by ridging on the 45th day after sowing
Tiandougou-Coura	Treat the seeds with Apron star at a dose of 10g for 4 kg of seeds	Sow between June 26 and July 15	0.75 m between sowing lines and 0.50 m between seed holes	Thin out 2 to 3 seedlings/hill between the 15th and 20th day after sowing	100 kg/ha of ammonium phosphate at sowing, i.e. 1 kg per 100 m2 and 50 kg/ha of urea at bolting, i.e. 0.5 kg per 100 m2	Weed on the 15th and 30th days after sowing followed by ridging on the 45th day after sowing
CSM-388	Treat the seeds with Apron star at a dose of 10g for 4 kg of seeds	Sow between July 1 and 15	0.75 m between sowing lines and 0.50 m between seed holes	Thin out 2 to 3 seedlings/hill between the 15th and 20th day after sowing	100 kg/ha of ammonium phosphate at sowing, i.e. 5 kg for 100m2 and 50 kg/ha of urea at bolting, i.e. 0.5 kg per 100m2	Weed on the 15th and 30th days after sowing Followed by ridging on the 45th day after sowing
KIT-19	Treat the seeds with Apron star at a dose of 10g for 4 kg of seeds	Sow between July 1 and 15	0.75 m between sowing lines and 0.50 m between seed holes	Thin out 2 to 3 seedlings/hill between the 15th and 20th day after sowing	100 kg/ha of ammonium phosphate at sowing, i.e. 5 kg for 100m2 and 50 kg/ha of urea at bolting, i.e. 0.5 kg per 100m2 100 kg/ha of ammonium	Weed on the 15th and 30th days after sowing Followed by ridging on the 45th day after sowing

Figures from field experiment on Sorghum and Groundnut

Figure 1. Sorghum cultivation on ridge

Figure 2. Delimitation and sowing of the plots of the groundnut experimentation system

Figure 3. First sorghum weeding after sowing and Addition of organic manure and the Cereal complex Nitrogen, Phosphorus and Potash (NPK) on the 15th day after sowing

Figure 4. Sorghum plot at the emergence stage

Figure 5. Groundnut plot at flowering stage

Figure 6. Monitoring of different varieties of sorghum at physiological maturity

Figure 7. Harvesting of different varieties of sorghum and storage in bags for drying

Figure 8. Weighs fresh and dry weight of straws of sorghum varieties

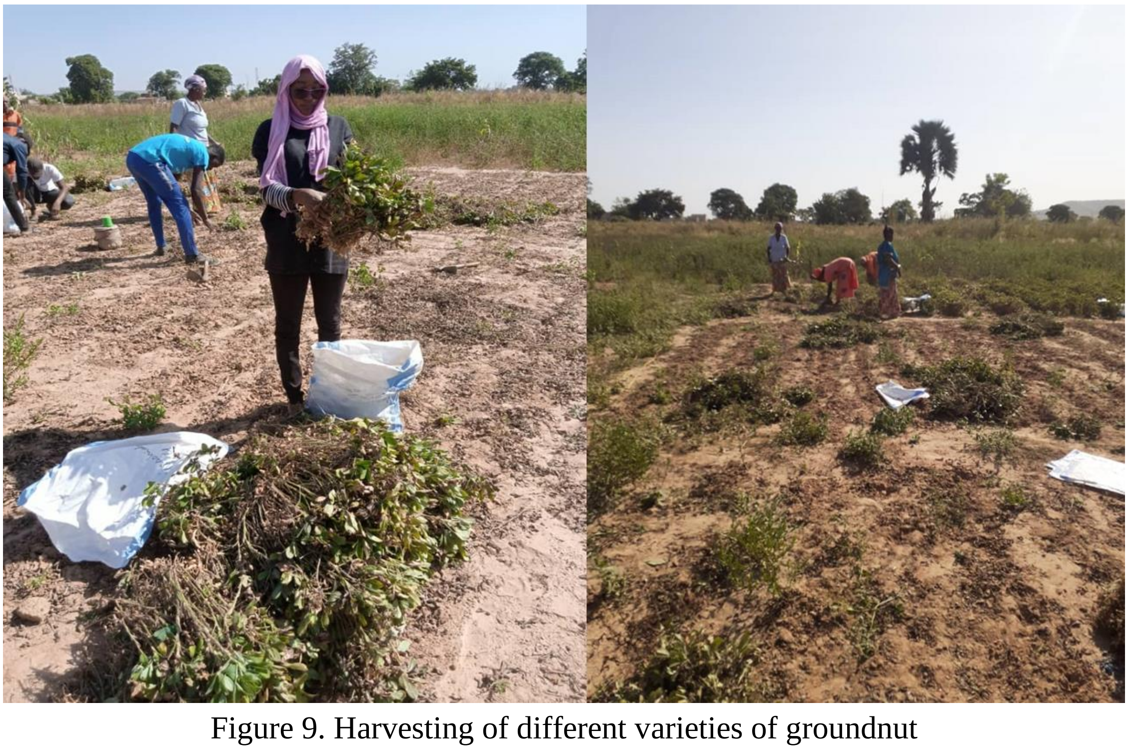

Figure 9. Harvesting of different varieties of groundnut

Figure 10. Shelling of different varieties of groundnut

Figure 11. Weighed different varieties of groundnut with the electronic scale