Agricultural practices and perceptions of climate change in Keur Samba Guéye village, Senegal, West Africa.

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Abstract

This research uses a mixed methods approach to analyze recent climate and land use changes, and farmers' perceptions of climate change and its impacts on traditional agriculture in the village of Keur Samba Guéye (KSG). This work looks at the influence of social beliefs in adoption of new strategies by small farmers in this region, a topic that has received little or no study to date. Traditional agriculture in KSG is not very productive at present because of the impoverishment of the area and traditional agricultures strong dependency on natural climatic conditions. In this research, I identified recent climatic trends, documented changes in land use/land cover (LULC) from 1989 to 2011, and assessed farmers' perceptions of climate change and their responses to such changes. To document climate trends and LULC, I analyzed climate data of twelve meteorological stations located across the country and created a classification of satellite images of KSG for two time periods. To examine farmers' perceptions and agricultural practices, I conducted surveys of the farmers of KSG and in surrounding villages. Most farmers reported negative impacts of climate change on their agriculture activities, and interest in adopting new agricultural strategies despite long-standing tradition. Increasing temperatures and irregularity of rainfall may have negatively impacted crop yields, but more climate data are needed to clarify this phenomenon. LULC has been influenced by both climate change and human pressure; agricultural land has declined, while bare soils have increased. Several recommendations are provided that may help farmers to cope with changing climate.

Dedication

To my mommy to whom I owe all my successes, and whom was the light of my life, mommy you were and will be forever my idol and reference because of your goodness, your piety, your purity, and your sense of sharing. Rest in peace, IMY.

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I wish to thank Lisa Kennedy, my advisor for her thoughtful criticisms, helpful guidance in working in a new linguistic context. Thank you also for your assistance on personal matters. You facilitated and encouraged me to forge ahead when things got tough because of my limited facility with the English language. I also thank my other committee members DrsYang Shao and Andrew Ellis for their helpful assistance and their constructive feedback. I thank the United States Agency for International Development (USAID) who gave me the opportunity to do this master. I thank the ministry of Ecology and Sustainable Development of Senegal my employers who gave me the authorization to stop working for almost three years to enable me to pursue my dreams. I also thank the National Agency of Meteorology and Civil Aviation of Senegal (ANACIM) for giving me the opportunity to do an internship and providing me some of the data for this study. In the same vein, I also want to thank the National Center of Agricultural Research (CNRA) that provided me with much needed data. I thank Maria Elisa Christie (OIRED-VT). I thank Laurent Gomis for facilitating my field work, Sega Diédhiou and his wife Kombé for feeding me during all my field work, the president of the rural council of KSG and all the indigenes of this village for their hospitality, Assane Séné (ANACIM), Mamadou Lamine Diop (ANACIM), Diabel Ndiaye (ANACIM), Médoune Guéye and his wife Aissatou, Sandy Graham, and my colleagues with whom I came to United States to do a master degree. I wish to thank my family and my friends for their continuous support and encouragements---you are my cheerleaders, and you faith in me and your prayers for me kept and keep me going.

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List of abbreviations

AFDS: French Agency Development in Senegal

ANACIM: National Agency of Meteorology and Civil Aviation of Senegal

ANCAR: National Rural and Agricultural Advisory Agency

CNRA: National Center of Agricultural Research

CSE: Ecological Monitoring Center of Dakar

DAPS: Department of Analysis, Projection, and Statistics

EPA: United States Environmental Protection Agency

GEF: Global Environment Facility

IPCC: Intergovernmental Panel on Climate Change

ISRA: Senegalese Institute of Agriculture Research

LDCF: Fund for Least Developed Countries

LULC: Land Use Land Cover

MEPN: Ministére de l'Environnement et de la Protection de la Nature du Sénégal

mm: millimeter

NAPA: National Action Plan for Environment

NIR: Normalized Indices of Rainfall

OMVS: Organization for the Development of the Senegal River

PAPAIL: Project of Support of Small Local Irrigation

UNFCCC: United Nations Framework Convention on Climate Change

USAID: United States Agency for International Development

USGS: United Stated Geological Survey

WFP: World Food Program

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Context

The study area of this thesis is Senegal, West Africa located along the Atlantic Ocean. Senegal has social and physical conditions that aggravate the dependence of the agricultural sector on natural conditions which render it vulnerable to potential negative impacts of climate change. The nation has developed a National Action Plan for Environment (NAPA), in which a number of priority actions for the implementation of its Environmental Policy are defined (Ministry of Environmental Protection MEPN, 2006). The plan identifies three priority areas: agriculture, water resources, and costal protection. Agriculture constitutes the main economic activity in Senegal and is highly dependent on annual rainfall. Senegal has considerable land resources suitable for agriculture, approximately 3.8 million km^2, or 385 km^2per 1000 population (MEPN, 2006). However, a large portion of its arable lands are in areas where rainfall is less than 500 millimeters (mm) per year: the area of the Senegal River, the Ferlo, the Niayes, and the northern part of the Groundnut Basin (Diaw, 2005).

Agriculture's dependence on annual rainfall makes it vulnerable to climate fluctuations. Most of the agricultural zones have inconsistent rainfall through time and across space. This inconsistent rainfall patterns have made it difficult for the lands to record yields that can ensure food security and self-sufficiency. Warmer conditions and changes in precipitation destabilize agricultural production, and the consequences may be harsh for poor and marginalized communities that do not have the means to withstand shocks (Ziervogel et al., 2008). Farmers in the region perceive that droughts instigated by climate change have caused most crops to dry up leading to reduced crop yield (Chipo et al., 2010). Farmers in the area have noticed that their incomes have decreased significantly because of droughts, with many social consequences resulting. Faced with increasing degradation of the agricultural sector, adaptation strategies are needed to permit agricultural activity to guarantee fully the supply of basic food resources for the population. The overall objective of this study was to document changes in traditional agriculture after impacts of climate change are experienced and to make some recommendations that may allow traditional agriculture to play fully its role in farmers' lives.

The research engages the framework of the Senegalese governmental policy to assess negative impacts of climate change in its agriculture sector (MEPN, 2006). Negative impacts in this region are wide-ranging, so this study focused mainly on the potential negative impacts of continued climate change on traditional agriculture perceived by farmers. This study examined local level action aimed at addressing the negative effects of climate change in the traditional agricultural sector in the village of KSG. It also analyzed how local farmers are implementing adaption strategies, the efficiency of these strategies, and the impacts of social beliefs on adoption of new strategies. Farmers of this area have developed strategies to adapt and to mitigate the effects of climate change. Given the importance of agriculture in Senegal, the nation's population is obligated to create methods of adaptation to maintain their agricultural productivity. Farmers have changed or expect to change their agricultural practices to satisfy their food and economic needs (Diaw, 2005). Many projects are designed to help the rural population to ameliorate these physical changes. Rural populations are helped by governmental agencies and sometimes through international cooperation with organizations, such as the French Agency Development in Senegal (AFDS) and the USAID.

This research employed multiple technics to investigate the research problem including analysis of remote sensing images, analysis of climatic data, data collected from surveys administered to local farmers as well as qualitative data gleaned from interviews.

The village of KSG was chosen for this study because for two main reasons. One, it is an area where agriculture is experiencing negative impacts of climate change. Two, the USAID program is currently engaged in a project of implementing adaptation strategies in this village and its immediate surroundings. Conducting this research may also help in assessing the efficiency of the responses engaged by farmers and adaptation strategies implemented by government so that they can be improved or duplicated in other areas that are undergoing similar changes. This study has applied significance because of its focus on the perception by farmers of the negative impacts of climate change in the domain of traditional agriculture and the formulation of specific proposals to mitigate negative impacts on this activity. The applied objective is to help the agricultural sector of the village of KSG (and possibly other communities by extension) to overcome obstacles that prevent it from maintaining a paramount place in the country's economy and its place in the lives of the rural populace.

Introduction to the Study Area

Physical Environment

The village of KSG is located in the rural community by the same name, KSG in the Center West of Senegal in West Africa (Figure 1.1). This rural community is one of 28 in the region of Fatick. The community of KSG (256 km^2) is bordered south by the Republic of Gambia. The topography is relatively flat and characterized by plateaus and watersheds in the center and northern parts (Ndiaye, 2007). In the southern part of the rural community, Ndiaye (2007) identified three types of soils: sandy soils efficient for a good infiltration of water and suitable for crops such as groundnuts and millet; hydromorphic soil, which is more fertile and suitable for crops such as rice and gardening; and finally semi-hydromorphic soil, suitable for corn and groundnut.

The climate of Senegal is mainly dominated with some disparities by the soudano-sahelian climate, which is characterized by two distinct seasons: a dry season without rain lasting about seven to ten months, and a rainy season that lasts three to five months. The dry hot Harmattan winds dominate during the dry season with maritime winds less prevalent. Monsoonal winds bring on moist, hot conditions during the rainy season (Diaw, 2005). Climate parameters such as rainfall, temperature, and humidity will be analyzed more deeply later in this study. The study area is characterized by relatively high precipitation, allowing the development of vegetation cover that is characterized by an herbaceous and a tree stratum. **T**he vegetation in the area is generally degraded by deforestation for agricultural activities, firewood, bushfires, and continual drought (Ndiaye 2011), which explain the present scarcity of trees and disappearance of some tree species; however, the rural community has two protected forests: Baria and South Pakao.

The hydrographic network is mainly represented by the Djikoye River, which is 20 kilometers long. The Djikoye stretches from the forest of Ndenderling, passes through the villages of Simong Hamadallaye, Keur Samba Nosso before dividing into two branches. The presence of water in the Djikoye remains highly dependent on rainfall variations. Many distributaries form from the valley a set of seasonal ponds. The hydrographic network of KSG has felt significant depletion. However, underground water is available, and is of high quality, and is recharged from annual rainfall (Ndiaye, 2011).

Human Landscape and Activities

The census of Senegalese population does not provide population data at the village level. Only data at the rural community are available. In 2004, the census estimated the population of the rural community at 21,620 which is equivalent to 84 habitants per Km2; in 2006 population increased to 29,125 (114 habitants per Km2). In 2011 and 2012, the rural council updated the population data to 23,237 and 23,838 habitants respectively. Overall from 2004 to 2012, the population increased by ~10.25% in only eight years. Population data at the village level were obtained from the rural council, but they covered only two years, 2011 and 2012. Across one year, the village of KSG experienced a substantial increase of 33.44%.

Research objectives, questions, and hypotheses

The village of KSG was studied to ascertain the effectiveness of and interactions among responses adopted by local communities in mitigating the negative effects of climate change on traditional agriculture. Three objectives, research questions, and hypotheses guided this study:

- Objective 1 was to identify the trends through analysis of climate data. Question 1: what is the evolution of the climate over the past three to forty decades in this area? Hypothesis 1: Climate has changed in a way that negatively affects present agriculture.
- Objective 2 was to analyze land use/land cover (LULC) change over the time period 1989 to 2011 through analysis of satellite imagery and link it to climate trend and human activities. Research question 2: How has LULC changed through time? Hypothesis 2: The evolution of LULC is affected by the negative impacts of climate change and human activities.
- Objective 3 was to assess the impacts of climate change on traditional agriculture and strategies implemented by farmers. This objective was addressed through a survey of farmers

and village leaders. Research question 3: How do local farmers experience the impacts of climate change on their activities and what strategies have they implemented to mitigate problems related to negative impacts of climate change. Hypothesis 3: Given the importance of agriculture in their lives and the intensity of negative impacts of climate change, farmers are obligated to respond with methods that may allow a maintaining agriculture.

1.2 Literature review

The term climate change is defined by the United Nations Framework Convention on Climate Change (UNFCCC p.7, 1992) as "A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." Climate change according to this definition includes two essential aspects: climate change caused by a modification of the physical conditions of the planet due to human actions and changes due to natural variability. In the book, The Human Dimensions of Climate Change, (Liverman et al., 2003), analyzed the human causes and impacts of global change in societies. They paid a close attention to LULC change because it may be useful in our understanding of some of the drivers or causes of climate change. Understanding human dimensions of climate change can provide insights into the drivers giving rise to these changes and therefore provide a critical basis for politicians to adopt mitigation and adaptation policies (Liverman et al., 2003).

Almost all scientists agree that climate change is a real phenomenon, and it is a worldwide issue. The world is facing higher air and oceans temperatures, engendering consequences, such as melting snow cover and glaciers and increasing sea levels (IPCC, 2007). For decades, concerns about climate change have become stronger because of the rapid growth of greenhouse gases since the industrial revolution of the 20th century. Between 1970 and 2004, global emissions of greenhouses gases increased by 70% (IPCC, 2007). A product of human activities, the increased concentration of greenhouse gases is an alarming phenomenon and is most likely the cause of a rapid temperature increase in recent decades (EPA, 1990). Temperature is gradually increasing according to IPCC (2007) and the period between 1995 and 2006 is among the warmest decades noticed since 1850 (IPCC, 2007). Records from land stations and ships indicate that the global mean surface temperature has increased by about +0.74°Celsius since 1910 (Hervé et al., 2007).

The effects of climate change may differ greatly according to the economic context; specifically, whether the effects are realized in developing or developed countries. Climate change effects on agriculture may not be very significant in developed countries, but developing countries may endure a huge decrease in crop productivity, and adaptability may be difficult because of the lack of economic resources and technologies (Mearns et al., 2000). Impacts on human health also differ as a function of the economic strength of a country. Mortality rates increase in some areas because of climate change (Mearns et al., 2000). Because of the continuing population growth in cities, water resources serving urban areas might be decreasing and a change to a drier climate would exacerbate this issue; in contrast some areas may face a wetter environment similar to what has been occurring in the mid-Atlantic region of the United States (Mearns et al., 2000). These examples illustrate the potential for both negative and positive impacts. For example areas that face increasing precipitation may use its efficiency by collecting water for an efficient use in irrigated crops.

Given the consequences that it can cause in people's lives now and in the future, the problem of the negative impacts from climate change has attracted the attention of the international community. Many nations and organizations have felt the need to coordinate efforts to find solutions that will help to address this problem. For this purpose, the issue of climate change has been officially included in the roadmap of the United Nations, beginning in 1992 with the adoption of the UNFCCC. The convention has grown to 191 members states. In 1997, the Kyoto Protocol was created as an extension of the UNFCCC, and the agreement primarily devoted to the reduction of greenhouse gas production in developed countries. The agreement currently has 174 members (UNFCCC, 1998). UNFCCC set a number of objectives to overcome the negative effects of climate change. To outline its goals, the UNFCCC set up a system of funding projects that help countries to adopt economic systems to reduce environment degradation. This financing is made available through the Global Environment Facility (GEF) that assists developing countries in overcoming the negative effects of climate change. The goals of the UNFCCC are implemented through the GEF's secretariat's Fund for Least Developed Countries (LDCF) to support them in implementing adaptation strategies to the negative effects of climate change (GEF, 2010). Senegal is member of the LDCF and has benefited from the financing of many projects currently under implementation or already completed.

Climate change is largely believed to have begun in the decade of the 1970s, and it is associated with a global decrease in rainfall (Fabre, 2010). At the same time, rainfall has considerably increased between 1900 to 2005 in some parts of the world, such as portions of North and South America, North Europe, and North and Central Asia. Conversely, decreased rainfall is evident in the Sahara desert region of Africa, the Mediterranean region across South Africa and across portions of South Asia (IPCC, 2007). Increases in carbon dioxide concentrations have occurred because of various economic activities, such as use of fossil fuels and land cover changes that act to decrease the rate of sequestration of carbon dioxide by vegetative cover. Most of the rise in the average global temperature since the mid-twentieth century is likely due to an increase in the greenhouses gases of human activities. It is likely that all continents except Antarctica have been subject to a significant anthropogenic warming over the last 50 years (IPCC, 2007). A significant phenomenon is the occurrence of extreme events such as cyclones, drought, and heavy precipitation that have caused economic, demographic, and physical catastrophes (UNFCC, 2007). Climate change may also cause increases in the occurrence of various tropical diseases in humans, such as malaria, which may increase in Africa in the future (Tanser et al., 2003). However, according to the literature, these events have always existed but their frequency and intensity may have increased. Continued emissions of greenhouse gases at current levels or at faster rates should increase warming and deeply modify the climate system during the twenty first century, and it is possible that changes will be greater than during the twentieth century (IPCC, 2007). Significant changes to the climate system have had many negatives consequences on societies and the physical environment across the world, but mainly on societies more vulnerable because of a lack of economic resources and suitable technologies to adapt. Effects will vary depending on the geographical context, such as developed or developing countries, tropical or non–tropical areas, rural or urban areas, and poor or wealthy populations. In the agricultural sector like in other sectors, an increase in productivity may be noticed in some areas, and a decrease in productivity in others depending on a multitude of factors, such as intensity of impacts and capability to implement suitable adaptation strategies. In northern regions, warming may increase the growing season and stimulate plant growth (Mearns et al., 2000). However, droughts and floods may be very harmful extreme events for agriculture in some areas, such as the study area of this study.

The agriculture of Senegal is seasonal and influenced by precipitation patterns. Most farmers combine both cash crops (groundnut, cotton) and food crops (millet, sorghum, maize) that constitute the basic food. Rice is traditionally cultivated in the southern region of the country, but it now constitutes a large intensified portion of the agriculture in the Senegal River Valley (MEPN, 2006). Agriculture is generally practiced by farmers who inherited lands from their parents. Subsistence farming is generally entirely for family consumption through the year, and a small part is kept for seeds for planting during the following agricultural season. Most of the time, crops do not match the family's food needs for the whole year. Agricultural techniques in Senegal are often rudimentary (Fabre, 2010). Soils are also overexploited for several years, and methods of fertilization cause many damages to the environment. Over time in this region, soils lose their organic properties and more lands have become inappropriate for any agricultural activity (MEPN, 2006). A change to a warmer and drier climate would exacerbate the vulnerability of soils that have become very sensitive to wind and water erosion (UNFCC, 2007). Loss of soils nutrients is aggravated by human pressure on forest resources for energy needs. With population growth and increased energy demand, the availability of resources is less compared to the needs (Liverman et al., 2003). Crop yields are more affected because less precipitation reduces biomass, which in turn affects soil quality leading to its physical, biological, and chemical degradation. However, agriculture has begun to be modernized and intensified in some areas, such as the Senegal River Valley, which has a large river-fed water resource. Through the Organization for the Development of the Senegal River (OMVS), Senegal built a dam to irrigate farmlands. In the Senegal River valley, the main crops cultivated are rice, onions, and industrial tomatoes. Another form of agriculture, urban agriculture exists in Senegal but is not prevalent and does not yield a large crop volume. It is practiced by rural people living in the urban periphery as a secondary activity (Diaw, 2005). The weaknesses of the country's economic resources and the lack of an advanced technology to support the agricultural sector reduce the chances of agricultural development.

Senegal, like many West African countries, is among the most vulnerable areas to climate variability and climate change - a situation aggravated by the interaction of several factors acting at different levels. Negative impacts of climate change are experienced in the biophysical, social, and institutional environments related to agricultural production. The inconsistency of rainfall over the last several decades has profoundly affected the agricultural productivity and type of crops grown in Senegal and in many parts of Africa. Climate is already a key driver of food security (Challinor et al., 2007). The changes in precipitation are coincidental with climate change. Agriculture is highly sensitive to warming, mainly in developing countries because of many factors: yields may considerably decrease with higher temperature, while causing an augmentation of weeds and pests (Traore et al., 2000). The decrease in rainfall in some areas such as the study area raises the probability of having to reduce the quantity of traditional crops produced, and this threatens food causing many social problems, and agricultural communities are more vulnerable. Technological progress known in developed countries is not yet integrated in the agricultural production systems of developing countries (Liverman et al., 2003). Some researchers predict a decrease in quantities of foods crops, such as cereals because of hydric stress and land degradation. Yields for crops, such as maize are well correlated with the fallow-cropland ratio; the impact of popular climate scenarios on maize yields in Sub-Sahara Africa is decrease). Senegal is among the areas projected to decline by 50% or more within the period 2021–2050 (Gaisera et al., 2011) (Figure 1.2). This situation will be reinforced by the imbalance between population and crop production. Furthermore, this situation will be accentuated by some social factors already present like a lack of economic resources and trends of economic globalization.

Adaptation to climate change means that new strategies should be developed to face a new situation. The main goal is to mitigate the negative impacts through implementation of adequate adaptation measures to address the negative effects of climate change in general. In this context, I focused on responses to negative impacts of climate change related to agricultural activities. The existing literature offers much information about analyzing adaptation strategies in developing countries to overcome agriculture difficulties. Many kinds of adaptation strategies have been developed, but their efficiency may differ from one another. Mertz et al., (2010) studied how climate factors play a limited role for past adaptation strategies in West Africa. Traore et al., (2000) examined the adaptability of millet and sorghum to the new climatic conditions, to check if the phenological plasticity of local varieties can serve to respond to drought. For full success, actions must be coordinated. Adaptation to climate change should also entail adjustments and changes at every level – from community to national and international (UNFCCC, 2007).

Climate change effects can be negative or positive depending on how climate's characteristics change. For example, higher precipitation may increase production or decrease production, depending on the phenological characteristics. Farmers are very sensitive to any change in their surrounding environment. To face the uncertainty of these changes, agricultural communities should develop their own strategies using local knowledge to mitigate the risks of climate change and benefit from the positive impacts of change. Some African farmers, for instance, have developed several coping options to mitigate climate variability, but these options are insufficient (Traore et al., 2000). Famers shift planting dates to take advantage of the longer growing season which is permitted by higher winter temperature (Lotze et al., 2009). Also, according to these authors, new varieties of crops can be introduced, which adapt to drought or wetter environments; however, cultural beliefs constitute an obstacle for farmers to change their agricultural practices, and none of the reviewed literature mentioned this aspect and the role it plays. In some areas with water bodies, increasing precipitation may be sufficiently used by introducing irrigated crops combined with rain-fed crops. Water can be also sustainably managed by reducing its infiltration, runoff, and evaporation with the use of some local techniques. These adjustments, alone or in combination, can minimize climate impacts on agriculture. On average, adaptation can provide around 10–15% yield benefit compared to no adaptation practice (Lotze et al., 2009). However, studies do not reveal assessment of local responses' efficiency and durability.

Adaptation is more organized at a national level, and takes into account the local practices of adaptation that already exist. The most efficient adaptation will allow the giving up of practices not respectful to environmental protection and conservation. Local adaptations using local knowledge often do not respect environmental rules; however, it is sometimes because of ignorance. The Senegalese government has developed a document that summarizes its adaptation priorities in the agriculture sector by focusing on transferred and local technology and research. This document is the reference for the Least Developed Countries Fund (LDCF) in financing adaptation projects by the GEF. Already, many programs of adaptation are being implemented to act in synergy with local communities, helping them to develop the most efficient and sustainable adaptation plan. Technology transfer through international cooperation has permitted the introduction of efficient modes of production and conservation of agricultural resources. For example, Senegal has many broad programs that cover all agricultural areas in the country being implemented with international cooperation aid. Retention ponds are built in areas with specific physical characteristics that allow durability of the infrastructure. Runoff is collected and used for gardening, and that constitutes an important source of revenue for populations, especially women. The reviewed literature also omitted a key element, the use of local strategies that should be taken into account because of their importance. Also, local communities must be integrated to any adaptation process in their areas. Their participation may be a factor of success or failure.

This first chapter has discussed the situation of traditional agriculture, documented research already done on this subject, and identified the gap in the reviewed literature. It also discussed the objectives and importance of the research. Chapter 2 describes the methods used to achieve the goals of the study.

Figures

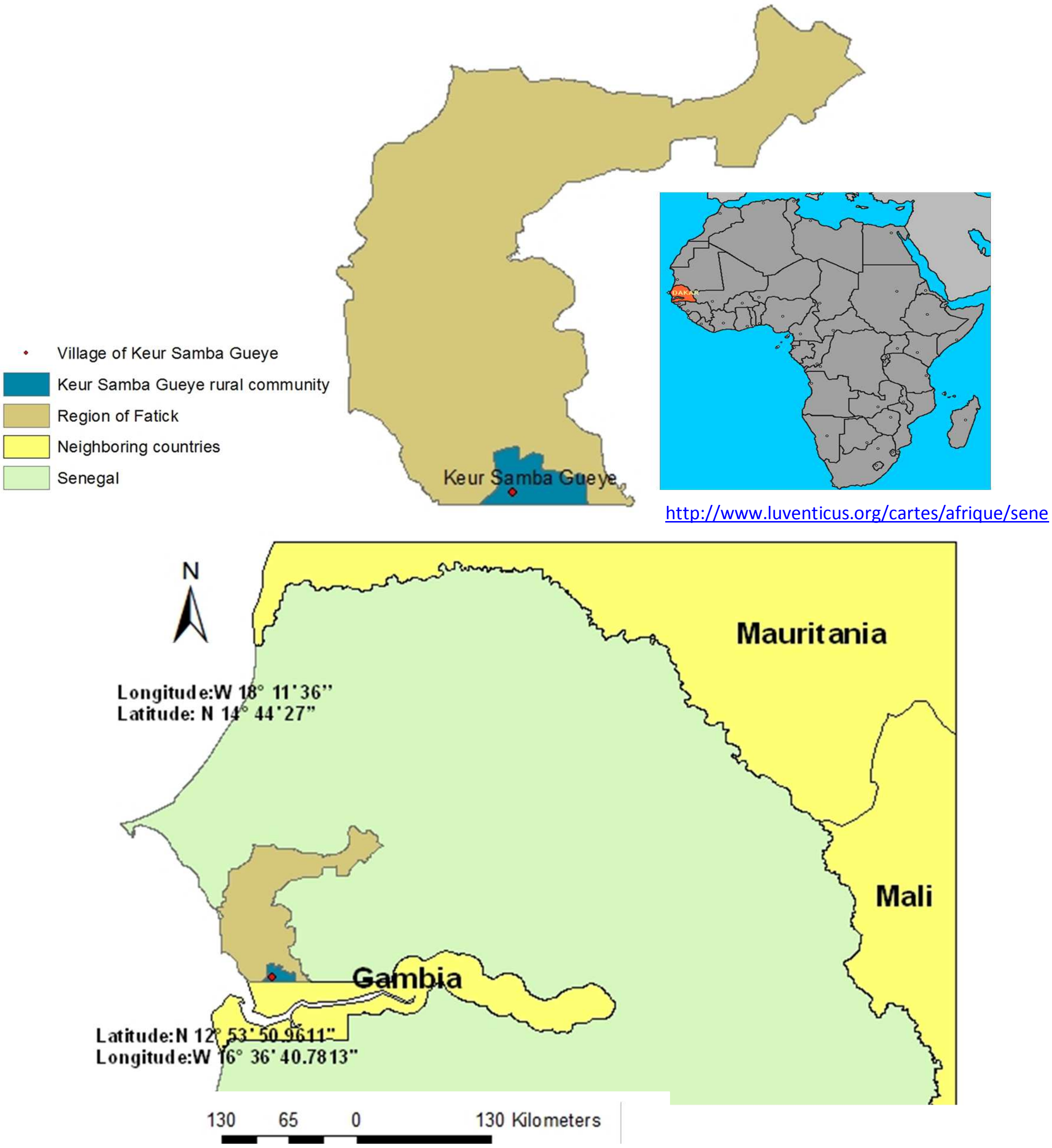

Figure 1.1: Situation map of the study area at the top. The bottom figure shows the position of the study area in Senegal. (Map done by author).

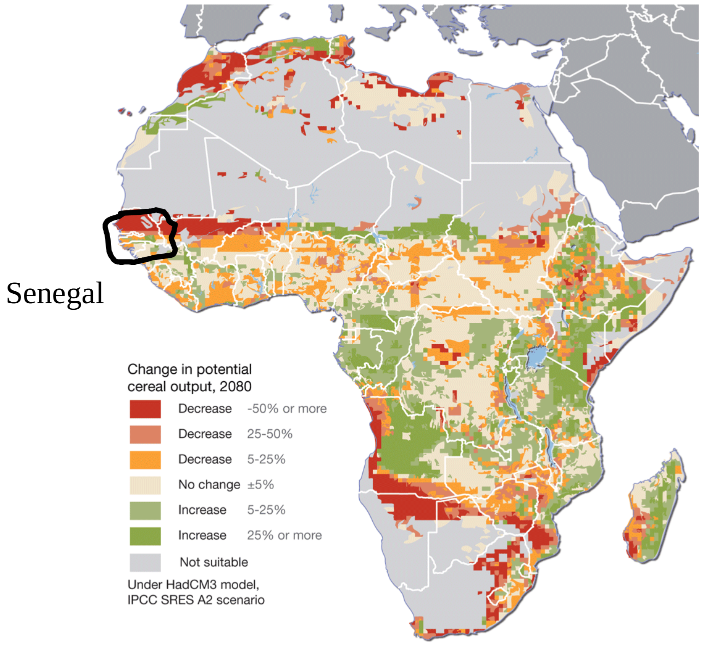

Figure 1.2: Change in potential cereal output in Africa in 2080. Modified from http://reliefweb.int/node/12268 (2009)

CHAPTER 2: METHODS

This research is based on both qualitative and quantitative data. Quantitative methods are defined as research methods concerning numbers and anything that is quantifiable. Counting and measuring are common forms of quantitative methods. The result of the research is a number, or a set of numbers. In this study, analysis of quantitative data helped to clarify relationships between the variables, such as area farmed and yield with average precipitation per year. From the quantitative approach, data gathered from the sample of farmer are generalized to the entire population of farmers. Qualitative data were collected through the survey questionnaire to gain additional insights into the perceptions and practices of the participants (farmers of KSG).

2.1 Climate data

Climatologic data for 12 stations (Figure 2.1) located around the country were analyzed to examine climate variability across space and through time. I examined data from stations at Aéré Lao, Dakar, Ziguinchor, Tamba, Linguére, Podor, Matam, Kédougou, Diourbel, Kaolack, Vélingara, and Nioro; data were provided by ANACIM. The instrumentation at the rainfall station of KSG did not appear to be adequate for production of reliable data, so I used data from the station of Nioro that is a more reliable station closest to the study area (65 km distant). Climate data (rainfall, temperature, and humidity) from 1980 to 2010 were collected from all stations, but in the case of nearby Nioro, 40 years of precipitation data were available. There are two types of synoptic stations: at ground and under shelter. Synoptic stations under shelter measures temperature and humidity, using wet/dry thermometers to record temperature minima and maxima. Synoptic stations at the ground measure rainfall, evaporation with a water tub, and temperature of water with a floater thermometer. In sum synoptic and agro-meteorological measure nearly the same parameters, while rainfall stations measure only rainfall, with tubs (at ~1 m height) that record the height of water received.

Daily rainfall data over a period of 42 years from 1969 to 2010 (from the National Center of Agricultural Research (CNRA)) were acquired to allow a deeper analysis of precipitation trends in the study area. Daily rainfall data from 1980 to 2010 originated from the National Agency of Meteorology and Civil Aviation, and rainfall data from 1971 to 1979 were obtained from the CNRA. In a careful data review, I found missing temperature and moisture values of 6.18% and 3.22% respectively. Monthly and daily rainfall data were however complete. Overall rates of missing data were <10%, a value which permits proper processing and analysis (Burt et al., 1996).

Processing and analysis of these data provided an overview of the tendency of climate variability across the country during this period. I used the software Instat v3.36-Plus to process the daily rainfall data of the agro-meteorological station of Nioro. The daily rainfall data were imported from Excel to Instat (Figure 2.2). This software takes into account non-leap years, calendar year, missing values, and trace precipitation. Non-leap year was coded as 9988, trace precipitation as 8888, and missing values as 9999. Variables derived included length of the rainy seasons, the trend in annual totals, monthly means of rainfall, dates of beginning and end of rainy seasons, intensity of rain, and Normalized Indices of Rainfall (NIR). Descriptive statistics were calculated using Microsoft Excel and Instat+ V3.36 to summarize the climatic trends and relationships.

2.2 Land use land cover (LCLU) analysis

Remotely sensed images of the study area were downloaded from the United Stated Geological Survey (USGS) for two time periods, 1989 and 2011, for analysis of changes in land cover land use (LCLU) (figure 2.3). The first image was taken during the rainy season when all valleys were flooded by rainfall water in September, and the 2011 image was taken during the dry season. Supervised classification of Landsat images of the study area was conducted using the ENVI software program to identify the main types of land cover land use (figure 2.4). The ERDAS software program was also used in image processing. Mapping of land cover classes for the two times period, 1989 and 2011, was completed with ArcMap10. Statistical analysis and graphing was completed using Microsoft Excel. Field validation of images was not possible for this project. Instead, I did a visual interpretation using the Landsat images for both time periods using Google Earth to improve the classification as much as possible.

2.3 Survey questionnaire

To assess the perception of climate change on traditional agriculture and strategies implemented by farmers, I implemented a survey of farmers in the study area (figure 2.5). Climatic variability and change most strongly affects farmers and thus their opinions and knowledge about this phenomenon is therefore of paramount importance. In the traditional rural context of Senegal, there are two types of farms: the family farm and the agro-business farm, which is far less widespread. At the village of KSG, only the family farm exists. There each house is called “square” and may contain several households. In each house there is a supreme leader, generally the oldest man of the house, who leads the whole family or all households who live in there. He is usually living with his sons or youngest brothers and their respective families.

However, the head of the family can be a woman—typically a widow who has only young children who are not old enough to marry.

The village of KSG has 118 houses and in each house, one farm is shared by all households who live there and who also share the costs and farming work. All the households were practicing agriculture. A total of 40 out of 118 households were randomly selected; this was equivalent to 34% of the total, a proportion that should yield reliable information. The survey data were mainly used to gather basic descriptive information about farming in the study areas, such as the mean acreage per household, the mean yield per year, and percentages of decreasing or increasing yields and acreages farmed per year.

The village of KSG is a village center and headquarters of the rural community that bears its name; the rural community encompasses 43 other villages. To develop an idea of the agricultural context in the area, I conducted two interviews each in five others villages located in the north and south of the rural community: one with the chief of the village and another with a head of a farm. The results of these interviews were corroborated with other resources such as published articles and literature.

I also conducted in-depth interviews with researchers and program managers from national and international agencies that have implemented programs for agricultural development in the study area. These programs work very closely with local farmers and have been collecting data for many years.

Finally, data on yields of sorghum, corn, groundnut, and cowpea were collected from the National Agency of Agriculture. These data reflected yields from 1971 to 2010 except for cowpea, which derived from 1997 to 2010. The yield data have a rather high rate of missing data—about 10%. I also obtained recent yields data (2010 and 2011) representing farmers using conservation farming methods to compare them with yields of farmers who do not use this technique. These data represent a regional scale, but they served to illuminate the efficiency of the conservation farming.

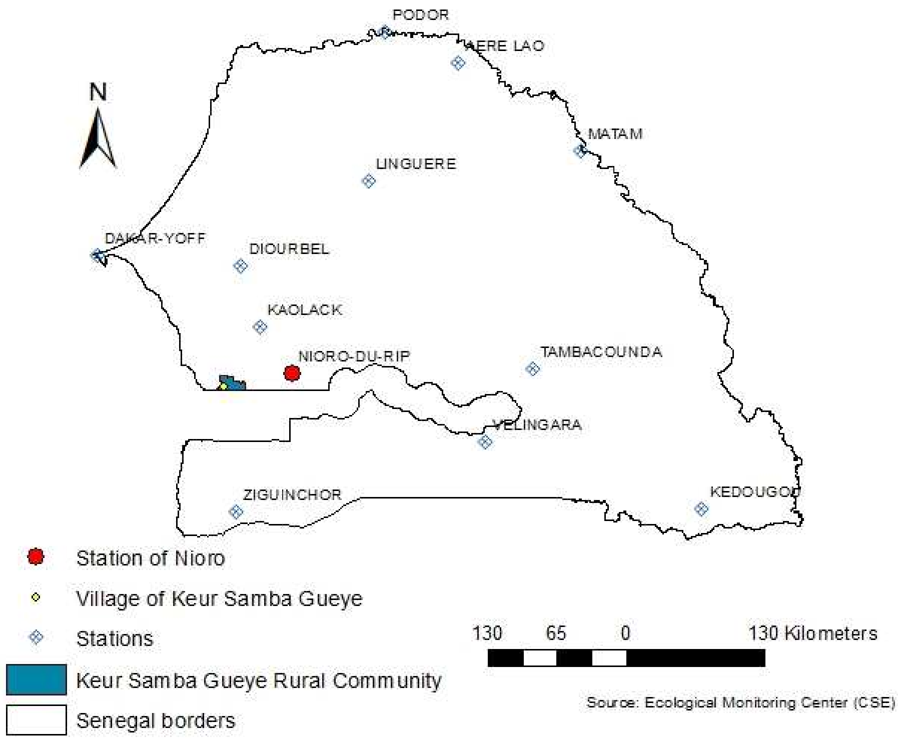

Figure 2.1: Map showing the spatial localization of the twelve stations used to collect climate data. The station of Nioro used to analyze climate parameters of the study area is highlighted in red.

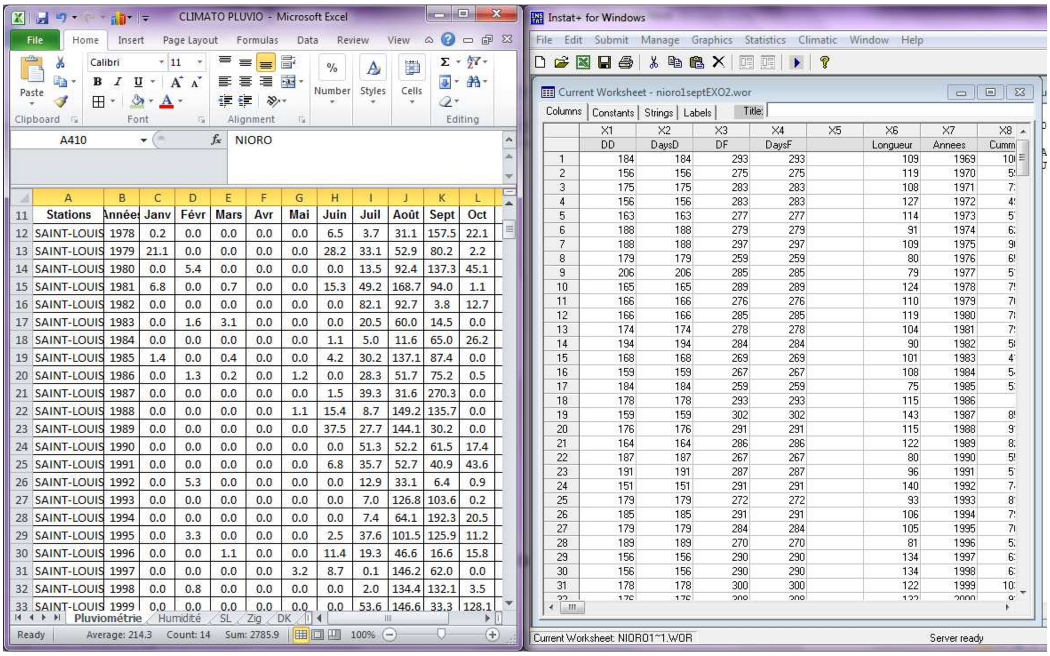

Figure 2.2 Processing of climate data using the program Instat+ V3.36 by author.

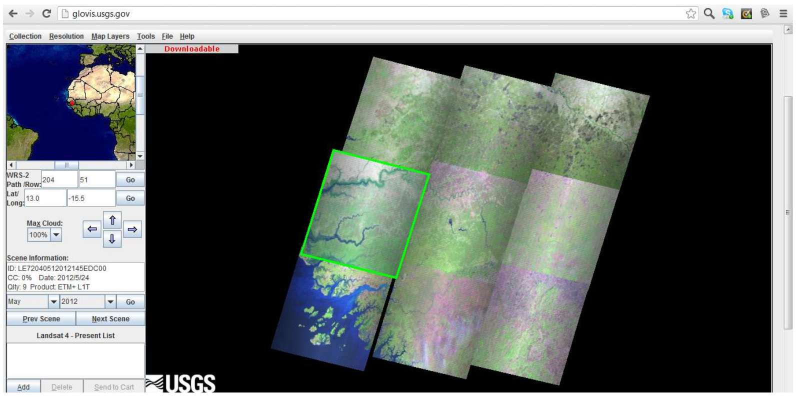

Figure 2.3 Landsat images of the study area downloaded from United States Geological Survey (USGS) web site

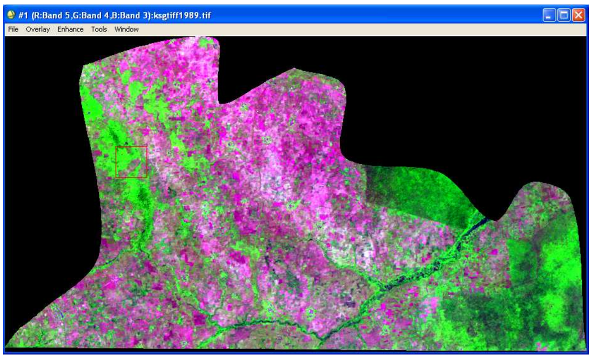

Figure 2.4: Supervised classification of remote sensed image using ENVI program. Done by author

Figure 2.5: Introduction of the survey questionnaire in the village of KSG by author

CHAPTER 3: RESULTS

3.1 Climate Data

Precipitation

Annual rainfall of all stations over a period of 31 years (1980-2010; Figure 3.1) show a pattern of decreased rainfall from south to north, but inter-annual trends are similar at all stations. The northern and northwestern stations of Podor, Matam, and Aéré Lao are the driest, while the southern stations of Ziguinchor and Kédougou have the highest rainfalls. The geographical position of the central station of Nioro, nearest the study area, has a rainfall pattern near the middle of the range for the stations.

Average monthly rainfall for the 12 stations (Figure 3.2) shows that the rainy season duration varies from four to seven months, depending on the geographical position of the station. Stations located in the south of the country such as Ziguinchor, Kédougou Vélingara record the longest rainy seasons unlike stations like Matam and Aéré Lao with rainfall seasons of four months at most. Ziguinchor has recorded an average of almost 400 mm just for the month of August, the wettest month for all stations. Rainfall can occur during the dry season in December or January, but is not linked to the rainy season.

Rainfall of Nioro's Station

Figure 3.3 represents annual rainfall over 42 years from 1969 to 2010 of the station of Nioro. The inter-annual variability of rainfall at Nioro is clearly shown. It is also clear that rainfall has increased during the period of study. The least rainy year was recorded in 1983 with

417.5 mm of rainfall compared to 1226.9 mm of rainfall for the wettest year in 2010, a difference of 193%.

Length and the descriptive statistics of the rainy season of each year from 1969 to 2010 revealed that the probability of the rainy season to last at least 95 days was 20%, the probability of the rainy season to last at least 115 days was 50%, and the probability of the rainy season to last at least 126 days was 80% (Table 3.1 and 3.2). The figure 3.4 illustrates the length of the rainy seasons; it also reflects the same irregularity of inter-annual irregularity of rainfall of Nioro's station. The data show that long rainy seasons do not always coincide with high annual rainfall. The shortest rainy season in Nioro lasted only 75 days in 1985 versus 143 days for the longest rainy season in 1987 two years later. The average duration of the rainy season during this period is 112 days.

For a more precise analysis of the rainfall character, NIR for the period 1969-2010 were calculated with the following formula: I = Annual average - average rainfall (1969-2010) / standard deviation of the average rainfall from 1969 to 2010. The following legend represents values of NIR and corresponding meanings: I> 2 very wet, 1.5 <I <1.99 humid -0.99 <I <+0.99 normal, -1.49 <I <-1 moderately dry, -1.99 <I <-1.5 sec and I <-2 very dry (Centre Régional Agrhymet Niamey, 2009). This parameter identifies years that can be considered dry, moderately dry, wet or moderately wet. An analysis of NIR shows a clear differentiation of the wet years from the dry years (figure 3.5). The data show that over the last 42 years, the number of wetter than average seasons were far higher than the number of drier than average seasons (Table 3.3) The year 1983 was the driest; the years 1972, 1977, 1991, 1980, 1996, 1985, 1984, and 1990 are moderately dry. Twenty eight years were considered normal. Two years 1999 and 1975 were wet and only the last 2010 year was very wet.

The date of beginning is defined as the date of the first rain of at least 15 mm in one or two days, with the condition that there is no 15 days dry spell within the next 30 days (Sambou, 2009). Sambou (2009) defined the date of ending as the date that receives the last significant rain with at least 5mm and a water balance close to zero. Dates of start and end of the rainfall data were reorganized to have an ascending order for facilitating the identification of early and late dates (Table 3.4 and 3.5). The gap between the earliest date, May 30^{th} and the latest date, July 24^{th} of the beginning of the rainy season was very important, almost two months of difference. The calculation of the normal range identifies the years that have had a proper beginning of the rainy season. The average starting date is June 21^{st} and the standard deviation is thirteen days (Table 3.6). The normal range is located between June 21^{st} minus thirteen days and June 21^{st} plus 13 days, which is equivalent to the interval that goes from June 8^{th} to July 4^{th}. Twenty four years are in this range among the 42 years. Accordingly, more than half of the years of record had a correct beginning of their rainy seasons. Dates of end of the rainy seasons show the same tendency as dates of the beginning. The earliest end date is September 15^{th} and the latest date of end is November 3^{rd}. The average date is October 11^{th}, with a standard deviation of twelve days. The normal range here is the period from September 30^{th} to October 23^{rd}. Thirty one years among the forty two years lay within this range.

Temperature Data

Annual monthly averages of maxima, minima, and means of temperature of the eleven stations from 1980 to 2010 (Appendix A) reveal homogeneity through the time period. The curves are nearly uniform; however, they sometimes show large deviations between averages of maxima and minima. The station of Dakar that is almost surrounded by the sea has recorded the lowest gaps between maxima and minima. Day and night temperatures during the dry season were weak. During the wet season, temperatures were high during the day and night. Almost all stations had the same profiles with large deviations between minima and maxima during the dry season and slight deviations during the wet season. The station of Nioro (Figure 3.6), which I used to analyze climate characteristics of the study area displayed an identical tendency. Annual averages of temperature of this station from 1981 to 2010 indicate a trend of increasing (Figure 3.7). During the dry season the gaps between maxima and minima were very important, during the wet season these deviations have decreased.

Humidity

To see the link between rainfall and humidity clearly, these two parameters were represented in one figure for all stations (Appendix B and Figure 3.7). Curves of monthly averages of humidity indicated the same tendency as the curves of monthly averages rainfall for the time period 1980 to 2010. A marked increase in humidity's values during the rainy seasons was seen. Trend of maxima and minima of humidity was represented in Appendix C. Deviation of humidity's values during the dry and the rainy season is more accentuated with the values of minima. Stations that show the more accentuated deviations between maxima and minima and between dry season and rainy season were those located far from the ocean and northbound such as the station of Nioro (Figure 3.8).The difference that emerged with the station of Dakar was clear; here the deviations between seasons were less accented for both minima and maxima values.

3.2 Images classification

The Landsat images of 1989 and 2011 of the rural community of KSG were classified. The classified maps show the visual changes of the LULC. Areas occupied by each class and for each year are in Table 3.7. The classification image identified five LULC classes: 1) residence areas and bare soils, 2) temporary water, 3) agriculture, 4) dark green forest, and finally 5) light green forest (Figures 3.9 and 3.10). Residential areas and bare soils are combined because they are very similar in the images, and are thus difficult to be separated. The temporary water class drastically decreased from 30.17 km2 in 1989 to 0.44 km2 in 2011. The agriculture class also decreased while the forest class increased. I did a visual accuracy assessment by using the original image. The program ENVI has a tool that generates samples of points for each class that can be verified in the original image. I chose to set eight points for each class. The results of the verification process are summarized for each image in Tables 3.8 and 3.9. For the 1989 image, 81% of accuracy is derived and for the 2011 image 83% of accuracy is derived. The errors were mainly regarding agricultural land that was incorrectly classified as bare soil.

3.3 Survey Questionnaire

Demographics and economic activities

The first part of the questionnaire provided an overview of demographics and main economic activities of the village of KSG. Population data collected from the survey questionnaire reveal the composition of the population by sex and ethnic groups. The survey represented 34% of the total population, and a number of 908 inhabitants were identified. Adult female were 30.95% (281) of the population, adult males 28.2% (256), and children were 40.85%. (371).These data show a young population dominated by females. The population was also ethnically diverse representing six ethnic groups: Wolof, Sérére, Diola, Mandings, Soninkés, and Peul. Wolofs represented 60% of the total population, while Manding, Soninkés, Sérére, and Diolas each accounted for about 20%. The interviews revealed that 42% originated from the village, 25% originated from surrounding villages, and 6% came from foreign countries. Most of the heads of houses (about 72%) who were interviewed did not go to modern school, 98% of them learnt the Curran because the population is at 100% Muslim in the village of KSG. The highest level of formal education is middle school.

Agriculture remains the first economic activity of the village as shown by results of the survey questionnaires. Of the fifty heads of households interviewed, agriculture was the first economic activity for 47, and even for the three others, it still practiced as a second activity. These three heads of household explained that they use agriculture as a secondary economic activity because agriculture is no longer productive. However, all the farmers agreed that agriculture is important because of two reasons: one, it is part of their cultural and traditional heritage, and two, it is the only opportunity available for them to fend for themselves and their families. Husbandry is practiced by only a few houses; however, in each house, some animals are raised by women in case of bad yields, for family ceremonies, and for furniture. Commerce was the second most important that comes after agriculture.

The second and third parts of the survey questionnaire are about perceived negative impacts of climate change on traditional agriculture and implemented adaptation strategies by agencies and responses of farmers. I tried through this survey to gather from farmers their perceptions about the negative changes that have occurred due to climate change. The survey provided an overview about the main crops grown and the conditions of traditional agriculture in the village of KSG.

Perceived Negative Impacts of Climate Change on Agriculture

The main crops are per order of importance millet, groundnut, corn, rice, sorghum, and cowpea. Millet constitutes a primary crop for 96% of farmers; corn was the primary crop for 4% of farmers. All other crops were secondary crops. These yields were decreasing for 60% of farmers. The main reasons given are soil's poverty, the irregularity of rainfall, lack of economic means to support agriculture, and finally the rural exodus. Yields were increasing for 34% of farmers mainly due to increased acreages or efficiency. None reported climate change as a factor behind the increases. Some have increased acreages that also depend on their financial possibilities to get enough seeds and fertilizer. Some farmers were using an efficient method taught by the program Wulanafa, the conservation farming using natural fertilizer that allowed higher yields. This technique will be explained later in this study. For 32% of farmers, acreages were increasing mainly they reported, due to an increasing size of families, and thus more people to feed. And with crops being the main source of alimentation and economic sustenance, the decreasing of productivity in agriculture was a cause for concern. 56% of farmers affirmed that acreages were decreasing because of irregularity of rainfall, loss of soil's fertility, no efficient support from the government concerning seeds and fertilizer, and non-availability of efficient materials. 6% of farmers noticed a stagnant evolution of acreages.

Negative changes on agriculture related to climate change were noticed by farmers; about 76% of them have noticed changes about five to fifteen years ago mainly related to irregularity of rainfall. Farmers reported difficulty in knowing exactly when the rainy season will start. Dates of beginning and ending of rainy seasons are fluctuating; they may be very early or very late. According to farmers, soils are poor because of erosion due to lack of rainfall in some years, loss of vegetal resources, and loss of soil moisture. Soil salinization was also a problem for farmers. However, 24% of farmers did not notice any changes related to climate change.

Responses to perceived negative impacts of climate change

The main strategies employed to adapt to changing conditions were the use of natural fertilizer (about 66% of farmers), crop change was used by 24% of farmers, new planting techniques was used by 22%, crop calendar by 6%, arboriculture and culture diversification by 4%, and finally fallow culture and wind break to protect soils against erosion by 2%. Crop calendar is the duration of the rainy season needed for crops to grow. These strategies were practiced by heritage for 82% of farmers and learning for 50% of farmers. They are highly efficient for 92% of farmers, mainly the natural fertilizer. Natural fertilizer has long been used by farmers because of its availability and low cost. With the Wulanafa program the use of natural fertilizer was improved for better yields and environmental protection. It was called Conservation Farming System. Wulanafa is a program of USAID. The word comes from two local dialects Pular and Soninké. Wula means "bush" in Soninké and Naforé means "interest" in Pular. Natural fertilizer is stacked with domestic wastes during the dry season (figure 3.11). Before the beginning of rainfall, it is transported by farmers with carts to the fields (figure 3.12). The Conservation Farming System prepares lands for minimizing soil's disturbances. This system also requires a correct preparation of soils for a better integration of farming strategies such as fallow culture, pests' management, and composting. The land is drawn with precise measurements for an animal traction (figure 3.13). Conservation farming involves a number of practices that combined protect the soil moisture, allow efficient use of fertilizer, protect soils against rain splash and runoff, and allow water retention. The Conservation Farming System concerns only millet and sorghum. In KSG Conservation Farming for all farmers interviewed that practice it used the system for millet only. It requires higher labor investment that farmers often lack. To obtain good results, farmers are expected to follow five steps:

- soil adaptability must be tested to avoid sites where the soil is too sandy or has a high percentage of clay
- crop residues must be retained to protect moisture and biological properties of the soil. If necessary, farmers can add vegetal residues, but they should not contain seeds to avoid invasive plants
- fields should be plowed with furrows of 15 to 20 centimeters by farmers during the dry season right before beginning of rain and a second plowing should be conducted just after the first rain to allow the furrow to retain water. Furrows must be separated by a distance of 70 to 80 centimeters for millet and sorghum crop and 60 to 80 centimeters for corn crop
- farmers must use an efficient system of natural fertilizer to avoid development of invasive plants. The fertilizer is put where it is needed under seeds (figure 3.14)
- planting of seeds must respect proper distance between seeds for maximizing the use of lands

Farmers are responding to negative impacts of climate change, they may change to rice or arboriculture, change crop calendars, and adopt new economic activities such as commerce, employment as a driver, or they may immigrate.

Support of traditional agriculture

Farmers of KSG reported that government support was weak and diminishing. Support from government mainly included subvention of seeds and organic fertilizer, however, they were reported to be typically insufficient and usually distributed very late after the beginning of the rainy season. Some governmental agencies such as ANCAR assist farmers by learning them some planting techniques, efficient use of fertilizer, crop protection against pests, and the incentive system of modernized rice crop and corn crop. The agency also constitutes the intermediary between farmers and financial institutions to facilitate access to credit, and help them build capacities for running their farms efficiently. Others structures such as the Project of Support of Small Local Irrigation (PAPIL) and the World Food Program (WFP) are working with farmers to help them overcome problems noticed in traditional agricultural activities. The only international agency that helps farmers of KSG is the program Wulanafa. They also assist farmers in credit access to buy agricultural inputs, such as seeds and fertilizers, for supporting their activity.

Another aspect of the survey questionnaire related to the social impact on adoption of new adaptation strategies. Only 24% of respondents said that their social beliefs prevent them from leaving their traditional agricultural practices. About 76% of farmers were interested in changes of practices to allow agriculture to play the role that they expect from it. Many farmers mentioned the need for assistance to overcome the negative impacts of climate change on agriculture, such as financial support to buy seeds and fertilizer, technical assistance to adopt the best and most efficient agricultural techniques, training, and good communication between farmers and government agents to overcome some obstacles related to social beliefs.

Evolution of yields data

Crop yields of millet (from 1971 to 2010), corn (from 1971 to 2008), groundnut (from 1971 to 2010), and cowpea (from 1998 to 2010) of the rural community were compared with average annual totals of rainfall of the same period (Appendix D). High yields do correlate with high annual totals of rainfall; however, for some years, rainfall and yields production do not correlate. Some years recorded a net increasing of rainfall while yields were decreasing. In 1973 millet yields (Appendix E) have highly decreased from 640 tons to 90 tons while rainfall has increased from 493.80 mm to 576.80 mm. The opposite was also noticed, in 1997 and 1998 annual rainfall was 630.20 mm for both years, however 1998 yields were much higher with 1,315 tons of millet, and 1997 recorded only 922 tons. Crop yields production do not depend only on quantities of rainfall but the characteristics of rain such as duration, intensity, beginning, and end of rainy seasons are important. Yields were highly irregular from one year to another.

Crop yields at the region level of millet, sorghum, and corn of farmers using Conservation Farming and yields of farmers who did not use Conservation Farming were compared. Yields concern millet, corn, and sorghum. Data from Wulanafa program confirmed (Appendix F) that the conservation farming allowed a net increasing of yields of crops for these three crops in 2010 and 2011 (Figures 3.15 and 3.16). In 2010 yields of corn of farmers who were using Conservation Farming was 2,634 tons and yields for farmers who did not use Conservation Farming were only 1,550 tons with same acreages.

Figures and tables

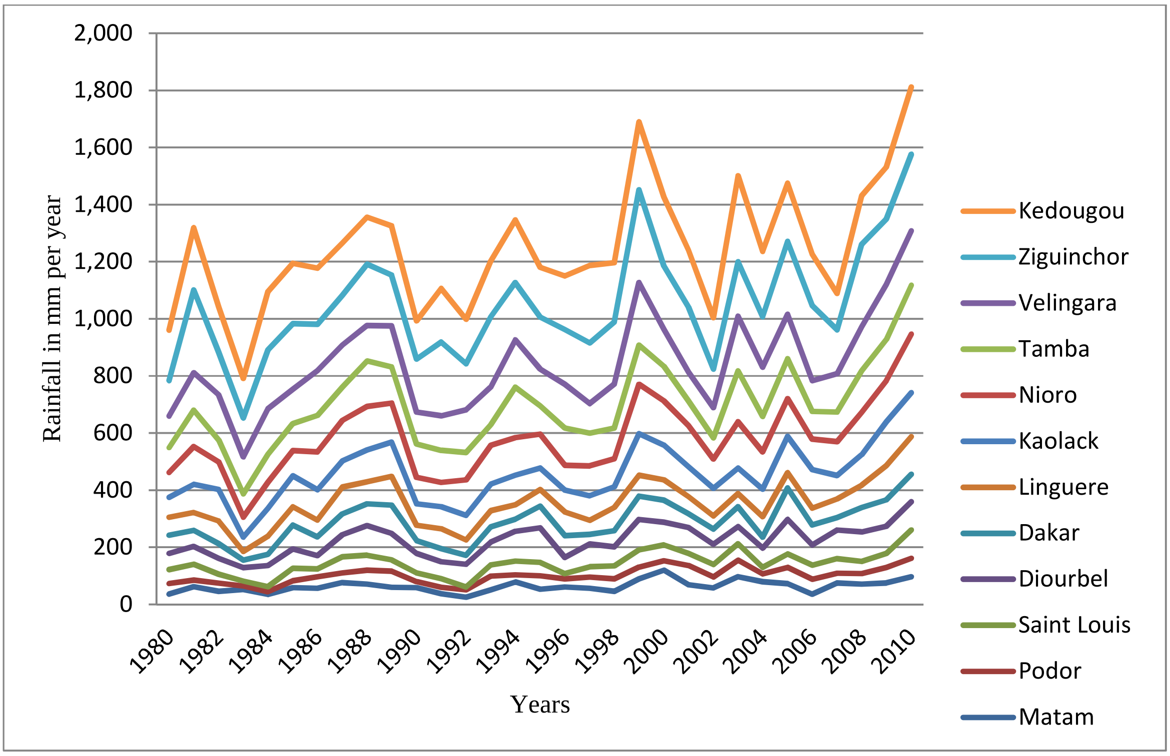

Figure 3.1: Averages of annual totals of rainfall of the twelve stations from 1980 to 2010. Source: ANACIM

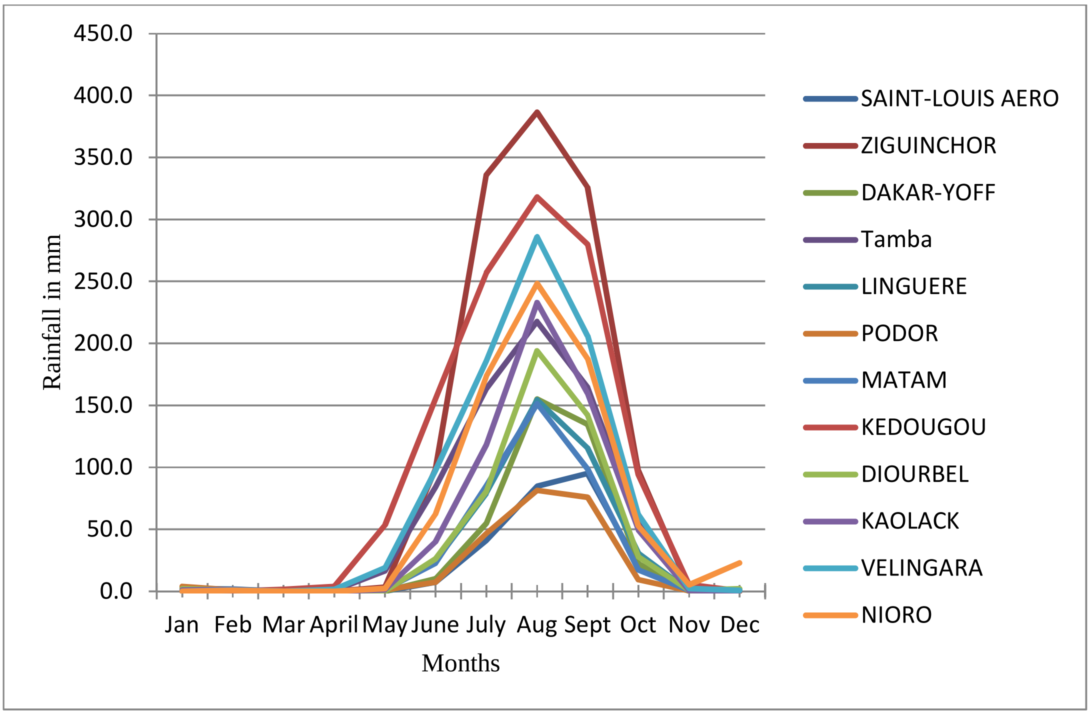

Figure 3.2: Monthly means of rainfall of the twelve stations from 1980 to 2010. Source: ANACIM

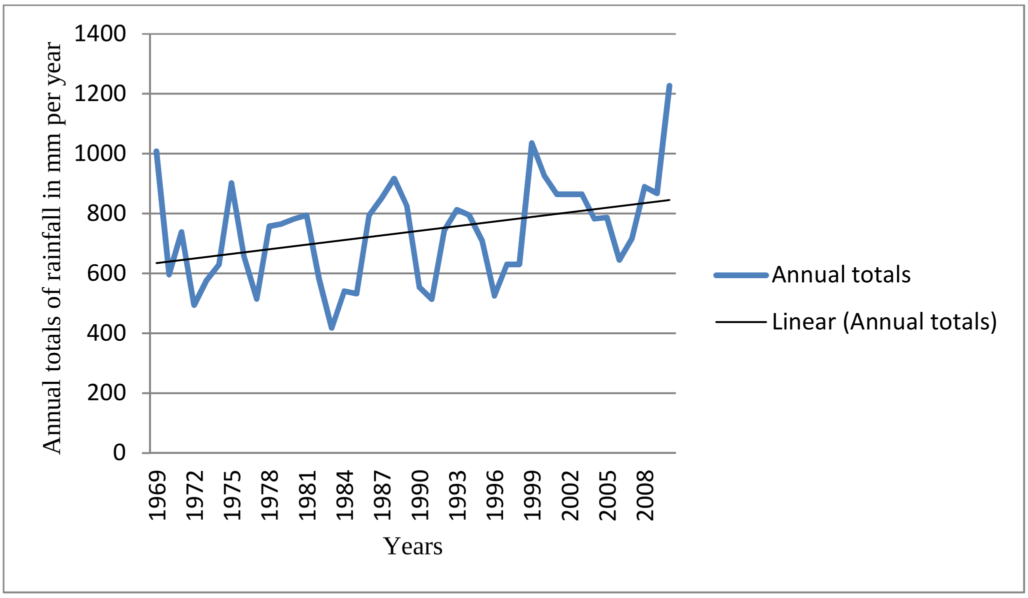

Figure 3.3: Annual totals of rainfall from 1969 to 2010 of Nioro's station. The blue line indicates the trend of rainfall and the red line indicates rainfall evolution during this time period. Source: ANACIM and CNRA

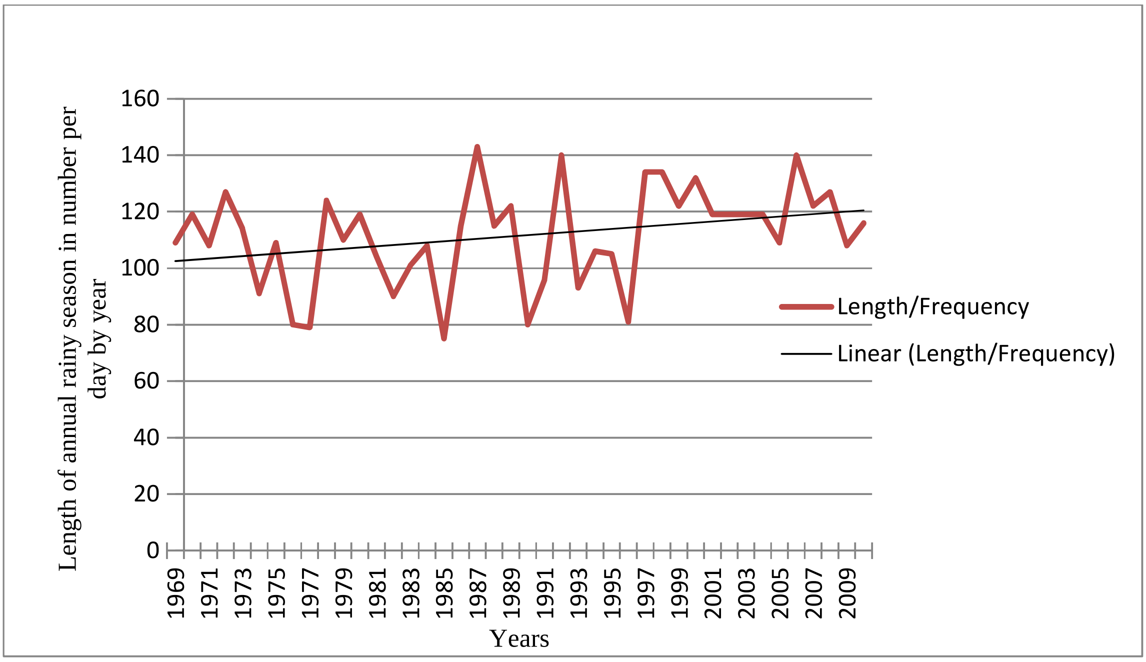

Figure 3.4: Length of rainy seasons of the station of Nioro from 1969 to 2010 indicated by the red line. The black line indicates the trend line of the frequency of rainfall. Source: ANACIM and CNRA

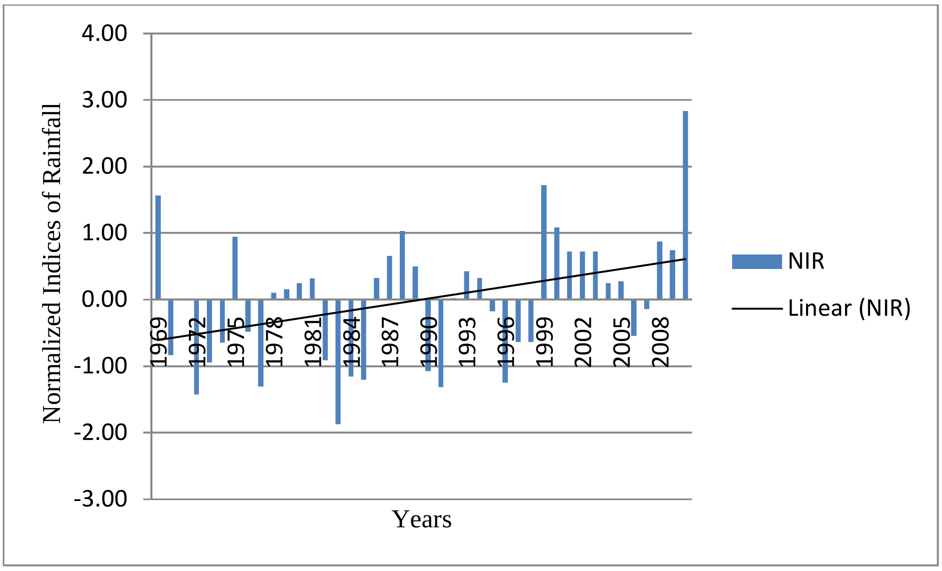

Figure: 3.5: Normalized Indices of rainfall of Nioro's station from 1969 to 2010 indicated by blue lines. Positive values indicate years of normal to very wet rainy seasons. Negative values indicate dry rainy seasons. The black line indicates the trend of the time period. Source: ANACIM and CNRA

Table 3.1: Length of annual rainfall of the station of Nioro from 1969 to 2010 in number of days of rain per year. Source: ANACIM and CNRA

Years	Length	Years	Length	Years	Length
1969	109	1983	101	1997	134
1970	119	1984	108	1998	134
1971	108	1985	75	1999	122
1972	127	1986	115	2000	132
1973	114	1987	143	2001	119
1974	91	1988	115	2002	119
1975	109	1989	122	2003	119
1976	80	1990	80	2004	119
1977	79	1991	96	2005	109
1978	124	1992	140	2006	140
1979	110	1993	93	2007	122
1980	119	1994	106	2008	127
1981	104	1995	105	2009	108
1982	90	1996	81	2010	116

Table 3.2: Descriptive statistics of the length of rainy seasons of the station of Nioro from 1969 to 2010. Source: ANACIM and CNRA

Statistics length rainy seasons

Minimum	75
Maximum	143
Range	68
Mean	111.5
Std. deviation	17.44
20th percentile	94.8
50th percentile	114.5
80th percentile	125.2

Table 3.3: Normalized indices of rainfall of the station of Nioro for the time period from 1969 to 2010. Source: ANACIM and CNRA

Years	Indices	Years	Indices
1969	1.56	1990	-1.08
1970	-0.84	1991	-1.32
1971	0.00	1992	0.02
1972	-1.43	1993	0.43
1973	-0.95	1994	0.32
1974	-0.64	1995	-0.17
1975	0.95	1996	-1.25
1976	-0.48	1997	-0.64
1977	-1.31	1998	-0.64
1978	0.10	1999	1.72
1979	0.15	2000	1.09
1980	0.25	2001	0.73
1981	0.32	2002	0.73
1982	-0.91	2003	0.73
1983	-1.87	2004	0.25
1984	-1.16	2005	0.27
1985	-1.21	2006	-0.55
1986	0.32	2007	-0.14
1987	0.65	2008	0.87
1988	1.03	2009	0.75
1989	0.50	2010	2.84

Table 3.4: Ascending dates of beginning of the rainy seasons of the station of Nioro from 1969 to 2010. Source: ANACIM and CNRA

Years	Beginning dates	Years	Beginning dates	Years	Beginning dates
1992	30-May	1979	14-Jun	1993	27-Jun
2006	1-Jun	1980	14-Jun	1995	27-Jun
1970	4-Jun	2004	14-Jun	2009	30-Jun
1972	4-Jun	1983	16-Jun	1969	2-Jul
1997	4-Jun	2007	18-Jun	1985	2-Jul
1998	4-Jun	1981	22-Jun	2005	2-Jul
1984	7-Jun	1971	23-Jun	1994	3-Jul
1987	7-Jun	1988	24-Jun	1990	5-Jul
2001	7-Jun	2000	24-Jun	1974	6-Jul
2002	7-Jun	2010	24-Jun	1975	6-Jul
2003	7-Jun	2008	25-Jun	1996	7-Jul
1973	11-Jun	1986	26-Jun	1991	9-Jul
1989	12-Jun	1999	26-Jun	1982	12-Jul
1978	13-Jun	1976	27-Jun	1977	24-Jul

Table 3.5: Ascending dates of ending of the rainy seasons of the station of Nioro from 1969 to 2010. Source: ANACIM and CNRA

Years	Ending dates	Years	Ending date	Years	Ending dates
1976	15-Sep	1974	5-Oct	1988	17-Oct
1985	15-Sep	1971	9-Oct	1992	17-Oct
1984	23-Sep	1972	9-Oct	1994	17-Oct
1990	23-Sep	1982	10-Oct	2007	18-Oct
1983	25-Sep	1995	10-Oct	2010	18-Oct
1996	26-Sep	1977	11-Oct	1969	19-Oct
1993	28-Sep	1980	11-Oct	1986	19-Oct
1970	1-Oct	2004	11-Oct	2005	19-Oct
1979	2-Oct	1989	12-Oct	2006	19-Oct
1973	3-Oct	1991	13-Oct	1975	23-Oct
1981	4-Oct	1978	15-Oct	1999	26-Oct
2001	4-Oct	1997	16-Oct	1987	28-Oct
2002	4-Oct	1998	16-Oct	2008	30-Oct
2003	4-Oct	2009	16-Oct	2000	3-Nov

Table 3.6: Descriptive statistics of dates of beginning and ending of rainy seasons of the station of Nioro from 1969 to 2010. Source: ANACIM and CNRA

Beginning of rainy season		End of rainy season	
Minimum	May 30th	Minimum	September 15th
Maximum	July 24th	Maximum	November 3rd
Mean	June 21st	Mean	October 11th
Standard Deviation	13	Standard Deviation	12
Range	55	Range	49

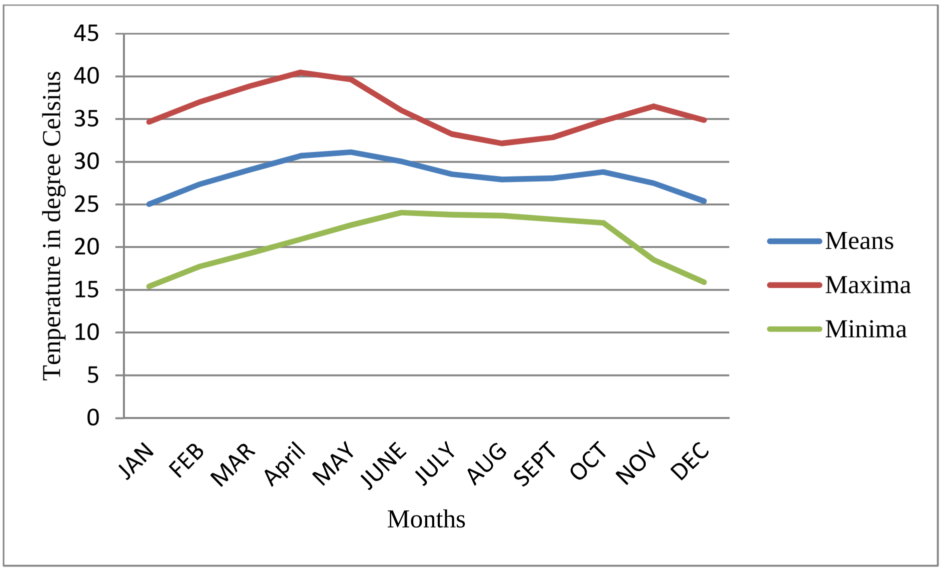

Figure 3.6: Monthly averages of temperature means, maxima, and minima of the station of Nioro from 1980 to 2010. Source: ANACIM.

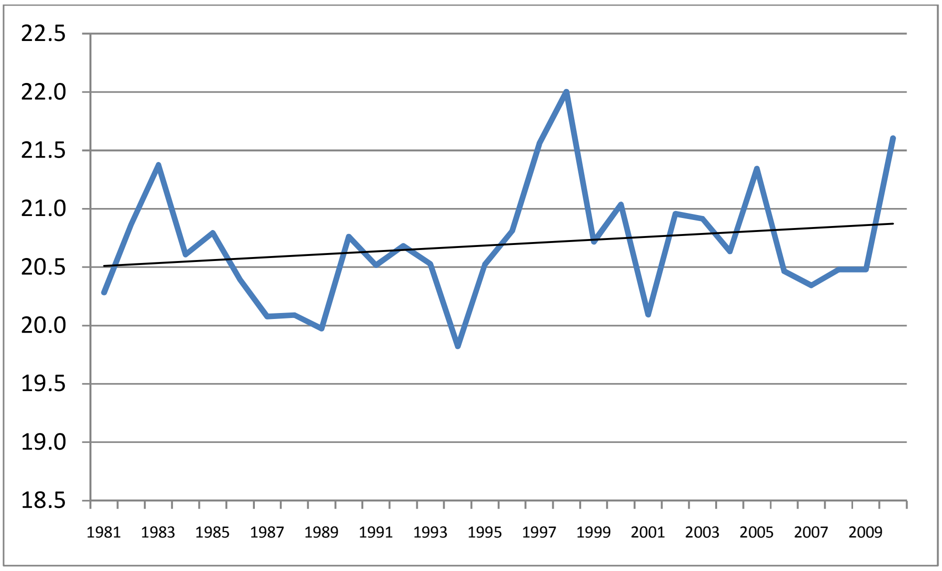

Figure 3.7: Annual averages of temperature of the station of Nioro from 1981 to 2010. Source: ANACIM.

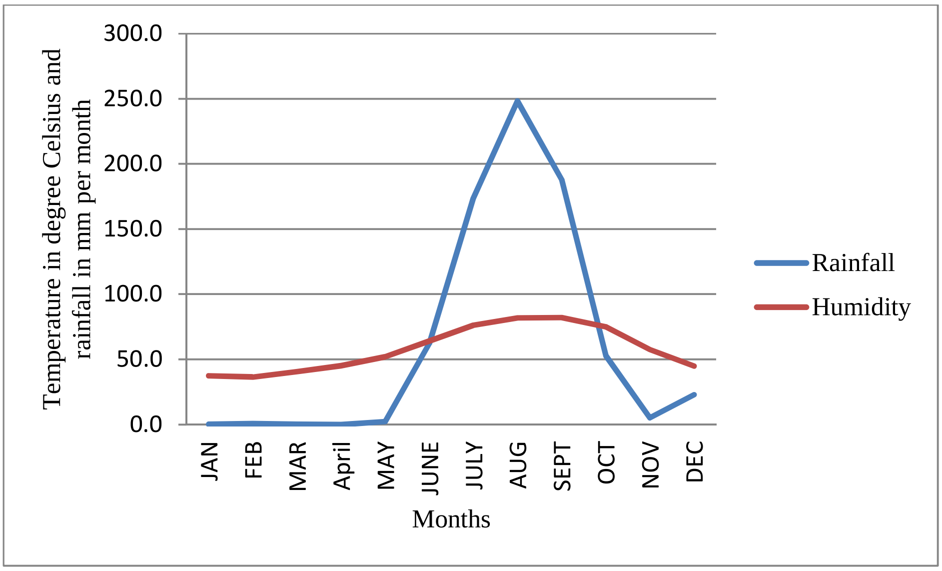

Figure 3.8: Evolution of monthly averages of rainfall and humidity from 1980 to 2010 of the station of Nioro. Source: ANACIM

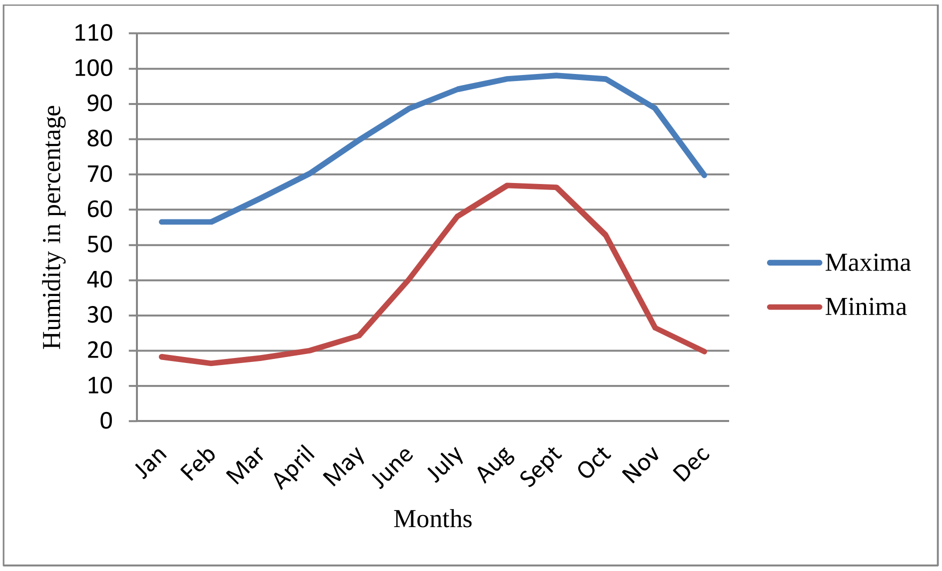

Figure 3.9: Monthly averages of humidity maxima and minima of the station of Nioro from 1980 to 2010. Source: ANACIM

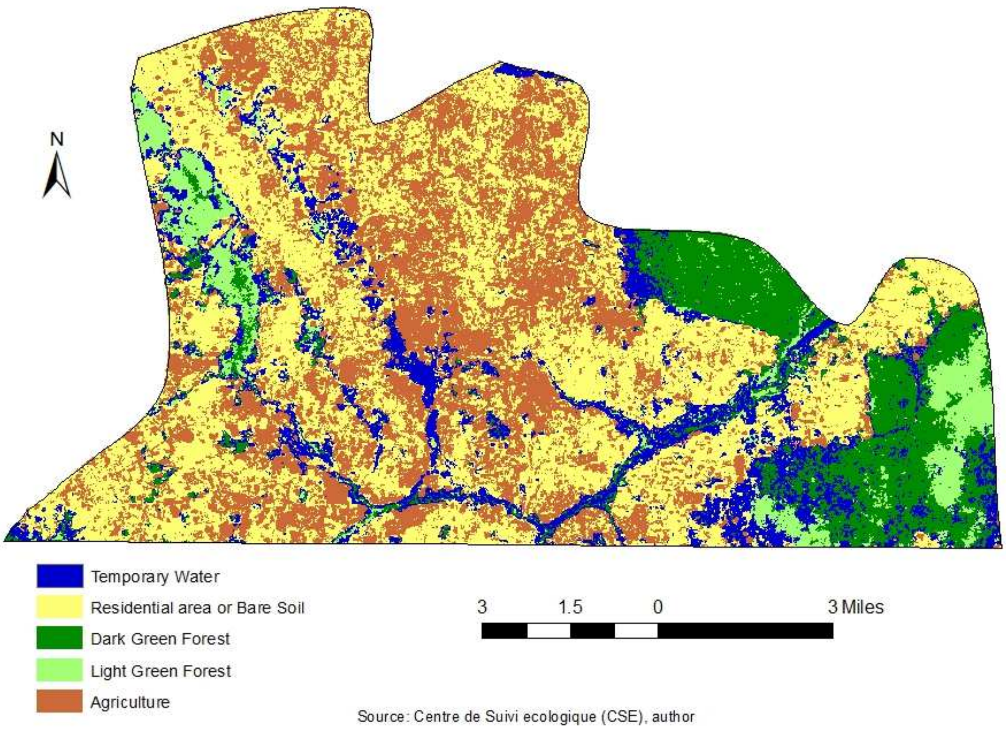

Figure 3.10: Land Use Land Cover of KSG in 1989. Map done by author.

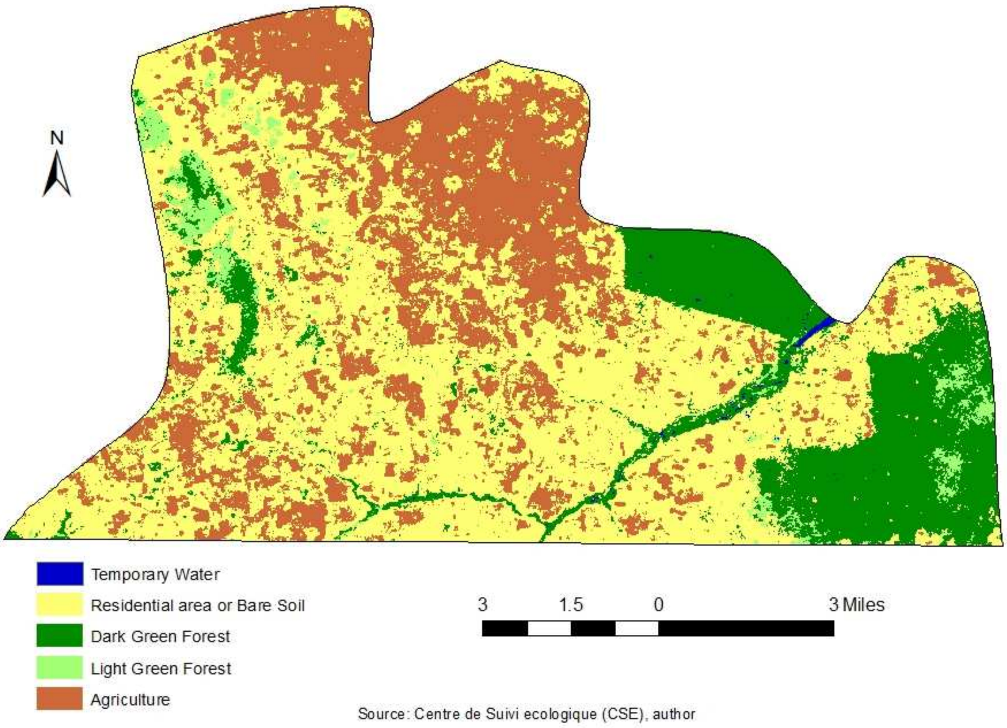

Figure 3.11: Land Use Land Cover of KSG in 2011. Map done by author.

Table 3.7: Superficies in square kilometers and percentage of change of Land Use Land Cover classes between 1989 and 2011 of the rural community of KSG.

LULC Classes	1989 (Km2)	2011(Km2)	Percentage of Change (%)
Agriculture	78.3123	72.48	-7.45
Forest	46.15	52.56	13.89
Temporary Water	30.17	0.44	-98.54
Residential Areas or Bare Soils	104.07	133.2	28

Table 3.8: Accuracy assessment of the classified image of the rural community of KSG in 1989.

1989		Reference image							
		Agriculture1	Agriculture2	Residential area/Bare Soil	Temporary Water	Light Green Forest	Dark Green Forest	Total	%Correct
Classified image	Agriculture1	4	0	2	2	0	0	8	50
	Agriculture2	0	8	0	0	0	0	8	100
	Residential areas/Bare Soil	0	0	5	0	0	3	8	50
	Temporary Water	0	0	0	7	1	0	8	100
	Light Green Forest	0	0	0	0	8	0	8	100
	Dark Green Forest	0	0	0	1	0	7	8	100
	Total	4	8	7	10	9	10	48	
	% Correct	100	100	71	70	89	70		

Table 3.9: Accuracy assessment of the classified image of the rural community of KSG in 2011.

2011		Reference image							
		Agriculture1	Agriculture2	Residential area/Bare Soil	Temporary Water	Light Green Forest	Dark Green Forest	Total	%Correct
Classified image	Agriculture1	4	0	3	0	1	0	8	50
	Agriculture2	0	8	0	0	0	0	8	100
	Residential areas/Bare Soil	0	0	4	0	0	4	8	50
	Temporary Water	0	0	0	8	0	0	8	100
	Light Green Forest	0	0	0	0	8	0	8	100
	Dark Green Forest	0	0	0	0	0	8	8	100
	Total	4	8	7	8	9	12	48	
	% Correct	100	100	78	100	89	67		

Table 3.10: Responses of farmers to perceived negative impacts of climate change

Strategies	**% of practice**
Natural fertilizer	66
Crop change (rice)	24
Crop calendar	6
Arboriculture	4
Fallow culture and wind break	2

Figure 3.12: Natural fertilizer stacked in the house mixed with domestic waste. Picture taken by author

Figure 3.13: transportation of natural fertilized mixed with domestic wastes by farmers from the village to the fields using a cart. Picture taken by author

Figure 3.14: Plotting of fields for conservation farming. Work done before beginning of rainfall. Picture taken by author

Figure 3.15: Manual application of natural fertilizer by farmers in the plotting fields before the beginning of rainfall. Picture taken by author.

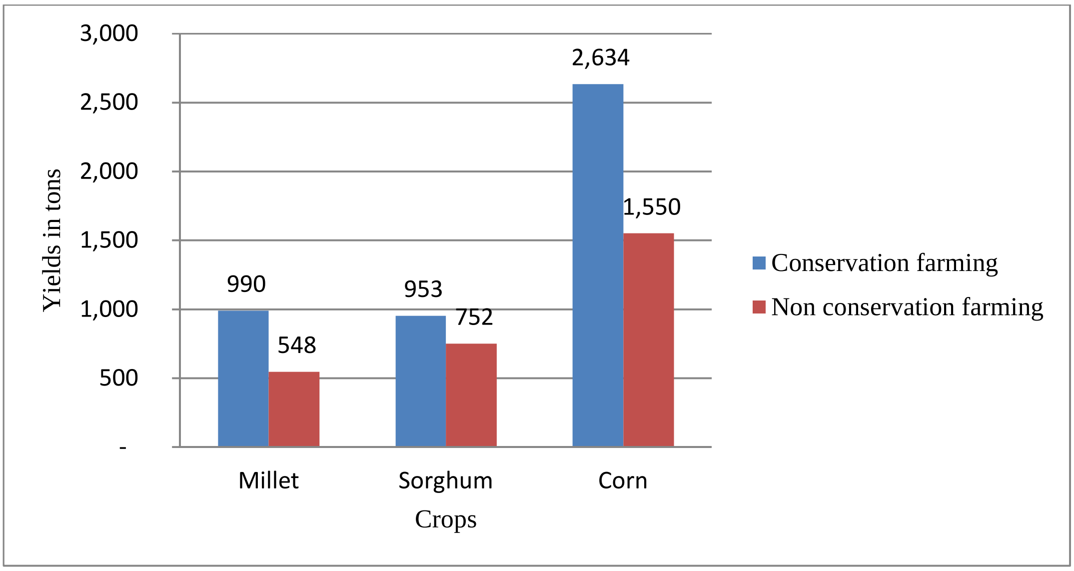

Figure 3.16: Comparison of yields in tons per year of fields using conservation farming and not conservation farming in 2010 of millet, sorghum, and corn of the region of Fatick. Source: Program Wulanafa Dakar.

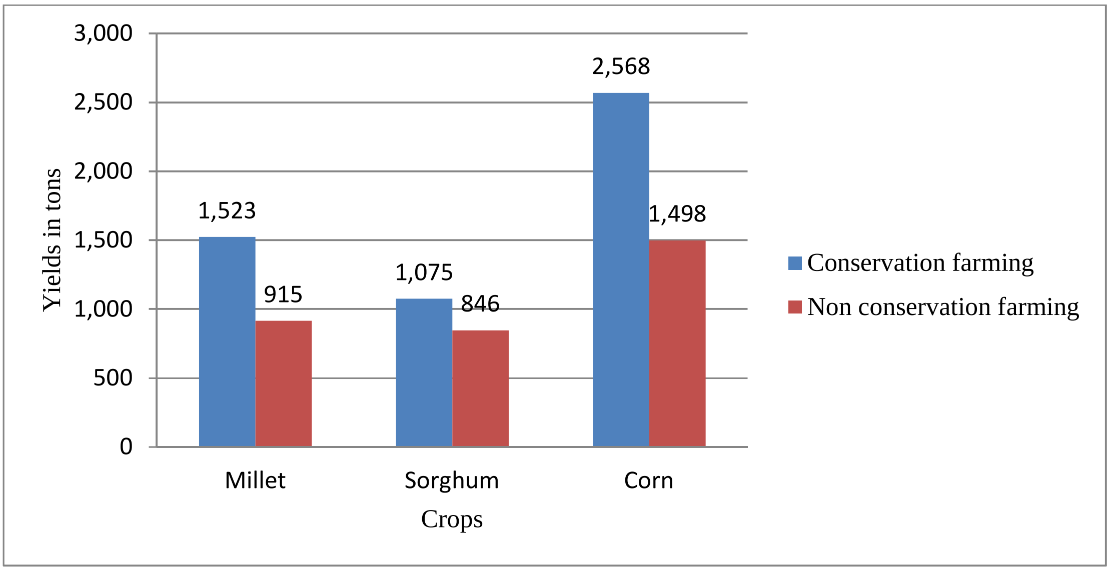

Figure 3.17: Comparison of yields in tons per year of fields using conservation farming and not conservation farming in 2011 of millet, sorghum, and corn of the region of Fatick. Source: Program Wulanafa Dakar.

CHAPTER 4: DISCUSSION AND RECOMMENDATIONS

4.1 Discussion

Climate change

The irregularity of rainfall data through time and space as shown by this research has multiple explanations. Spatial differences in annual rainfall totals and length of rainy season in Senegal are related mainly to marine influence and to proximity to the Intertropical Convergence Zone (more prominent in the south); stations located in the south receive more rainfall and have a longer rainy season than those located in the north, and coastal areas also have higher rainfall. The monsoon (seasonal shift in wind direction) has a strong influence on timing of the rainy season, which progresses from north to south in start date.

The irregularity of rainfall is the most important issue for farmers and more complex to explain. Irregularity of annual rainfall of Senegal may be related to effects of climate change; it can be related to human activities and or natural processes (IPCC, 2007). Climate change can cause a modification of rainfall cycle and extreme events such as low annual rainfall or very high annual rainfall, such as those uncovered by this analysis. The frequency and the intensity of these extreme events have increased (IPCC, 2007). The dates of beginning and end of rainfall can also vary through time and may become increasingly irregular, making it difficult for farmers to know when to plant crops. The length and character of the rainy season is also related and can present a major challenge for farmers. The pattern through time alternates years of long rainy seasons and years of very short rainy seasons. If the rainy season begins early and interrupts for a time before resuming, it can damage crops development and so decrease yields. An early beginning does not always coincide with high annual rainfall or a normal rainy season. Large quantities of rainfall can be received in a few days or small quantities in many days.

The normalized indices of rainfall of the station of Nioro (figure 4.1) revealed that the station has had a tendency of increasing rainfall over the recent 42 years. This trend does not mean good rainfall conditions for agriculture. Rainfed crops need an adequate distribution of rainfall through time according to the plants water needs. Farmers cultivate plants adapted to the rainfall characteristics of the area, thus a substantial change in any aspect of the rainfall pattern can disturb the development of crops and provoke a decrease in yields as noticed by the respondents. The frequency of long droughts during this time period from 1969 to 2010 has led to a decline of traditional agriculture, in the village of KSG where crops are completely rainfed. Traditional agriculture in this village is highly dependent on climate conditions that are a key driver of yields production (Appendix D). Rainfall is the only source of irrigation for crops in KSG and can be greatly influenced by changing climate.

The growing season is wedged between the start and the end of the rainy season. If a dry spell (defined as 15 consecutive non-rainy days by Sambou, 2009) occurs during this period, it can reduce germination or harm seedlings such that farmers are obligated to conduct another sowing. This is a waste of labor and resources for farmers. The analysis of rainfall and crop yields (Appendix E) indicate that years of high rainfall do not always coincide with high yield production. In 2006 Séne modeled the impacts of climate change on farmers' incomes in relationship to temperature and rainfall variability. According to his study, an increase of one mm of rainfall causes an increase of about $90 in farmers' incomes, with similar income decrease caused by decreasing rainfall. A rainfall threshold exists, however, after which increasing rainfall can cause a decrease of incomes.

Like in all tropical zones, temperatures in the region of KSG are high. Human activities play a role in this evolution. The scientific consensus is that global land and sea temperatures under the influence of greenhouse gases will continue to warm regardless of human intervention for at least the next two decades (IPCC, 2007). In Senegal, temperature patterns relate strongly to the relative proximity of a location to the Atlantic Ocean, and to rainfall totals, with higher rainfall stations have lower annual ranges. Stations that recorded the largest annual range of temperature were Tamba, Matam, Linguére, Kédougou, Podor Diourbel, Kaolack, Ziguinchor and Vélingara. All are well inland from the Atlantic coast except the Ziguinchor station has also estimated the impact of the fluctuation of temperature. According to Séne (2006) an increase (or decrease) of one degree Celsius causes an increase (or decrease) of about $550 of farmers' incomes. Clearly fluctuation of rainfall and temperature can negatively impact traditional agriculture.

The humidity is an important element to understand the quantity of rainfall. Data are represented with rainfall data in order to understand its impacts on rainfall evolution. The relationship between humidity and rainfall is due to the fact that humidity can considerably increase the water content of the rising air and therefore increase the amount of precipitation. That is why evolutions of rainfall and humidity are homogeneous. Humidity varies depending on the temperature of the air. It reduces temperature values and the difference between maxima and minima. This situation explains the low temperature for stations located along the Atlantic coast where humidity is high.

The probability of increasing variation in rainfall and temperature patterns is high and will promote even greater challenges for farmers. According to IPCC (2002) climate change scenarios predict further increases in temperature and simultaneous decreases in rainfall for tropical zones. Loss of soil fertility noticed since about two decades ago is a major problem related to climate change in this area. Soil poverty provokes a net decreasing of agriculture productivity. Due to a lack of economy and support, farmers in KSG use rudimentary and inefficient tools that destroy soil structure and facilitate erosion, thus they cannot maximize agriculture productivity. After a long history of cultivation of the same land, the soil is no longer productive and farmers are obligated to deforest new lands for agriculture, leaving the former land impoverished.

Crop yield

The strong relationship between rainfall and crop yields (Appendix D) indicates that rainfall can be strongly related to crop production. The comparison of rainfall and yields per hectares would provide more relevant insights about the impact of rainfall in yields production. The possible relationship can be sometimes interrupted by marginal factors, such as rainfall that is high but not well distributed through the time of agriculture, an early or late rainy season, locust peril, insufficient seeds, or insufficient fertilizer. The economic state of Senegal also has a role in crop yields. The farmer interviews for this research indicated that the government does not offer sufficient support in fertilizer and quality seeds to farmers. Farmers find it difficult to keep seeds for the next growing season, but government-provided seeds are sometimes of low quality. Combined with deteriorating climatic conditions and loss of soil, farmers face major obstacles in terms of yield consistency.

Land Use/Land Cover Change

The analysis of LULC showed many changes from 1989 to 2011 related to climate change and human activities. Agricultural land has decreased mainly because of the decreasing size of cultivated land for many farmers. Because of climate change, farmers now prefer to cultivate smaller areas in order to reduce risks and maximize yield per hectare. It is useless for farmers to cultivate a large area without enough seeds or fertilizer that can minimize the effects of climate change. Forested land has increased because most of the forested area in KSG is in government-protected areas and benefit from a plan of sustainable management to minimize human pressure. Residential areas have also increased reflecting population expansion and emphasizing the importance of sustainable farming practices that can feed a greater population. The increase in bare soil relates to agricultural abandonment due to loss of soil fertility, lack of labor force, and uncertainty of agriculture according to farmers in part due to increasing climate variability. Thus, climate change can be reflected in LULC change, which is in turn exacerbated by human pressure.

Challenges and Responses to Negative Impacts of Climate Change

The most important concern for the traditional farmers of KSG is to have the highest yield production after the growing season; however that goal is threatened by changes farmers noticed in climate conditions. A high percentage of farmers that participated in our survey mentioned negative impacts of climate change on agriculture. Perception about climate change can be different from one farmer to another because of their specific situations. Irregular rainfall, loss of soil fertility, and decreasing of yields production are shown by many studies as climate change impacts on agriculture in tropical zone. Climate variability has negative consequences on soils fertility, yield decreasing, and decreasing of farmers' incomes (Vyve, 2006). The general poverty of KSG exacerbates the perceived impacts of climate change on agriculture in this area. Farmers do not have the economic means to adopt the best practices that preserve soils and help mitigate climatic variability. Their tools degrade soil structure and human pressure on natural resources accelerate deforestation and destruction of the vegetal cover. The lack an appropriate response from the government to help farmers in adopting the best techniques of sustainable agriculture exacerbates the situation.

To meet these challenges to agricultural productivity in the face of climate change, international organizations, the government, and the farmers themselves have developed many adaptation strategies and responses. Responses of farmers are simple and require little means to accomplish. The most popular is the use of natural fertilizer because of its availability and efficiency. This technique is inexpensive and efficient in increasing soil fertility and yields. One limitation of using natural fertilizer for crops is that animal husbandry is not well developed in this area; however in traditional villages like KSG, each house has at least some livestock. The availability of natural fertilizer is controlled by the number of animals owned and farmers who have few or no livestock are limited in practicing this technique.

The natural fertilizer technique taught by the program Wulanafa of the USAID can be highly beneficial because of its high efficiency. A small quantity can be used for a large field because the fertilizer is applied only to the seed beds. This technique can also help to solve the problems of land pressure and deforestation because cultivated acreages are decreased while yields are increased. Farmers do not need to cultivate more extensive lands because productivity is higher.

Farmers are limited in practicing crop change, another response, because of the role that traditional crops (millet and corn) play in food needs of the population. Tradition makes it difficult for them to adopt new crops. Millet and corn constitute the primary sources of diet and groundnut is cultivated to have incomes for other needs of the family such as health care and familial ceremonies. The only change crop that is also part of the main diet is rice. Even farmers who change to rice continue cultivating millet and/or groundnut. Rice is limited by rainfall quantity because it is practiced on flooded lands during the rainy season. Rice cultivation can help to solve the basic food needs deficit.

Arboriculture has many economic and ecological benefits. It can be an efficient method to increase farmers' incomes. Fruit trees planted with crops in fields can increase soil fertility and be an efficient method to stop soils' nutrients erosion during the dry season as fruit trees planted along fields margins.

Some farmers chose to adopt new activities or to seasonally migrate in order to continue to practice agriculture. Farmers can change the crop calendar, for example moving up or back the date for planting. It is complicated for farmers to change the crop calendar according to meteorological conditions. Farmers are not used to considering forecasts before sowing and the government does not have a system to transmit a reliable forecast to farmers. Instead, farmers change their crop calendar based only on the feeling they have about humidity of air. This technique can be accurate or wrong. Social beliefs do not appear to have a large impact on adoption of new strategies. Most farmers are now open to adoption of modern strategies despite the importance of tradition. Farmers are very attached to tradition, but the gravity of the perception they have about impacts of climate change obligates them to try new strategies to maintain agricultural activities.

The economic context of the country of Senegal accounts for the weakness of support of agriculture from government. This situation does not help farmers to overcome problems related to negative impacts of climate change on agriculture. The support is declining even more because of the worldwide economic crisis. International cooperation has also decreased assistance to developing countries.

4.2 Recommendations

New research confirms that Africa is one of the most vulnerable to climate change because of its weak capacity to adapt (Séne et al., 2006). The importance of agriculture in farmers' lives explains the necessity for government to implement an efficient agriculture policy well-structured to support this activity. A program of intensification of agriculture may reduce problems related to climate change. Deforestation, pressure on lands, loss of soil fertility, and erosion can be halted or reduced considerably. The program of protected forest should be maintained and expanded. Bare soils should be revegetated to stop soil erosion and increase soil organic matter. Government should put an emphasis on a policy of soil management because of its importance on agriculture. All practices that result to soil degradation such as over use of mineral fertilizer, prolonged cultivation of lands, and use of non-adapted material that destroy soil structure should be banned.

The government of Senegal should support its farmers. The current system of distribution of seeds and fertilizer should be improved to allow farmers to get them on time. Promotion of a combination of crop cultivation and animal husbandry can be efficient to restore soil fertility and a sustainable method of fertilization. The combination of crop cultivation and arboriculture allows a diversification of sources of incomes, increases soil resistance from erosion, and can diversify farmers' food. The KSG area is surrounded by intermittent stream valleys that are flooded during every rainy season. Rice cultivation can be reinforced by a system that retains water for a longer period. Implementing basin retention to retain water runoff for dry season crops can help reduce the yield deficit and poverty.

An efficient agriculture able to adapt to the new context of climate change should insist on research in order to find short cycle species more adapted to lower rainfall. The Senegalese

Institute of Agriculture Research (ISRA) has undertaken work on this issue and has developed new varieties adapted to drought and a shorter rainy season. An efficient system like a radio forecast to alert farmers to unexpected climate events should be implemented by the national service of meteorology. Then farmers would be able to set the crop calendar according to the weather characteristics.

The low education level of farmers explains sometimes their misunderstanding of the causes and implications of climate change and practices that can aggravate it. The government should combat illiteracy as better education can help farmers understand the possible effects of climate change on agriculture and open their views toward adoption of new techniques and strategies necessary for sustainable farming and environment. This study showed that farmers with higher education were better prepared to adopt new strategies for adaptation.

The government should support farmers by implementing adaptation projects able to mitigate climate change. Farmers should be involved from beginning to end of such projects. Communication between farmers and government should be established to alert farmers to the project's activities. Farmers should be informed about the objectives, the processes, and actions of the project, so that after the project farmers can continue the activities themselves. Local knowledge should also be taken into account because it can be valuable.

Using a mixed methods approach, this study has provided insights on how climate change is perceived by farmers in the village of KSG, how they are adapting, and how the government is responding. The research has provided baseline data on how climate and land use/land cover have changed in this study area. Further research using more climate data is needed to learn more about the negative impacts of climate change on traditional agriculture.

Figure

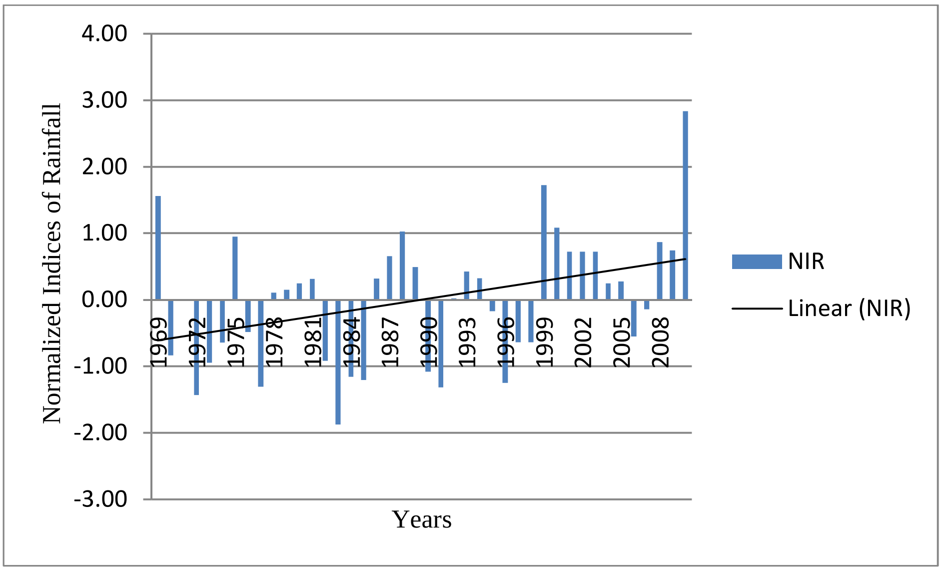

Figure 4.1: Normalized Indices of rainfall of Nioro's station from 1969 to 2010 indicated by blue lines. Positive values indicate years of normal to very wet rainy seasons. Negative values indicate dry rainy seasons. The black line indicates the trend of the time period. Source: ANACIM and CNRA.

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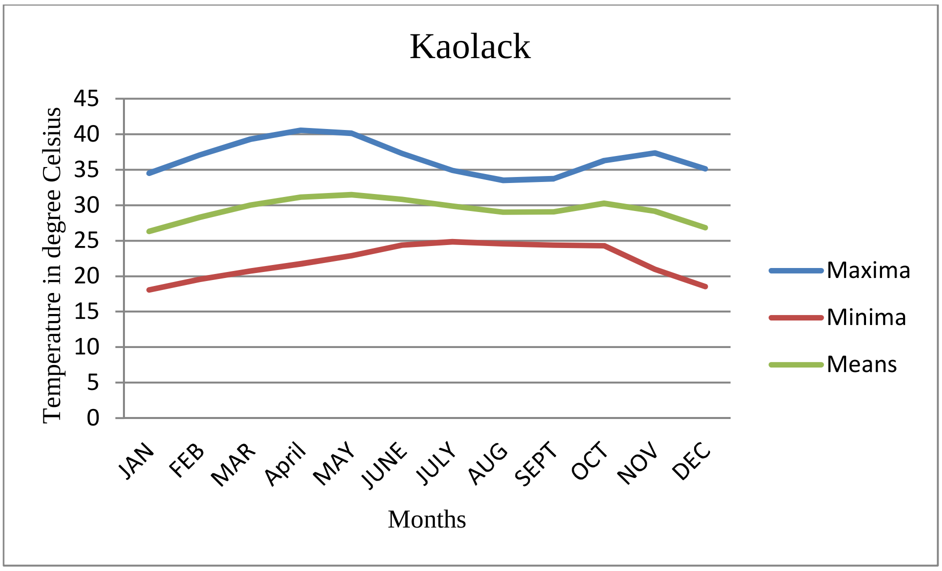
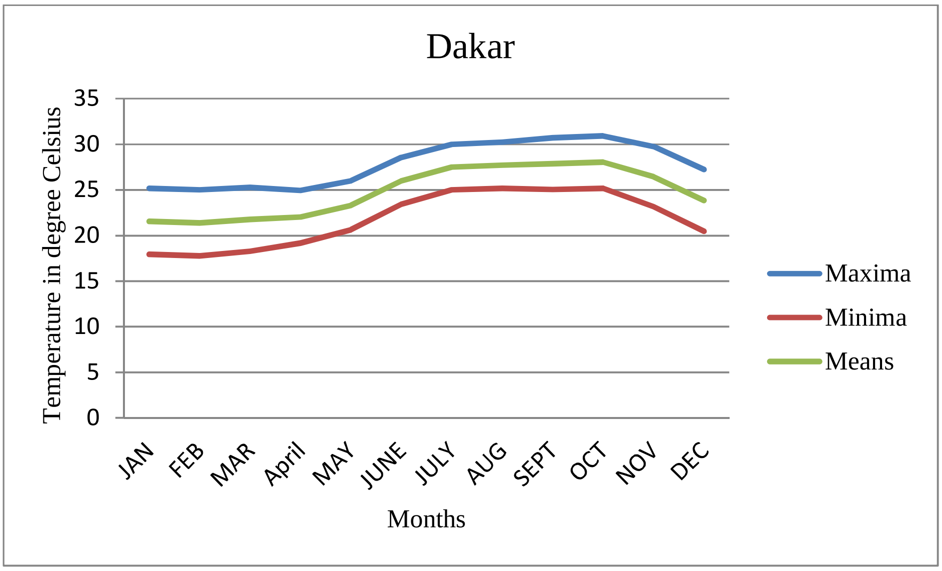
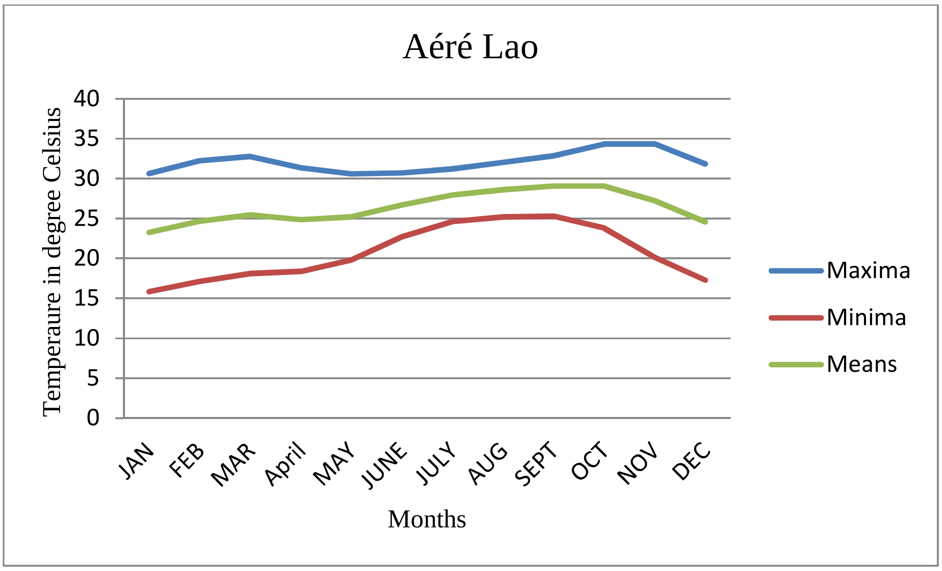
Appendices

Appendix A: Monthly averages of temperature means, maxima, and minima of 11 stations located across Senegal from 1980 to 2010. Source: ANACIM



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Temperaure in degree Celsius
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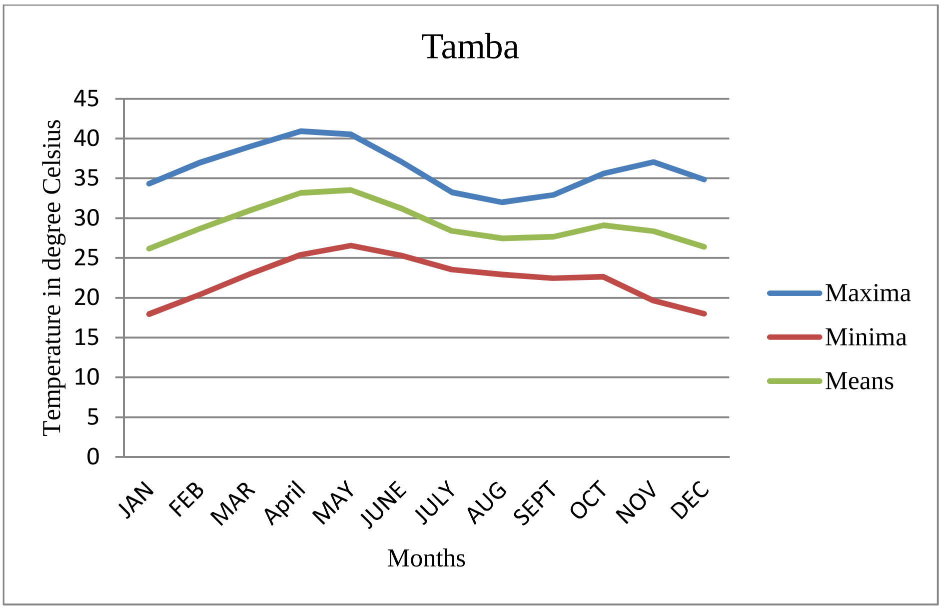
Tamba
Temperature in degree Celsius
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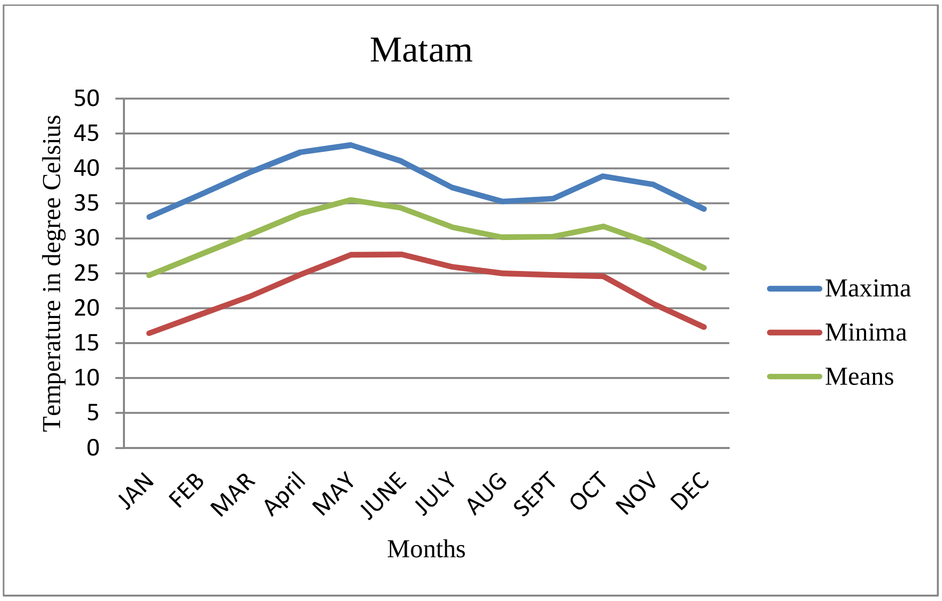
Matam
Temperature in degree Celsius
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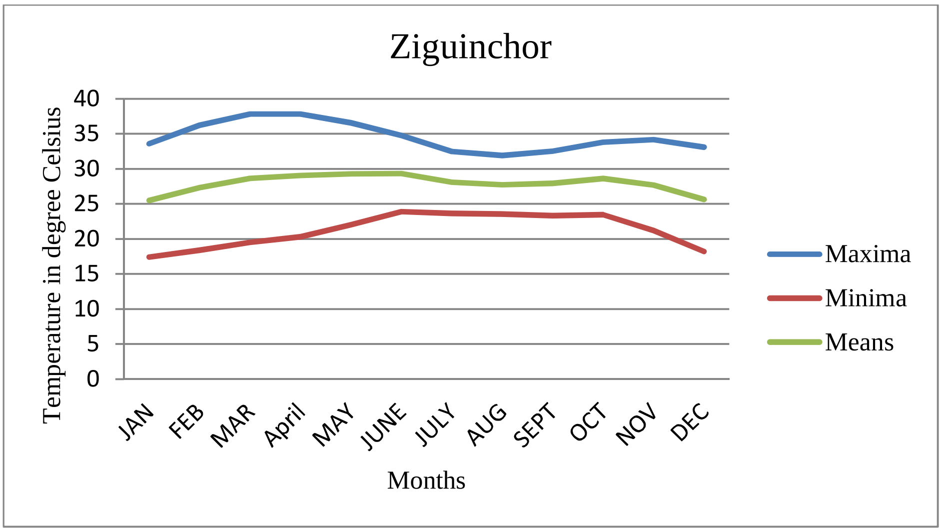
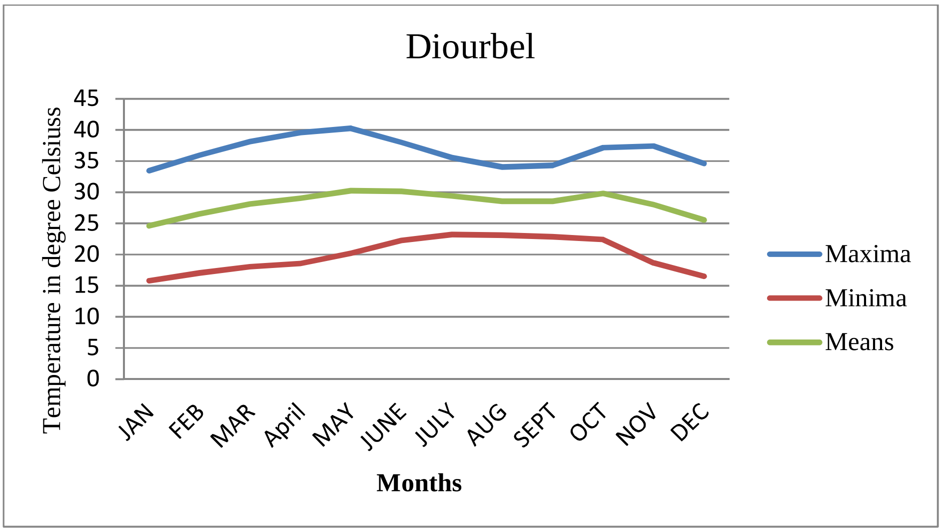
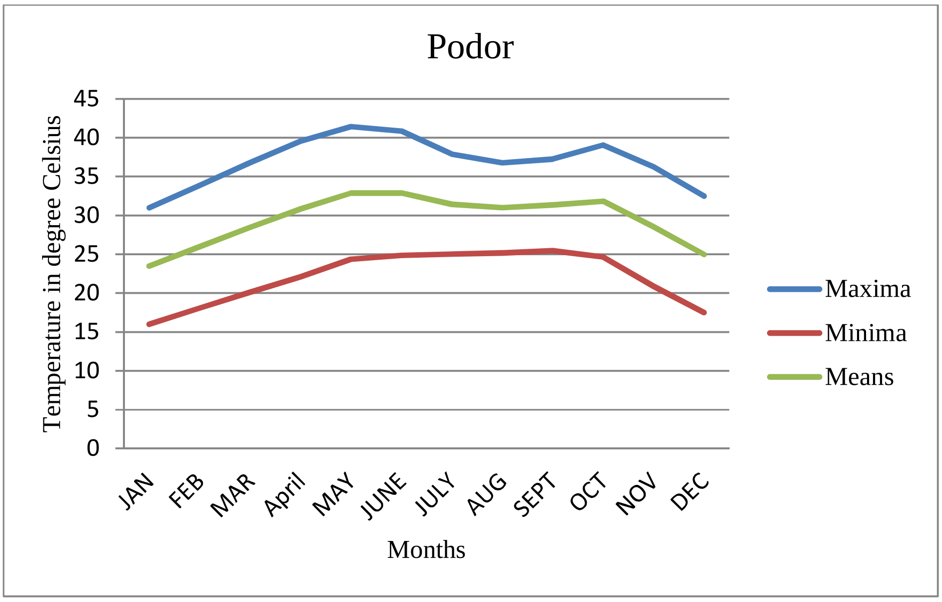
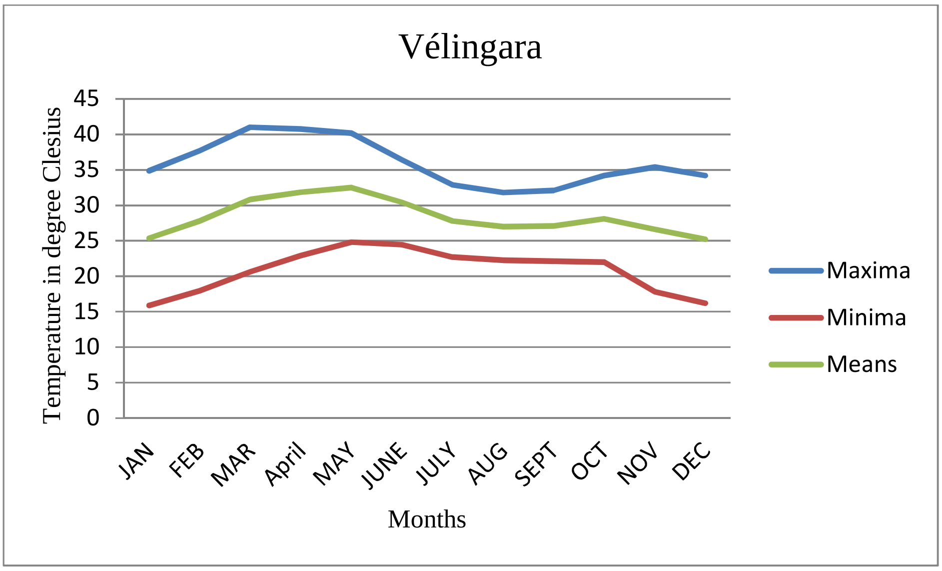
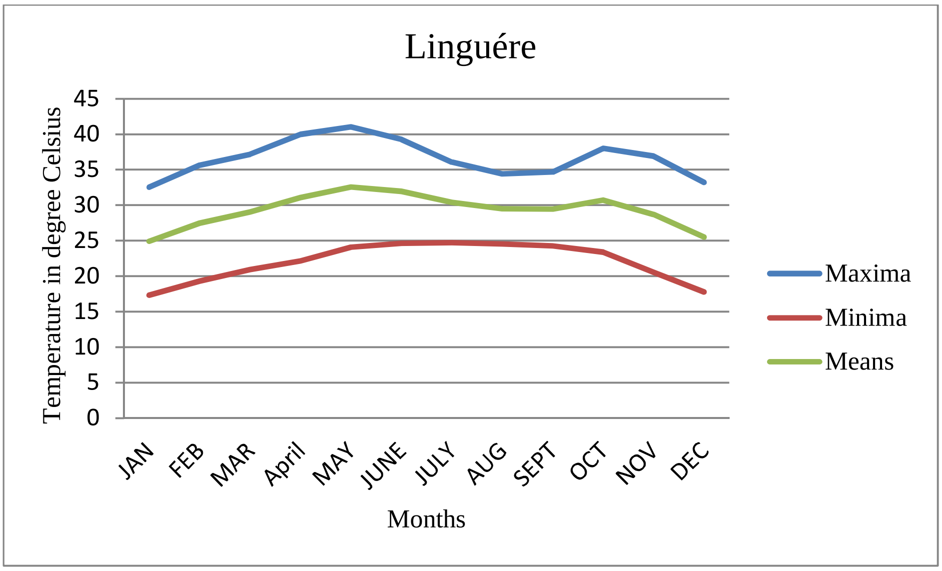
Minima
Means

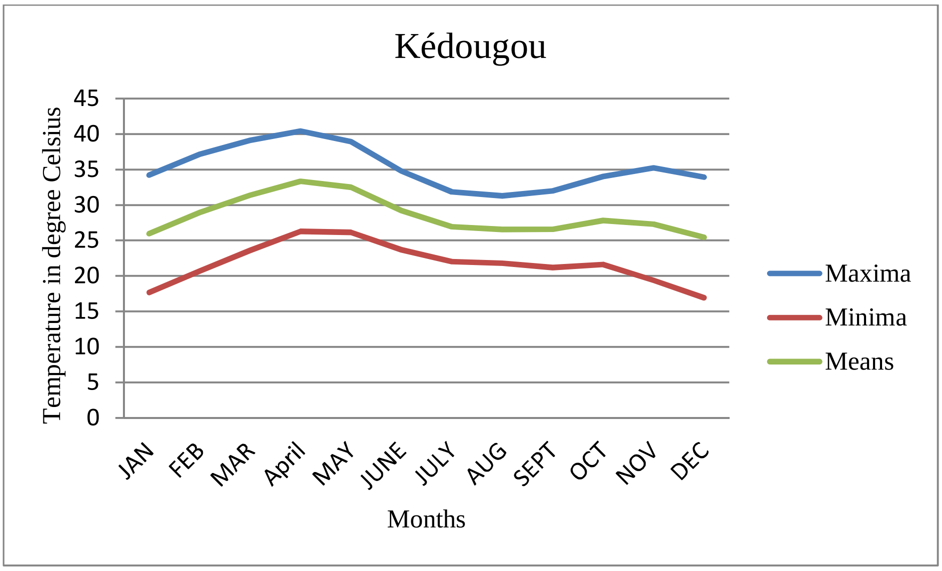

Ziguinchor
40
35
30
25
20
15
10
5
0
Temperature in degree Celsius
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Maxima
Minima
Means


Diourbel
45
40
35
30
25
20
15
10
5
0
Temperature in degree Celsiuss
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Maxima
Minima
Means

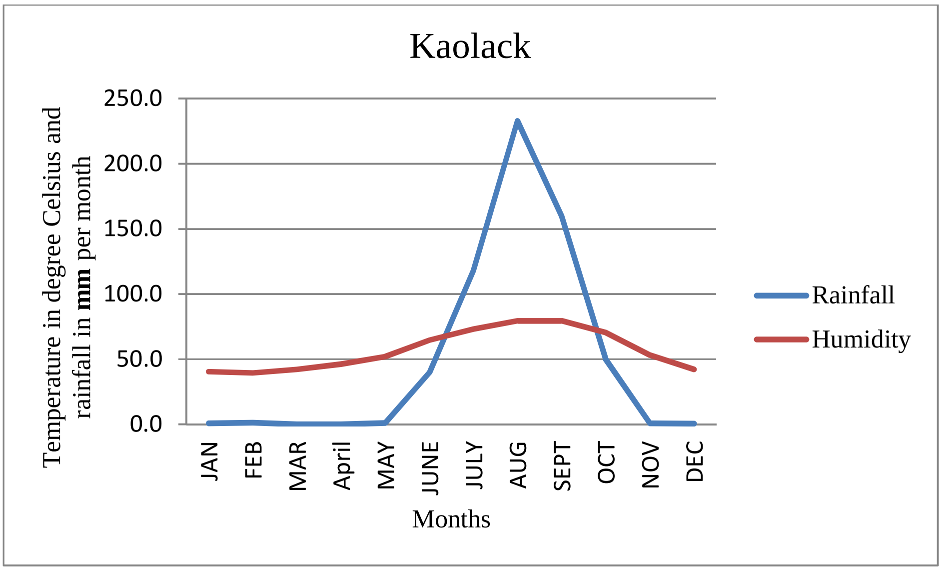

Podor
Temperature in degree Celsius
45
40
35
30
25
20
15
10
5
0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Maxima
Minima
Means

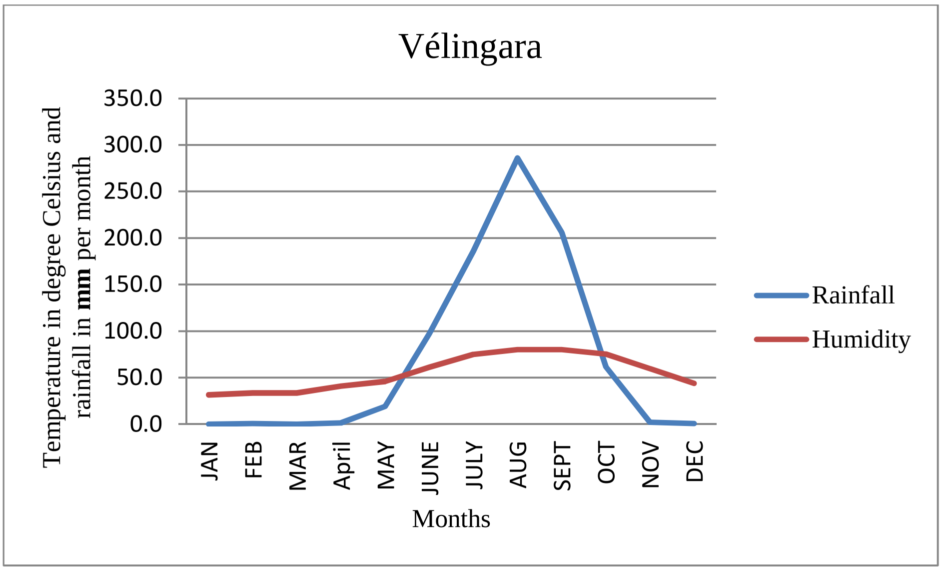

Vélingara
Temperature in degree Clesius
45
40
35
30
25
20
15
10
5
0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Maxima
Minima
Means

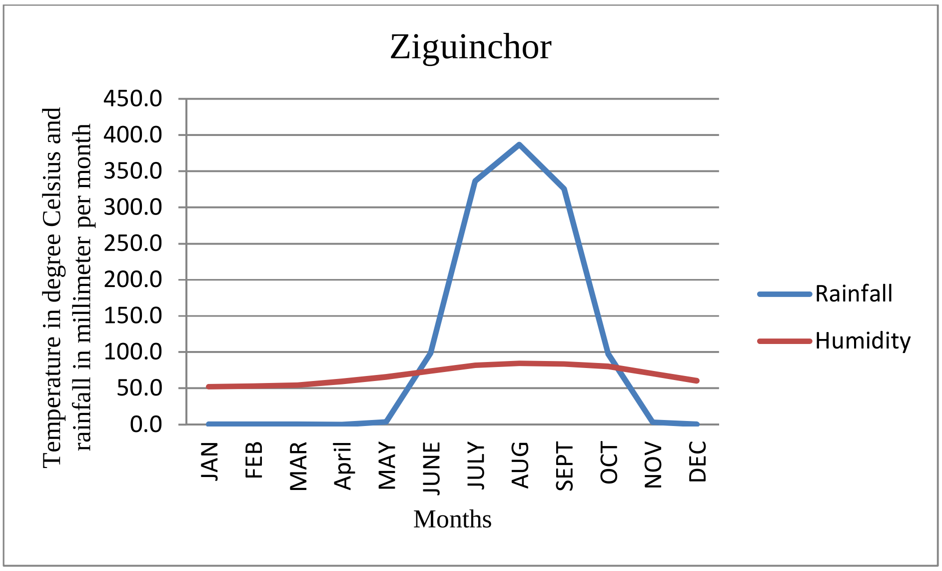

Linguére
Temperature in degree Celsius
45
40
35
30
25
20
15
10
5
0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Maxima
Minima
Means

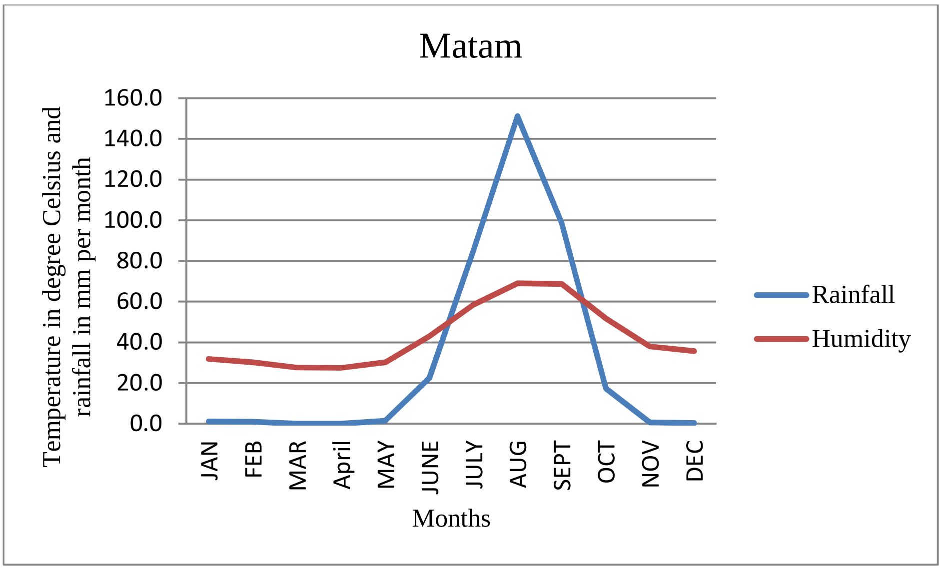

Kédougou
Temperature in degree Celsius
45
40
35
30
25
20
15
10
5
0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Maxima
Minima
Means

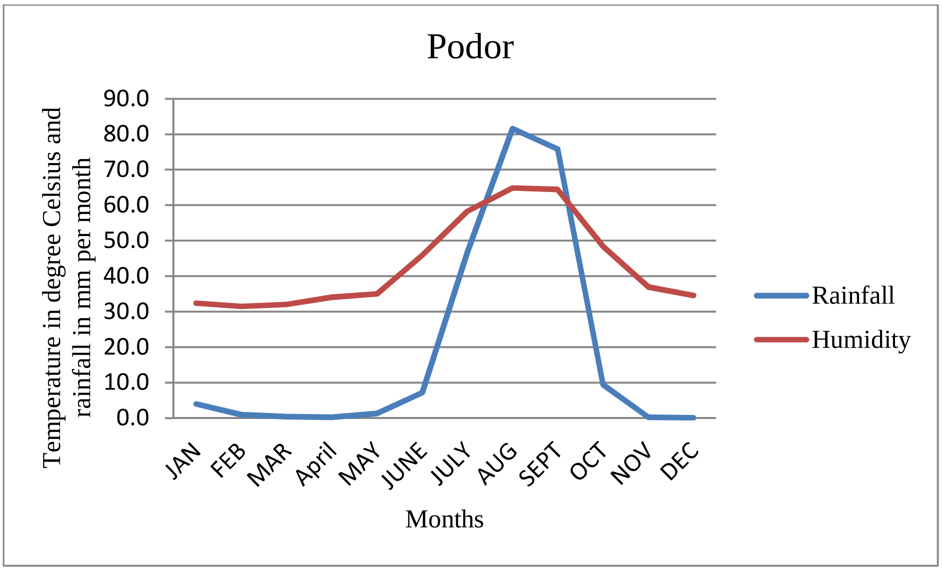
Appendix B: Monthly averages of humidity and rainfall of 11 stations located across Senegal from 1980 to 2010. Source: ANACIM



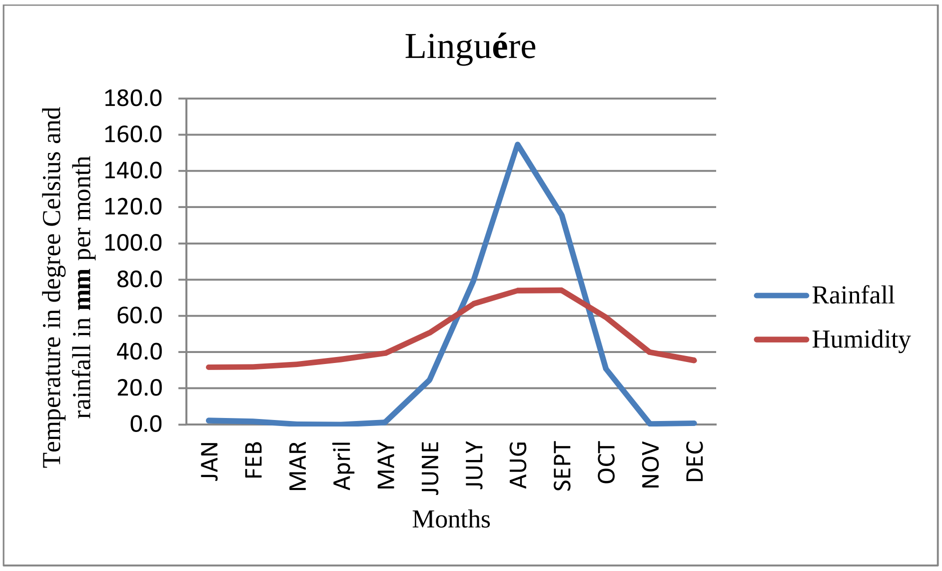



Ziguinchor
Temperature in degree Celsius and rainfall in millimeter per month
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Rainfall
Humidity

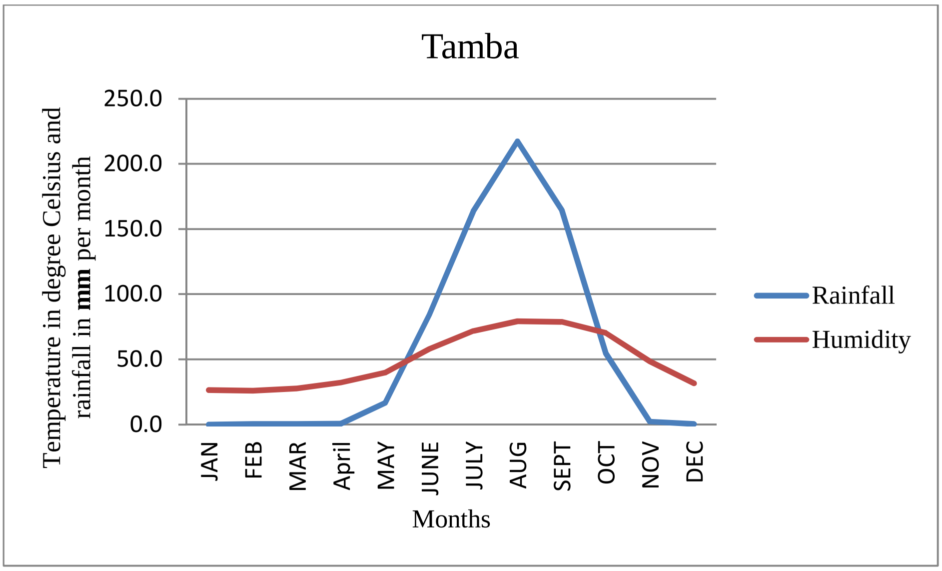

Matam
Temperature in degree Celsius and rainfall in mm per month
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Rainfall
Humidity



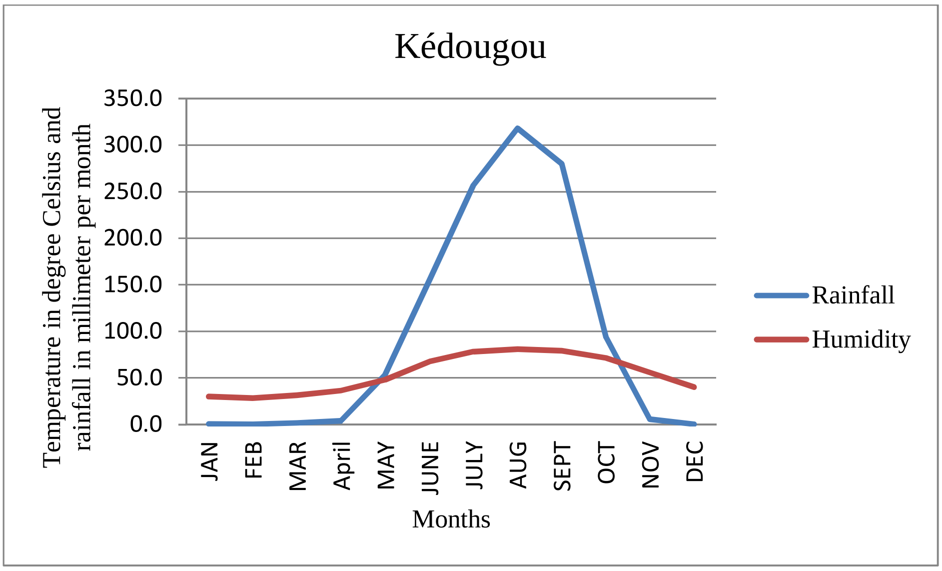
Podor
Temperature in degree Celsius and rainfall in mm per month
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Rainfall
Humidity



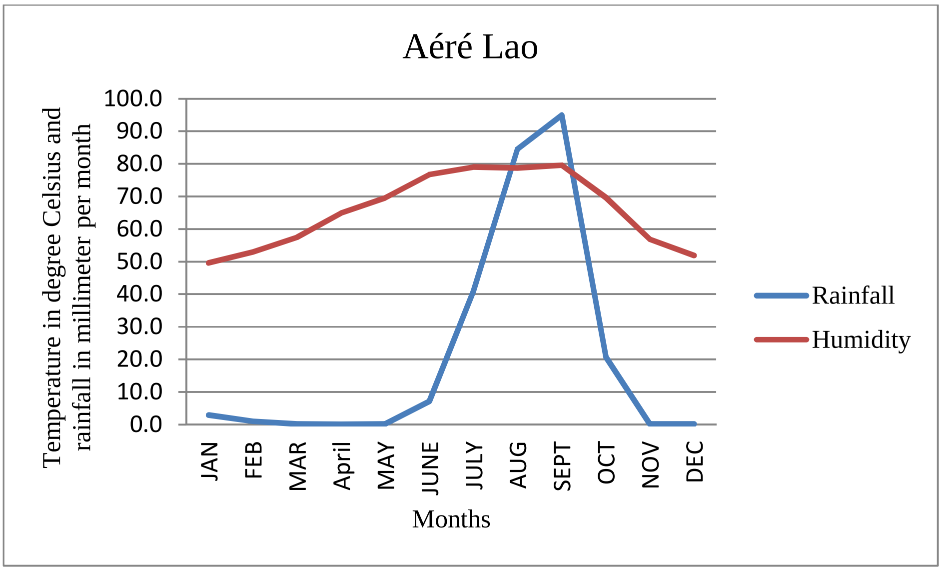
Linguére
Temperature in degree Celsius and rainfall in mm per month
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Rainfall
Humidity



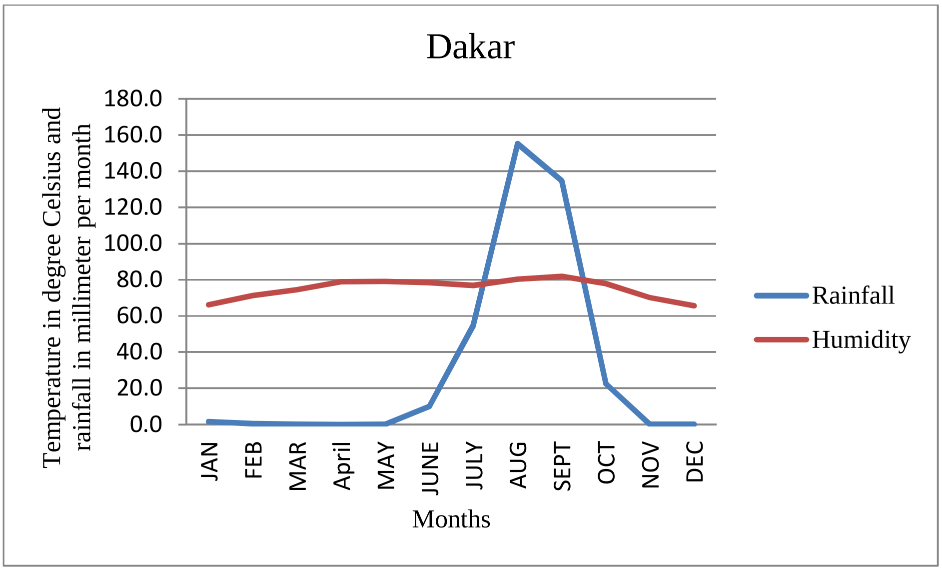
Tamba
250.0
200.0
150.0
100.0
50.0
0.0
Temperature in degree Celsius and rainfall in **mm** per month
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Rainfall
Humidity

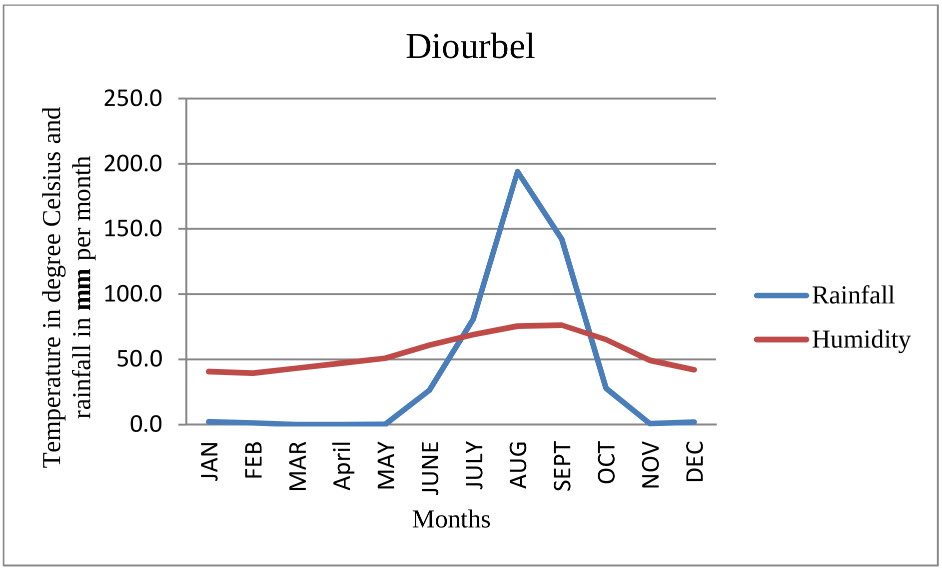


Kédougou
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Temperature in degree Celsius and rainfall in millimeter per month
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Rainfall
Humidity

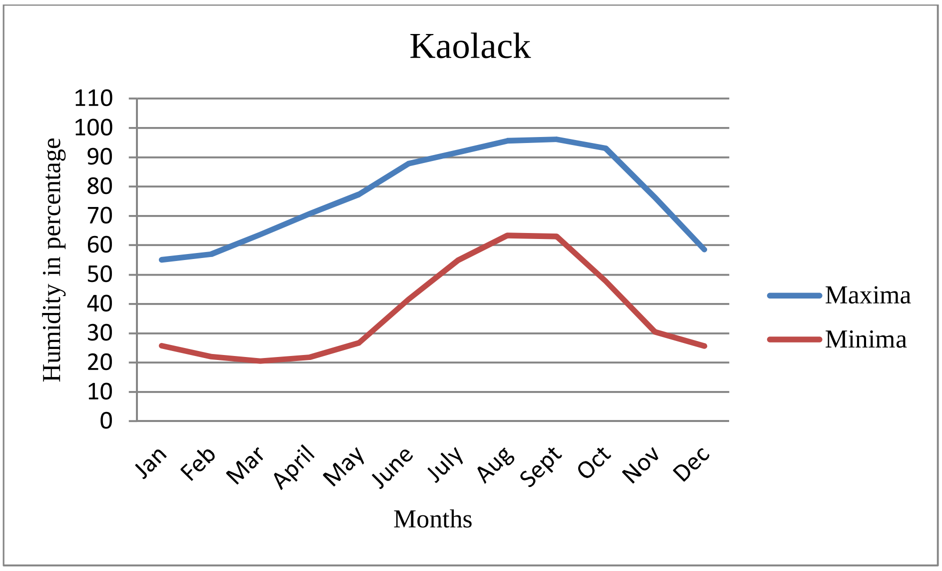


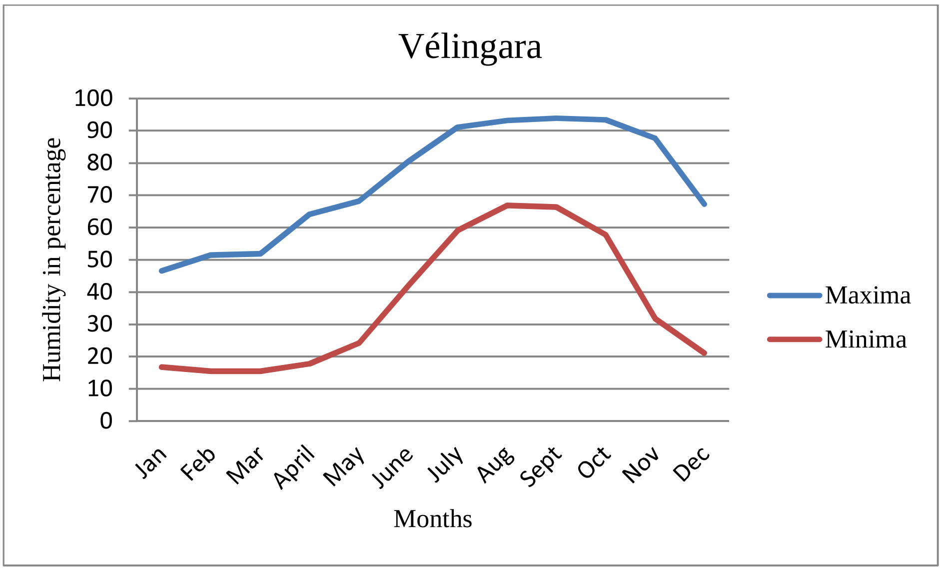
Aéré Lao
Temperature in degree Celsius and rainfall in millimeter per month
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Rainfall
Humidity

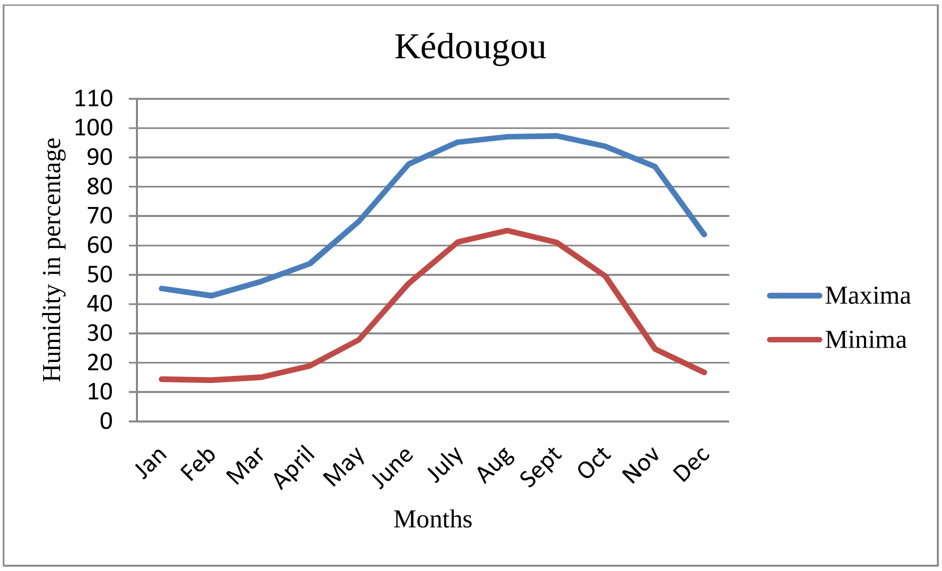

Dakar
Temperature in degree Celsius and rainfall in millimeter per month
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Rainfall
Humidity

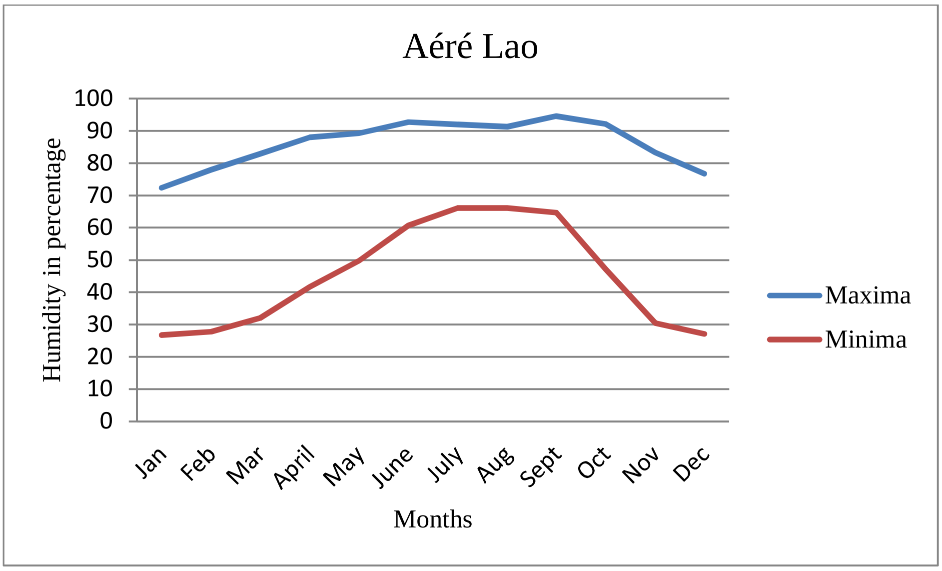

Diourbel
Temperature in degree Celsius and rainfall in **mm** per month
250.0
200.0
150.0
100.0
50.0
0.0
JAN
FEB
MAR
April
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
Months
Rainfall
Humidity

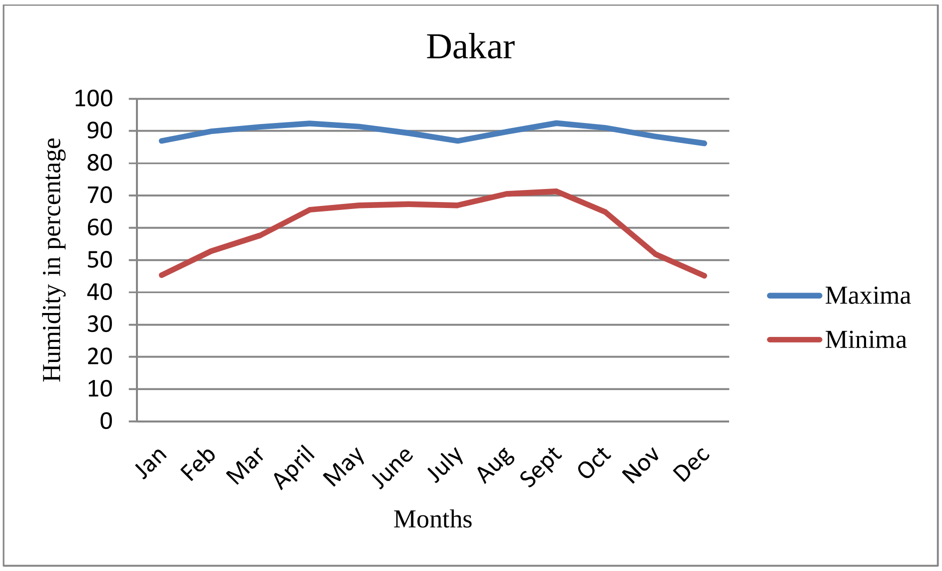
Appendix C: Monthly averages of maxima and minima of humidity of 11 stations located across Senegal from 1980 to 2010. Source: ANACIM

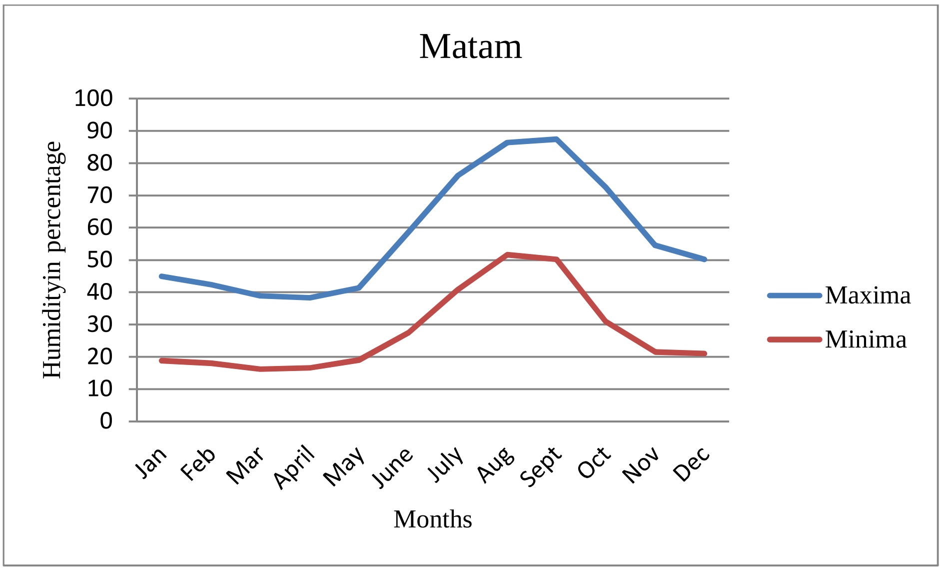


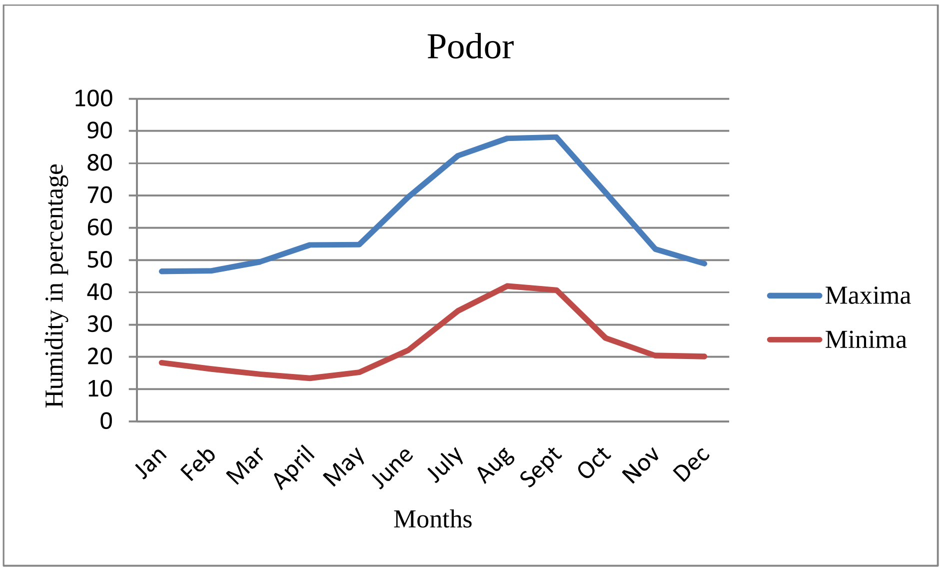


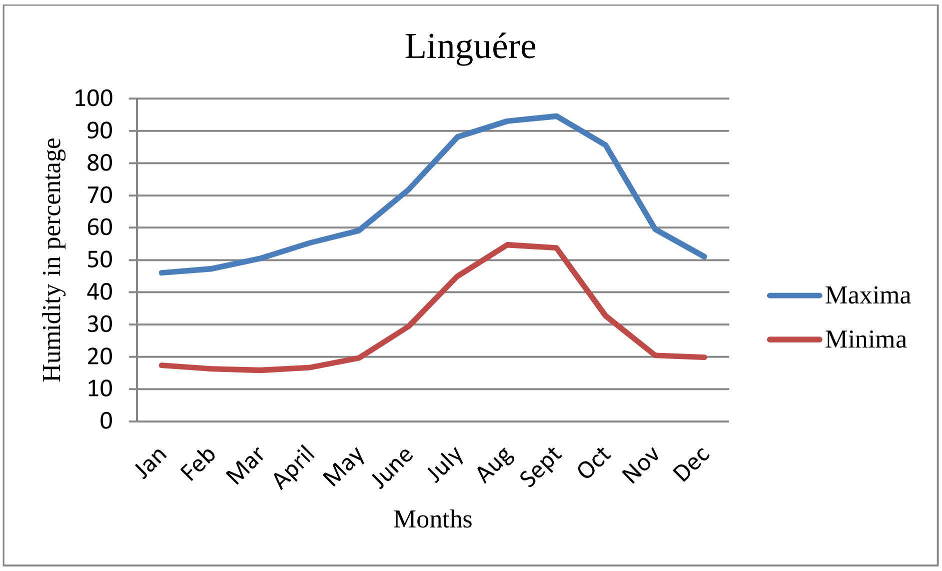

Kédougou
Humidity in percentage
110
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Months
Maxima
Minima

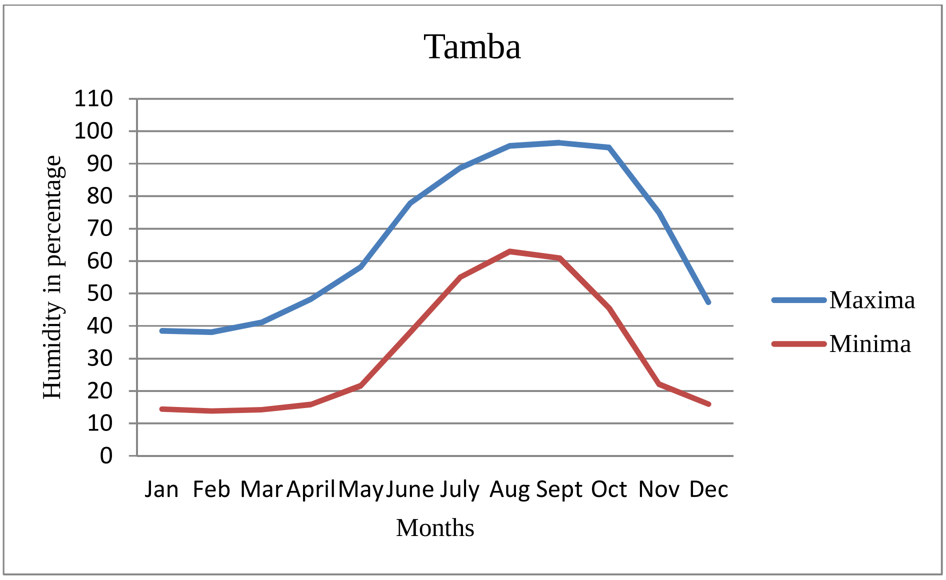

Aéré Lao
Humidity in percentage
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Months
Maxima
Minima

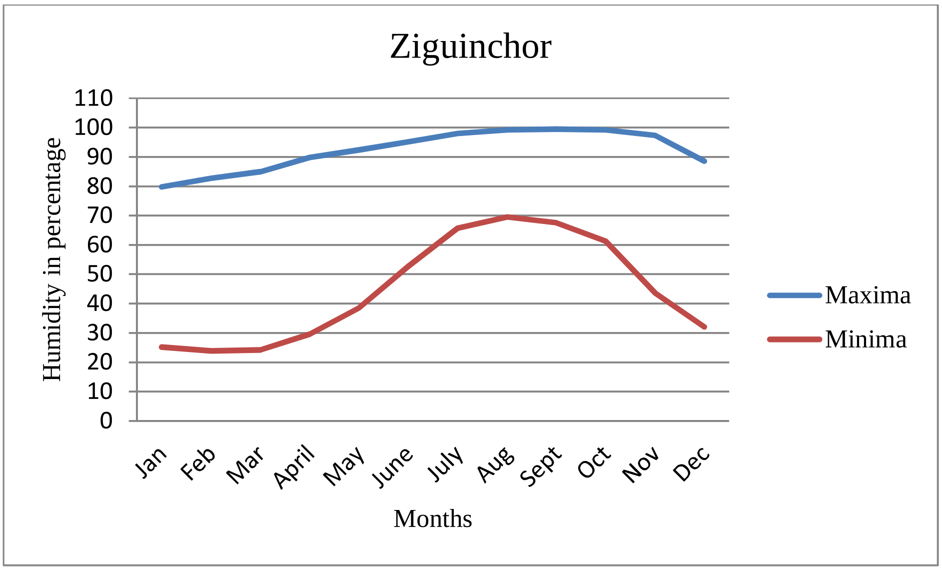

Dakar
100
90
80
70
60
50
40
30
20
10
0
Humidity in percentage
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Months
Maxima
Minima

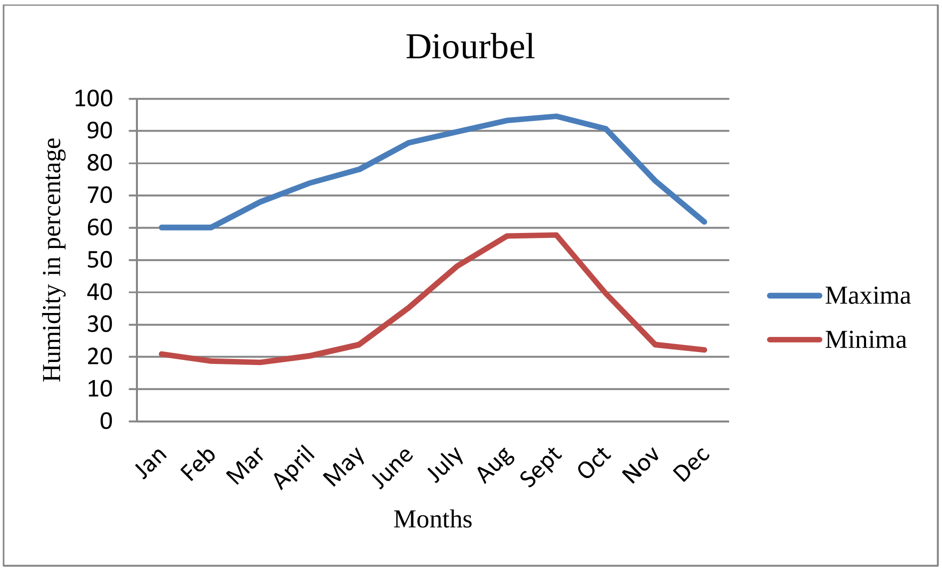

Matam
100
90
80
70
60
50
40
30
20
10
0
Humidityin percentage
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Months
Maxima
Minima


Podor
Humidity in percentage
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Months
Maxima
Minima

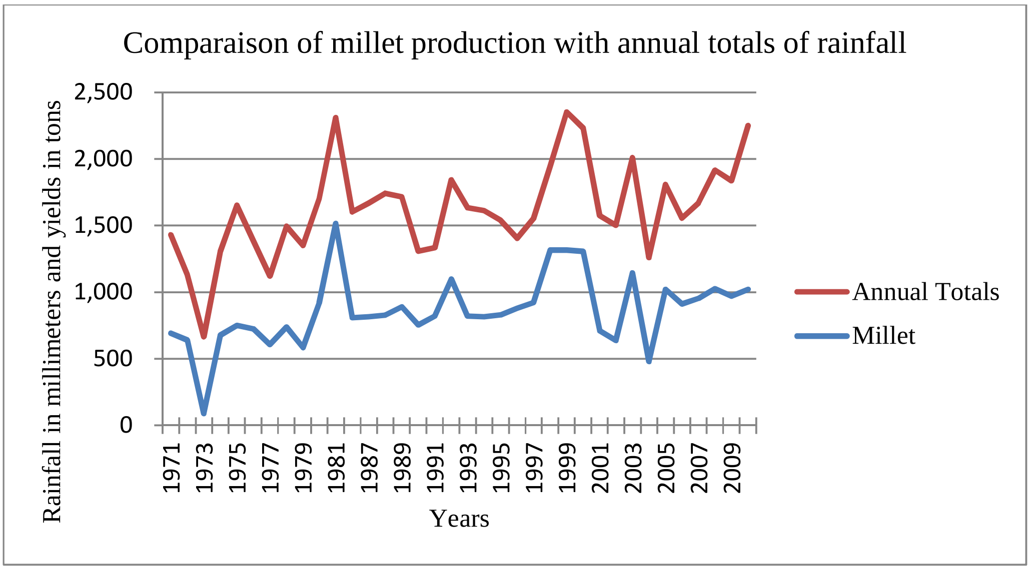

Linguére
Humidity in percentage
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Months
Maxima
Minima

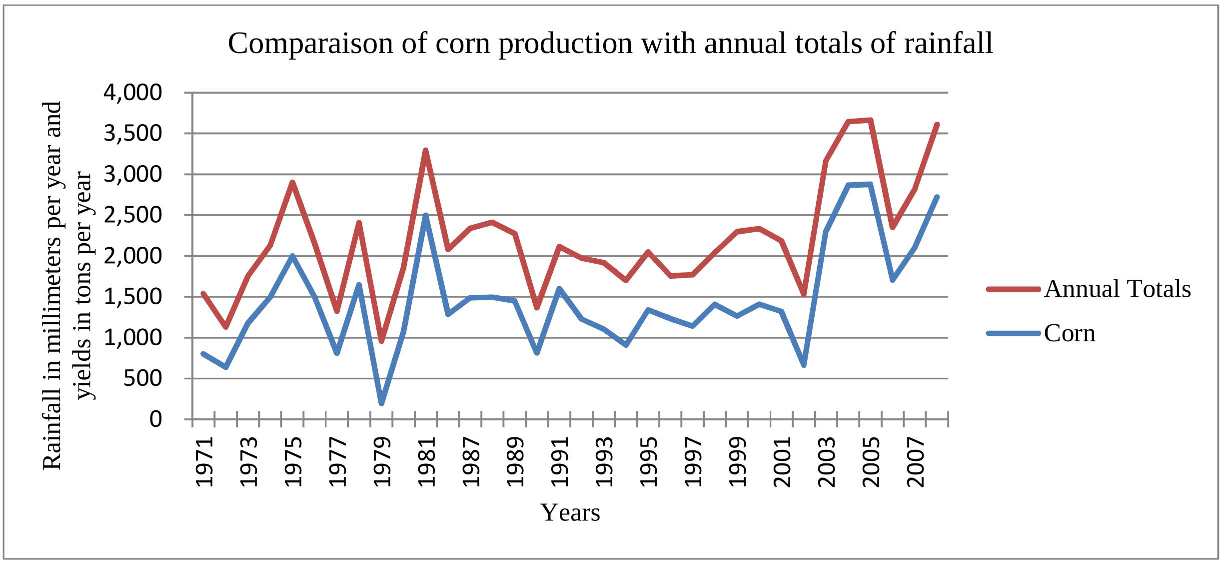

Tamba
Humidity in percentage
110
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Months
Maxima
Minima

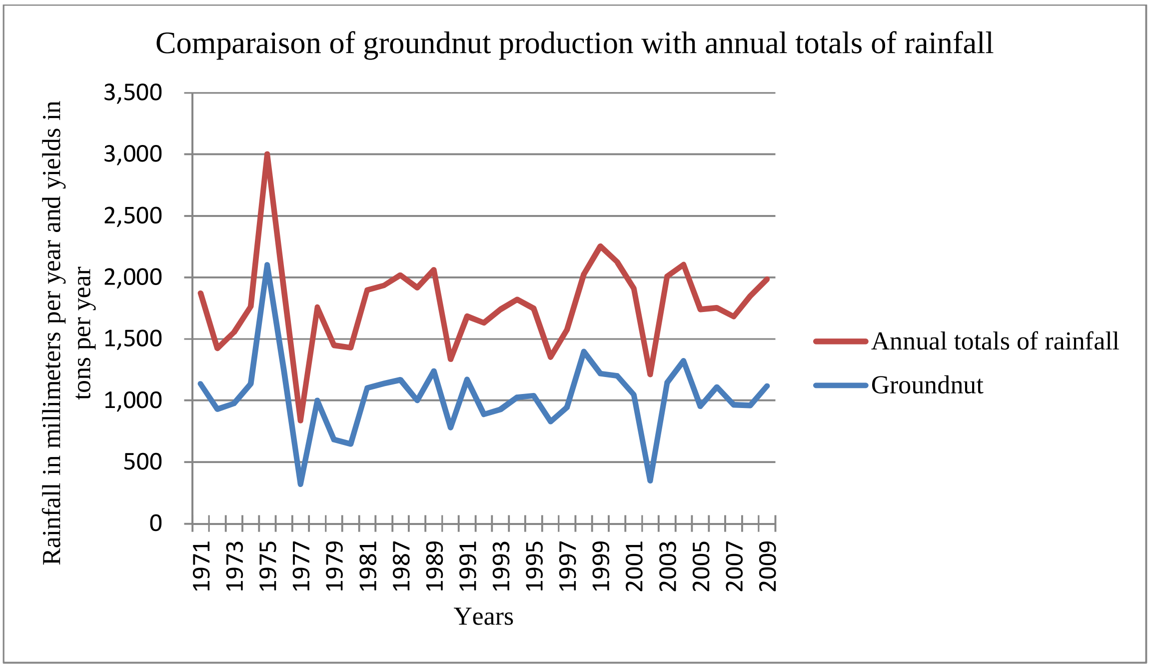

Ziguinchor
Humidity in percentage
110
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Months
Maxima
Minima


Diourbel
Humidity in percentage
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Months
Maxima
Minima

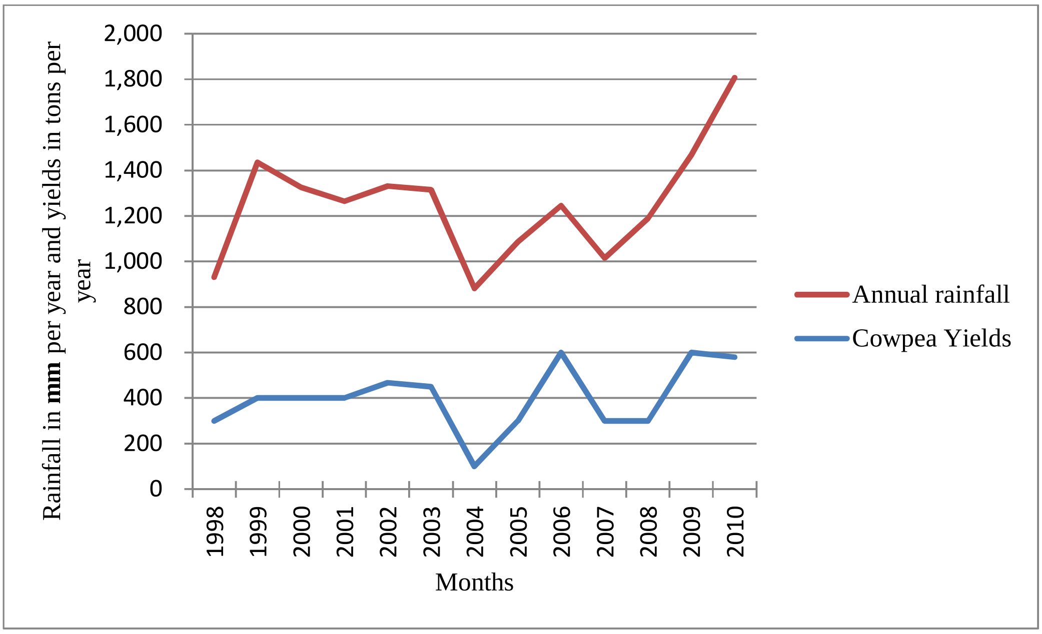
Appendix D: Yields production of millet (from 1971 to 2010), corn (from 1971 to 2008), groundnut (from 1971 to 2010), and cowpea (from 1998 to 2010), production compared to annual rainfall of the rural community of KSG. DAPS and ANACIM







Comparaison of groundnut production with annual totals of rainfall
Rainfall in millimeters per year and yields in tons per year
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1971
1973
1975
1977
1979
1981
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
Years
Annual totals of rainfall
Groundnut



Rainfall in **mm** per year and yields in tons per year
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Months
Annual rainfall
Cowpea Yields

Appendix E: Yields production of millet (from 1971 to 2010), corn (from 1971 to 2008), groundnut (from 1971 to 2010), and cowpea (from 1998 to 2010), production compared to annual rainfall of the rural community of KSG. DAPS and ANACIM

Years	Millet Yields (Tons per year)	Annual Totals (mm per year)	Years	Millet Yields (Tons per year)	Annual Totals (mm per year)
1971	691	738.70	1993	819	812.80
1972	640	493.80	1994	816	795.20
1973	90	576.80	1995	830	709.90
1974	677	628.70	1996	879	524.90
1975	749	902.10	1997	922	630.20
1976	725	656.70	1998	1,315	630.20
1977	607	514.60	1999	1,316	1034.90
1978	738	757.40	2000	1,305	925.90
1979	585	765.70	2001	710	864.20
1980	919	781.90	2002	637	864.20
1981	1,515	793.70	2003	1,144	864.20
1986	808	795.00	2004	478	781.90
1987	816	851.80	2005	1,021	786.60
1988	827	916.50	2006	911	644.90
1989	889	824.60	2007	954	715.20
1990	755	554.10	2008	1,026	889.00
1991	820	513.30	2009	969	867.40
1992	1,099	743.50	2010	1,022	1226.90

Years	Corn Yields (Tons per year)	Annual Totals (mm per year)	Years	Corn Yields (Tons per year)	Annual Totals (mm per year)	Years	Corn Yields (Tons per year)	Annual Totals (mm per year)	Years	Corn Yields (Tons per year)	Annual Totals (mm per year)
1971	800	738.7	1980	1,072	781.9	1992	1,228	743.5	2001	1,322	864.2
1972	637	493.8	1981	2,500	793.7	1993	1,106	812.8	2002	665	864.2
1973	1,175	576.8	1986	1,287	795.0	1994	909	795.2	2003	2,300	864.2
1974	1,500	628.7	1987	1,488	851.8	1995	1,338	709.9	2004	2,865	781.9
1975	2,000	902.1	1988	1,497	916.5	1996	1,231	524.9	2005	2,878	786.6
1976	1,500	656.7	1989	1,450	824.6	1997	1,141	630.2	2006	1,705	644.9
1977	810	514.6	1990	813	554.1	1998	1,409	630.2	2007	2,108	715.2
1978	1,650	757.4	1991	1,600	513.3	1999	1,262	1034.9	2008	2,723	889.0
1979	193	765.7				2000	1,409	925.9			

Years	Annual Totals (mm per year)	Groundnut Yields (tons per year)	Years	Annual Totals (mm per year)	Groundnut Yields (tons per year)	Years	Annual Totals (mm per year)	Groundnut Yields (tons per year)
1971	738.7	1,134	1987	851.8	1,167	1999	1034.9	1,218
1972	493.8	930	1988	916.5	1,001	2000	925.9	1,200
1973	576.8	977	1989	824.6	1,238	2001	864.2	1,046
1974	628.7	1,134	1990	554.1	781	2002	864.2	347
1975	902.1	2,101	1991	513.3	1,170	2003	864.2	1,144
1976	656.7	1,239	1992	743.5	888	2004	781.9	1,323
1977	514.6	321	1993	812.8	927	2005	786.6	953
1978	757.4	1,000	1994	795.2	1,027	2006	644.9	1,109
1979	765.7	683	1995	709.9	1,039	2007	715.2	966
1980	781.9	647	1996	524.9	829	2008	889.0	961
1981	793.7	1,102	1997	630.2	946	2009	867.4	1,118
1986	795.0	1,139	1998	630.2	1,398	2010	1226.9	1,103

Years	Cowpea Yields (tons per year)	Annual Totals (mm per year)
1998	300	630.20
1999	400	1034.90
2000	400	925.90
2001	400	864.20
2002	467	864.20
2003	450	864.20
2004	100	781.90
2005	300	786.60
2006	600	644.90
2007	300	715.20
2008	300	889.00
2009	600	867.40
2010	580	1226.90

Appendix F: Yields production of millet, sorghum, and corn crops using the technic of conservation farming and not using conservation farming in 2010 and 2011 of the rural community of KSG. Source: Wulanafa Program

2010	Conservation Farming (Tons)	Non Conservation Farming (Tons)	Difference (%)
Millet	990	548	81
Sorghum	953	752	27
Corn	2,634	1,550	70

2011	Conservation Farming (Tons)	Non Conservation Farming (Tons)	Difference (%)
Millet	1,523	915	66
Sorghum	1,075	846	27
Corn	2,568	1,498	71

Appendix G: Survey questionnaire introduced by author to local farmers of the village of KSG.

PART 1 : IDENTIFICATION

Name: Sex: F M

1. Ethnic group: Peul Sérère : Wolof : Other to be specified :

2. Number of males in the household: Number of females in the household:

Number of children in the household:

3. Main activity: Second activity: Others to be specified:

4. Level of study: No Study:

5. Permanent resident: Yes No

8. If permanent resident are you originated from the village: Yes No

9. If no, where do you come from? Since when have you been living in the village?

10. Number of active people in the house? (From 15 to 70 years):

- Farmers :
- Husbandry :
- Stockbreeders :
- Others :

PART 2: AGRICULTURAL ACTIVITIES AND CHANGES

When have you been practicing agriculture?

Reasons why you practice it rather than others activities:

1. Where agriculture is practiced?

- Basin :
- Between basin :
- Other to be specified :

2. Agriculture type: Rainfed (%) Gardening (%): Horticulture (%):

Arboriculture (%): irrigated agriculture (%): Others to be precised (%)

3. rainfed crops (most to less important) :

4. irrigated crops (most to less important):

5. Others (most to less important)

5. Yields per crops

6. Acreages per crops:

7. Acreages evolution: increasing decreasing

8. If increasing why?

9. If decreasing why?

9. Yields evolution: increasing: decreasing:

10. Periods when changes have been noticed:

11. causes (most to less important).

PART 3: ADAPTATIONS STRATEGIES

1. What local strategies have been adopted to face negative changes?

- Change crops
- Change of crop calendar
- Agricultural techniques (traditional or modern)
- Others to be specified

2. Origin of these technics (heritage, learning, others)
3. Effects of new strategies on crop production (estimation of increasing or decreasing)
4. Efficiency of strategies: High average: weak:
5. Support from governmental agencies :

- Fertilizer
- Seeds
- Technical supports
- Others to be précised

IV. Role of International agencies

- Fertilizer
- Seeds
- Technical support
- Others to be specified

V. Role of others to be specified

- Fertilizer

- Seeds
- Technical support
- Others to be specified

VI. Link between social believes and agricultural techniques

VII. Impacts of social beliefs in adoption of new agricultural techniques

VIII. Needs to improve adaptation strategies

- Financial needs
- Technical needs
- Training needs
- Social constraints