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Assessing the impacts of Climate Change in Senegal: A Case Study of Casamance Region

Defended on 08/11/2020 Before the Following Committee:

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By my signature below, I declare that this thesis is my original work. I have followed all ethical principles of scholarship in preparation, data collection, data analysis, and completion of this thesis. I have given all scholarly matter recognition through accurate citations and references. I affirm that I have cited and referenced all sources used in this document. I have made every effort to avoid plagiarism.

Therefore, I declare that the presented work in this report is my own contribution for the partial fulfilment of the award of the Master's degree in Water Policy. The content of this report may be used for further research in similar topics at the Pan African University Institute of Water and Energy Sciences, including Climate Change – PAUWES, as well as in all Pan African Universities – PAU Institutes. I declare that I have not submitted this document to any other institution for the award of an academic degree, diploma, or certificate.

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I hereby declare that I supervised the preparation of this Master thesis submitted therein in accordance with the guidelines on supervision of Master thesis laid down by the Pan African University Institute of Water and Energy Sciences, Algeria.

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ABSTRACT

Different theories emphasize the role climate change plays in the actual abnormal occurrence of climate related natural disasters. Climate change continues to pose a threat to the sustainability of natural resources. Global warming has several impacts in the Casamance region, especially on water resources, agriculture, coastal zones and human health. This is a stressful issue for researchers, scientists and politicians due to inevitable loss and the impacts it exerts on the environment. Therefore, by following these theories, climate change would be qualified as barriers to the development and well–being of human beings, especially in developing countries, since they are the ones that are more vulnerable to climate change due to lack of means of resilience to the latter's harmfulness. Senegal, one developing country, was taken as a case study, with the main objective of evaluating its impacts in the Casamance Region in main strategical sectors with relevant scientific evidences. Historical records of hydrological and climate data (precipitation, temperature and streamflow) that occurred in Ziguinchor and Kolda stations, were the parameters used to achieve the main objective of this study. Based on the obtained results, climate change in Casamance is not negligible. According to recent climatological data, the climate of Casamance underwent abnormal evolutions during the period going from 1987 to 2016. Thus, climatic parameters such as temperature and precipitation were modified. The result of the analysis also indicates much fluctuation in both rhythm and quantity of precipitation as a result of weather disturbances. There has also been a considerable decrease in the Casamance River flow in the past. The aggression of the vegetation cover, deforestation, GHG emissions (linked to agricultural practices, transport and industrial sector), and biomass combustion in Casamance have increased the risk of vulnerability to climate change. When the temperature rises, seawater spills into the river, which causes salinization, sea level rise, coastal erosion, a decrease in marine species. The shortening of the seasons also affects agricultural sector, reducing yields, causing shortages. Rainfall irregularities and the rise in temperature have marked the lands to the point of upsetting them (salinization / acidification of the soils, silting up of the shallows, etc.). Today, the hydrological dysfunction means that the Casamance River functions like a veritable estuary characterized by high concentrations of salt, thus compromising the supply of drinking water to the populations and their agricultural activities.

Key-Words: Climate Change, Natural resources.

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RÉSUMÉ

Différentes théories mettent l'accent sur le rôle que joue le changement climatique dans l'occurrence anormale réelle des catastrophes naturelles liées au climat. Le changement climatique continue de menacer la durabilité des ressources naturelles. Le réchauffement climatique a plusieurs impacts dans la région de la Casamance, notamment sur les ressources en eau, l'agriculture, les zones côtières et la santé humaine. C'est une question stressante pour les chercheurs, les scientifiques et les politiciens en raison de la perte inévitable et des impacts qu'elle exerce sur l'écosystème. Par conséquent, en suivant ces théories, le changement climatique serait qualifié d'obstacles au développement et au bien-être des êtres humains, en particulier dans les pays en développement, car ce sont eux qui sont les plus vulnérables au changement climatique en raison du manque de moyens de résilience à la nocivité de ce dernier. Le Sénégal, un pays en développement, a été considéré comme une étude de cas, l'objectif principal étant d'évaluer les impacts dans la région de la Casamance dans les principaux secteurs stratégiques avec des preuves scientifiques pertinentes. Les enregistrements historiques des données hydrologiques et climatiques (précipitations, température et débit) effectués dans les stations de Ziguinchor et de Kolda ont été les paramètres utilisés pour atteindre l'objectif principal de cette étude. Sur la base des résultats obtenus, le changement climatique en Casamance n'est pas négligeable. Selon des données climatologiques récentes, le climat de la Casamance a subi des évolutions anormales au cours de la période allant de 1987 à 2016. Ainsi, les paramètres climatiques tels que la température et les précipitations ont été modifiées. Le résultat de l'analyse indique également une grande fluctuation du rythme et de la quantité des précipitations en raison des perturbations météorologiques. Il y a également eu une diminution considérable du débit du fleuve Casamance dans le passé. L'agression du couvert végétal, la déforestation, les émissions de GES (liées aux pratiques agricoles, au transport et au secteur industriel) et la combustion de la biomasse en Casamance ont augmenté le risque de vulnérabilité au changement climatique. Lorsque la température monte, l'eau de mer envahit le fleuve, ce qui provoque la salinisation, l'élévation du niveau de la mer, l'érosion côtière, une diminution des espèces marines. Le raccourcissement des saisons affecte également le secteur agricole, réduisant les rendements, provoquant des pénuries. Les irrégularités pluviométriques et la hausse des températures ont marqué les terres de cultures au point de les déranger (salinisation / acidification des sols, envasement des bas-fonds, entre autres). Aujourd'hui, le dysfonctionnement hydrologique fait que le fleuve Casamance fonctionne comme un véritable estuaire caractérisé par de fortes concentrations de sel, compromettant ainsi l'approvisionnement en eau potable des populations et leurs activités agricoles.

Mots-clés : Changement climatique, ressources naturelles.

DEDICATION

This work is dedicated To my father Modou Fall and my mother Fatou Djigal, who have unconditionally supported me, to my brothers, sisters, friend and entire family, who heartened me to work hard in order to accomplish the best.

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ACRONYMS

°C	-	Degree Celsius
ADEME	-	Environment and Energy Management Agency
ANACIM	-	National Agency for Civil Aviation and Meteorology
CC	-	Climate Change
CO_2	-	Carbon Dioxide
GDP	-	Gross Domestic Product
GHG	-	Greenhouse Gases
GIEC (IPCC)	-	Intergovernmental Panel on Climate change
ICZM	-	Integrated Coastal Zone Management
NASA	-	National Aeronautics and Space Administration
NGOs	-	Non-Governmental Organizations
PANA	-	National Adaptation Action Plan
RCPs	-	Representative Concentration Pathways
SDGs	-	Sustainable Development Goals
SNMO	-	Initial National Implementation Strategy

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1. INTRODUCTION

1.1 Background

During current and recent past times, climate change has been a subject of concern for both scientists and policy makers over the world. The effects of climate change often lead to weather disturbances and associated harsh natural disasters, and threaten both directly and indirectly human life on earth, especially in developing countries where the degree of vulnerability to climate change is higher.

Climate change, as it is understood and observed today, is to be distinguished from the natural variability of the climate. Indeed, scientific work on the issue, compiled in the various IPCC reports has largely demonstrated that the climate changes were mainly due to human activity (Coalition eau, 2014). Because of the importance of the greenhouse gases they generate, these activities have, in fact, upset the balance of the natural system that controls the elements of the earth's climate (temperature, precipitation, winds) (MEPN, 2005).

Climate change impact is becoming a serious issue in our continent, Africa. Recent IPCC reports predict extreme weather events, including floods, droughts and tropical storms that will increase in frequency and intensity, especially in the African continent (Faye & Sané, 2015). According to (Elbouqdaoui et al., 2006); Rosine et al., 2014), Sahelian countries are the most affected, due to the impact on rain-fed agriculture.

Senegal is a West African country and evidently showed climate change variability of rainfall pattern and increase of temperature were verified by researchers at basin level. However, Senegal, like the other West African countries, has been seriously affected by the drought of the 1970's. As a result, it caused a 23 % drop in rainfall across the country (Bodian, 2014). Given the atmospheric and climatic changes, the two major challenges facing the country are, on the one hand, the structural irregularity of precipitation which makes agricultural production systems vulnerable and, on the other hand, air pollution (MEPN, 2005).

Casamance is a highly rural area whose economy depends on agricultural activities. Its production system is dependent on climatic variations. Belonging to the Sudanese climatic domain, Casamance remains the rainiest zone in Senegal. The importance of precipitation and the hydrographic network gives it its originality. In fact, water is the driving force behind the structuring of landscapes and human activities. However, climate change is deeply contributing to the destruction of the environment. (Sané et al., 2010). Casamance, the wettest area in Senegal, has suffered from strong climatic variability since the early 1970's, often with disastrous environmental and socio-economic consequences (Sané et al., 2010). The main manifestations of this climatic variability relate to more or less significant rainfall deficits and the rise in temperatures. This deterioration in climatic conditions results in the salinization of soil and water, the acceleration of the decline in agricultural production in general, the decline in rice cultivation in the lowlands in particular and the destruction of natural resources (Sané et al., 2010).

1.2 Research Problem

Climate change has diverse effects on the socioeconomics of Senegal and its effect will continue if proper mitigation and adaptation measures are not in place. It is because Senegal is a low-income, food-deficit country of 14 million people. Approximately 80 percent of the population works in agriculture, depending on exhausted soils and rainfall that fluctuates from year to year. The study of climate change at the scale of a territory is a growing concern both for the scientific community and for local stakeholders. It aims to characterize recent climatic variations in order to put in place adaptation strategies on operational spatial scales like the region (Faye & Sané, 2015).

Understanding climate change impacts is vital for developing sustainable mitigation measures and will help decision makers for a better planning approach in resources management. It is necessary to put in place adaptation strategies which must promote water savings in order to reduce the vulnerability of populations. (Diop et al., 2019). These adaptation plans will contribute to the realization of agenda 2063 of the African Union and the realization of the United Nations Sustainable Development Goals (SDGs) especially SDG 13 and subsequently SDGs 6, 3, 2 and 1. SDG 13 is concerned with taking urgent action to combat climate change and its impacts and as this is done, it will ensure a future where there is enough fresh water for all to practice good sanitation and hygiene (SDG 6: Water and sanitation). Availability of water will promote agricultural activities: production of food thereby eradicating hunger (SDG 2: Zero hunger). Attainment of SDG 6 will in effect promote good health and wellbeing of the population (SDG 3: Good health and well-being) and this will increase productivity of the population, improve economic and social living standards contributing to eradication of poverty (SDG 1: No poverty).

1.3 Research Significance and Objectives

Climate change driven natural disasters greatly affect the economic development and threat human lives especially in developing countries including Senegal. This kind of research work is very important for Africa and Senegal in particular, since it can be used to set out appropriate strategies and precaution measures to reduce damages caused by climate-related natural disasters.

This study is aimed at evaluating the potential impacts of climate change on the Casamance region and understanding its implication for natural resources management.

The specific objectives are to:

1. identify the causes and impacts of climate change in Senegal and in Casamance at a local level,
2. evaluate the impacts of climate change in Senegal and in Casamance,
3. identify the strategies for resilience and adaptability for climate change in Senegal and in Casamance at a local level.

To achieve the objectives of the study, historical records data since the earliest years, were collected and processed. A conclusion will be made referring on the obtained results from the analysis. Lastly, appropriate strategies and precautionary measures will be recommended to alleviate the damages and gravity of disasters on Senegalese population. Different strategies to achieve efficient resilience to these changes will be recommended as well.

2. LITERATURE REVIEW

2.1 Aspect of Climate Change

Emmanuel (2013) defined climate as the average weather conditions of a particular neighbourhood observed over a given period. Climate includes a number of variables (temperature, precipitation, winds) and is described as a system where all of its variables are linked. Climate variability or climate change is not a new phenomenon. The Earth has always known over long geological times, successive periods of cooling and warming, but also lighter variations over shorter times. The realization that the climate was changing has come about gradually. The contemporary and industrial period also knows climatic changes, but scientists' studies show that the climate changes more quickly and more importantly than the climatic and natural variables predicted it (Coalition eau, 2014).

This climate variability can be explained by factors internal to the Earth's climatic system, notably the interaction between the atmosphere and the ocean, and natural factors such as volcanic activity and even solar activity. This assertion is the subject of an almost unanimous scientific consensus, but also of a strong political consensus since the United Nations Framework Convention on Climate Change (UNFCCC) established in 1994 following the Rio Summit, and signed by almost all the countries of the planet. This convention defined climate change as "changes in the climate which are directly or indirectly attributed to human activity altering the composition of the global atmosphere and which are added to the natural variability of the climate observed during comparable periods (Coalition eau, 2014).

The atmosphere is a set of gases that surround our planet. It is composed of nitrogen (78%), oxygen (21%) and many "rare gases" such as argon, neon, helium, krypton, and other gases such as ozone, carbon dioxide, nitrous oxide, methane, as well as water vapor, which represent 1% (MEPN, 2005). These gases play a major role in the transfer of the energy flows at the origin of certain climatic processes (MEPN, 2005). They form an insulating layer around the planet. By transfer of solar radiation to the earth and by reflection of the radiation emitted from the earth's surface and the lower atmosphere, there is a caloric effect for thermal radiation which is called greenhouse. This process, essential for maintaining a climate conducive to life on earth, is the result of a number of so-called "greenhouse gases" (MEPN, 2005). Water (H_2O) vapour, carbon dioxide (CO_2), nitrogen dioxide (N_2O), methane (CH_4) and ozone (O_3) are the main greenhouse gases that are found in the Earth's atmosphere (Coalition eau, 2014). Human activities have, however, changed the composition of the atmosphere by increasing these greenhouse gases, leading to global warming which contributes to climatic changes (MEPN, 2005). At the beginning of the industrial era, the concentration of CO_2 (the main greenhouse gas produced by human activities) was 280 parts per million (ppm) (Coalition eau, 2014). In the course of 2013, it reached 400 ppm. New GHG emissions will imply continuous warming and changes affecting all the components of the climate system. (Coalition eau, 2014).

Nowadays, sustained interest manifests itself around the climate change and its increased variability, because of sometimes tragic consequences they can cause on ecosystems, environment and populations (Beyene et al., 2013). The idea that these changes could have a significant impact on human activities emerged in the 1950s, but it was with the publication of the first IPCC report in 1987 that the issue of climate change emerged as a public problem. Many studies have revealed that variability and change of climate are major threats for developing countries (Sambou et al., 2009). Many works at worldwide scale have highlighted the negative effects of climate fluctuations on rainfall and flow (Kouassi et al., 2008 and 2010). They contribute to the increased incidence of floods and drought, the spread of diseases and the increased risk of conflicts due to the scarcity of land, water and the advancing seas on the continents as well as the melting of the ice caps (GIEC, 2007). They are mainly characterized by a decrease of the quantity, frequency of rainfall in time and space and a change in timing of occurrence, seasonal changes of rainfall, changes of basin response, causing a rise of temperature (Kingumbi et al., 2005). Climate change risks causing a decrease in surface flows and therefore a reduction in the country's surface water resources. (MEPN, 2005).

The combined effect of rising sea levels and evapotranspiration exposes freshwater to salinization (MEPN, 2005), making part of the surface water and groundwater unsuitable for many uses. According to Biazen, (2014), the severity of climate variability and change profoundly influence social and natural environments throughout the world. The study indicated also that climate change strongly influences forest productivity, species composition, and the frequency and magnitude of disturbances that impact forests. This is why Piyoosh and Bhavna (2015) affirms that climate change is one of the most serious threats that humanity may ever face. To limit climate change, it will therefore be necessary to significantly and permanently reduce GHG emissions (Coalition eau, 2014).

According to public and policymakers' perceptions, the predictions on different scenarios of climate change impacts in the coming decades are thought to be overstated by scientists due to their stiffness in extinction of some species, increase of temperature and other negative effects on the biodiversity in the coming decades. It is recommended to policymakers to first consult environmental biologists before making any decision on the issue of climate change and use transparent, standardized metrics of expertise when deciding which scientists to consult in order to make reasonable and reliable decisions (Javeline et al., 2016). This could help to avoid the overestimation on different scenarios related to climate change, and make as well efficient measures and strategies that could help in climate change mitigation or resilience.

One of the approaches to sustainably achieve climate change management should be based on the ecosystem functioning. Therefore, this approach should rely on the ability to enhance natural systems to survive on climate change impacts, thus resulting in reliable and sustained climate change adaptability strategies (Day et al., 2011). Since it is noticed that GHG emissions are the main cause of climate change, all the nations should be committed in reducing those emissions in order to reduce the rate of global warming. The population should be put aware of the climate change impacts exposed to them and be given all the facility and information on how to protect themselves (Wilbanks et al., 2014).

2.2. Causes of Climate Change

In this section, the different causes of climate change are discussed.

2.2.1. The greenhouse effect

2.2.1.1 Definition and mechanism of the greenhouse effect

The greenhouse effect is a natural phenomenon allowing the earth to have a favourable temperature to flowering. It can be defined as the retention of heat in the lower layer of the atmosphere, caused by to the absorption and re-emission of light by clouds and certain gases. When the solar radiation reaches the Earth's atmosphere, a part (about 28.3-30 %) is directly reflected, that is to say returned to space, by the upper layer of the atmosphere.

Incident rays that have not been reflected back into space are absorbed by the atmosphere (20.7 %) and the earth's surface (51 %) (Kenfact, 2016). This last part of the radiation absorbed by the surface of the ground gives it heat which is restored, day and night, towards the atmosphere. The transfer of heat between the Earth and the atmosphere takes place, in accordance with the second principle of thermodynamics, from hot (earth) to cold (atmosphere). It is done by convection (heating and humidification of the air in contact with the ground, then rise of this air and release of the latent heat of the water vapour when it condenses in clouds) and in the form of far infrared radiation. The greenhouse effect is only concerned with these radiations, which will be partly absorbed by greenhouse gases (Dufresne et al., 2011).

The infrared rays absorbed by the GHGs are re-emitted in all directions in the form of heat; a part is discharged in space, but another part returns towards the Earth what increases the terrestrial temperature. Without the greenhouse effect (which implies in particular: without water vapour and without clouds), and at constant albedo, the average temperature on Earth would drop to −18°C (Baruch, 2007). But at this temperature, the ice would spread over the globe, the terrestrial albedo would increase, and the temperature would probably stabilize below −50°C. This mechanism can be illustrated by Figure 1.

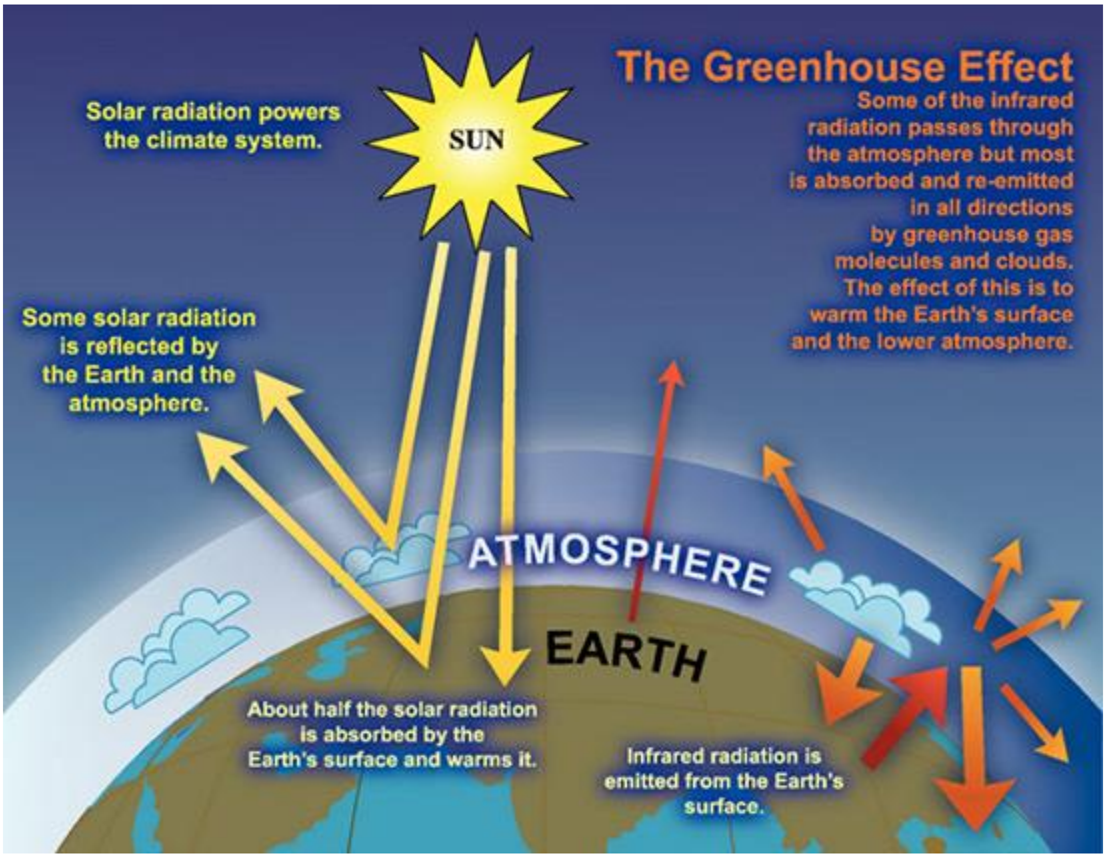

Figure 1: Mechanism of the greenhouse effect

Source: (ADEME, 2017)

2.2.1.2. Main greenhouse gases

Greenhouse gases are gaseous components of the atmosphere that contribute to the greenhouse effect. These gases have the common characteristic of absorbing part of the infrared rays emitted by the Earth's surface.

The main greenhouse gases are water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (or nitrous oxide, of formula N_2O) and ozone (O_3). Industrial greenhouse gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (IPCC, 2006). The contribution and concentration of GHGs differ from one gas to another. And according to the IPCC, the approximate contribution of GHGs can be estimated at 60% for water vapour, 28% for carbon dioxide, 8% for ozone and 6% for methane and nitrous oxide. These approximations may lead us to think that other GHGs (industrial gases) do not contribute to the greenhouse effect, while SF_6 is more efficient than carbon dioxide.

2.2.1.3. Summary of GHG emissions by sector

GHG emissions are increased by human activities as we said above. We can see in a simplified way in Figure 2, how human activities contribute annually to the greenhouse effect by sector of activity (Le Moel, 2009). Here the year taken as an example is the year 2000.

This figure shows how different human activities contribute to the increase in greenhouse gases. We can clearly see that it is energy production that is the most threatening sector for climate balance. The energy sector is followed by industrial processes and then agriculture. Biomass combustion promotes the increase of carbon dioxide from nitrogen oxides and methane. Biomass consists of carbon, hydrogen, oxygen and nitrogen. During the combustion reactions, there will be release of greenhouse gases as described in the figure.

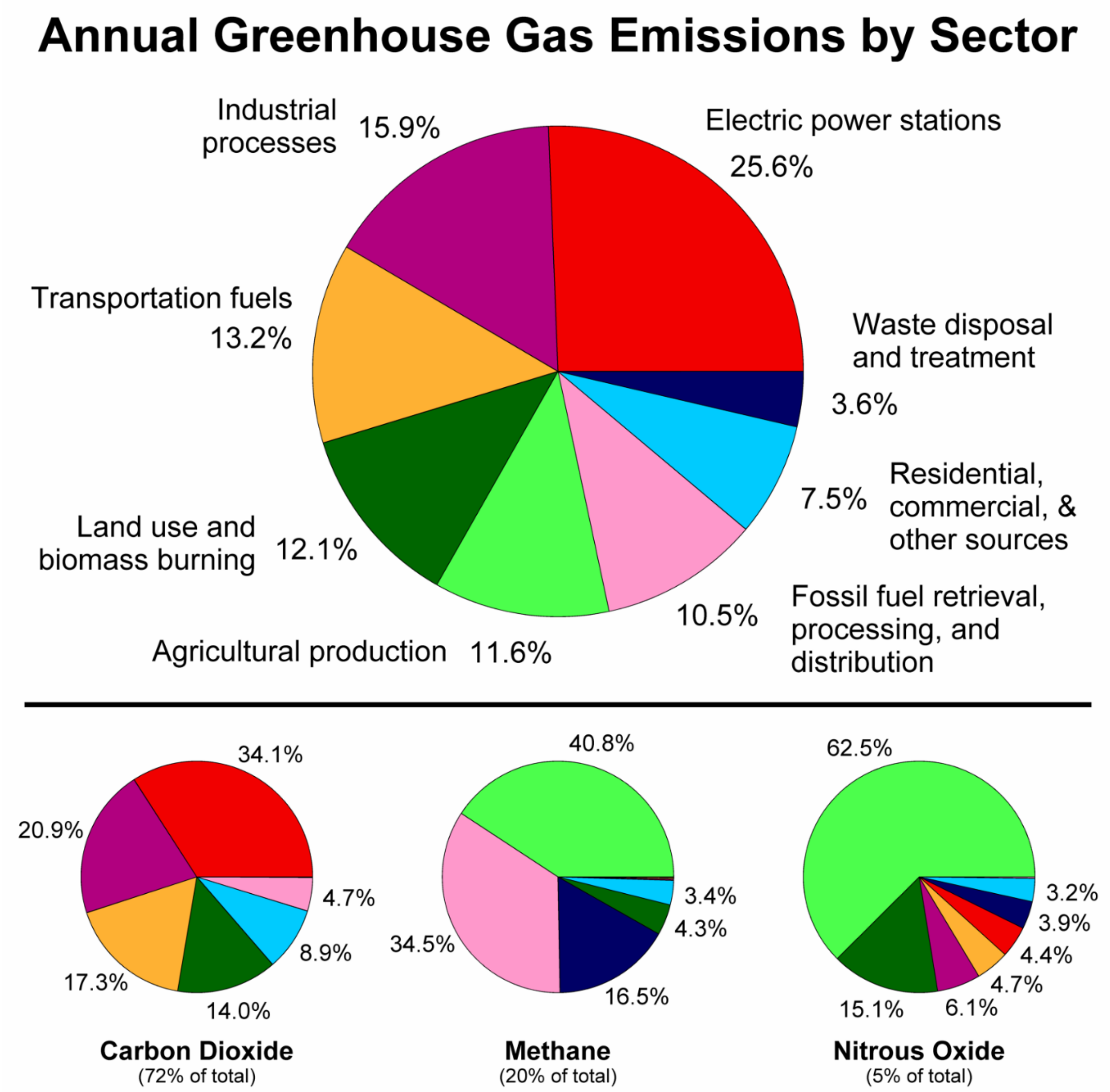

Figure 2: Summary of GHG emissions for the year 2000

Source (Le Treut et al, 2009)

2.2.1.4. How does the greenhouse effect promote climate change?

The greenhouse effect can be thought of as the retention capacity of solar heat by the Earth's atmosphere. With this in mind, it is obvious that it will modify the climate by increasing the average temperature of the planet. This increase is called global warming. Global warming modifies the climatic factors which are: biodiversity, polar ice caps, precipitation, fauna, flora, snowfall, oceans, sea level, mountain glaciers, winds, rainfall, and seasons. Other studies have shown that for the temperature of the earth-atmosphere system to be stable, the energy balance at the top of the atmosphere and at the surface must be zero, which would be impossible due to the additional greenhouse effect (Paulin, 2017). In 2009, in a study (Besancenot et al., 2012), appraised this balance sheet, by adding and subtracting all of the energy exchanges estimated from observations and models: solar radiation reaching the atmosphere, the absorbed and reflected part, heat generation from the surface, etc. In the end, it was estimated that the energy balance at the top of the atmosphere and at the surface is surplus by 0.9 (from 0.7 to 1) W/m^2 (energy flow per square meter). According to this study, this excess energy, responsible for a warming of the earth-atmosphere system, comes from the additional greenhouse effect: that which is caused by an excess of greenhouse gases released into the atmosphere by human activities (Besancenot et al., 2012).

2.2.2 GHG emissions in Senegal

In Senegal, if the impact of human activities on the concentration of greenhouse gases is low, given the country's level of development, the fact remains that climate change has a strong impact on ecological systems and humans (MEPN, 2005). Senegal's contribution to greenhouse gases (GHG) emissions is relatively low. The two studies carried out in 1994 and 1995 (MEPN, 2005) as part of the implementation of the Framework Convention on Climate Change made it possible to assess national emissions and the main sources contributing to the greenhouse effect. Total emissions are estimated at 9,572.7 Gg ECO_2 (MEPN, 2005).

These are mitigated by the residual forest sequestration capacity, which is 6,001 Gg ECO_2. This results in net emissions of 3,538 Gg ECO_2. The main sources of greenhouse gas emissions are in order of importance:

- energy, 41% of emissions;
- agriculture, 31.3% of emissions;
- waste, 23.8% of emissions;
- industrial processes, 3.9% of emissions.

The predominant share of energy in greenhouse gas emissions is explained by the importance of the use of fossil products such as coal, oil and industrial gas. However, Senegal has few energy resources and the energy sector remains faced with dependence (MEPN, 2005). Crude oil and gas reserves are low (around 16 Gm^3). Most of the oil consumed is imported. Cumulative natural gas production over the period 1987 to 1997 is estimated at 6,833 TJ or 621 TJ/year on average. Biomass (wood and charcoal) is the main source of energy in the country, providing nearly 92% of household needs. The average annual production of coal during the period 1994-1997 is 3,881 TJ while that of electricity is 857 GWh/year. GHG emissions related to the transformation of wood into charcoal and the use of charcoal became increasingly important (exceeding 400 Giga-grams in the mid-1990s) due to the growing needs for charcoal of cities and more particularly of Dakar. Regarding firewood, GHG emissions mainly due to their use were constant and stabilized around 10 Gg per year until 1992 before increasing to more than 20 Gg since the end of the quota. The preponderance of the energy sector in the emissions is attributable to the consumption of petroleum products in the field of transport and industry. These two subsectors alone account for 76% of energy sector emissions (MEPN, 2005). The importance of emissions from the agricultural sector results from the increase in livestock.

2.3. Impacts of Climate Change in Senegal

It is difficult to predict with precision all the impacts that climate change can have on humans and their environment because of the imprecision of the models but also because of the uncertainties linked to the hypotheses of future greenhouse gas emissions (UNDP, 2009). This is why climate scenarios have been developed. The quality of these scenarios will determine the relevance of the adaptation strategies developed. The impacts of climate change will be examined in four sectors: agriculture, health, water resources and the Senegalese coasts.

2.3.1. Seasonal and agricultural impacts

The effects of climate change on the length of the seasons cannot be ignored. Some extend while others decrease. Just because of the presence of CO_2 in the atmosphere, the reproduction of certain plants is prolonged, leading to a long season. The disruption of the seasons has consequences for agricultural production (Jancovici et al., 2003).

With climate change, farmers face increasing uncertainty and variability, with increased frequency of droughts and floods. However, these impacts are extremely variable from one place to another. Studies (Wade et al., 2015) have shown that high temperatures will favour agriculture in the northern latitudes, while large areas of the arid and semi-arid tropics will experience reduced rainfall and runoff, which is a bleak prospect for developing countries.

On the other hand, due to the rising sea level, the salinity of the agrarian lands increases in the coastal regions, thus reducing both the quality and the quantity of the food crops. The populations are then in situations which deserve an effective solution for their survival

(Moussa et al., 2015; Delecolle et al., 1999). In some regions of the world, yields are increasing, for example in areas of high latitudes. In areas of low latitudes, the increase in temperature has negative effects on agricultural yields.

In addition, global warming will have increasingly serious repercussions in all regions. Lack of water and the distribution of rainfall over time will create increasing production constraints. Climate change will require a re-examination of the issue of water storage to cope with the effects of increasingly extreme precipitation patterns, increasing intra and inter-seasonal variations and increasing evapotranspiration rates in all types of ecosystems (Easterling et al., 2008). The cultivable spaces are reduced, which pushes us to cut down certain forest spaces. We know that the forest is a contributing factor in improving the rains. If trees are continued to cut down, it will lead to a decrease in agricultural productivity.

It should be noted that there is linkage between agriculture and climate change. Because agriculture influences the increase in greenhouse gases such as nitrogen oxides and CO_2, while climate change in turn modifies agricultural yields (Thiare, 2018).

Populations, particularly those in rural areas, are the most exposed to the impacts of climate change because of their production, livestock or crop systems which are less efficient and closely dependent on rainfall (Bazzaz and Sombroek, 1996). For example, Sultan (2015) indicates that this dependence on rainfall is very strong for agriculture, which occupies nearly 93% of cultivated land in West Africa (Noblet et al., 2018) while their access reduces to technological adaptations and the demographic growth, limited economic and institutional capacities constitute factors aggravating the socio-economic impact (Berg et al., 2013; Berg, 2011; Challinor et al., 2007; Müller et al., 2011; Roudier et al., 2011; Salack et al., 2015; Salack et al., 2012; Sultan et al., 2014).

Senegal, like most West African countries, is also affected by changes in climatic parameters. The changes in climatic variables in the last 50 years, previously described above, have had important consequences on the Senegalese agricultural sector, of which more than 90 % of the crops are rainfed. This heavy dependence on rainfall, which varies greatly from year to year, makes Senegalese agriculture one of the sectors most vulnerable to the effects of current variability and climate change (Noblet et al., 2018).

Indeed, the factors behind the impact on the agricultural sector are the crop water deficit due to the increase in evapotranspiration but also the warming which is at the origin of the disturbance of the varietal map of the countries (MEDD, 2016). These impacts are one of the causes of poor performance by Senegalese agriculture and a notable drop in its contribution to the country's Gross Domestic Product (GDP) which fell from 6.8 % in 2013 against 7 % in 2012 (CSE, 2015; MEDD, 2016). National agricultural production fell remarkably in 2014, due to the drop in cereal production (1,249,000 tons compared to 1,269,000 tons in 2013) (Noblet et al., 2018).

The worsening climatic conditions that have been observed in Senegal for more than thirty years represent a major constraint to the development of the agricultural sector. After a long drought (1968-1986), it is now mainly the increase in extreme events that is causing difficulties for agriculture. Several consequences stem from this situation of climate insecurity (Gaye et al., 2015):

- An increase in evaporative demand which, in 2000, already amounted to 1,435 million m^3;
- An unsuitability of the production systems with as a corollary the drop in yields, linked to the shortening of the rainy season;
- A decrease in freshwater resources linked to the rise of the salt bevel and the penetration of oceanic waters in estuarine areas.

The Casamance region is among the most exposed areas of the country because, in addition to climatic variability, there is a sharp reduction in cultivable areas due to the salinization of the land, especially in the western part of the region. Much of the cultivable land requires large quantities of organic or mineral agricultural inputs, which are often less accessible to populations because of their high cost but also because of the delay in their distribution compared to the start of the agricultural season. Indeed, based on the analysis of the evolution of the productivity of Senegalese agriculture through an optimistic scenario and a pessimistic scenario (occurrence of climatic hazards: flood, drought), the T21 model developed by the Directorate of National Planning (DPN) shows that without adaptation measures, climate change risks limiting yields in the agriculture sector by 2035 (MEDD, 2016) (Noblet et al., 2018).

2.3.2 Impacts on health

It is evident that health is by many estimations' dependent on environmental factors in general, and the climate context in particular. Climate change can have direct or indirect health impacts.

The risks of food shortage and famine could increase in certain regions of the planet: South East Asia, East Asia, tropical regions of Latin America. Warmer climate favours tropical diseases such as malaria, yellow fever, dengue, encephalitis, etc. (Dron et al., 2002). Malaria today affects 350 million people, i.e. 1 in 20 inhabitants. With global warming, 60 % of the world's population could be exposed to it, especially in the tropics and in temperate zones (Europe, Asia, and America). In France, the mosquito carrying the West Nile African virus (encephalitis), already observed in New York in 1998 (hence a massive use of malathion in the streets of New York) then in Italy, appeared in the Camargue in August 2000 During the past ten years, malaria has crossed the 1800 meter coast in East Africa and Madagascar, an altitude which it did not previously exceed. Projections for the year 2050 show that malaria will threaten three billion human beings by that date (Dron et al., 2002; Le monde diplomatique, 1999).

In its 1996 report, the IPCC indicated that tropical diseases were most likely to spread in developing countries and less in temperate zones. Public health is also linked to other factors such as the sanitation of urban areas, improved nutrition, and access to drinking water or accessibility to health services (Dron et al., 2002). According to IPCC (2007), projections of climate change exposures are likely to affect the health of millions of people, and in particular those with low adaptive capacity, through:

i. Aggravated malnutrition and ensuing dysregulations, with implications for the growth and development of children;
ii. An increase in the number of deaths, illnesses and accidents due to heat waves, floods, storms, fires and droughts;
iii. More frequent chronic diarrheal diseases;
iv. More frequent cardiovascular conditions due to higher ground-level ozone concentrations caused by climate change; and,
v. The modification of the spatial distribution of certain vectors of Infectious diseases.

2.3.3 Impacts of climate change on hydrology and water resources

The hydrological cycle is affected in all its aspects by climate change: modification of rainfall patterns, runoff, rise in sea level, desertification process, etc. (Coalition eau, 2014). In general, the disparities in the distribution of water resources will widen: episodes of drought should be more frequent in the already arid regions, while the availability of water should increase in the northern latitudes of the planet (Coalition eau, 2014). The climatic water cycle is one of the major manifestations of the climate (Ndiaye et al., 2017). Therefore, its monitoring will allow apprehending certain aspects of climate evolution (Ndiaye, et al., 2017). Ouarda et al. (1999) indicated that the adapted variables to the climate monitoring are: river flows, lake levels, rainfall, temperatures, and the groundwater level. The analysis of the vulnerability of water resources to climate change is based on rising temperatures and changes in precipitation (drought and heavy rain) (Diop et al., 2019). According to Doumouya et al. (2016), among these variables, rainfall represents the most important climate factor for population, environment and ecosystems. Halmstad et al. (2012) revealed that rainfall plays a key role in the planning and management of sustainable water resources, particularly as the fundamental design parameter for dam safety and flood risk analyses and Hadgu et al. (2013) added that rainfall is the main source of water for crop production as irrigation covers only 5 % of the cultivated land in many African countries.

The availability of water resources is also affected by non-climatic factors such as land use change, construction and management of reservoirs, emission of pollutants, treatment of wastewater, but also by use made of resource (Coalition eau, 2014). This vulnerability will be accentuated by a number of factors such as population growth which will impact water uses, the socio-economic context, and the occupation of space and by the governance of the water sector (Diop et al., 2019). Climate change is an additional factor which influences water stress although socio-demographic factors remain the main determinants of water stress (Bates et al., 2008).

Changes in the water cycle are not without consequences for societies and ecosystems (Coalition eau, 2014). According to Radinovié and Curié (2009), future climate change would influence all characteristics of rainfall in terms of intensity, frequency and duration. It is for these reasons that climate and increased climate variability have recently become a pressing issue in various development, environment, and political forums at the national, regional, and international levels (Hua Chen et al., 2007). Water resources will be threatened and affected in many regions, with impacts on all areas of development (access to water, food security, health, etc.), while the risk of water-related disasters will increase (Coalition eau, 2014). The vulnerability of water resources to the effects of climate change impacts other sectors of activity, in particular agriculture, livestock, fishing, tourism, housing and the living environment, energy, health, etc (Diop et al., 2019).

Goulden et al., (2009) reported that the impact of future climate change on hydrographic freshwater systems will amplify problems caused by other constraints such as population growth, changing economic activity, changes in land use and level of urbanization and adding, water demand (irrigation, household consumption, hydropower) will increase in the coming decades. Thus, according to IPCC projections, beyond 2 °C of warming by reference to 1990, each additional degree could lead to a reduction of renewable water resources by 20% for at least 7% of the world population (Bates et al., 2008). Those who feel the impacts of these changes the most will be the most vulnerable (Coalition eau, 2014). If safe access to drinking water depends more on infrastructure than on the amount of runoff and the capacity to renew groundwater, the decrease in groundwater in certain regions, due to climate change, makes it more difficult and more costly to achieve access to drinking water for all (Bates et al., 2008). So, to try to elucidate this problem of water lack, it is essential to analyze the rainfall series and evaluate the effect of their gradual reduction (or not), taking into account climatic conditions (Ndiaye et al., 2017).

Simulations show that, for Senegal, all water resources, underground or surface, will be affected (Ndiaye, 2009). Surface water will experience an exceptional decrease in correlation with the drop in rainfall. A process of drying up the Casamance in Kolda could even occur (Ndiaye, 2009). Similarly, studies predict around the horizon 2100, a significant drop in groundwater ranging from –5 m for the most favourable scenario to -10 m for the most pessimistic scenario (UNDP, 2009). As the temperature increases, evaporation, which is a determining element of the hydrological cycle, also increases. The result is the general modification of the different terms of the water balance. The level of the aquifers as well as the flows in the rivers have dropped considerably. Flow modelling studies have shown that the decrease could exceed 30 % with the increase in evapotranspiration. In the Nidas horst, the piezometric level of the aquifers is currently more than 30m below sea level in some places, which favours the advance of the salty bevel and the increase in the salinity of the aquifer. The already high demand for water could increase due to the increase in the population, the growth of urban areas even if efforts are made. Climate change could exacerbate supply problems in a context of reduction or even scarcity of the resource. To this end, for Africa alone, projections indicate that towards the year 2020, 75 to 250 million people will be exposed to increased water stress due to climate change. Coupled with increasing demand, there will no doubt be detrimental to livelihoods and will worsen water-related problems (UNDP, 2009).

2.3.4 The Senegalese coasts

The warming of the atmosphere induced by the emission of greenhouse gases, will lead to sea level rise rates which should accelerate and become 2 to 5 times greater than current rates. The African coast is one of the most exposed to the risks of flooding linked to the average sea level rise (Noblet et al., 2018).

In Senegal, studies (Dennis et al. 1995) carried out on the vulnerability of the Senegalese coastal zones to climate change have shown that these rates of sea level rise could lead to an acceleration of coastal erosion, to floods of low coastal areas (mangrove estuaries in particular) and increased salinization of soil and surface and underground water (MEPNBRLA, 2009). On the entire Senegalese coast and for a sea level rise of 1 m by 2100, (Dennis et al., 1995) predicted that 55 to 86 km^2 of beaches would disappear following a resurgence of coastal erosion phenomena while about 6000 km^2 of low areas, mainly estuarine areas, would be flooded. This would be equivalent to the disappearance of all of the current mangroves (UNDP, 2009). In Senegal, various works allow to assess the evolution of the sea level. Indeed, Senegal was a forerunner of studies in West Africa, with data from the Dakar tide gauge which over 11 years of measurement during the period between 1943 and 1965 makes it possible to detect an average increase in sea level by 1.4 mm per year (Elouard et al., 1977). On the basis of this 1.4mm rise per year, the PANA report (2006) states that the most vulnerable areas remain localized in particular in the coastal region of Ziguinchor, or even on the small coast. However, since PANA, recent studies indicate a rise in sea level to 3.5 mm/year (Noblet, 2018). By 2080, due to rising sea levels, 75 % of the coastline will be at risk of erosion, compared to 25 % today. Furthermore, according to (Dennis et al. 1995), changes in sea level could result in increased salinization of surface water and groundwater, thereby compromising the water supply of populations and livestock as well as economic activities including agriculture (Noblet, 2018).

We also know that climate change will impact:

- Upwelling and therefore potentially the fishery resource;
- Swells and winds and therefore potentially reinforce erosion and degrade marine and coastal ecosystems;
- The temperature of ocean waters and therefore potentially marine biodiversity and the spatial distribution of fishery resources;

- Ocean acidification which should increase with a potential impact on biodiversity and coastal ecosystems, in particular shellfish.

Concerning marine biodiversity, certain projections of the effects of climate change on the spatial organization of the specific wealth of 1066 species of fish and marine invertebrates show that the Senegalese maritime space will be among the most impacted by 2050. This change is faster and faster and affects the resilience of the estuarine ecosystem, undermining its balance (Noblet et al., 2018).

The coasts of Senegal comprise the major part of the human settlements, infrastructures and equipment of the country. The level of exposure of this coastal region makes the country particularly vulnerable to the effects of climate change and the hazards it encompasses. In addition to the economic losses it can cause, climate change can lead to forced displacements of populations with humanitarian consequences which it is still difficult to measure. Island villages and densely populated coastal areas, under-equipped and poorly protected, are the most vulnerable and the most exposed to the risks linked to sea level rise and floods (Noblet et al, 2018).

- **Impacts on human settlements**

The manifestations of climate change will be felt in several ways. Rising sea levels, floods, coastal erosion and drought will all have significant consequences for settlements in Senegal (UNDP, 2009). These phenomena will directly or indirectly affect the living environment of populations. Sea level rise could have the most serious direct consequences. The invasion of inhabited areas and the loss of economic production facilities such as landing ports and their annexes can result. The effects of floods, depending on their mode of occurrence, can be understood in three ways:

- A sudden rise in water can have destructive effects on infrastructure and equipment,
- Stagnation of water can lead to forced displacement of the population
- The long duration of stagnation can create the conditions for the development of diseases such as malaria, cholera or bilharziasis. The example of the recent Dakar flood events is a perfect illustration of this.

Figure 3: Abandoned houses due to flooding

Source rapport GEO, ville de Dakar

The indirect consequences on human settlements are linked to the effects of climate change on production activities. Drought and salinization of the land, due to their impact on agriculture, can reduce the incomes of populations who, even in urban areas, still depend heavily on these activities.

Figure 4 : Flooding of 2003’s: cemetery at the south of Guet Ndar in Saint-Louis (Senegal)

- **Impacts on infrastructure**

Climate change will have certain negative effects on the country's infrastructure and equipment. Communication, transport and energy distribution networks, airport and port facilities and buildings are under threat, especially in the coastal zone, which gathers most of them. (UNDP, 2009). Extreme conditions that are likely to become more frequent or intense in some areas include storm surges, floods and landslides caused by local showers, strong winds and forest fires, and bush fires caused by to drought**.**

Figure 5 : Coastal erosion in Toubab Dialaw (Senegal)

The sectors most affected by the unexpected, abrupt changes and extreme conditions are agro-industry, hydroelectricity production, biomass and other forms of renewable energy, energy use, building, transport-related activities or infrastructure located on the coast, or other vulnerable areas (UNDP, 2009).

2.4. Mitigations and adaptation strategies to climate change

Some of the mitigations and adaptations strategies to climate change that have been studied and recommended are discussed in this section.

2.4.1 Mitigation of greenhouse gas emissions

Mitigating GHG emissions simply means reducing their emissions. For a more effective reduction, the most relevant solution is to attack the sources of GHGs and act by sector of activity. But it is possible to act on the gases already emitted to transform them into other substances useful for our activities or to develop the storage of these gases.

From an energy and transportation perspective, GHG emissions can be reduced by substituting fossil fuels with other forms of energy (ADEME, 2018). In this perspective we can make use of the production of energy by photovoltaic cells, electrochemical and nuclear energy, although it is not clean energy. In general, the use of renewable energies (geothermal energy, wind energy, solar energy) is an effective response to the problem of the greenhouse effect. However, their share in global primary energy demand is expected to remain low over the next 30 years (ADEME, 2018). The development of electric vehicles also improves environmental performance linked to transport, provided that electricity produced from a renewable resource is used (ADEME, 2018). On the agricultural and forestry level: the reduction of GHG emissions can be debited by making the connection between reduction and agricultural productivity. The question to ask is how to increase agricultural productivity with less GHG emissions. From the double drainage of the rice fields, yields can improve. The methane that should be released would be consumed in the rice field itself, which can reduce methane emissions by 80% (IRD France, 1999). In fact, this in situ consumption is largely not possible in the paddy fields. On another point, it is useful to improve the means of fertilization. The likely evolution of the chemical fertilizers used for soil fertilization must also be studied.

At the same time, GHG mitigation in connection with the forest requires the reduction of sources of greenhouse gases. At this level, forest fires must be reduced and deforestation reduced. Thus, around 80% of forest clearing operations for shifting or sedentary agriculture can be eliminated and replaced by sustainable cropping systems (Lashof et al., 1989). Maintaining existing carbon sinks requires compliance with forest protection standards. For example, in papermaking, it is interesting to recycle, and replace the useful trees with small plants.

The development of carbon sinks requires an idea of the qualities required for an increased and normal capture of carbon dioxide. For example, identify plants with maximum CO_2 sequestration capacity. This is what made it possible to know that it is by developing plants growing in forests that we are increasing carbon sinks. A young plant consumes more carbon. Studies have shown that several planting mechanisms could be adopted and also that there is more suitable land for the maintenance of forests. As a result, these studies (Lashof et al., 1989) have made it possible to affirm that a type of degraded land potentially suitable for plantations is salty land, provided that it is not used by populations without any other source of land.

In the United States, there are an estimated 46.8 million ha of cultivated land and pasture capable of bearing trees best suited to these environments (Sampson et al., 1992). There are also opportunities to plant fast-growing trees for fuel production. If large areas were planted with trees, they could constitute an additional carbon storage capacity of 66 to 210 million tons per year (Sampson et al., 1992). The development of agroforestry should be given considerations because agroforestry plantations are of capital importance for carbon storage. Agriculture and forestry go hand in hand, if we want to talk about GHG mitigation. By combining the two we can reduce GHG emissions and store as much carbon as possible.

But a problem arises if the efforts to provide mitigation do not go so far as to find systems which will make it possible to eliminate the GHGs emitted.

To provide a surplus, we are interested in what follows in the management of gases already emitted into the atmosphere. The effects of GHGs on the atmosphere can be reduced by causing reactions, which in the long term may modify the polluting nature of these substances.

It is quite possible to transform CO_2, after recovery, into other organic products which can be used for other purposes. For example, carbon dioxide can be converted to methanol or ethanol (Wambach et al., 1999; Alper et al., 2017). The reaction for converting CO_2 into methanol takes place in the presence of dihydrogen and is exothermic, the equation is written in Equation 1 (Wambach et al., 1999; Alper et al., 2017).

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O \qquad \Delta H_{298\,K} = -90.70 \text{ kJ/mol} \tag{1}$$

In addition, methane can be a very important energy source in the future. One possible application is its transformation into methanol, which has the advantage of being a liquid and therefore easier to handle. Methanol could then be used as fuel in fuel cells. Methanol can be prepared from synthesis gas at high pressure and high temperature, but direct conversion of methane to methanol at pressure and at room temperature would be extremely useful (Raffart et al., 2002). Such a transformation is carried out by bacteria which use methane as a source of carbon and energy. The first transformation carried out by these bacteria is the oxidation of methane to methanol according to the Equation 2 (Raffart et al., 2002):

$$CH_4 + O_2 + 2e^- + 2H^+ \rightarrow CH_3OH + H_2O \tag{2}$$

2.4.2 Adaptation strategies to climate change

Adaptation consists in making systems or territories less vulnerable to climate change, through actions that reduce the effective impacts of climate change, or improve the response capacities of societies and the environment. Adaptation is defined by the IPCC as: "adjustment of natural or human systems in response to present or future climatic stimuli or their effects, in order to mitigate the harmful effects or exploit beneficial opportunities».

It is therefore also a question of anticipating the effects of climate change on the environment and therefore on the economy, society, health and daily life, or even valuing certain aspects of it where and when it appears possible.

2.4.2.1 Adaptation options and strategies by sector

1. **Agriculture**

In the agriculture sector, the recommended adaptation solutions are inspired by technological advances, either national or international. They also take into account the feasibility and as much as possible the economic profitability. Some of these techniques are long-term investments which must necessarily be supported and subsidized by the public authorities (MEDD, 2016). In the short term, adaptation strategies are articulated with drought and desertification control programs carried out in Senegal for several years. we can highlight:

- Crop diversification,
- The use of short-cycle varieties,
- The use of varieties tolerant to salinity,
- Water collection and saving (hill reservoirs, retention ponds, fight against water erosion, erection of anti-salt structures, and the installation of windbreaks),
- The dissemination of reasoned fertilization techniques,
- Reorganization of farming systems,
- The establishment of an early warning system in rural areas,
- Institutional support and training of political decision-makers on scientific challenges of climate change, to strengthen their capacities for analysis and anticipation and consequently their reactivity,
- Water control / promotion of local irrigation,
- The promotion of Sustainable Land Management (SLM) technologies,
- Promoting the use of climate information,
- Improving the availability of food (fodder crops, use of agricultural by-products),
- Genetic improvement of species,
- Promotion of suitable endogenous species,
- The fight against emerging diseases,
- Promotion of agricultural / pastoral insurance,
- The scaling up of the concerted management of natural resources.
- Other authors (Descroix, et al., 2015) suggest the development of techniques for infiltrating very useful reserve rainwater, or concentrate it to develop small hydro-agricultural perimeters.

In addition, research activities should focus on:

- The fight against desertification,
- Improving the use of water in agriculture,
- Better recovery of wastewater for agricultural production,
- The selection of varieties of plants tolerating the adverse environmental conditions,
- The development of suitable technical itineraries

For the long term, Senegal, like all countries, must favour activities that generate less greenhouse gases. In the agricultural field, this must translate into a promotion of sources of fertilization which can reduce the need for mineral fertilizers. The promotion of these organic fertilizers can go through sequestration carbon activities which will make it possible to halt the phenomena of degradation of soils linked to land clearing and inappropriate practices

2. Water resources

Climate variability in Senegal is a reality and its impacts on water resources during the last decades have been demonstrated through several studies. Today, the major challenges of preserving water quality in rural areas are based on:

- Shortcomings related to water treatment solutions;
- The inadequacies linked to the monitoring and protection mechanisms of the water quality and the state of knowledge on the quality of water resources and
- Shortcomings related to the quality governance system of the water resources.

The State of Senegal through the Ministry of Hydraulics and Sanitation has initiated adaptation measures to combat the impacts of climate variability (Noblet et al., 2018). By way of illustration, supply networks for access to drinking water have been implemented by the state to provide solutions in the islands of lower Casamance in Ziguinchor. The "Basse Casamance" Islands Drinking Water Supply Project aims to meet the drinking water needs of the populations of the Casamance River Delta zone, limit the exodus of populations and improve their sanitary conditions facilities. It also aims to reduce poverty promote economic activities related to water supply. The project enabled:

- The Realization and equipment of 10 boreholes, supply and installation of 5 generators; Construction of 11 water towers; Completion of the supply and distribution networks over a total length of 142 km; And the realization of 250 fire hydrants.

- The multiplication of water points (by the multi-village option);
- User awareness

3. Coastal Zone

The potential and/or proven effects of climate change on coastal systems (extreme events, increasing sea level rise, erosion and accentuated marine submersions, etc.) increasingly question the vulnerabilities and adaptive capacities of these systems (Wong et al., 2014). From the beginning of the 1990s, the (IPCC, 1990) formulated three options for adaptation in coastal areas which are still the references today:

- Protection, which refers to the construction of hard structures such as dikes, as well as flexible solutions such as dunes and vegetation, to protect land from the sea. These developments allow the maintenance of existing use of land;
- Accommodation (raising or lowering housing), which implies that people continue to use the land at risk, but do not seek to prevent the land from being flooded. This option includes the construction of emergency shelters to protect themselves in the event of a flood, the raising of buildings on stilts, the conversion of agriculture to fish farming, or crops tolerant to floods and salt by example (Noblet et al., 2018).
- Withdrawal, also called strategic withdrawal or "relocation of goods and activities in the face of coastal risks" (MEDDE, 2012), consisting in moving and relocating goods and activities subject to sea weather hazards in the hinterland and associated risks. The withdrawal implies that no effort is made to protect the land from the advancing sea. This choice may be motivated by the fact that protective measures could have excessive economic or environmental impacts.

These options are considered in Senegal. The Initial National Implementation Strategy (SNMO), for example, envisaged in 1998 in its climate action plan the protection of coastal areas and the rehousing of populations.

However, in practice, the various documentary sources consulted reveal various adaptation measures implemented by the government with a predominance for protective measures. Indeed, erosion being an ancient phenomenon in Senegal, the government has been trying for several decades to counter the negative impacts of this natural phenomenon by so-called hard protection measures: dikes, protective wall, breakwater, stabilization of the cliffs. The results of these various measures remain mixed. Indeed, these works, in addition to their high cost (around US $ 16 million since 2010), will not really reduce the climate vulnerability of coastal communities in the long term. Especially since in the case of Senegal, the coasts are mainly low and sandy, the hard structures tend to disturb the sedimentary transit and reinforce the vulnerability of the zones located on both sides. In addition, their lifetime is relatively short (10-15 years maximum). This reactive approach only saves time, but it is not a durable and resilient solution. Several studies have also shown that heavy protective structures have the effect of reinforcing the phenomenon of erosion and amplify the vulnerability of communities in the long term. In addition, the majority of these works erected several years or decades ago are not set up to face the real impact of climate change and therefore cannot be considered as options for adaptation to climate change in a strict sense. In addition, in terms of so-called soft protection, several reforestation campaigns have been observed on the coast over the past decades (measures taken by the government and also by NGOs); but also, artificial beach recharging as at Pilote Barre (there is also a beach recharging project underway in Saly).

Regarding the withdrawal option, some measures have already been observed in the past, notably rehousing operations for populations threatened or affected by coastal erosion at Palmarin Diakhanor in the years 1987. More recently, in 2015-2016, residents of several localities of Saint Louis affected by erosion and marine submersion phenomena (Doun Baba Dièye in Bountou Ndour, Diél Mbame, Mbambara, Guet Ndar and Goxxu Mbacc) have been relocated to social housing in Bango / Ngallèle.

Finally, the government of Senegal recently developed with the support of the European Union its National Strategy for Integrated Coastal Zone Management (ICZM) which integrates the dimension of climate change and adaptation measures into its action plan. . However, this strategy is not very known and its implementation remains limited due to the lack of resources available.

3. METHODOLOGY

3.1 Study Area Description

3.1.1. Geographical location of study area

Casamance is a natural area of Senegal in south-west between latitude 12°20' to 13° North and longitude 16° to 16°50' West with a total area of 52,000 km^2 on 200km length (Figure 6). It is bounded in the north by Gambia, in the south by Guinea Bissau and Guinea, in the east bythe region of Tambacounda and to the west by the Atlantic Ocean. (Ndiaye et al., 2017).

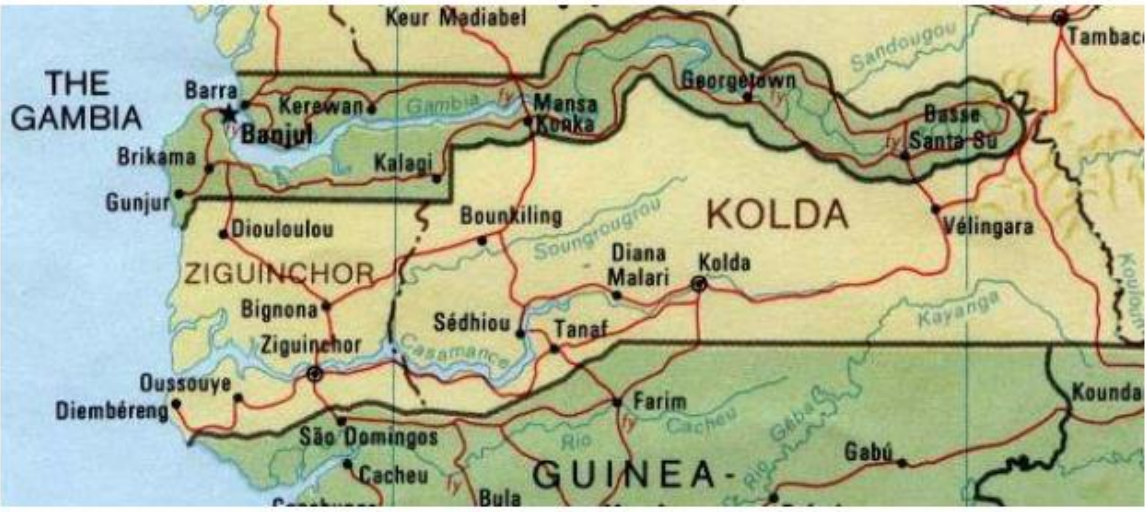

Figure 6 : Geographic location of Casamance regions

It is partially isolated from the rest of the country by the Gambian territory (Cormier, 1991). Casamance river is a small coastal river whose almost entire watershed (20,150 km^2) is located in the territory of Senegal. Only a small southern part of the basin extends to Guinea Bissau. The Casamance basin is composed of low Casamance, middle Casamance and high Casamance.

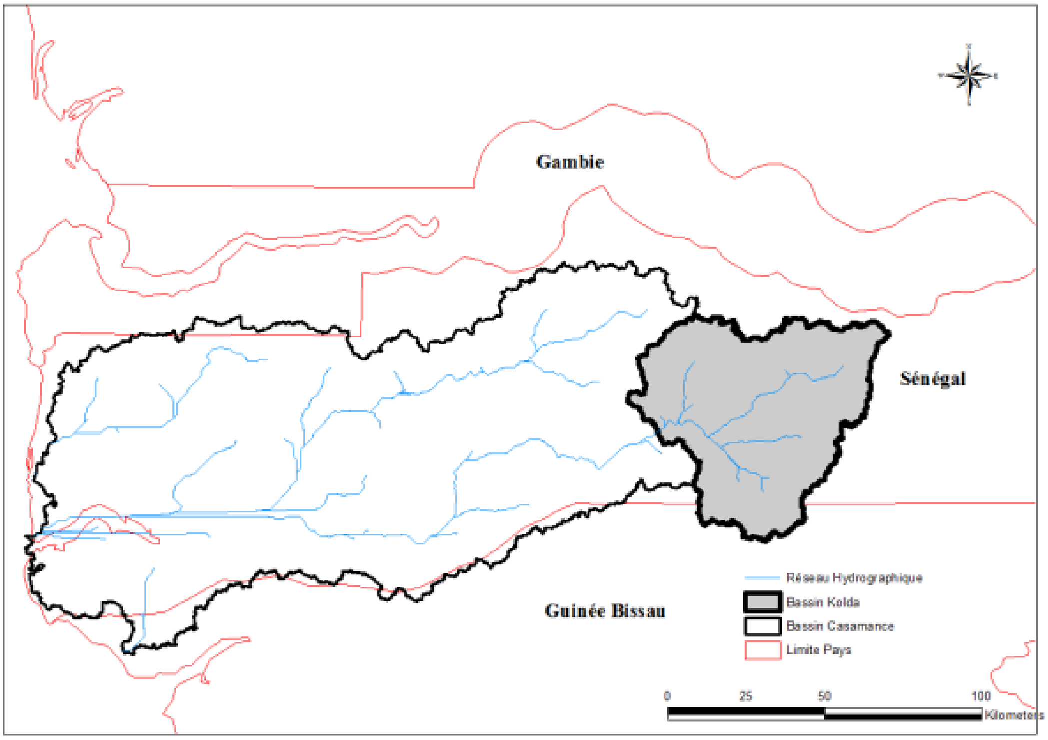

Figure 7 : Geographic location of Casamance basin

3.1.2. Climate

The climate is tropical, sub Guinean type with a strong maritime influence and two seasons: a dry season from November to May and a rainy season from June to October. August is the wettest month (Olivry, 1987). Average annual rainfall is about 1150mm at Ziguinchor and Kolda rain gauges (Dacosta, 1992), Figures 8 - 10. Minimum temperatures range from 15°C to 20°C from December to February. From October to November and March to April, the maximum temperatures turn around 36°C. From July to September, they can reach 33°C (Ndiaye, et al., 2017).

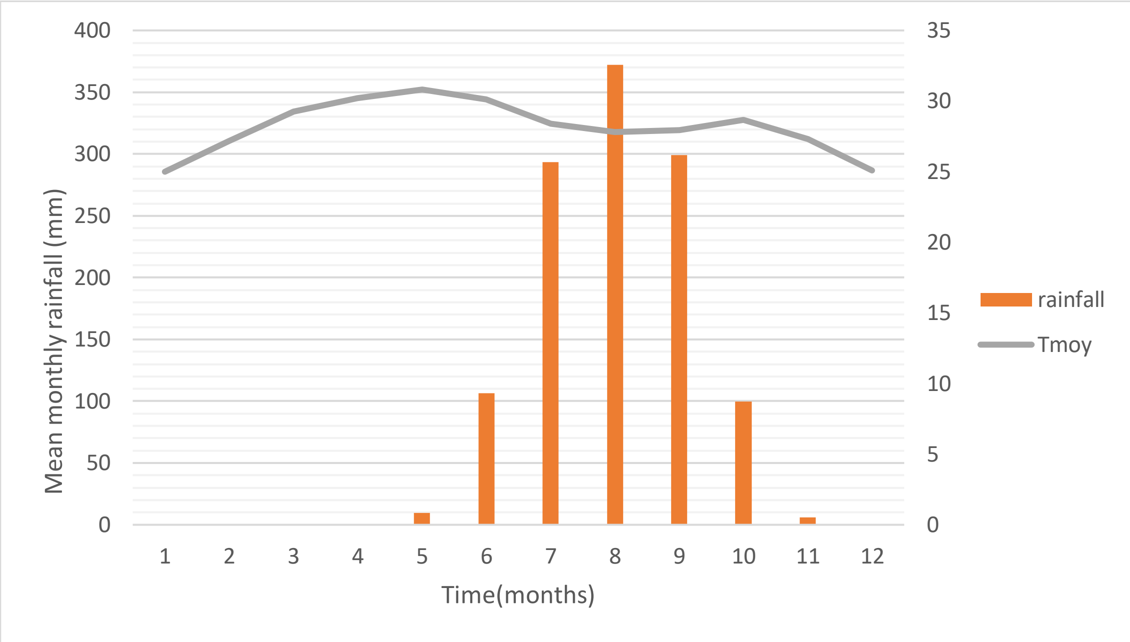

Figure 8 : Mean monthly rainfall and temperature for the period of 1987-2016

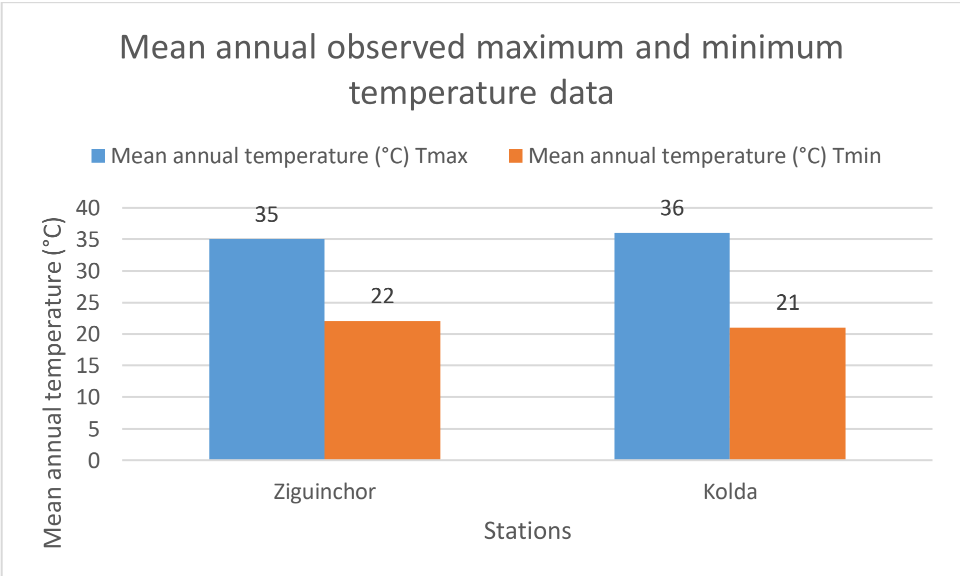

Figure 9 : Mean annual observed maximum and minimum temperature data in Ziguinchor and Kolda stations

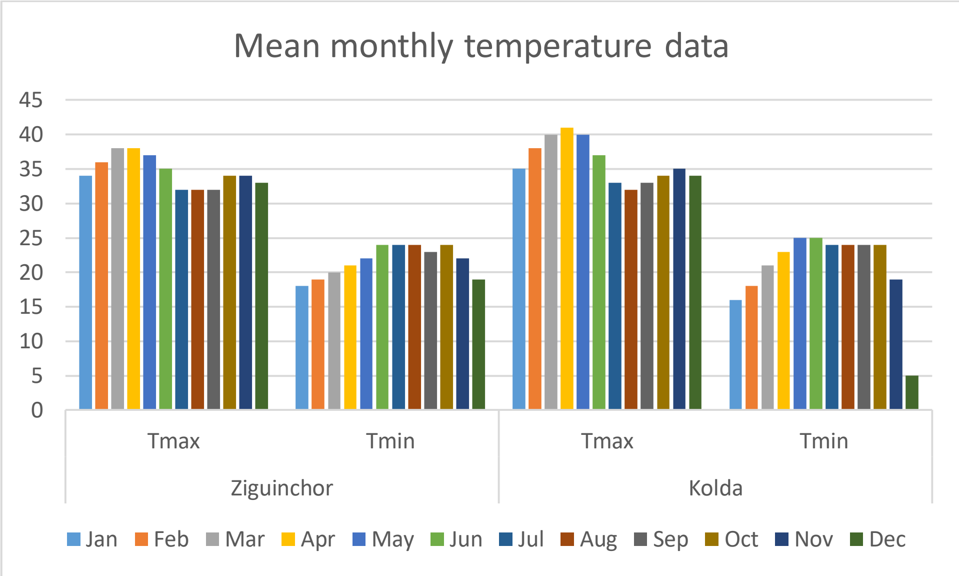

Figure 10 : Mean monthly temperature data in Ziguinchor and Kolda stations

The average temperature is estimated at 28°C. From November to April, the prevailing winds are from North to Northwest sector although we note the presence of hot dry winds (Ndiaye et al., 2017).

3.1.3. Soil types

On the plateaus and terraces that form the lower watershed, the soils are mainly ferrallitic while in the estuary they are hydromorphic or saline. From a soil point of view, at the middle catchment level, the highlands are essentially formed of ferruginous and ferrallitic soils. The soils at the upper basin, essentially ferruginous, cover a lateritic cuirass which outcrops in certain places. (http://www.fao.org/3/x6815f/X6815F06.htm#3134).

3.1.4. Vegetation

The originality of this area lies in its particular ecology which is clearly distinguished from that of the rest of Senegal by higher humidity and denser vegetation.

The vegetation of Lower Casamance is mostly dense semi-dry forest type. It is characterized by sub-Guinean species, the most representative of which are Khaya senegalensis (Caïlcedrat), Afzelia africana (Linké), Parinari excelsa (Mampato), Ceiba pentandra (Fromager), Chlorophora regia (Iroko), Antiaris africana (Tomboiro), Detarium senegalense (Detah) and Erythrophleum guineense (Tali). In the estuary, the mangroves of Rhyzophora and Avicennia take over an area of around 100,000 ha. Vegetation has also been declining there for at least two decades, as a result of land clearing, lawless lumbering, bush fires and drought. (http://www.fao.org/3/x6815f/X6815F06.htm#3134).

The vegetation of the middle Casamance basin is characterized by Sudano-Guinean type formations dominated by Daniellia oliveri, Pterocarpus erinaceus and Bombax costatum. It is also very affected by drought (disappearance of the mangrove, mortality in the palm grove, etc.), the intensification of cutting and bush fires.

The vegetation of Upper Casamance is marked by stands with a Sudanese-Guinean affinity which become lighter as we progress towards the East. Four species predominate in the tree layer Bombax costatum, Pterocarpus erinaceus, Daniellia oliveri and Cordyla pinnata, with an undergrowth composed of combretaceae and Terminalia macroptera (Wolosa). The herbaceous carpet, more consistent than in the rest of the area, is mainly composed of high grasses.

The other main factor in the regression of the forest cover observed since 1980 is constituted by manual agricultural clearings A forest plantation program has been initiated in this sub-area since the late 1950’s for the production of timber with two exotic species, Tectonia grandis (2,400 ha) and Gmelina arborea (1,500 ha).

3.1.5. Hydrography

The hydrographic network of the Casamance basin can be divided into two parts (Dacosta, 1989):

- The sea basin network influenced by the tide
- The continental basin network, where flow measurements are taken.

The hydrographic network includes a vast estuary with a catchment area of around 20,150 Km^2. The water body is essentially made up of the Casamance River with a length of 350 km and numerous tidal channels in the direction of the north. The Directorate of Water and Forests, Hunting and Soil Conservation, estimates the area of water bodies at 300,000 hectares (flood) and 150,000 (low water) (Casamance, 2015). during wet years, the annual module of the river is very low, 2.7 m^3/s with a monthly peak of 32 m^3/s while in dry years, the average annual flow is 1.7 m^3/s. freshwater inputs are estimated at 60 million cubic meters per year at Kolda. (Casamance, 2015).

3.1.6. Slope

From a topographic point of view, the watershed of Casamance is characterized by the low relief. Indeed, all rivers originate on the plateau of the Continental terminal. The weakness of the slopes explains the deep invasion of the sea inside the Casamance basin, thus causing the salinization of agricultural land.

3.1.7. Economic activities

Agriculture constitutes the backbone of the economy of the Casamance basin which meets the ideal rainfall, soil and topographic conditions. The sector employs about 80 % of the population. The primary sector occupies around 90 % of the region's workers for 3 to 4 months of the year (Casamance, 2015). It provides income for producers and plays a key role in feeding the population. Rice cultivation is the most widely practiced (Casamance, 2015).

It is only after the rice harvest that the Casamance people embark on other activities. Men fish, build or maintain homes and harvest palm wine, called "bunuk", 300,000 litres of this alcohol are produced each year. Women do market gardening, picking salt, mangrove oysters, shellfish, processing fish and preparing palm oil.

The potential for fishery products from continental fishing is estimated at 100 tonnes / year per coastal kilometre (Casamance, 2015). Industrial activity is confined to Ziguinchor, processing and packaging of fish, shrimp and fruit, wood factories, and especially peanut oil which generates 90% of the port's activities for the transport of oil.

3.2. Data Collection

The data used are temperature (minimum, maximum, and average), cumulative rainfall and streamflow data. Climate data were collected with the National Agency for Civil Aviation and the Meteorology of Senegal (ANACIM). All data came from Ziguinchor and Kolda stations. Streamflow data was collected with the Ministry of Water and Sanitation of Senegal. The sample size was based on the recommendations of the World Meteorological Organization which advocates the use of a minimum observation period of 30 years for any study on climate change.

3.3. Data Processing Methods

This study is based on the assessment of historical records of temperature, precipitation and streamflow data, recorded since 1987 until 2016. All these historical records were used to make a clear trend of those parameters.

The plotting of trends for analysis was made using Microsoft excel.

4. RESULTS AND DISCUSSIONS

In this chapter, all the data to be used are processed with the purpose to find the trend for each considered parameter. The found results are analyzed and interpreted to assess if any increase or variability in temperature, rainfall and flowrate, has occurred so far.

4.1. Historical Records of Streamflow and Observed Climate Data in Casamance

The Casamance region has a tropical climate. In winter, the regions of Ziguinchor and Kolda are characterized by less rain than in summer. The average annual temperature is 26.7 ° C. Over the year, the average precipitation is 1,269 mm (Debenay et al., 1994).

4.1.1. Temperature

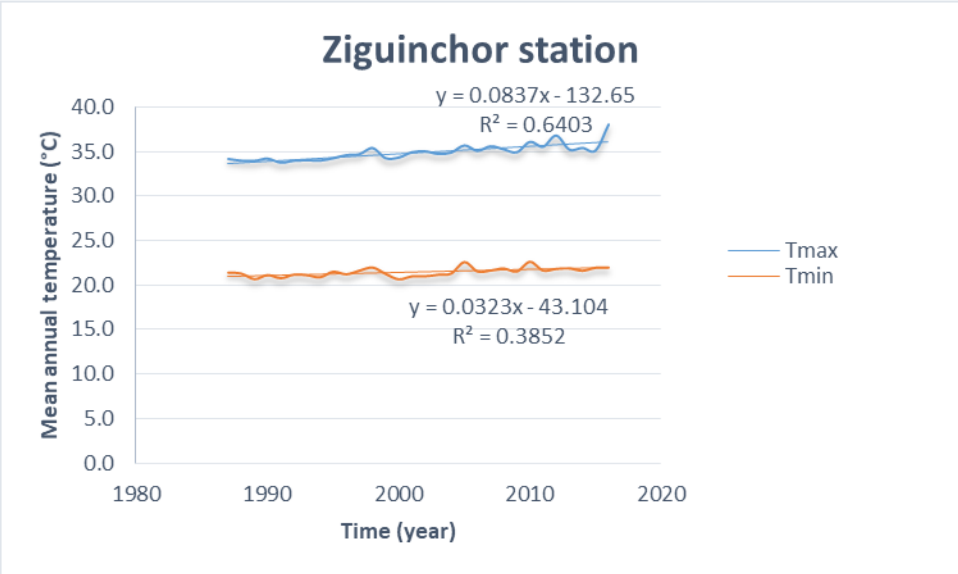

Figure 11 : Annual temperature trend at Ziguinchor station

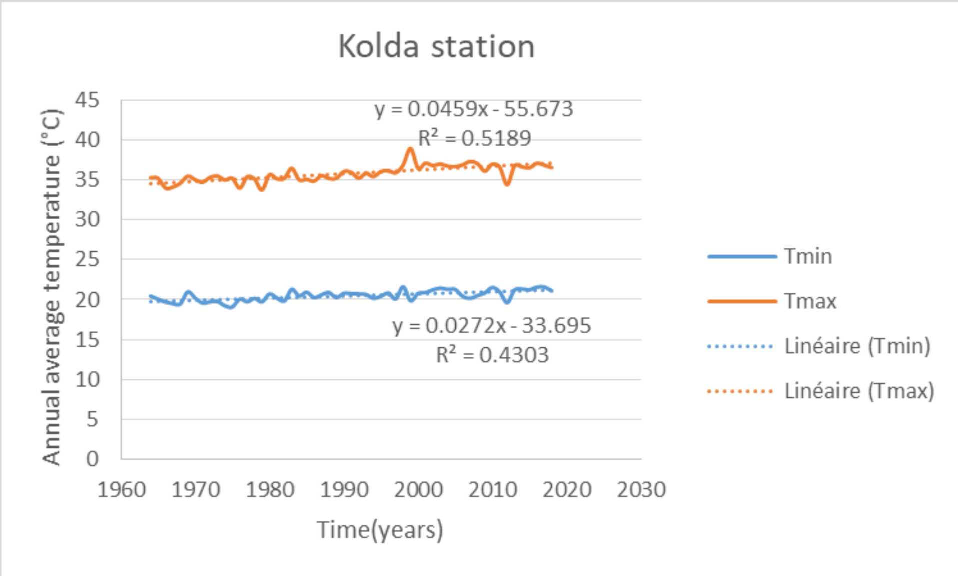

Figure 12 : Annual temperature trend at Kolda station

The plotted temperature trends (Figures 11 and 12) indicate the rise of the temperature in the considered stations**.** According to recent climatological data, the climate of the region of Ziguinchor underwent abnormal evolutions during the period going from 1987 to 2016. Thus, these data show that the climatic parameters such as the temperature, the pluviometry were modified. This development can be illustrated by graphs based on climate data. So:

- At the temperature parameter: there are modifications from 1987 to 2016: The figure represents the maximum and minimum annual average of each year
- 2016 remains the hottest year, based on the maximum and minimum annual average temperatures. This rise in temperature coincides with the highest temperature observed in 2016 worldwide.
- This change in temperature during this period has repercussions on the other climatic parameters. A warming lead to an evolution of the climate as a whole.

4.1.2. Precipitation

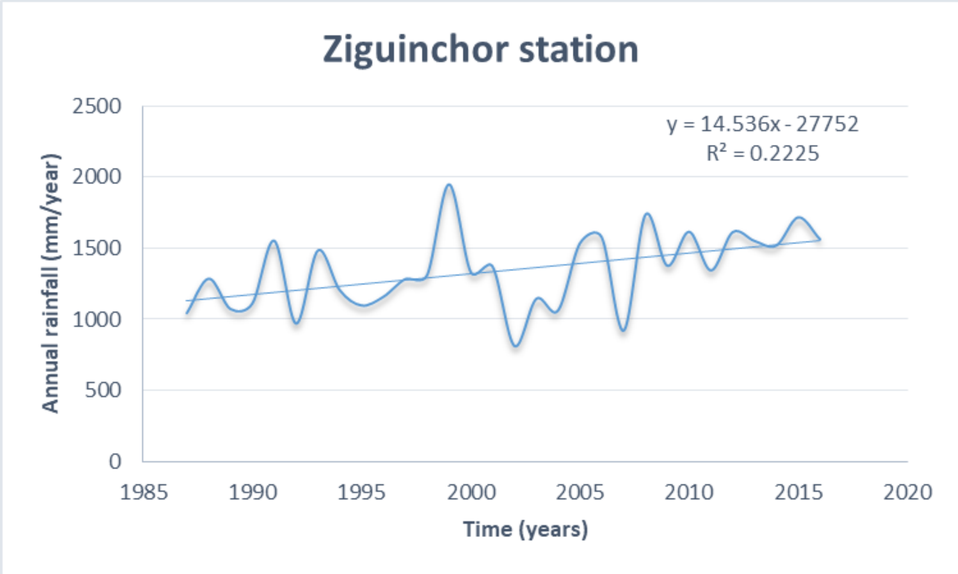

Figure 13 : Annual mean precipitation trend at Ziguinchor station

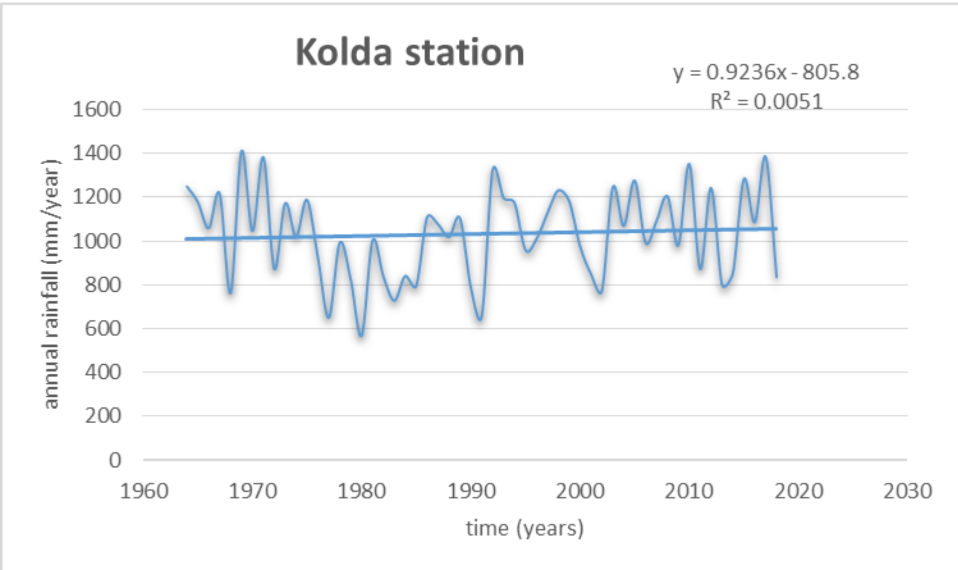

Figure 14: Annual mean precipitation trend at Kolda station

As shown in the Figures 13 and 14, the quantity of precipitation have been varying especially during the period 1970 to 2016.Rainfall trends present too much instability in their variation and quantity.

- At the Ziguinchor station (Figure 13), around the years 1995 to 1997, there was a drop in rainfall while it intensified around 1999 and then returned to a considerable decrease of four years. This region did not experience torrential rains until around 2009, and witnessed a very wet season in 2014.

- In Kolda (Figure 14), around the years 1975 to 1990, there was a drop in rainfall while it intensified around 2000. This region did not experience torrential rains until around 2016.
- Indeed, the evolution of the pluviometry from 1989 to 2016 testifies to modifications of the climatic conditions of the region. No doubt, the results show that there are abnormal changes in the climate whose causes remain to be found.

4.1.3. Streamflow trend at Kolda station

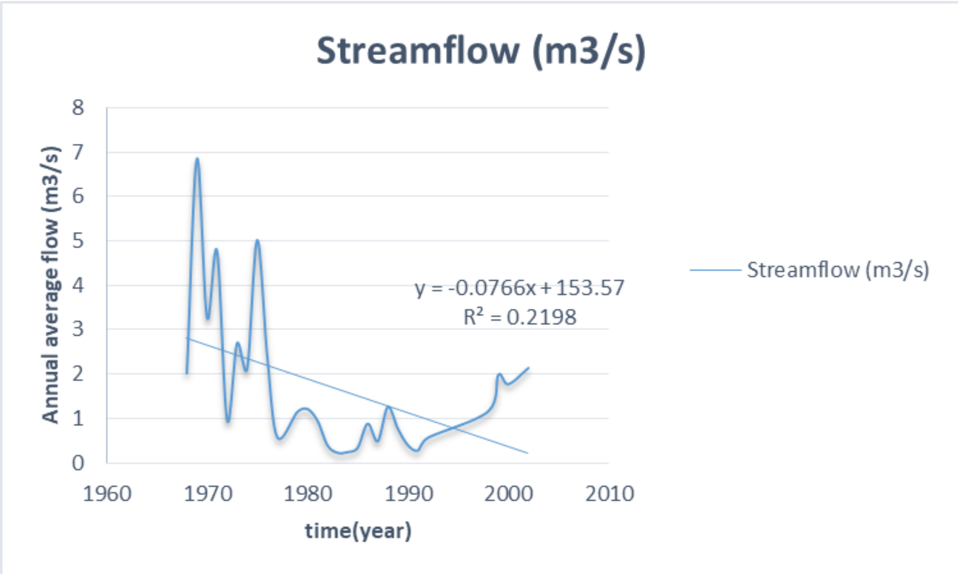

Figure 15 : Streamflow trend at Kolda station

Figure 15 shows a variation of the flow over the period 1964-2002 at the Kolda station. Around the years 1964 to 1977, there was an increase in the flow of the river whereas it returned to a considerable decrease from 1977 until 1995. There has therefore been a considerable decrease in the flow of the river in the past.

To better understand the daily variations, the curve of classified flows was established which gives on the ordinate the value of the daily flow which has been reached or exceeded during the number of days corresponding to the x-axis (Bodian et al., 2015). The characteristic flows were calculated after classification of the daily flows in decreasing order and determination of the various characteristic flows. The general shape of the daily classified flow curves (Figure 16) reveals a very pronounced concavity which reflects the immoderation of the regime. The analysis of Figure 16 highlights the following remarks:

- The flow of the basin greater than 5 m^3/s does not exceed 4 months over the study period 1964-2007;
- Over the current dry period (1977-2007), the flow greater than 5 m^3/s does not exceed 1 month;

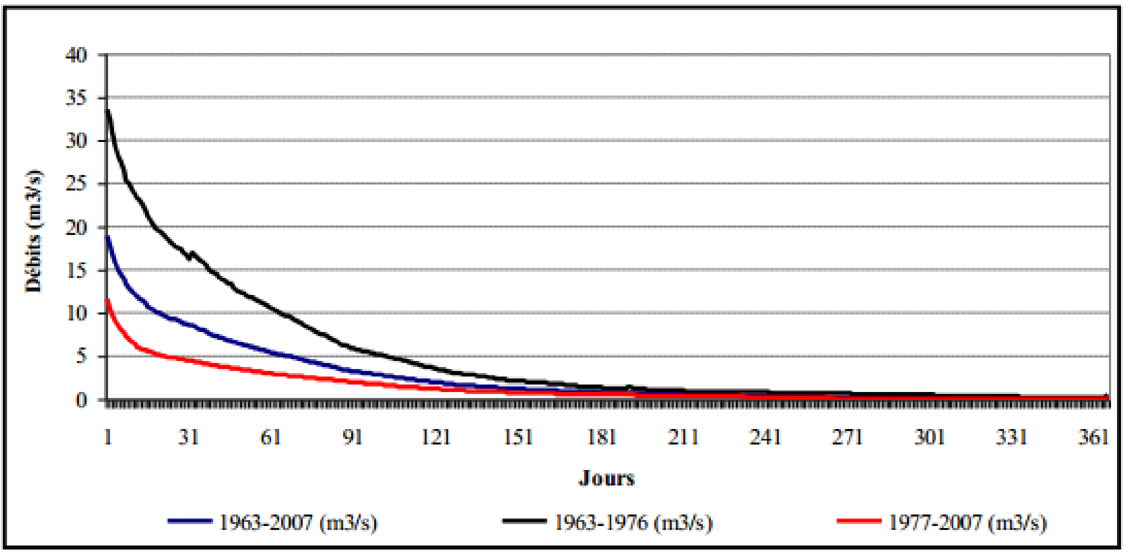

Figure 16: Characteristic flow rates of Kolda Station

Source (Bodian et al., 2015)

The low flow rates mean that today the Casamance bed is gradually being occupied by the urban front of the city of Kolda. This urbanization of the river bed (Fig. 17) in addition to the development of market gardening activities on the banks and in the river bed limit the speed of the water and to a certain extent the water supplies to the part downstream of the basin. (Bodian et al., 2015)

Figure 17: Some illustrations of Casamance River at Kolda during the low water period (a) and during the flood period (b)

4.2. Causes of climate change in the study area

4.2.1 Causes related to the forest

The forest is the sustainable development driver in the lower Casamance, even if the populations are little aware of it. Climate change is accentuated by the degradation of the forest, in the regions of natural Casamance as everywhere else in the world. Among the causes of climate change linked to the forest, logging is prominent. The aggression of the vegetal cover goes back to many years on all the northern facade of the region of Casamance especially in the department of Bignona. The phenomenon experienced a more sustained increase from 2005.

This increased deforestation may be mainly linked on the one hand to the insecurity prevailing in this region. Indeed, the inhabitants of the remote areas fleeing the zones of insecurities, fall back in the cities. However, in these cities, the populations do not have the income necessary for survival. They will return to the forests near the cities of the region. As a result, an uncontrolled cutting of trees is predominant, thereby reducing carbon sinks. This decrease leads to an increase in greenhouse gases such as carbon dioxide and therefore climate change. This shows through this photo that the cut is unplanned.

Figure 18: Logging has become a reality (Ndarinfo, 2015; 2016 survey)

Notably, forest fires are more important in the departments of Bignona and Ziguinchor. It can no longer be denied that this is a threat to the environment, because the compounds entering into combustion during these forest fires contain the carbon element which will be released in the form of CO_2 thus disrupting the radiative system of the earth. As an exemple, the formation of CO_2 from methane can be represented by the reaction given in Equation 3.

$$CH_4 + O_2 \rightarrow CO_2 \quad (3)$$

Charcoal furnaces are also activities that lead directly to increased CO_2 emissions and lower carbon sinks.

4.2.2 Causes related to agriculture

Agriculture is another factor driving climate change in this area. It accentuates CC in two ways: It acts directly through nitrogenated fertilizers which release GHGs upon decomposition. In addition, forest fires linked to agricultural practices release GHGs, the most threatening of which is CO_2. Rice fields also produce methane, one of the GHGs.

Agriculture indirectly decreases carbon sinks. Indeed, its practice requiring well-appointed spaces, farmers will promote deforestation in order to have a good yield. Notably, arable lands increase every year and sometimes new lands are used, so deforestation will be unequivocal.

4.2.3 Impacts of transport and industry

In this region, threats from transportation and industry are very minimal or negligible. But industry and transportation still release small amounts of GHGs. The transport sector emits more greenhouse gases than industry because this area is relatively poor in industries.

4.2.4. Causes related to the combustion of biomass

The combustion of biomass also promotes the increase of GHGs. Biomass is mainly composed of carbon (C), oxygen (O), hydrogen (H) but also nitrogen (N) and mineral matter (found in the ashes) (Hiblot, 2010). Almost every day, people burn household waste and sometimes in large quantities. For example, in Ziguinchor where household waste causes inconvenience to the population, the only way to get rid of it is to burn it. During these operations, greenhouse gases such as CO_2, methane and nitrogen oxides are released. As we have already pointed out, these gases are factors directly influencing the greenhouse effect, which in turn will cause changes in the local climate.

4.3. The Impacts of CC in Casamance Region

4.3.1 Impacts of CC on coastal zones

CC impacts such as sea level rise have recurring consequences on the coasts of the region. The erosion of the Casamance coasts has been noted for some time, which in turn leads to soil degradation and recurrent floods. When the temperature rises, seawater spills onto the river, which causes the water level to rise. In addition, the increase in temperature causes maximum evaporation, which will raise the salt concentration of the sea. This salinization of the sea causes serious problems; the population of marine species decreases and the dwarfism of certain fish is noted. In parallel, the advancement of the sea in turn leads to salinization of the soil.

About 86 km long, the Casamance coastline is an attractive place for significant economic activities especially tourism and high concentrations of people. It is marked with coastal erosion, especially in the islands and other localities on the Atlantic coast (Kafountine, Abéné, Carabane etc.). Evidence of coastal erosion combined with rising sea levels is clearly visible. As an illustration, the Diogué lighthouse is today more than a hundred meters in the water. In less than 40 years, therefore, the sea has gained more than 100 m on land, forcing neighbourhoods to relocate, populations to abandon rice fields, fields and sacred groves. The tourism industry is affected by the destruction of often expensive infrastructure. The scale of erosion is such that many small hotels have had to be converted while the wealthy try to fight this phenomenon in their own way (Sané et al., 2010).

4.3.2 Impacts of CC in agriculture

The economy of Casamance is dominated by agricultural activities: rice, peanuts and cotton, in particular. However, rice cultivation remains a strong tradition and whose imprint is everywhere visible across the agrarian landscape. The ingenuity of the peasants appears through the rice landscape at the edge of the plateaus, under the palm groves, in the shallows, in the mangroves, on salty soils etc. Water shortages and the rise in temperatures have marked the lands to the point of upsetting them (salinization / acidification of the soils, silting up of the shallows, and extension of the valve areas). This crisis in rice cultivation within Diola community (an ethnic group in the region) results from both the rainfall deficit, the decline in soil fertility and the massive departure of young people to urban centres. Another consequence of climate change is a shortening of the rainy season; for example, in 2016, in Djibidione in the region of Bignona, the rain stopped before the rice fields reached their maturity, which reduced the agricultural yield, causing food shortages. Again, by its indirect effects, CC can promote the rapid growth of certain plants and crops, which can lead to huge crop losses if the rain continues (Sané et al., 2010).

4.3.3 Impacts of CC on forests

Still favoured by relatively acceptable ecological conditions, Casamance hosts the most important forest reserves in Senegal with a variety of increasingly anthropogenic landscapes. Lower Casamance covers deciduous species with Guinean affinity such as Chlorophora regia, Borassus aethiopum, Bombax costatum and Khaya senegalensis. The geographic distribution of plant formations is highly dependent on the climate, which at the same time explains their stress in a context of climate crisis. In general, there has been a drop in the area of the Senegalese forest estate of 45,000 ha/year. This situation is explained by rainfall irregularities, high anthropogenic pressure, bush fires, salinization of waters. Furthermore, due to salinization and excessive exploitation, the mangrove has regressed in Casamance since the 1970’s. Its area was estimated at 93,150 ha in 1973 by (Sall, 1980) while (Badiane, 1986) evaluated it at 88,750 ha (Sané et al., 2010). We note a migration of animal species, the forest no longer being adapted to their living conditions, they migrate to areas not yet invaded.

4.3.4. Impacts of CC on water resources

A defining feature of the landscape in Casamance, fresh water has greatly contributed to the emergence of an agrarian civilization of ingenious rice farmers, especially in Lower Casamance, and to shaping the landscapes. Today, the hydrological dysfunction means that the Casamance river functions like a veritable estuary characterized by high concentrations of salt over most of its large watershed significantly affecting adjacent land. The salinization of the waters of the river goes back to around Diana Malary. As for the surface layers of the Continental Terminal, they are more and more affected by the salty bevel especially in island villages like Bandial, thus compromising the supply of drinking water to the populations and their agricultural activities (Sané et al., 2010).

- Evolution of water availability in the Casamance basin at the horizon 2028 (bodian)

Bodian et al, (2015) used climate model outputs to force the GR2M hydrological model in order to make projections on water supplies from the Casamance to Kolda by 2028. Figure 19 presents a series of whiskers boxes which show the statistics of the annual flows projected for 2028 compared to those of the reference period 1983-2007. As an average assumption (RCP 4.5 scenario), two out of five climate models (CCSM4 and MIROC5) predict a decrease in average annual flows varying between -3.3% and -32%. The CNRM, ICHEC and HADGEM2_ES climate models predict an increase in flows of 10%, 41.76% and 138.4% respectively. The average calculated from the simulations of the five climate models gives an increase in flows of 31%. In a pessimistic hypothesis (RCP 8.5 scenario), three of the five climate models predict a drop in flows of between -7.8% and -42.5%. Only two climate models predict an increase of 7.5% to 115.7% in runoff. For the RCP 8.5 scenario, the average of all simulations produces a 12.5% increase in average annual flows (Bodian et al., 2015).

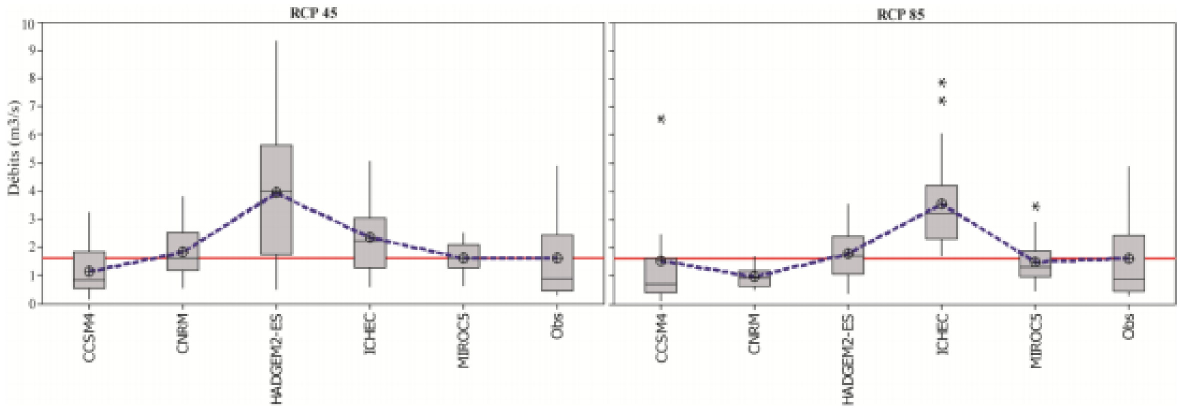

Figure 19 : Evolution of Casamance flows by 2028 (2016-2040) compared to the reference period 1983-2007

Source (Bodian et al., 2015)

The red line represents the average of the values observed over the 1983-2007 reference period.

These results allow us to be optimistic about the future availability of water resources in the basin for the development of agricultural activities. This increase in flows, consequently, of water availability in the Casamance basin is in agreement with the current trend of rains on the scale of Senegal which is characterized by a return to humid conditions even if the precipitated volumes are still lower than the quantities before the great drought of the 1970's (Bodian et al., 2015). However, these results must be handled with great care due to some inherent difficulties both in hydrological modelling and in the uncertainties from climate models.

4.4. Mitigation and Adaptation Strategies at Local Level

4.4.1. Mitigation of local level

In Casamance, human activities contribute to the greenhouse effect, as everywhere in the world. As a result, everyone must comply with standards for the preservation of their environment. This environmental management will necessarily involve reliable actions to minimize GHG emissions. But the problem is how to locally reduce these emissions, and possibly sequester those that are already emitted. Deforestation should be avoided as much as possible, minimize forest fires linked to agricultural practices; make planned cuts and develop agroforestry, as shown in the study by (Bassène F., 2011). The regeneration of forest areas is important in order to increase carbon sinks, that is to say that for any large tree to be cut, to have one or more replacement plants in order to perpetuate the forest.

On an agricultural level, in this region where agriculture is the basis of the economy, it would be useful to review the system of crops and soil fertilization. For example, in rice fields, staff must have training to properly drain. Indeed, a local rice field is a source of large quantities emissions of methane. GHG emissions can be reduced by avoiding this type of rice cultivation. In addition, waste management could help reduce GHGs. If household waste recovery stations are developed in this region, it will reduce greenhouse gas emissions. A solution for sequestering the GHGs emitted must be found and in fact, the recovery and transformation of greenhouse gases is recommended as proposed by several studies (Lashof et al., 1989; Ciesla W. M., 1997). Mitigation can also go through the development of participatory development programs, training and empowerment for all. It is with this in mind that the Association of Volunteers for Environmental Protection and the Young Volunteers for Environmental Protection, were created in the regions of Sédhiou and Ziguinchor for good management of the forest area. Man’s activity is still dominant because he always seeks to live better, and in luxury. Sometimes their needs are decisive in the face of disadvantages, and then become inevitable. Therefore, an adaptation would be better for him.

4.4.2. Adaptations to climate change in the Casamance region

Adaptation to climate change could be better for this local population who live under the impacts of CC. To adapt to climate change, different strategies can be undertaken. Among so many others are:

- In terms of crops: use of short cycle crops, taking into account the reduction in the length of the seasons, and favour irrigated agriculture, so as not to depend on rainfall, vary the seeds and develop agroforestry.
- Build salt retention dikes to deal with salinization and develop a plant culture capable of producing in salty soils.
- Encourage: reforestation, to maintain forest areas, and maintenance of mangroves and their regeneration in order to increase carbon sinks and minimize soil salinization.

- To counter soil erosion, populations can be introduced to the surface protection equipment of cultivable areas, by developing windbreak plants.
- As coastal erosion takes place, people near the coast must be informed of their exposure and leave the area. Otherwise adapt the infrastructure, build dikes to prevent the sea from advancing
- On water management: it is possible to increase the rainwater recovery systems, and to store it.
- Bring people together, in order to better adapt. For example, in Africa health adaptation strategies were developed by African governments. Within this framework, they define the establishment of the Framework for Adaptation of Public Health to Climate Change.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Nowadays, there is a common understanding between scientists and policy makers that climate change is one of the greatest challenges that humanity faces in the 21st century. Climate change appears to be a prolonged modification of climatic parameters such as temperature, rainfall, humidity, sea level. The changing climate is accentuated by human activities. The latter continues to develop its science, the result of which is an uncontrolled GHG emission. GHGs, the most considered of which are CO_2, methane, nitrogen dioxide, ozone, etc., are mainly released by the agricultural, forestry, industrial, transport and above all energy sectors worldwide. The research study on climate change and its impacts in Senegal focused first to point out evidence of climate change in Casamance and secondly to identify the causes, impacts and mitigation and adaptation strategies. For this study, historical records of the climate data that include temperature and rainfall at the Ziguinchor and Kolda stations since 1987 until 2016 were considered. After processing the temperature and rainfall's data records, the climate change was clearly manifested in terms of a much rise of the temperature and changes in usual rainfalls. The temperature increases differ from one station to other. The analysis of rainfall manifested much variation in rainfall's rhythm at all the considered stations. CC are also noted in the region of Casamance: the sea level rises, the rainfall decreases, the forest areas are threatened. In the region, it is the forestry and agricultural sectors that emit more GHGs and the dominant gas remains CO_2 as at the global level. The consequences of CC remain visible in general and in particular in the region of Ziguinchor which weighs more heavily on its agriculture and its forest, its water resources, and its coastal area. But sometimes there are mitigation and adaptation strategies consistent with the changing climate, such as: reducing GHG emissions and carbon sequestration. Support measures have been provided to the populations most affected by this CC, which the State of Senegal has not missed since it has ratified several agreements at the global and national levels. A perspective that will upset the data on climate change would be found if certain gases can be effectively recovered and transform these greenhouse gases profitably. In brief, the results of this study indicate that the observed climate change in Casamance has impacts on many sectors. It is important to note that climate change driven natural disasters events in Casamance have been also amplified on the other hand by human activities and by high density of the population that survive on agriculture.

5.2. Limitations and recommendations

One of the limits in understanding climate change and its impacts is the lack of understanding of the distinction between natural climate variability, the effects of climate change, and anthropogenic effects. Even today, the distinction between these different aspects is not always obvious. This confusion is particularly true in the sector of the coastal zone in Senegal where the current vulnerability is strongly linked to the harmful actions of man on the coast.

In addition, it should be noted that the state of knowledge on climate change in Senegal, especially in the Casamance region, shows that there has been little progress on the real identification of the climate impacts and risks incurred in the medium and long term. Also, it is difficult to have in-depth impact chain studies on strategic sectors, such as water resources and agriculture. Thus, in order to ensure that the issue of climate change is properly taken care of, particularly in policies, it is essential to improve the level of knowledge by taking into account the gaps and limits discussed above. To this end, it is essential to invest in research. More human, financial and technical resources must be made available to the appropriate scientific and climatic services.

Moreover, the latter must benefit from training. This step is all the more important and fundamental as the current systems for monitoring and tracking climate issues are not robust or sufficiently equipped to monitor the impacts of climate change at all levels (national and local). There are also gaps to be addressed in the area of adaptation. Adopting relevant adaptation measures would reduce the vulnerability of populations and the magnitude of the impacts on development sectors. Also, it is a question of advancing on the one hand on the assessment and management of climate risks which can have serious socio-economic repercussions, and on the other hand to take into account the intersectoral consequences in order to develop concrete initiatives on the long term.

Finally, the available scientific knowledge must be regularly discussed and updated, and strongly integrated into the various national policy documents and plans for effective management of climate change.

In order to ensure the safety of its population and its future generation, policy makers should join the global effort and initiative for sustainable development that aim to reduce effects of climate change. Efforts should be improved in regard to environment protection and climate change mitigation. It should be noticed that all the nations are concerned with the harmful impacts of climate change.

In order to reduce the impacts of shift in season and extreme weather events on the agriculture production, modern techniques of agriculture such as affordable irrigation using renewable energies, drainage in wetter land, crop rotation and intercropping, and protected production (using greenhouses), have to be taught and sensitized to the population and make a follow up of their implementation. The current initiated study can serve as a basis for more extensive study. A further and deep research is therefore encouraged and recommended.

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Budget Master thesis Proposal

Tableau: Master Thesis Expenditures

S/No	Item	Quantity	Unit cost ($)	Total cost($)	Total amount (francs cfa)	Link to research activity
(A) Materials and supplies						
2	Internet services	5	36	180.2	100011	access to online trainings and information
5	Scanning, Printing and Binding of Document, Poster and Thesis		0,1 per page	198.2	110001	To have a clear vision of my work, to print some documents and thesis and bind it
	final Total cost			**2325**	**1290375**	