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Par

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CLIMATE CHANGE, MIGRATION AND FOOD IN(SECURITY) IN WEST AFRICA COASTAL ZONES: A CASE STUDY OF SENEGAL

PhD. THESIS

Presented and defended publicly on the 13th November 2025 for the obtention of the grade of Doctor ès Economics Sciences

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CLIMATE CHANGE, MIGRATION AND FOOD IN(SECURITY) IN WEST AFRICA COASTAL ZONES: A CASE STUDY OF SENEGAL

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November, 2025

DECLARATION

I, Khodia Sow, declare that this thesis submitted for the degree of PhD in Economics (option, Climate Change Economics) at the University Cheikh Anta Diop of Dakar (UCAD) /Senegal in the Graduate Program of West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) is my entire work and has not been submitted before wholly or in parts at any other University.

I am also responsible for any error in thinking and omission that could be parts of this dissertation.

DEDICATION

To

God for all grace in my life

All those who participate in my academic journey until this level,

My Father Aliou Sow and My Mother Loly Seck,

Also, to my Husband Djily Diop, My son Mouhamed Rassoul Diop,

My siblings, my Family and Family in-law,

Late Professor Fatou Gueye Lefevre,

My Late Kids, Aminata Diop, and

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ACRONYMS AND ABBREVIATIONS

ACP : African, Caribbean and Pacific

ANSD : National Agency of Statistics and Demography of Senegal

CC : Climate Change

CILSS : Permanent Interstate Committee for Drought Control in the Sahel

CLM : Malnutrition Control Unit

CMU : Universal Health Coverage

CO_2 : Carbon dioxyde

CSI : Coping Strategy Index

ECOWAS : Economic Community of West African States

ELCSA : Latin American and Caribbean Food Security Scale

FAO : Food and Agricultural Organization

FAOIU : FAO Indicator of Undernourishment

FCFA : Franc African Financial Community

FCS : Food Consumption Score

FGT : Foster-Greer-Thorbecke

FI : Fond Insecurity

FIES : Food Insecurity Experience Scale

FSC : Food Security Commission

FSN : Food Security and Nutrition

GDP : Gross Domestic Product

GGW : Great Green Wall

GHI : Global Hunger Index

HDCA : Human Development and Capability Approach

HDDS : Household Dietary Diversity Score

HFIAS : Household Food Insecurity Access Scale

HFSAS : Household Food Security Access Scale

HFSSM : Household Food Security Survey Module

HHS : Household Hunger Scale

HLPE : High Level Panel of Experts on Food Security and Nutrition

IFAD : International Fund for Agricultural Development

IFRC : International Federation of Red Cross and Red Crescent Societies

IHS5 : 5 integrated household survey

ILO : International Labor Organization

IMR : Inverse Mills Ratio

IMT : International Migration Stock

IOM : International Organization for Migration

IPCC : Intergovernmental Panel on Climate Change

MDG : Millennium Development Goal

MPEM : Ministry of Fisheries and Maritime Economy

NAPA : National Adaptation Programme of Action

NASA : National Aeronautics and Space Administration

NELM: New Economics of Labor Migration

NPA : New Agricultural Policy

OLS : Ordinary Least Squares

PAEP : Drinking Water Supply Program

PAISD : Program for Support of Solidarity Initiatives for Development in Senegal

PAPSA : Programme to Accelerate the Pace of Senegalese Agriculture

PCA : Principal COMPONENT Analysis

PNBSF : National Family Security Bursary Program

POU : Prevalence of Undernourishment

PRA : Participatory Research Approach

PSE : Emerging Senegal Plan

SLIVA : Sustainable Living Approach

SNPS : National Strategy for Social Protection

SRV : Senegal River Valley

SVAR: Structural Vector Autoregression

UN : United Nations

UNDP : United Nations Development Programme

UNFCCC : United Nations Framework Convention on Climate Change

UNISDR : United Nations Office for Disaster Risk Reduction

USAID : United States Agency for International Development

VAR : Vector autoregressive

WACA : West Africa Coastal Areas Program

WBI : World Bank Development Indicator

WFC : World Food Conference

WFP : World Food Program

WFS : World Food Summit

WMO : World Meteorological Organization

RESUME

Cette thèse vise à analyser le lien entre le changement climatique, les migrations et la sécurité alimentaire au Sénégal particulièrement dans les ménages pécheurs. Elle se concentre tout d'abord sur l'analyse de l'impact du changement climatique sur la sécurité alimentaire des ménages de pêcheurs sénégalais, ensuite, analyser les migrations comme stratégie d'adaptation climatique pour améliorer de sécurité alimentaire et enfin, elle étudie l'interconnexion entre le changement climatique, les migrations et la (in)sécurité alimentaire. Cette thèse a utilisé des données primaires collectes auprès de 570 des ménages pécheurs sénégalisés mais également des données secondaires. Les techniques d'estimations sont : les moindres carrés généralisés (GLS), Heckman et d'auto-régression vectorielle structurelle (VARS). Les résultats suggèrent que le changement climatique a un impact négatif sur les ménages de pêcheurs sénégalais en réduisant leur revenu quotidien moyen. Les résultats montrent également que la migration est une stratégie d'adaptation au changement climatique pratiquée par les pêcheurs sénégalais. De plus, il y`a une relation bidirectionnelle entre la migration, la sécurité alimentaire et le changement climatique. Il est recommandé, de promouvoir la migration saisonnière, de contrôler également les captures, éviter la surpêche et de promouvoir des stratégies d'adaptation au changement climatique en créant d'autres activités. Ainsi, le gouvernement sénégalais devrait orienter sa politique dans ce sens afin de relancer le secteur de la pêche et de réduire la migration illégale des pécheurs.

Mots clés : Changement climatique, sécurité alimentaire, insécurité alimentaire, migration, pèche, Sénégal

ABSTRACTS

This thesis aims to analyse the link between climate change, migration and food security in Senegal, particularly among fishing households. It focuses first on analysing the impact of climate change on the food security of Senegalese fishing households, then on analysing migration as a climate adaptation strategy to improve food security, and finally, it studies the interconnection between climate change, migration and food (in)security. This thesis used primary data collected from 570 Senegalese fishing households, as well as secondary data. The estimation techniques used were generalised least squares (GLS), Heckman and vector autoregression (SVAR). The results suggest that climate change has a negative impact on Senegalese fishing households by reducing their average daily income. The results also show that migration is a strategy used by Senegalese fishermen to adapt to climate change. Furthermore, there is a bidirectional relationship between migration, food security and climate change. It is recommended to promote seasonal migration, control catches, avoid overfishing and promote climate change adaptation strategies by creating other activities. Thus, the Senegalese government should orient its policy in this direction in order to revive the fishing sector and reduce illegal migration of fishermen.

Keywords : Climate change, food security, food insecurity, migration, Fishing, Senegal

GENERAL INTRODUCTION

The compounding impacts of climate change are reshaping the contours of human development globally. Nowhere is this more evident than in West Africa's coastal zones, where climatic stressors progressively threaten environmental sustainability, economic life support, and food security[1]. These zones home millions of people whose survival and well-being strongly rely on natural resources, especially fisheries. With growing climate variability, these communities are at the forefront of environmental disruption, facing encroaching sea levels, increased flood extent, and erosion, and increasingly frequent extreme weather conditions (Robalino et al., 2025).

In West Africa, and even more in Senegal, small-scale fisheries constitute an integral part of rural and urban economies. It is a main source of subsistence for a significant portion of the population, sustains nutritional needs through fish diets, and is a major source of income and cultural identity. The fishery sector is, nevertheless, highly susceptible to climatic factors. Changes in sea surface temperature, salinity, ocean currents, and seasonal cycles directly affect the availability of fish species and their migratory routes (Mohammed & Uraguchi, 2013). The fishing communities, in turn, are experiencing reduced catches, declining revenues, and increasing uncertainty, which heighten their vulnerability to household food insecurity (Ding et al., 2017).

Migration has become one of the main reactions to such stressors. As environmental and economic conditions deteriorate, some fishermen or their family members migrate voluntarily or are forced to do so in search of new livelihood opportunities, both within and across borders according to the report of OIM[2], (2009). Migration is not a silver bullet, though. It creates new vulnerabilities even as it opens opportunities (Huckstep & Clemens, 2023). The linkages between climate change, migration, and food security are thus multidimensional, interconnected, and complex. Such connections have not yet been examined in a thorough and systematic manner in context-specific terms in the West African coastal context, where empirical research is limited (Huckstep & Clemens, 2023).

[1] https://www.wacaprogram.org/sites/waca/files/knowdoc/7501_WACAreport_final_WEB%20%28002%29.pdf

[2] https://efaidnbmnnnibpcajpcglclefindmkaj/https://publications.iom.int/system/files/pdf/migration_initiatives_09_en.pdf

Food insecurity and climate change are connected phenomena that negatively impact individuals, households, countries, and worldwide migration patterns. For example, (Rostow, 1960) states that as countries modernize, agricultural production and food security should improve with improved technology and capital, which decreases rural labour demand. This decrease in agricultural demand leads to an excess in rural labour supply, and rural residents are thus prompted to migrate to urban settlements, which also attracts migrants through jobs in manufacturing and services.

In addition, it is common to explain the relationship of climate-related migration using the agricultural pathway (Nawrotzki & Bakhtsiyarava, 2017). Authors used the agricultural pathway as shorthand for hypothesizing links between climate change, generally measured by climate anomalies, and rural out-migration that is triggered by impacts on the agricultural sector. More specifically, it is hypothesized that negative climate change impacts on food production push rural individuals and households into urban settlements or onwards to international destinations. Hoffman et al. (2022) have demonstrated that climate change impacts food security by damaging crops and causing livestock mortality or morbidity, negatively influencing livelihoods, which in turn triggers rural out-migration as either for livelihoods diversification or survival strategy, depending on the severity of the impacts Falco et al., 2018).

Senegal is a developing country in the western part of the African continent with around 18 million inhabitants in 2024, and it covers an area of 196,722 km2. The country experiences significant climate variability, especially with rainfall patterns. And this variability is expected to increase with climate change[3] (Ahmed et al., 2021, and Msangi, 2014). Such climate variability significantly affects agricultural systems and the livelihoods of many people, leading to food insecurity, droughts, floods, and head waves. Indeed, in Senegal, floods have displaced more than 56000 people in the east of the country and have destroyed crops and buildings along the Senegal River in 2024[4]. In 2023, floods in Ballou destroyed 80 hectares of rice fields[5]. These factors lead to food insecurity. About 519 000 people were

[3] https://climateknowledgeportal.worldbank.org/country/senegal/climate-data-projections-general
[4] https://www.lemonde.fr/afrique/article/2024/11/04/au-senegal-des-inondations-font-plus-de-56-000-deplaces-dans-l-est-du-pays_6376074_3212.html
[5] https://www.lemonde.fr/afrique/article/2024/11/05/au-senegal-des-inondations-sans-precedent-devastent-les-futures-recoltes-dans-l-est-du-pays_6377819_3212.html#:~:text=En%202023%2C%20ses%20rizi%C3%A8res%20ont,de%20hauteur%20dans%20le%20village.

acutely food insecure during the 2024 lean season in Senegal, but in 2023, the number of food insecure people was much higher, 1.3 million during the lean season (June-August)[6].

These factors combined are pushing some Senegalese to migrate legally or illegally. For example, those who can finance their trip move out of the country legally, but those who cannot afford the amount of money for their travel migrate illegally. Indeed, in 2023, over 32000 people landed on the Canary Islands, and the majority of whom were Senegalese[7]. In 2024, there is an increase in the number of attendees, thus 63970[8]. This irregular migration is mostly practiced by fishermen, and this is very dangerous because it causes many deaths. In 2019, there were 653 deaths compared to 30000 deaths in 2023, but people continue to migrate illegally even though it's dangerous because of a lack of resources, the need to diversify risk, and because of most of the sector's collapse due to climate change and other impacts. Empirically, Steiner et al. (2025) argue that irregular migration is an adaptation strategy.

Additionally, overfishing is also negatively impacting the fishery sector, leading to irregular migration. According to Africa news (2025), overfishing by foreign vessels is decimating fish stocks in the West African country of Senegal, which is in turn fuelling migration to Spain. It found that 57% of fish stocks in Senegal are in a state of collapse, with foreign vessels playing a significant role in declining numbers. The report also states that 43.7% of licensed vessels in the country are foreign controlled, predominantly of Spanish and Chinese origin. This overfishing depletes fish stocks because of this, local fishers are facing income loss, and many of them have turned to migration as a last resort[9].

This thesis is situated in this critical juncture. It aims to explore how climate change affects food security in coastal fishing households, how migration emerges as an adaptation measure at the household level to increase the level of food security, and finally, look at the interlink between climate change, migration, and food (in)security. By bringing Senegal, a country blessed with a long coastline, a vibrant fishing sector, and increasingly significant migration flows, into the spotlight, this research feeds into the quest for stronger insights on the socio-

[6] https://www.google.com/search?q=number+of+food+insecure+people+in+senegal+in+2024&rlz=1C1YTUH_frSN1031SN1031&oq=number+of+food+insecure+people+in+senegal+in+2024&gs_lcrp=EgZjaHJvbWUyBggAEEUYOdIBCTEzMjA3ajBqN6gCALACAA&sourceid=chrome&ie=UTF-8

[7] https://www.euronews.com/2023/11/06/record-breaking-32000-migrant-arrived-in-the-carnary-islands-so-far-this-year

[8] https://www.frontex.europa.eu/media-centre/news/news-release/eu-external-borders-irregular-crossings-drop-by-20-in-first-5-months-of-2025-zF3N3O

[9] https://www.africanews.com/2025/05/14/senegals-fishing-crisis-overfishing-migration-survival/

economic consequences of climate change and the policy actions needed to enhance the resilience of vulnerable communities.

The central issue addressed in this thesis is the climate change susceptibility of West African coastal fisher communities and the resulting socio-economic implications. While worldwide climate models predict widespread warming and oceanic agitations for West Africa, knowledge of the localized, human-centred ramifications, particularly on food security supporting industries like fisheries and rural livelihoods, is lacking (Huckstep & Clemens, 2023). Fishermen are among the poorest and least insured social groups regarding climate risk. Their dependence on weather-sensitive resources, limited access to financial services, lack of formal social protection, and geographical exposure to sea-level rise make them highly exposed (Huckstep & Clemens, 2023). In Senegal, several coastal communities have already been affected by changes in fish availability and catch patterns, leading to decreased incomes and the inability to meet basic consumption requirements (Jönsson, 2019). As conditions of worsening food insecurity intensify, household members come to consider migration as a way of adjustment and gaining substitute livelihood sources (Weldemariam et al., 2023).

But migration is not an automatic or one-size-fits-all solution. Its effects on household food security are both positive and negative, depending on who migrates, to where, and how remittances are used. For some, migration enhances food security by diversifying incomes and reducing reliance on fishing. For others, it can lead to labor shortages, breakdown of families, and dependence on volatile remittance flows (Sadiddin et al., 2019). Moreover, food insecurity is not only an effect of migration but also a cause. As local food availability declines, families may be forced to send members abroad, under sometimes perilous conditions, as a final coping mechanism. This cycle of food insecurity and migration, fuelled by climate change, raises important policy and theoretical issues. From this perspective, we ask certain questions.

The general research question guiding this thesis is:

How are climate change, migration, and food security interlinked in West African coastal areas, particularly in Senegal?

This broad research question is unpacked through three specific research questions, which are:

(1) How does climate change impact food security in Senegalese fishermen's households?

(2) Is the Senegalese fishermen's migration a climate adaptation strategy that improves household food security?

(3) Is food insecurity in Senegal both a driver and an outcome of climate change-related migration?

Hypothetically, the thesis has three hypotheses:

(H1) Climate change in Senegalese coastal areas hurts food security.

(H2) Households with a migrant member are more food secure than those without a member who migrates in coastal Senegal.

(H3) Food insecurity in Senegal is a driver and outcome of climate change-related migration.

This research is based on two interlocking theoretical frameworks:

The Human Development and Capability Approach (HDCA) was introduced by Drèze and Sen (1989), which is centred on real freedoms that individuals have to achieve well-being. It shifts the focus from income or material resources to what individuals can do and be. In the context of this research, this theory calls upon the capacity of fishing households to cope with climate shocks to meet their consumption needs. In other words, this research theoretically seeks to assess, in the face of climate shocks, the capacity of households to meet their consumption needs. Climate change is understood as a force that erodes fishermen's abilities, such as access to healthy food, finding decent work, and remaining in their communities with dignity.

Faced with this major challenge, Senegalese fishermen will implement adaptation strategies in response to the decline of the fishing sector, and among these strategies, the most recurrent is migration. Generally, fishermen send one or more family members to migrate, regardless of the route, whether regular or irregular. Thus, this practice of migration is often a collective decision made by the head of the household to diversify risks. Thus, the migration theory on which this study is based is the New Economics of Labor Migration (NELM). It was developed by Stark & Levhari (1982). The theory considers migration as a household decision, rather than an individual decision. Under it, migration is often undertaken to avoid market failure, share risk, and increase household utility. Migration, according to this view, does not merely appear as a response to poverty, but as a calculated effort to deal with environmental as well as economic risk, particularly so in the context of climate variability.

The thesis employs a mixed-methods empirical strategy, combining household-level survey data with macro-level panel data to discern both microeconomic behaviour and broader systemic trends.

For Essays 1 and 2, data were collected through a structured survey conducted in June–August 2023 among 570 fishermen aged 17 to 70 years in eight key Senegalese coastal centres: Saint-Louis, Kayar, Mbour, Joal Fadiouth, Soumbedioune, Rufisque, Djiffer, and Yarakh. Multivariate regression techniques, including Generalized Least Squares (GLS) and the Heckman selection model, were used to assess the determinants of food security and the role of migration.

For Essay 3, a macro-level panel dataset covering the period from 2000 to 2022 was assembled based on indicators from the World Bank Development Indicators and the Climate Change Knowledge Portal. A Structural Vector Autoregression (SVAR) model was employed to detect causal links between food insecurity, migration flows, and climate indicators of precipitation.

This research adds empirically and theoretically to the existing literature on adaptation to climate change, food security, and migration specially. By focusing on a highly exposed but previously understudied population, Senegalese fishing households, it illuminates the mundane dynamics of environmental change and the diverse strategies that are employed by households in response to this. Indeed, this community, highly representative in the coastal regions of Senegal, plays a significant role in the Senegalese economy because in the country specially in the coastal areas, fishing is the main income-generating activity, accounting for 86% of direct and indirect employment. This is essential as it is not only a source of income but also the primary source of protein in the country. It should also be noted that fishing is the country's main export sector, representing a significant portion of Senegalese exports and contributing 3.3% to Senegal's GDP. Therefore, we focused our attention on this key sector of artisanal fishing.

The second contribution of this thesis to the literature is the proposal of a new food security index that captures at the same time the 6 components of food security. Because in the literature, no indicator considers all dimensions of food security. Indeed, the indicators proposed in the literature generally only address one aspect of food security. For example, the Food Consumption Score indicator proposed by captures food diversity or utilization, while the Household Food Insecurity Access Scale indicator proposed by does not allow for

measuring food sufficiency, as mentioned by Vurukrumu (2014), who emphasizes that utilization does not allow for measuring the quantity of food consumed. Finally, this study, by focusing on this particular community, which is the fishing household, will provide an answer on why fishermen use several fishing strategies, the most common being international migration, which is certainly very dangerous, but they continue to practice it to improve their level of food security. Finally, this community is understudied when it comes to evaluating the impact of climate change on food security by community in Senegal.

The final contribution this thesis makes to the literature is that the problem of irregular migration among Senegalese fishermen has not been addressed in any previous articles. Therefore, it became necessary for us to conduct this study to better understand the concrete reasons that drive this community to engage in irregular migration to ensure their food security in the face of the decline of the fishing sector due to certain constraints such as climate change and overfishing.

My main motivation to investigate this problem is two facts. Firstly, the phenomenon of illegal migration, which is fatal, but Senegalese fishermen keep practicing it. Secondly, the importance of the fishery sector to the Senegalese economy, which is collapsing due to climate change, overfishing, and marine pollution, leading fishermen to migrate irregularly.

This thesis, like all scientific works, has some limitations. The first is about the time for the two studies that used primary data and do not include all fishing centres, because of this, we cannot compare them with other West African countries like Mauritania, Gambia, and Ghana to explain the phenomenon of irregular migration that most fishermen from these countries practice. Also, the primary data does not allow us to capture well the impact of climate change and food security because the variables are dynamic and should be considered at least for several observations. The second limitation of this thesis is the fact that for chapter 2, we do not have information on the fishermen who migrate related to their new occupation, income, or their level of food security at the host country, and finally, it will also be useful to know when fishermen migrate. The third limit is related to the fact that taking all West African coastal areas will be more beneficial in terms of representativity.

The thesis is structured into three empirical essays, each addressing a specific aspect of the overall research problem, followed by a general conclusion section. After the general introduction, the first chapter presents the stylized facts. Chapter 2 focuses on Climate Change and Food Security in Senegalese Coastal Zones. Chapter 3 tries to answer the following

question: Is Senegalese fishermen's migration a climate adaptation strategy to improve food security? Chapter 4 studies the interlinkages between climate change, migration, and food (in)security. After this chapter, the general conclusion follows.

CHAPTER 1: STYLISED FACTS ABOUT CLIMATE CHANGE, MIGRATION AND FOOD (IN) SECURITY IN SENEGAL

RESUME

Le changement climatique est un phénomène mondial qui touche particulièrement les pays d'Afrique subsaharienne, les plus vulnérables à cette variabilité climatique. Le Sénégal, avec son vaste littoral, voit sa jeunesse migrer malgré les difficultés qu'elle rencontre. L'insécurité alimentaire sévit également dans certaines régions, notamment pendant la période de soudure. Pour relever ces défis, le gouvernement sénégalais a mis en œuvre des politiques importantes visant à améliorer les conditions climatiques, à répondre aux besoins de consommation des ménages sénégalais et à réduire le nombre de migrants, en particulier ceux en situation irrégulière. Concrètement, en promouvant une agriculture durable et un secteur de la pêche résilient, le gouvernement vise à accroître les revenus de ces secteurs, améliorant ainsi la sécurité alimentaire et limitant les migrations. Cependant, plusieurs définitions ont été proposées pour chaque concept relative au changement climatique, a la migration et sécurité alimentaire.

Mots clés : Changement climatique, (in)sécurité alimentaire, migration, Sénégal

ABSTRACT

Climate change is a phenomenon that impacts worldwide, particularly sub-Saharan African countries, which are the most vulnerable to this climate variability. Senegal, with its vast coastline, sees its young people migrating despite the challenges that they faced. Food insecurity is also occurring in certain areas, especially during the lean season. To address these challenges, the Senegalese government has implemented significant policies to improve climatic conditions, meet the consumption needs of Senegalese households, and reduce the number of migrants, especially undocumented ones. Specifically, by promoting sustainable agriculture and a resilient fishing sector, the government aims to increase income in these sectors, thereby improving food security and limiting migration. Therefore, several definitions have been proposed for each concept namely, climate change, migration and food security.

Keywords: Climate change, food (in)security, migration, Senegal

Introduction

Climate change, migration, and food insecurity are among the major challenges facing the global population, particularly Senegalese. Regarding climate instability, since 1980, floods in Senegal have become recurrent and increasingly severe, with persistent climate instability[10]. This also leads to the loss of biodiversity in the areas of fishing, agriculture, livestock farming, as well as grazing and forestry. In agriculture, climate change has been exacerbated, especially by reduced harvests, land degradation (Habibullah et al., 2022, Pratchett et al., 2011). This has resulted in a vulnerable and less attractive agricultural sector. Indeed, many farmers are now seeing their children change professions, leaving rural areas for urban areas in search of new income-generating activities. The fishers also are leading the sector while other integrating it.

Faced with these challenges, Senegalese fishermen migrate abroad. This migration impacts food security through remittances from migrants. Migration, a strategy that diversifies income as advocated by the New Economics of Labor Migration (Stark & de Bloom), is also a climate adaptation strategy (Gemenne, 2015). This coastal country is characterized by a vast fishing industry, while agriculture plays a central role in income generation. Indeed, in rural areas, agriculture employs a significant portion of the population and contributes to Senegalese exports. Fishing, on the other hand, is the primary activity in coastal areas.

However, faced with environmental, democratic, and socioeconomic constraints, the income of Senegalese people has decreased, negatively impacting the consumption basket of Senegalese households (Leihr et al., 2016). To address this, Senegalese have attempted several action plans, some of which are interconnected, particularly regarding climate change and food security. To deal with all these issues, the Senegalese government have implemented several policies. Migration are mostly policies or monitoring programs aimed at supporting returning migrants and their economic and social reintegration. While food security and climate policies are generally interconnected.

The main objective of this chapter is to provide a detailed overview of the key concepts of this study, to assess the current state of these concepts in Senegal, and to present the various climate, migration, and food security policies.

[10] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.gfdrr.org/sites/default/files/publication/soi-senegal-flood.pdf

This chapter is structured as follows: first present the definitions of concepts such as climate change, migration, food security, and food insecurity. Next, we will present the general characteristics of Senegal in Section 2. Section 3 discusses climate policies, followed by Section 4, which examines food security policies. Section 5 outlines the various migration policies, and Section 6 concludes.

1.2. Definition of the concepts facts about changing climate, migration and food security

In this section, the diverse definitions of the terms used are provided. In the second part, the general characteristics of Senegal and these variables are described, and finally, the different policies to deal with climate change, migration, and food insecurity are presented.

a) Climate change definitions

Climate change (CC) remains a global concern because it damages the world and all its sectors directly or indirectly. The concept has several definitions presented below.

Climate change (IPCC, 1995) definition stated climate change as referred to in the observational record of climate occurs because of internal changes within the climate system or in the collaboration among its mechanisms, or because of vicissitudes in outside compelling, either for natural details or because of human doings/activities. According to this institute, climate change can be considered as "any change in climate over time, whether due to natural variability or as a result of human activity". This definition differs from the (United Nations Framework Convention on Climate Change, 1992. Article 1)[11] definition, which refers to climate change "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods".

Dellasala and Goldstein (2017) argue that changing climate refers to a change in means and variability of, for instance, temperature, precipitation, and wind over the course of months to millions of years. Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. Also, climate change is defined as the average weather over a long period, specifically 30 years or more (Chadwick, 2019).

[11] https://unfccc.int/resource/ccsites/zimbab/conven/text/art01.htm

Climate change can be referred to as only human-induced changes in the climate system (UNFCCC, 1995).

Climate change refers to long-term changes in average weather conditions (WMO, 1992, 2005).

According to NASA's scientists [12]climate change is "a broad range of global phenomena created predominantly by burning fossil fuels, which add heat-trapping gases to Earth's atmosphere. These phenomena comprise the rising temperature trends described by global warming but also cover sea-level rise; ice mass loss in Greenland, Antarctica, the Arctic, and mountain glaciers worldwide, and extreme weather events". Furthermore, Dugué (2012) argues that climate change is a delay in the arrival of rains, a variation in the height of rainwater, and increase in the frequency and violence of extreme weather events such as cyclones and floods.

Climate is the average pattern of weather for a particular place over several decades (at least three decades) (Olayide et al., 2016).

Climate change refers to the long-term changes in the Earth's climate that are warming the atmosphere, ocean, and land (Climate dictionary, 2023)[13].

The terms environmental change and environmental degradation can also refer to climate change. Environmental change is changes in the physical and biogeochemical environment, over a large scale, either caused naturally or influenced by human activities" (Foresight, 2011:50) (including industrial accidents), either through fast-onset or slow-onset events. While the reduction of the capacity of the environment to meet social and ecological objectives and needs is attributed to environmental degradation according to (UNISDR, 2009). Degradation of the environment can alter the frequency and intensity of natural hazards and increase the vulnerability of communities. The types of human-induced degradation are varied and include land misuse, soil erosion and loss, desertification, wildland fires, loss of biodiversity, deforestation, mangrove destruction, land and air pollution, climate change, sea level rise, and ozone depletion." (UNISDR, 2009).

[12] https://www.photoop.it/en/events/everydayclimatechange-fotografare-il-cambiamento-climatico/#:~:text=Climate%20change%20refers%20to%20a%20broad%20range%20of,with%20severe%20dramatic%20effect%20on%20our%20daily%20life.

[13] https://climatepromise.undp.org/news-and-stories/climate-dictionary-everyday-guide-climate-change

b) Food security definitions

Concepts of food security have evolved in the last thirty years to reflect changes in official policy thinking (Clay, 2002; Heidhues et al., 2004). The term first originated in the mid-1970s, when the World Food Conference (WFC, 1974) defined food security in terms of food supply - assuring the availability and price stability of basic foodstuffs at the international and national level:

"Availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices". In 1983, FAO analysis focused on food access, leading to a definition based on the balance between the demand and supply side of the food security equation: "Ensuring that all people at all times have both physical and economic access to the basic food that they need" (FAO, 1983). The definition was revised to include the individual and household level, in addition to the regional and national level of aggregation, in food security analysis. In 1986, the highly influential World Bank Report on Poverty and Hunger (World Bank, 1986) focused on temporal dynamics of food insecurity (Clay, 2002). The report introduced the distinction between chronic food insecurity, associated with problems of continuing or structural poverty and low incomes, and transitory food insecurity, which involved periods of intensified pressure caused by natural disasters, economic collapse, or conflict. This was complemented by Sen's theory of famine (1981), which highlighted the effect of personal entitlements on food access i.e., production, labour, trade, and transfer-based resources.

The widely accepted World Food Summit (WFS), (1996) definition reinforces the multidimensional nature of food security and includes food access, availability, food use, and stability. It has enabled policy responses focused on the promotion and recovery of livelihood options. Initially made popular by academics such as Chambers and Conway (1992), livelihood approaches are now fundamental to international organizations' development programmes. They are increasingly applied in emergency contexts and include the concepts of vulnerability, risk coping, and risk management. In short, as the link between food security, starvation and crop failure becomes a thing of the past, the analysis of food insecurity as a social, and political construct has emerged (Devereux 2000).

According to the World Bank (1986), food security is defined as "access to food at all times to enough food for an active and healthy life». This definition implies that indicators of warning systems for food insecurity are related to food production, distribution, and

consumption. The UNDP definition considers food security to be the possibility of access to food both physically and financially (UNDP, 1994).

Considering all meaningful aspects, the concepts around the food security definition, four pillars are involved to measure its availability, stability, access, and utilization. The food availability refers to having enough and appropriate quality food for consumption. It is provided via domestic production, distribution, imports, exchange, or food aid (Clay 2002; Webb and Rogers 2003). Food access relates to the ability of households or individuals to secure adequate resources/entitlements (i.e., sufficient food and a nutritious diet), be it through purchasing, producing, or from any other source (e.g., transfer, gifts).

Food utilization refers to meeting individuals' physiological needs to reach a sound nutritional well-being, and it stresses the significance of non-food inputs. It combines food safety and quality issues (i.e., clean water, sanitation, health care) with adequate diet intake to enable the absorption of nutrients (Clay 2002; Webb and Rogers 2003). Food safety (food hygiene) is defined as a scientific method describing handling, preparation, and storage of food in ways that prevent foodborne illness. The occurrence of two or more cases of a similar illness resulting from the ingestion of a common food is known as a food-borne disease outbreak[14]. This aspect of food security is very important because when it is not careful respected the food consumed can cause diseases.

The food stability dimension was ingrained in the literature after stipulating "all times" in the FAO's food security definition (1996). Food stability addresses the inherent, impending, or conditional risks such as a sudden shock (e.g., economic or climatic crisis) or cyclical events (e.g., seasonal food insecurity) that affect the other food security pillars such as availability, access, and/or utilization (Clay 2002; Webb and Rogers 2003).

The definition of the concepts of food insecurity is broad and includes many different understandings and its meaning has changed over time (FAO, 2003). The FAO's own definition of food insecurity is a "(. . .) situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active, healthy life".

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https://www.google.com/search?q=Texas+Food+Establishment+Rules.+Texas+DSHS+website%3A+Texas+Department+of+State+Health+Services.+2015.+p.+6.&rlz=1C1YTUH_frSN1031SN1031&oq=Texas+Food+Establishment+Rules.+Texas+DSHS+website%3A+Texas+Department+of+State+Health+Services.+2015.+p.+6.&gs_lcrp=EgZjaHJvbWUyBggAEEUYOdIBBzg5NGowajeoAgCwAgA&sourceid=chrome&ie=UTF-8

United Nations World Food Program (2016) defines food security as built on three pillars: (1) food availability, that is, sufficient quantities of food available on a consistent basis; (2) food access, or sufficient resources to obtain appropriate foods for a nutritious diet; and (3) food use, or the appropriate use based on knowledge of basic nutrition and care, as well as adequate water and sanitation. These dimensions of the food security concept, however, need to be viewed in a dynamic context, where food and nutrition insecurity compromises the resilience of poor people and developing countries with low income and thus worse economic insecurity, often eroding societal cohesion (von Braun, 2014). Therefore, these dimensions are linked in the way that availability, access, and utilization are hierarchical in nature. The dimension of food availability is necessary but not sufficient for access, and access is necessary but not sufficient for utilization (Webb et al., 2006).

A successful design of food policy addresses all three dimensions, including stability. When there are gaps in any of these dimensions at the national level, policymakers should pay attention to the dimension as a high priority. For example, there is plenty of food available in a certain country, but the consumers face challenges in accessing the food commodities, and/or the food stability or utilization in the country is lacking, then such a case represents a threat and requires the policy design to address such a lack (Fathelrahman & Muhammad, 2016).

It refers to the stability of the first three components, such as availability, access, and utilization. Food stability is when a population, household, or individual has access to food at all times and does not risk lose access because of cyclical events, such as the dry season (Fisher, 2017). At the Household level, stability of food means a household`s access to nutritious food of high quality at all times (FAO, 2012). Food stability can be compromised may climate conditions. Thus, under extreme climate conditions, food production may decline, which will impact food availability and food prices. Poor and ultra-poor households are the most affected by an increase in food prices. Food supply systems can also be destabilized due to government bioenergy policies that lead to the substitution of farmland for biofuel production (Elbehri et al., 2013).

Recently, two new dimensions have been added in food security pillars to better capture food security and meet the SDG2, which refers to achieving the goal of zero hunger in 2030. These two dimensions are agency and sustainability, each has been widely recognized in the scholarly literature as being relevant to food security for several decades (Clapp et al., 2022).

Figure 1: The six components of food system

Source: ***HLPE-FSN 2020***

The agency is the capacity of individuals or groups to make their own decisions about their engagement with food systems and their ability to participate in processes that shape food system policies and governance (HLPE, 2020). While sustainability refers to food system practices that contribute to long-term regeneration of natural, social, and economic systems, ensuring that the food needs of the present generations are met without compromising food needs of future generations, (HLPE-FSN, 2020; HLPE, 2021).

Food insecurity emerges from these definitions as a corollary and can be defined as any risk that could compromise food security. These risks relate to events that may affect food production, market access, or food prices. Climate change or extreme climate (floods, droughts, and heat waves) is certainly not without effects on food security. Another definition from the US department of agriculture is that, food insecurity can be defined as "a household-level economic and social condition of limited access to food" (Gundersen & Ziliak, 2016). According to (Thompson et al., 2010), food insecurity occurs when food systems are disturbed at the situation where food is not available (production, distribution, and exchange), accessible (affordability, allocation, and preference), or utilization (nutritional value, societal value, and safety) is constrained. Therefore, it can be defined as its sounds, when a person is without reliable access to enough affordable, nutritious, healthy food.

Famine and hunger have the same meaning as food insecurity. According to food security analysts, it has two general types of food insecurity. Food insecurity can be categorized as either chronic or transitory.

c) Migration definitions

Migration is the movement of a person or a group of people, either across an international border or within a state. It is a population movement, encompassing any kind of movement of people, whatever its length, composition, and causes.

(IOM, 2019)[15] state that a migrant is any person who is moving or has moved across an international border or within a state away from his/her habitual place of residence, regardless of (1) the person`s legal status; (2), whether the movement is voluntary or involuntary; (3) what the causes for the movement are; or (4) what the length of the stay is.

Migration in general, and international migration in particular, is a complicated concept because "its measurement depends entirely upon how it is defined in time and across space" (Skeldon, 2017).

Human beings have been moving from place to place for several reasons. This migration can be motivated by economic, social, political, or environmental reasons from the earliest days (Koser, 2016). But Kok, (1999) defines it as the movement of people that involves a change in usual residence across an administrative boundary such as a village, town, district, or country.

[15] https://weblog.iom.int/who-migrant

Migration has two forms. When it is described as the number of people entering a receiving area, it is immigration. The second form is emigration, which means the flow of people from a country over a given period. Moreover, there are two types of migration, namely internal and external migration. When migrants move within their country it is qualified as internal migrants; and international migration, which is a situation where migrants live outside of their country of birth for at least one year (Poulain and Perrin, 2001).

Additionally, Koser (2016) criticizes the definition of migrant because of four (4) reasons. According to him, defining a migrant as" someone living outside their own country for a year or more" does not provide a complete answer to the question "who is a migrant" for various reasons. First, the concept "migrant" covers a wide range of people in a wide variety of situations. Second, it is very hard to count migrants and to determine how long they have been abroad. Third, just as important as defining when a person becomes a migrant is defining when they stop being a migrant. Finally, it has been suggested that, because of globalisation, there are now new "types" of migrants with new characteristics, for example, comprising transnational communities or diaspora (Koser 2016, p. 14).

Migrants include also those who are forced into exile, and this connects to the idea that people migrate voluntarily or involuntarily for socio-economic and political reasons (Bauman 1996; Kempf 2006). Bauman, for instance, considers tourists those migrants who are displaced voluntarily. He calls vagabonds those who are forced to leave their country due to war, persecution, and extreme economic hardships in transit.

Accordingly, the term "migrant" encompasses displaced people: "individuals who are forced to move against their will" (Shamsuddoha et al. 2012, p. 18). People are also classed as internally or externally displaced depending on whether they crossed their countries' borders or not. Internally displaced people flee their homes, but they remain within their country of origin. They might receive a supply of relief materials such as food, medicines, and other basic facilities, but they are not entitled to refugee status under the UN convention (International Committee of the Red Cross, 2010). Refugees often cross international borders due to a lack of protection from their government. The 1951 Geneva Convention highlights the distinctive features of refugees.

1.3. General characteristics of Senegal

Figure 2 : Senegal and its border countries

***Source* : Britannica web site, 2006**

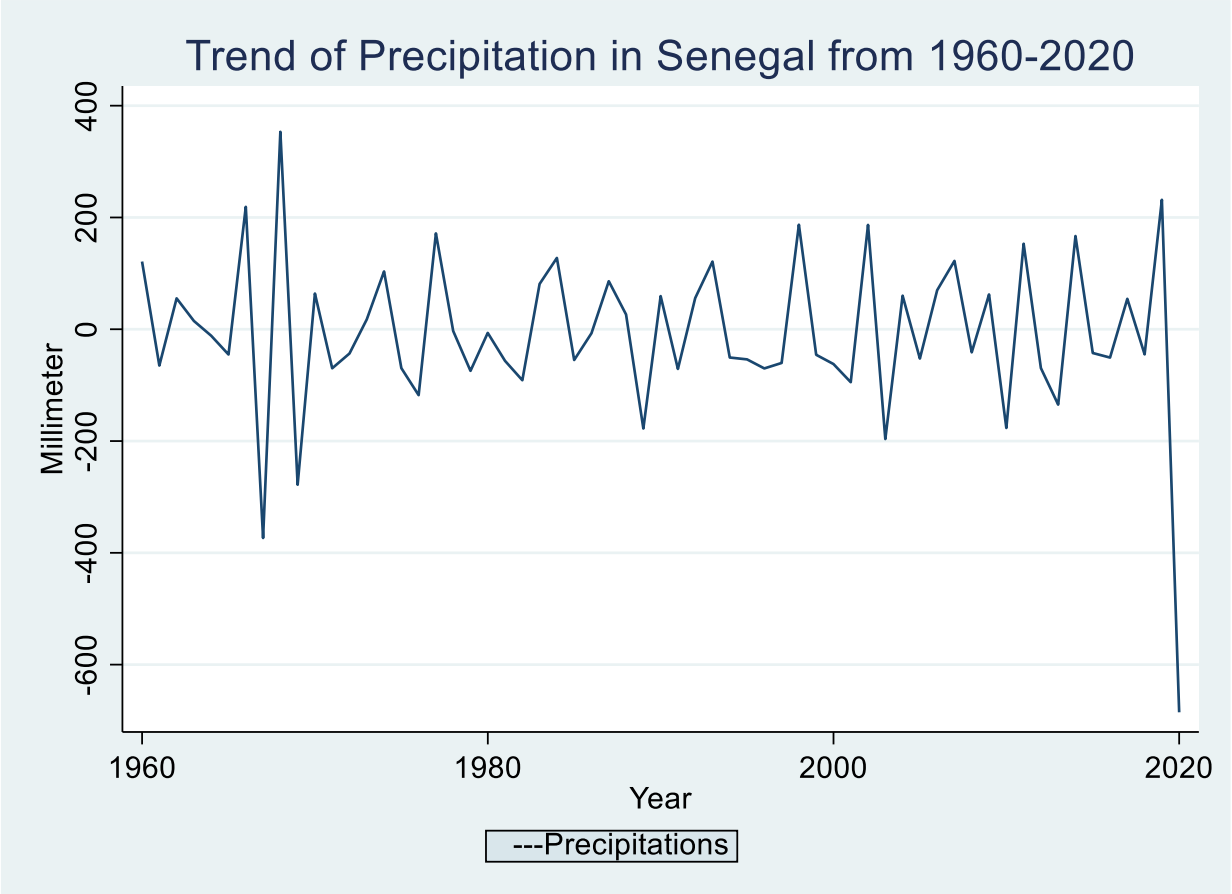
Senegal is in the western part of the African continent, more precisely in the Sudano-Sahelian zone of West Africa. The country is bordered to the west by the Atlantic Ocean, to the north by Mauritania, to the east by Mali, and to the south by Guinea, Guinea-Bissau, and The Gambia. Senegal covers an area of 196,722 km². In 2024, Senegal's population is estimated at 18,593,258 inhabitants 2024.

The climate in Senegal is primarily Sahelian to tropical, divided between wet and dry seasons. It is mostly influenced by the West African monsoon system and is highly sensitive to climate variability and change. The dry season is from November to May, dominated by Harmattan

wind (dry, dusty northeast wind from the Sahara). During this season, there is little or no rainfall. While the rainy season (monsoon) is between June and October, peaking in August-September. This period represents 70-90% of the year's precipitation. This rainfall is mainly due to moist south westerly winds from the Atlantic Ocean.

The country is divided into three climate types. In the northern part, it concerns Saint-Louis and Matam regions. In these zones, the climate is Sahelian semi-arid with low rainfall, hotter and drier. The centre group, Kaolack and Thies regions. The climate is transitional Sahelian Sudanian with more rainfall than the north. And the southern part is characterised by a tropical humid climate and high rainfall. The figure below presents the variation of Senegal`s rainfall from 1960 to 2020. It shows how rainfall is unstable in the country.

Figure 3: Precipitation Trend in Senegal From 1960-2020

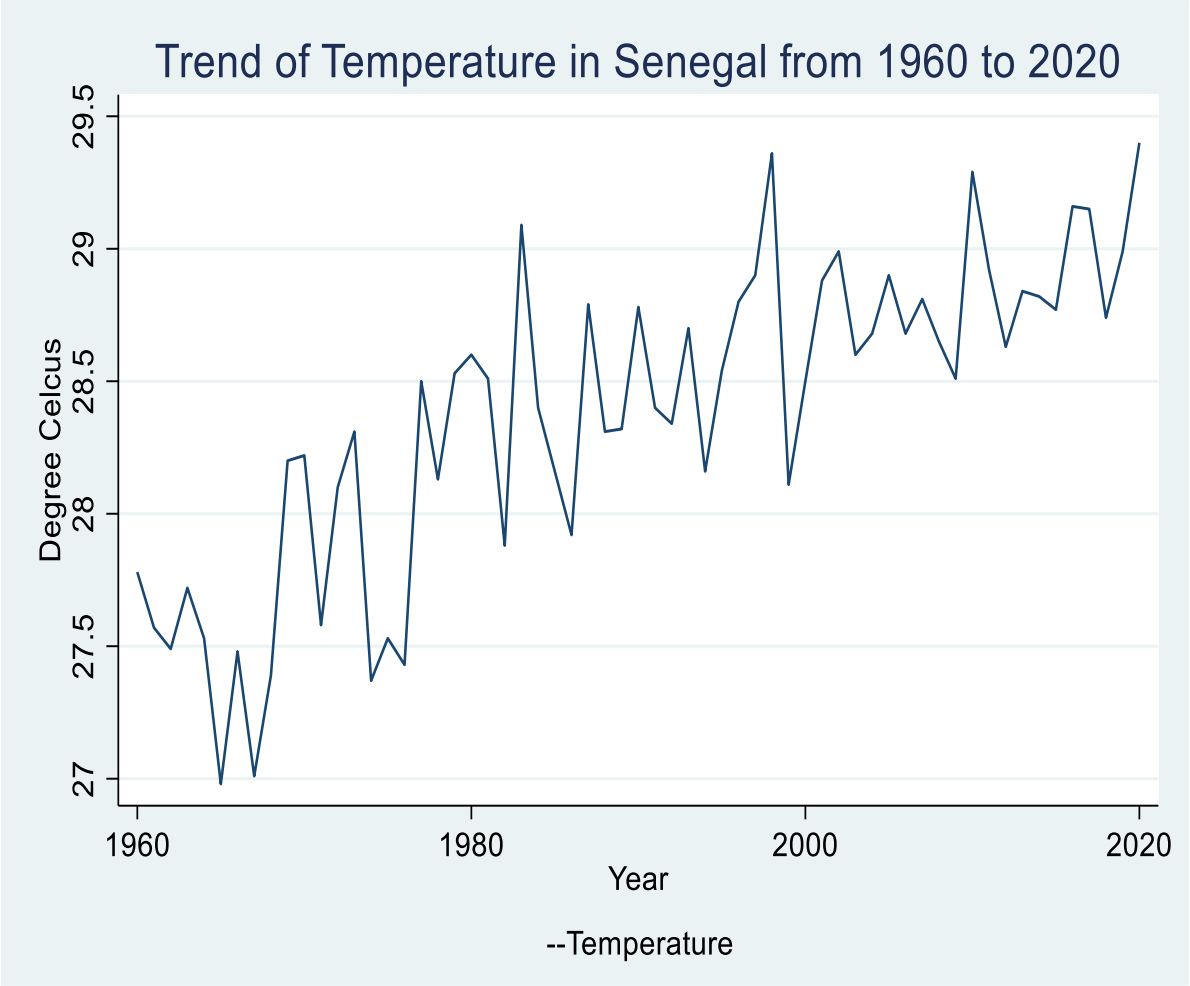


Source : Author, using WBI data, 2025

The country is also characterized by unstable temperatures from 1960 to 2020. The alarm`s information is the fact that, the temperature is increasing over time. This increase in

temperature impacts negatively the fishery sector, particularly because the sea surface temperature is also increasing, causing, sea level rise (Sakho et al., 2022).

Figure 4: Temperature trend in Senegal from 1960-2020



Source ***: Author, using WBI data, 2025***

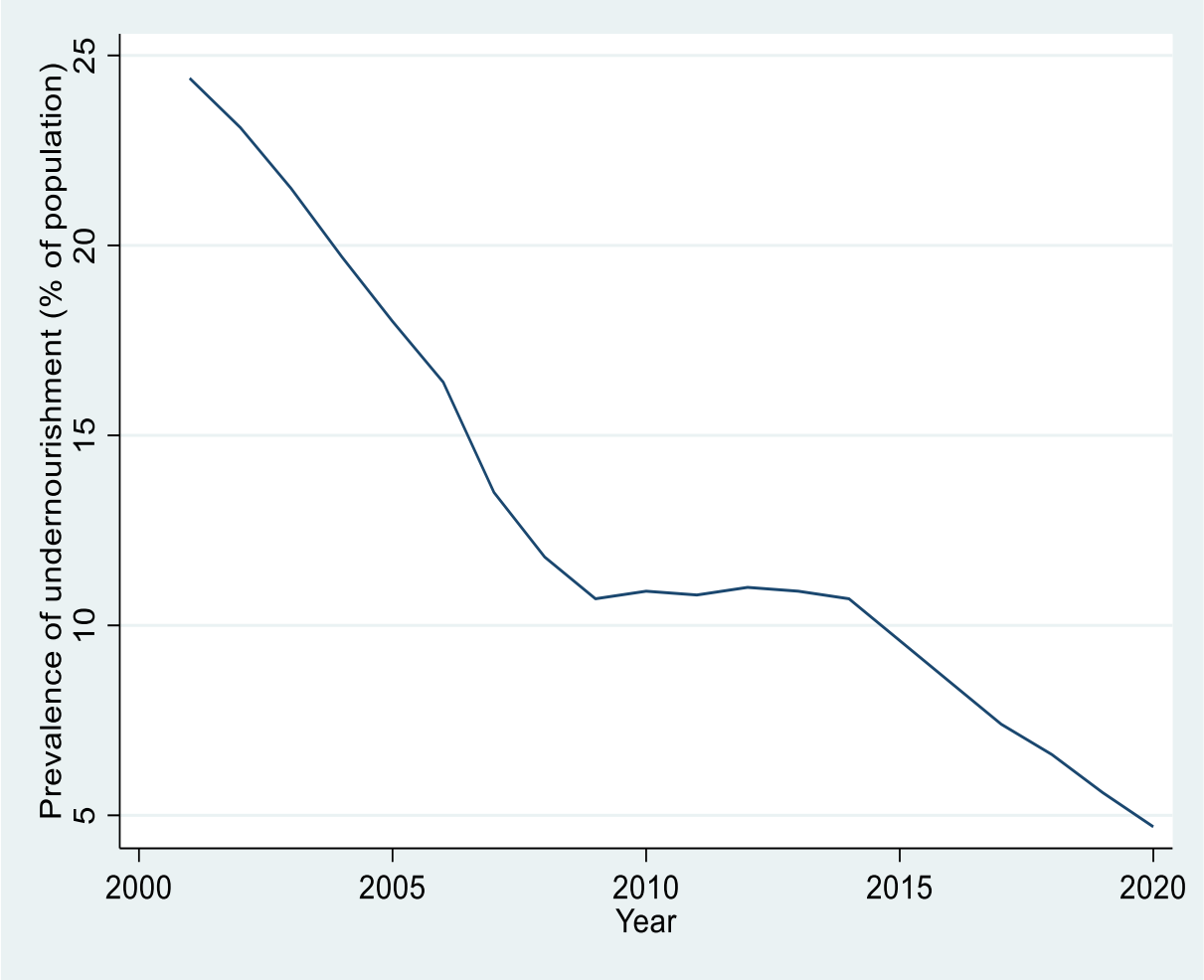
The country is affected by food insecurity, which impacts part of the population especially during June to August, that is the lean season. This period of the year in 2019, the FAO report stated that 341000 Senegalese faced a food crisis and required urgent food assistance. This is mostly affected in northern country. In Rarerou, for example, 15% of its 62000 people are asking for support. However, food needs decreased by more than 50% since the same period last year, and 750000 people faced crisis or worse across the country (USAID, 2019)[16]. According to the WFP, food insecurity and malnutrition in Senegal stand at 7.2% and 8.2% respectively, with major regional disparities (ENSANR, 2019). During the 2020 lean season,

[16] https://reliefweb.int/report/world/usaid-response-global-food-security-crisis-fact-sheet

about 770,000 people were estimated to be food insecure, a 124% increase compared to 2019. Food insecurity is more prevalent in rural areas, smaller households, and those headed by women or young people. The 2020 Global Hunger Index ranked Senegal 65th out of 107 countries, (Flora, 2022).

Senegal faces worrying levels of food insecurity, due to a combination of factors including inadequate access to food, inappropriate infant and young childcare and feeding practices, poor hygiene and sanitation practices, and insufficient access to drinking water and health services. In 2024, Senegal ranks 72 nd out of 127 countries for the Global Hunger Index (GHI), with a score of 15.3 indicating a moderate level of hunger (Global Hunger Index, 2024) report. At the same time, around 519000 individuals experienced acute food insecurity during the lean season, also because of unprecedented floods in 2024.

Figure 5: Prevalence of undernourishment (% of the population) from 2000-2020

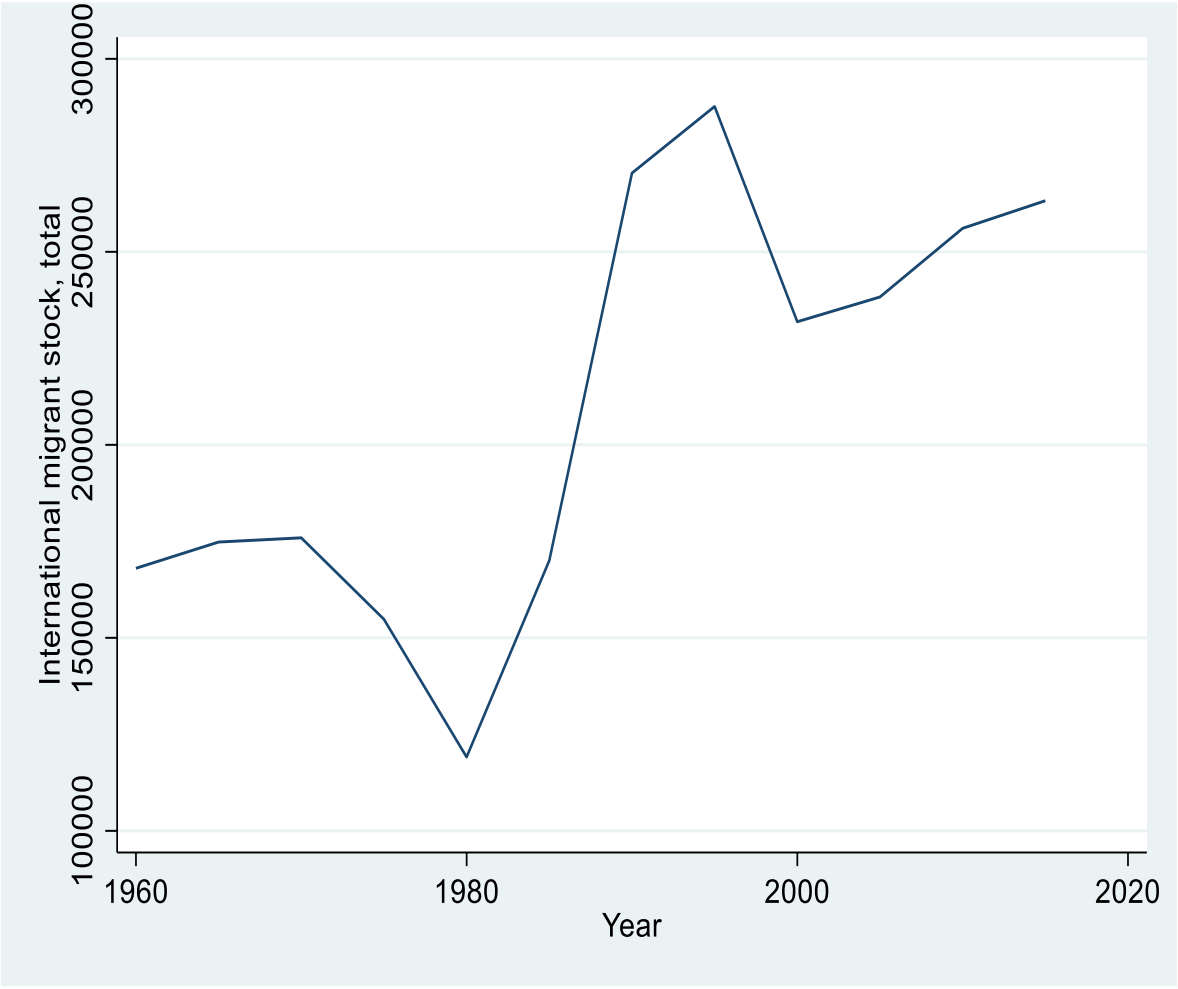


***Source** : Author, using FAO data, 2025*

This situation is more experienced by several departments, which are classified “under pressure”, where they are on the brink of similar seasonal stressors, leading to risk of food insecurity, (World Food Programme, 2022).

An analysis of the food situation in Senegal shows that the prevalence of moderate or severe food insecurity is below the 20% threshold. Food insecurity has fluctuated, decreasing from 24% to less than 5% in 2020. This means that even though the country has experienced food insecurity, the situation is much better compared to the situation in 2000, 2005, and 2010. It`s shown that certain Senegalese are now food secure.

Figure 6 : International migration stock from 1960-2020



Source : Author, using WBI data, 2025

Migration in Senegal dates to the pre-colonial and colonial periods when populations moved seasonally for pastoralism, agriculture, and trade across the Sahel and West African sub-region. This migration is driven by multiple factors such as limited local employment, aspirations for better income, family obligations, and social prestige associated with migration success. For many families, having a migrant abroad is viewed as a strategic investment in household welfare and status.

This table shows that the level of international migration in Senegal is on an upward trend. It should be noted that the level of migration is no longer what it was in the 1980s. This can be explained by the fact that during this period, the country implemented significant reforms that led to a decrease in this phenomenon, encouraging Senegalese people to remain in the country. Apart from this period, the number of migrants has increased significantly, especially in 2020, which corresponds to the COVID-19 period.

In addition to this international migration, there is internal migration, which is also important. According to (Duboz et al., 2020), about 2 million individuals, or 14.6% of the general population in Senegal, are internal migrants. This internal migration is mostly from rural to urban areas.

The Western Mediterranean route to Spain saw around 58,000 arrivals in 2018, with Senegalese among the top nationalities[17]. Arrivals to Spain's Canary Islands nearly doubled to 46,843 in 2024, driven in part by overfishing and declining coastal livelihoods, especially in fishing communities. Senegalese youth and fishermen are increasingly engaging in risky journeys across the Atlantic, the route to the Canary Islands being among the most dangerous globally[18]. The Senegalese navy has intercepted and rescued over 4,780 migrants so far in 2024, illustrating the ongoing nature of these journeys[19]. This practice is very dangerous because it causes a lot of deaths. For instance, from 2019 to 2024, a total of 4,888 deaths or disappearances occurred during crossings from West Africa[20].

[17] https://www.africanelements.org/news/shocking-senegal-migration-risks-deadly-truth/
[18] https://www.africanews.com/2025/05/14/senegals-fishing-crisis-overfishing-migration-survival/
[19] https://www.infomigrants.net/en/post/64560/report-links-allegations-of-overfishing-in-senegal-to-irregular-migration-to-europe
[20] https://lareleveetlapeste.fr/la-surpeche-industrielle-pousse-les-senegalais-sur-la-route-de-la-mort-vers-leurope/

Even though, irregular migration is dangerous, fishermen in Senegal keep doing this because of the importance of remittances that they send back to their families. This is one of the main sources of revenue and particularly household income. In Senegal, remittance flow remains one of the main sources of revenue and especially household income. Indeed, (Carrasco and Obucina, 2022), and the UN Capital Development Fund (UNCDF) (2022) the Senegalese diaspora sent 2.6 billion dollars, constituting between 10.5% and 10.7% of the GDP in 2020. These remittances reduced poverty by 30%. But, according to the (BCEAO, 2025), remittances to Senegal accounted for 1842 billion FCFA in 2023 and 1600 billion FCFA in 2022.

1.4. Politique to fight against food insecurity and achieve food security

To achieve SDG2 the Senegal government has implemented several programs. The first program was set up in 1977, an agricultural program that focuses on a food investment strategy to increase the production of cereal (millet and rice). This program promotes the diversification of crops with the introduction of horticultural crops, for example, sugar cane, cotton, industrial tomatoes, melon, green beans, peppers, bananas, avocado, and pineapple.

The next policy adopted by the Senegal government is the Malnutrition Control Unit (CLM), which has been operational since 2001, and coordinates national nutrition strategy. This policy focuses on child and maternal malnutrition, micronutrient deficiencies, nutrition sensitive agriculture. Works through community-based health/nutrition programs. "New Agricultural Policy (NPA)" in 2009, with the aim of achieving 80% self-sufficiency in food. The NPA was developed as part of structural adjustment program based on liberal policies. During its application, the NPA allowed an increase in cereal production from 607,284 tons in 1984/85 to 840.052 tons in 1992/93, an average growth rate of 3.1%. This programme is followed by the Programme to Accelerate the Pace of Senegalese Agriculture (PAPSA I) established from 2014 to 2019. This program aims to achieve self-sufficiency in rice and reduce dependence on food imports. The areas of interest are to increase yields in rice, millet, maize, onions, and groundnuts, promote agricultural mechanization, and expand irrigated land, particularly in the Senegal River Valley (SRV).

In 2014, the SEP was launched. The second pillar of this program includes the food security aspect. It highlights the mean points to achieve food security are agriculture, nutrition, infrastructure, education, and private sector involvement. This programme supports climate-smart agriculture, better value chains, and rural employment. Established in 2013, the

National Family Security Grant Programme (NFSGP) aims to transfer money to the poorest households. This transfer directly improves food access by increasing household income, education, and health services. It targets 300000 households.

Launched in 2015, the National Strategy for Social Protection (SNPS) integrates food assistance, safety nets, and climate resilience. It is built on PNBSF and other social programs. Strengthened in the 2000s, the National Food Security Stock (SNS) tries to maintain a strategic food reserve to respond to crises (droughts, floods, price shocks). It is managed by the Commissariat for Food Security (CSA), and is operational during lean seasons, and emergencies. Climate and Food Security Integration (2000–2020).

National Adaptation Programme of Action (NAPA) in 2006. It identified climate-sensitive sectors, including agriculture and food. Proposed early warning systems, drought-resistant crops, and water management. Great Green Wall (GGW) (Senegal participation since 2008) Aims to reduce desertification and food insecurity in northern and eastern Senegal. Combines reforestation with livelihood support (gardening, beekeeping, agroforestry). The Early Warning System, monitors rainfall, crop yield, and food availability. Allows early government response in times of drought or crisis. Linked with CILSS and FAO food monitoring.

1.5. Migratory policies in Senegal

In terms of migration policies, the earliest policy focused on combating irregular migration and illegal emigration rather than immigration. To fight against irregular migration, a ten-year national plan was presented in 2023 to reduce migration by 2033. This plan focuses on prevention, border management, cracking down on traffickers, and helping and reintegration for migrants.

The Intra-ACP Migration Facility is a development programme that aims to integrate migration issues into the development policies and strategies of ACP (African, Caribbean and Pacific) States. It focuses on intra-ACP migration, i.e., migration flows between ACP countries.

The PAISD is a mechanism for mobilising and supporting solidarity actions and economic initiatives by the Senegalese diaspora for the benefit of their country of origin. This mechanism receives financial support from the State of Senegal, the European Union, and the French Development Agency. It particularly targets Senegalese people living in France, Belgium, Spain, and Italy.

Supports and subsidises up to 80% of local development initiatives by diaspora associations in their countries of origin and promotes the savings of the Senegalese diaspora by supporting its business creation initiatives in Senegal. Undertakes studies on the subject in a forward-looking approach and mobilises highly qualified expertise and young people from the diaspora for short-term missions in Senegal.

Recently, the new government adopted circular migration phenomena. This circular migration between Senegal and Spain is a programme that allows Senegalese workers to travel to Spain for seasonal work contracts, particularly in the agricultural sector, and then return to Senegal. From this program, 17 Senegalese farmers migrate temporarily in Spain.

1.6. Conclusion

This chapter presents the stylised facts related to climate change, migration, and food (in)security in Senegal. In conclusion, we state that climate change is a key determinant of migration and food (in)security in Senegal. The findings have demonstrated that Senegal has a lot of challenges due to climate change, food insecurity, and migration, especially the phenomenon of irregular migration. This is firstly due to the lag of climate adaptation strategies. The problem of instable income is also a very serious issue for some households, particularly fishermen and farmers, because their production depends mainly on climate change. Moreover, food insecurity is due to a decrease of labour force due to climate change. In return, migration is explained by climate change and insufficient income, leading to food insecurity in Senegal.

CHAPTER 2: CLIMATE CHANGE AND FOOD SECURITY IN SENEGALESE COASTAL ZONES

RESUME

Le changement climatique représente une menace importante pour la sécurité alimentaire, en particulier dans les régions côtières qui dépendent fortement de la pêche pour leur subsistance, leur développement économique et leur culture. Cette étude examine l'impact du changement climatique sur la sécurité alimentaire dans les zones côtières sénégalaises, avec les cas des communautés de pêcheurs dans des centres clés tels que Saint-Louis, Kayar, Mbour, Joal Fadiout, Soumbedioune, Rufisque, Djiffer et Yarakh. À l'aide d'une analyse à plusieurs niveaux, cette recherche examine les réponses des ménages au changement climatique et les défis qui en résultent en matière de sécurité alimentaire. Les données ont été collectées dans le cadre d'enquêtes menées entre juin et août 2023 auprès de 570 pêcheurs âgés de 17 à 75 ans. Le modèle des moindres carrés généralisés (GLS) a été utilisé pour analyser les déterminants de la sécurité alimentaire, soulignant le rôle essentiel du revenu, de la perception de la hausse de la température de l'eau de mer, de l'éducation, de la situation professionnelle et des facteurs spécifiques à chaque district. L'étude souligne l'impact négatif de la perception de la hausse de la température de l'eau de mer et de la surpêche sur la sécurité alimentaire, mais le revenu quotidien moyen et l'accès au crédit ont une influence positive sur la sécurité alimentaire des ménages de pêcheurs sénégalais. Ainsi, le gouvernement devrait intervenir et adapter ses stratégies afin d'atténuer les effets du changement climatique, faciliter l'accès au crédit et éviter la surpêche afin d'améliorer la sécurité alimentaire et de soutenir des moyens de subsistance durables dans ces communautés vulnérables.

Mots Clés : Changement climatique, sécurité alimentaire, pèche, Sénégal, moindres carrés généralisés

ABSTRACT

Climate change poses significant threats to food security, particularly in coastal regions heavily dependent on fisheries for livelihood, economic development, and cultural sustenance. This study investigates the impact of climate change on food security in Senegalese coastal zones, focusing on the fishing communities in key centres such as Saint-Louis, Kayar, Mbour, Joal Fadiout, Soumbedioune, Rufisque, Djiffer, and Yarakh. Using a multi-level analysis, this research examines households' responses to climate change and the resulting food security challenges. Data were collected through surveys conducted between June and August 2023, targeting 570 fishermen aged 17 to 75. Generalized least square (GLS) model was employed to analyse the determinants of food security, highlighting the critical roles of income, perception of rising sea water temperature, education, employment status, and district-specific factors. The study underscores the negative impact of the perception of rising sea water temperature and overfishing on food security but average daily income and credit access influence food security in Senegalese fishermen households positively. Thus, the government should intervene and adopt strategies to mitigate climate impacts, facilitate credit access and avoid overfishing to enhance food security and support sustainable livelihoods in these vulnerable communities.

Keywords : Climate change, Food security, Fishing, Senegal, Generalized least square

2.1. Introduction

Climate change has caused significant damage worldwide and continues to be a major obstacle for all countries in various sectors. According to the (IFRC, 2020), extreme weather events have killed more than 410,000 people and affected 1.7 billion globally over the last decade. Economically, developing countries are projected to lose between US $290 billion and US $580 billion by 2030 due to climate change. The World Food Program's global crisis report (WFP, 2020) estimated that 98 million people in Africa were acutely food insecure and needed humanitarian assistance due to climate-related issues. Coastal countries have suffered significant income losses, as the small-scale fisheries sector, which generates over 80% of the GDP, is heavily impacted.

Fisheries are vital for many coastal communities worldwide, especially in West Africa, but African countries are among the most vulnerable to climate change. Climate variability in this region is characterized by rising sea levels, temperatures, and precipitation. Projections of temperature in West African countries show that, temperature will increase by 0.5°C per decade, leading to greater precipitation variability and intensity, and an accelerated sea level rise of about 1 meter per century (Bey et al., 2018). By 2030, sea levels in the West African coastal zone are expected to rise by 0.18 meters in Mauritania and Senegal, and by 0.1 meters in Benin, Togo, and Ivory Coast. Globally, a rise of 1 meter is expected by the end of the century.

Despite these threats, coastal areas remain crucial for economic activity. According to Mbaye et al., 2022, artisanal fishing, characterized by high labour intensity, is the most important economic activity on African coastlines, accounting for about 91% of total jobs in these areas. Severe coastal erosion compounds this issue, affecting one-third of West Africa's population and generating 56% of its economy. The annual volume of legal fishing in West African waters exceeds 1.6 million tons, valued at US $2.5 billion at the wholesale level. In addition to fishing, the coastline hosts major cities, ports, agro-industries, and offshore oil platforms (Oceans et al., 2022). Climate change impacts the economy of coastal areas by reducing available fish and shellfish, leading to decreased income for communities reliant on these resources. This situation forces people, particularly fishermen, to migrate, often irregularly, in search of better opportunities.

It affects negatively the food security status of several countries around the world. Due to this, since 2022, according to the (World Bank, 2022)[21] the number of people suffering acute food insecurity increased from 135 million in 2019 to 345 million in 82 countries by June 2022. Over the course of 2019, 2 billion people (25.9%) around the world have experienced hunger or they did not have stable access to nutritious and sufficient food (FAO, 2020). This link between climate change and food security has been study theoretically and empirically. While some authors have found positive links between these two variables, others have found a negative relation. Several studies have demonstrated the negative impact of climate change on food security mostly in the agricultural sector (Ogenrwoth et al., 2023). Even theoretical findings had already shown that. Other studies find a positive relationship between climate change and food security (Mahrous, 2019).

There are many definitions for the concept of food security, however, the FAO`s definition is the most commonly used and includes all four dimensions of the concept, namely availability, stability, access, and utilization (FAO, 2006, Webb et al., 2006, Lang et Banling, 2012, Napoli et al, 2011). According to the FAO (1996), food security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy lifestyle.

Ensuring food security is a significant challenge for coastal communities due to their dependence on climate events and lack of resilience and adaptation strategies. “A UN report” (2022) states that climate change will adversely affect food security and water resources. By 2050, the average agricultural yields for millet, sorghum, cowpeas, groundnuts, maize, and rice are expected to decrease by 12% to 25%. This decline could force up to 32 million people to migrate within the region. To address this issue, the Community of West African States (ECOWAS) has signed a regional strategy to combat global warming, aligning with the Paris Agreement. The West Africa Coastal Areas Program (WACA) was launched by the World Bank in 2016 during COP21 to protect West African coastal areas, including Benin, Ivory Coast, Mauritania, Senegal, Guinea, Ghana, and Togo.

The fishery sector is highly vulnerable to climate change. Lam et al. (2020) predict that fish stocks will have decreased by 40% by the 2050s under the RCP8.5 emission scenario, increasing the vulnerability of tropical countries with limited adaptive capacity. The billions of people dependent on tropical marine fisheries will face significant challenges as fish-

[21] https://www.worldbank.org/en/news/feature/2022/10/17/what-you-need-to-know-about-food-security-and-climate-change

species composition will be altered. Most fish landing sites in Senegal are in Dakar, Saint-Louis, Kayar, Joal-Fadiouth, Mbour, Rufisque, and Bargny (Bousso, 2022). The fisheries sector contributed 3.2% to Senegal's GDP, accounted for 10.2% of its exports, and generated US $400 million in value in 2021 (Bousso, 2022).

Given the importance of this sector to the Senegalese economy and its decline due to climate change, it is crucial to study the impact of climate change on food security in Senegalese fishermen's households. In other words, this study aims to evaluate the link between climate change and food security in Senegalese coastal area households. The study hypothesizes that climate change adversely affects household food security (H1), and that income positively impacts food security (H2).

The motivation for this study includes addressing illegal migration, which caused 633 deaths in 2023 in Senegal, and the significant role of the fishery sector in providing foreign currency and employment, for 15% of the working population. The second motivation is about the fact that literature did not explore concretely, this issue. Indeed, the fisher's community has left belong when it comes to evaluating the impact of climate change on local community. The farmers have mostly been the community of interest. So, feel this gap in the literature, we specially focus on this community which is vulnerable to this environmental degradation.

We contribute thus to the body of literature related to climate change and food security by first proposing a new food security index and by focusing on this community of fishers which is under study. Indeed, any food security index does capture all food security dimensions. For example, the food consumption score indicator captures food utilization dimension, literature propose The final contribution is to finding solutions to deal with this problem of irregular migration that strengthens the fishery sector.

This study is structured as follows: the next section presents the literature review. Section 3 deals with the conceptual framework, followed by a presentation of econometric modelling employed in this study. Section 5 discusses the findings, and the last section, section 6 concludes the study.

2.2. Literature review

2.2.1. Theoretical contributions review

To better understand the link between climate change, and food security, it is important to review the theoretical foundations of these concepts. The oldest theory of food security is the food availability approach, also known as the Malthusian theory. Popularized by Malthus

(1789), this theory suggests that food insecurity arises from the imbalance between population growth, which increases geometrically, and food production, which grows arithmetically. To maintain equilibrium, food availability must grow at a rate equal to or greater than population growth. According to this view, food security is a matter of aggregate (per capita) food availability, which depends on food production and stocks. Malthus argued that disequilibrium between population and food supply leads to famine, often exacerbated by climate events.

The basic need approach, developed by the International Labor Organization (ILO) in the 1970s, incorporates non-economic dimensions of development. This theory views development as a process aiming to satisfy basic needs, including food, shelter, and clothing (Stewart, 1985; Denton, 1990). Food is considered a fundamental need, as highlighted by Maslow (1943) and Magrabi et al. (1991), and is essential for human rights (Kent, 2005). The sustainable livelihoods approach, introduced by Chambers (1983) and later expanded by Chambers and Conway (1992), focuses on rural development and poverty. It emphasizes the importance of tangible and intangible assets, classified into five groups: natural, physical, human, financial, and social capital. A sustainable livelihood is defined by the ability to adapt to threats, maintain or improve capabilities and assets, and avoid compromising other livelihoods (Chambers and Conway, 1992).

Amartya Sen's entitlement approach (1981) shifted the focus from national food availability to individuals' access to food. Entitlements are determined by personal endowments (resources legally owned) and the set of commodities accessible through trade and production. Starvation results from a failure to secure a bundle of commodities with sufficient food, either due to a decline in endowments or a reduction in the exchange entitlement mapping (Sen, 1981). The income-based approach, as explained by Burchia & DeMuro (2015), revisits food security within a macroeconomic framework. This approach recognizes that food security cannot be viewed solely as an agricultural problem but must consider the broader economy. It emphasizes the role of income in ensuring food security, akin to poverty assessment, where food insecurity is seen as a lack of income to purchase necessary food (Sibrian et al., 2007; Sibrian, 2008).

The human development and capability approach, developed by Dreze & Sen (1989), focuses on nutritional capabilities rather than just access to food. This theory incorporates the capability to avoid undernourishment and freedom from hunger, considering various factors such as sex, age, climate conditions, and access to complementary inputs. The climate theory, established in the 1970s, links climatic factors such as droughts and floods to food insecurity.

Cox (1981) and Huscher (1959) argued that climate-linked phenomena cause serious hydrological imbalances and adversely affect crop production, leading to food insecurity.

2.2.2. Empirical evidence

Empirical studies provide evidence on how climate change affects food security across different regions and sectors. Mahrous (2019) analysed the impact of global climate change on food security in the East African Community (EAC) region using panel data from 2000-2014. The study found that rising temperatures adversely affect food security, while increased precipitation and cereal crop cultivation improve food security. Kinda et al. (2019) examined rainfall variability and food security in 71 developing countries from 1960 to 2016. Their results suggest that rainfall variability reduces food security by decreasing food availability per capita and increasing the percentage of undernourished populations. Randell et al. (2022) indicated that low rainfall and dry conditions negatively impact food security, whereas heavy rainfall can destroy crops and agricultural assets (Fallon and Betts, 2010). Affoh et al. (2022) studied the relationship between climate variables and food security in 25 Sub-Saharan African countries from 1985 to 2018. They found that rainfall positively affects food availability, accessibility, and utilization, while temperature negatively impacts food availability and accessibility. CO2 emissions positively impact food availability and accessibility but do not affect food utilization.

In addition to the body of literature that defend a negative link between climate change and food security, Ogenrwoth et al. (2023) study is align with this. The authors estimated the impact of climate change on food security among smallholder farmers in Uganda using household panel data from 2013 to 2020. The study found that weather shocks reduce food security, particularly in Northern Uganda and rural areas. Looking at the gender aspect, the authors show that female-headed households lacking literacy and assets are especially vulnerable, while non-farm businesses improve food security. The size of the household is part of the key determinant of food security in the context of climate change. Tesfaye and Alemayehu (2021) used the Household Food Balance Model to analyse food security in Ethiopia's Basona Werana region. Their study revealed that 62% of households are food insecure, with the highest food insecurity in the Dega agroecological zone. Weldearegay & Tedla (2018) found that climate variability increases hunger risks, with 84.3% of households in Tigray, Ethiopia, falling below the recommended daily calorie intake. Agidew & Singh (2018) evaluated food insecurity determinants in Ethiopia's Teleyayen sub-watershed, finding that 79.1% of households are food insecure. Female-headed households and younger

household heads with less farmland are more food insecure. Amare & Simane (2017) showed that 42.2% of households are food insecure in their study of 442 households.

Climate change also affects the fishing sector, particularly small-scale fishing, which is crucial for job creation and food security (Bene et al., 2016). Muringai et al. (2019) found that 78% of fishermen in Kaliba, Zimbabwe, considered their households food insecure due to decreased fish catches and income. Masipa (2017) highlighted that climate change poses a significant risk to food security in sub-Saharan Africa, affecting food availability, accessibility, utilization, and affordability. Murniati & Mutolib (2020) examined the impact of climate change on household food security among upland rice farmers in Indonesia. Using the Ordinary Logit Model, they found that these households are vulnerable to climate change impacts.

This negative impact of climate change on food security may be different depending on rainfall duration. Pickson & Boeteng (2022) investigated the link between climate change and food security in 15 African countries using the pooled mean group and Dumitrescu-Hurlin panel causality test. They found that rainfall is crucial for food security, extreme temperatures negatively affect food security in the short run, and a bidirectional relationship exists between climate change and food security. Few studies (Makame et al., 2015) have focused on the impact of climate change on food security in the fishery sector. Makame et al., (2015) found that households on Zanzibar's eastern coast are insecure regarding food sources due to climate challenges, leading to increased market dependence and vulnerability to food insecurity.

The literature demonstrates mostly the negative link between climate change and food security

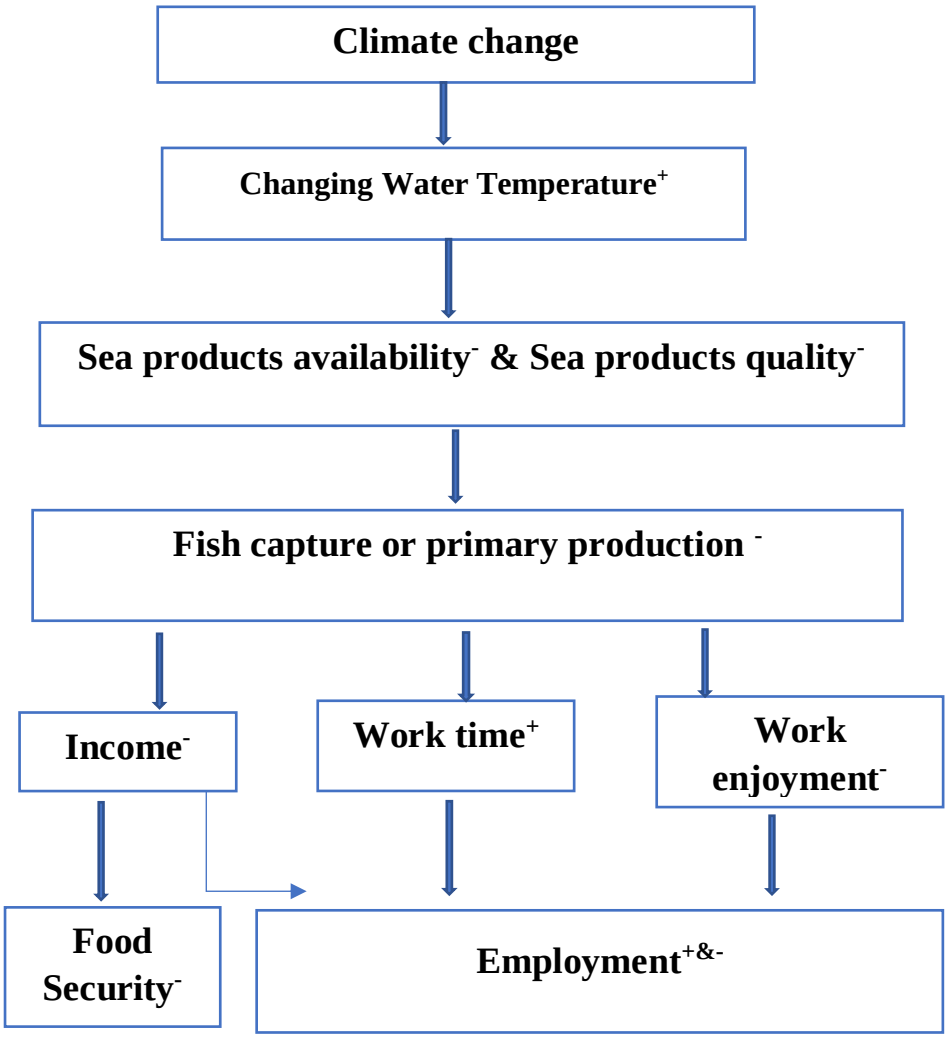
2.2.3. Conceptual frameworks

The conceptual framework in this study links climate change and food security. It is demonstrated that climate change impacts all sector and all countries around the world, but Africa is the most vulnerable to this changing climate. Among other effects, climate change is leading to an increase in sea temperature and salinity. In Senegal, surface waters have risen over the last few decades, causing certain fish species to migrate to waters with more favourable temperatures, but also leading to the disappearance of certain species from the Senegalese coast[22]. This rising temperature is also causing problems with reproduction and

[22] https://cdkn.org/story/feature-ocean-temperature-increase-along-senegalese-coast-could-reduce-sardine-fisheries

reducing the size of fish, as temperatures are not favourable for their growth (Vasconcelos et al., 2024).

Figure 7: Conceptual framework



Source: Autor compilation, 2023

However, it's also important to note that artisanal fishermen do not have the capacity to go very far, as their pirogues are not as efficient at covering 1,000 km. All these factors combined mean that Senegalese artisanal fishermen see their daily catch reduced, sometimes even to nil, due to unfavourable climatic conditions, and it is dangerous for them to go out to sea because they have no capacity to cope with tidal winds and are forced to return empty-handed, knowing that their income changes daily. As a result, their daily income decreases or even reaches zero, which can last for several days before weather conditions become favourable again. As a result, their catch or primary production falls, their working time increases due to the scarcity of fish, and their labour power also increases. That is why, some fishermen in the survey state that they no longer enjoy their work.

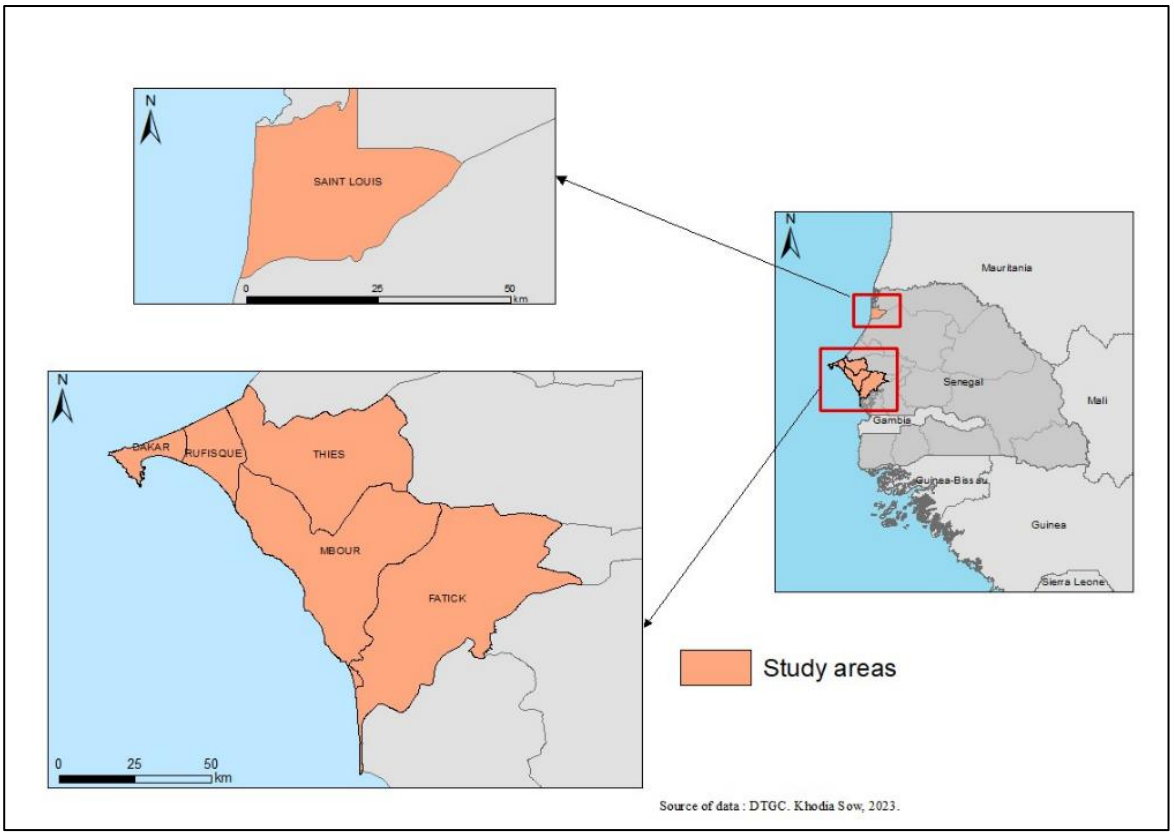
Costal erosion and increasing salinity are affecting the fishery sector the most. Those phenomena negatively impact sea food products thus reducing fishermen capture. Consequently, this decreases their income, and increases their work time. All these facts negatively impact food security and well-being. Due to this, many fishermen in the survey state that most of them are leaving the fishery sector and most of them migrate. Therefore, fishermen migration is a climate adaptation strategy that fisher men on the Senegalese coast use to improve their subjective well- being but also their food security trough remittances that they send back to their family.

2.3. Econometrics modelling

2.3.1. Study area

Senegal is characterized by an extensive coastal area of around 198,000 km², which hosts 58% of the country's population. This coastal region spans six regions: Saint-Louis, Louga, Thies, Dakar, Fatick, and Ziguinchor, contributing 68% of the country's GDP.

Figure 8 : Study area



Source: Author compilation, 2023

The fishery sector plays a significant socio-economic role in Senegal, being the main provider of foreign currency (generating around CFA 200 billion annually or 30% of export revenue), providing approximately 600,000 jobs (15% of the total working population), and supplying 75% of the animal protein needs. The dynamism of the small-scale fishing sub-sector, which accounts for more than 80% of national production, largely drives these economic and social achievements. In 2016, fishing topped the export ranking, accounting for 14.63% of total export earnings (Ministry of fisheries and maritime economy, 2017) report. According to a 2022 report, the fisheries sector contributes 3.2% to Senegal's GDP, accounts for 10.2% of exports, and generates US $400 million in value.

This sector employs over 600,000 people (Bousso, 2022), with small-scale fishing dominating 80% of catches, primarily in Dakar, Saint-Louis, Kayar, Joal-Fadiouth, Mbour, Rufisque, and Bargny (Bousso, 2022).

The most important fishing regions are Thies, Saint-Louis, and Dakar, which together account for 77% of the workforce, with 40%, 22%, and 15% respectively. This guided the selection of these fishing sites for the study, focusing on fishermen living in the largest artisanal fishing centres presented in figure 8.

Thies (Mbour, Kayar, Joal-Fadiouth), Saint-Louis (Guet Ndar), Dakar (Rufisque, Soumbedioune, Yarakh or Hann), and Fatick (Djiffer) (Figure 8). Given the importance of this sector to the Senegalese economy, it is crucial to study it in the context of climate change. The urgent need to investigate these communities, often overlooked in climate change studies, is pressing. Climate change is causing significant damage, from the loss of livelihoods to forcing inhabitants to leave their families and migrate to Europe, often unaware of the associated risks.

2.3.2. Sampling technique and data collection

Following Berzmen et al. (2019), this study employs a multi-leveled analysis of households living in coastal areas, focusing on key fishing centers such as Saint-Louis, Kayar, Mbour, Joal, Soumbedioune, Rufisque, Djiffer, and Yarakh. These locations were chosen because, as Teh and Pauly (2018) state, marine fisheries are vital to the well-being of people and society, particularly in the tropics, where coastal communities depend on fisheries for food security, livelihood, economic development, and culture. The survey will target fishermen households and be conducted in two stages. Initially, households in each locality will be randomly selected and contacted. Subsequently, the main survey will be conducted using a questionnaire with both fixed and open-ended items. The questionnaire will cover themes

such as (1) location and type of house, (2) socio-demographic characteristics of household members including migration experience, (3) economic characteristics of the household (the primary focus), (4) main household activities, and other explanatory factors.

Data collection occurred between June to August 2023, focusing on fishermen aged 15 to 75. The semi-structured questionnaire assessed fishermen's observations, interpretations of climate trends, and impacts of climate change on fisheries, well-being, and food security. Participants were selected based on their involvement in the fishery sector and having fishing as their main activity, with the household head and family residing in the study areas. The questionnaire comprises several sections. Section one covers general information about the site and its geographical coordinates. Section two focuses on the socio-economic characteristics of the household, distinguishing between individual households and compound households. This distinction is important as fishermen in compound households have more responsibilities. The types of households include single-person households, couples without children, couples with children, single-parent households, and extended family households.

- To determine the sample size, the Cochran method was used (Cochran, 1977; Tessema, 2017; Ceesay, 2022), suitable for studying a community where the sample size is unknown. Hence, the formula used is as follows: $n = \frac{z^2+p(1-p)}{E^2}$ with, n: the sample size, Z=1.96 (for 95% confidence), p = 0.5 (assumed proportion), and E = 0.05 (margin of error) (Agresti and Finlay, 2009). According to Mbaye et al. (2022), although reports suggest there are 600,000 Senegalese fishermen, the exact number is unknown. The minimum sample size required for the survey with unknown sample, is 384. However, to increase precision and quality, 570 fishermen were interviewed across eight coastal areas in Senegal, distributed as shown in the table below.

Table 1: Geographic distribution of the fishermen interviewed

Regions	Departments	Districts	Number of fishermen interviewed
Dakar	Dakar	Sombedioune	33
Dakar	Dakar	Hann Bel-Air (Kayar)	60
Dakar	Rufisque	Rufisque	40
Thies	Thies	Kayar	85
Thies	Mbour	Mbour (Tefess)	90
Thies	Mbour	Joal	111
Fatick	Djiffer	Djiffer	64
Saint-Louis	Saint-Louis	Guet Ndar	87
Total		570	

***Source:* Author's computation from field survey, 2023.**

The sample distribution was based on the report stating that 77% of active Senegalese fishermen are in Thies, Saint-Louis, and Dakar, with proportions of 40%, 22%, and 15%, respectively. Primary data were collected from fishing households in four coastal regions: Dakar, Thies, Fatick, and Saint-Louis. In Dakar, the areas of interest are Soumbedioune, Yarakh, and Rufisque. In Thies, the focus is on Kayar, Joal Fadiouth, and Mbour. In Fatick, Djiffer is the area of interest, and in Saint-Louis, it is Guet Ndar. These areas represent over 80% of the fishery sector. Thus, the study is limited to these areas, with 570 fishermen interviewed, distributed as follows (see table 1):

2.3.3. Review of methods of measurement of food security

The concept of food security was first defined during the World Food Conference in 1974 as the availability of adequate world food supplies to sustain a steady expansion of food consumption and offset fluctuations in production and prices (UN, 1975). Initially focusing on availability and price stability, the definition evolved to include economic access, ensuring all people always have both physical and economic access to the basic food they need (FAO, 1983). The World Bank (1986) further refined it to emphasize access by all people to sufficient food for an active and healthy life. In 1996, the FAO defined food security as a state where all people have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy lifestyle. This definition highlights four key dimensions: availability, access, utilization, and stability.

Recent expansions of the concept include ethical and human rights aspects, formally adopted by the World Food Summit in 1996, which underscored the right to adequate food. The latest definition by Ibarrola-Rivas and Galicia (2017) emphasizes access to sufficient and nutritious food for present and future generations. The most widely used definition in literature is the FAO, as it comprehensively addresses all four dimensions of food security (FAO, 2006; Webb et al., 2006; Lang and Banling, 2012; Napoli et al., 2011). Food availability involves the physical presence of food stocks, while food stability ensures continuous access to food, avoiding disruptions from cyclical events (Swaminathan & Bhavani, 2013; Battersby & Watson, 2018; Steenkamp et al., 2021). Food accessibility considers whether households have adequate resources to acquire nutritious food, encompassing both economic and physical aspects. Food utilization focuses on meeting physiological needs through safe and quality food, incorporating non-food inputs like clean water and healthcare (Clay, 2002; Webb and Rogers, 2003).

Recent additions to food security dimensions include food agency and food sustainability. Food agency refers to the empowerment to act throughout the food preparation process within a specific environment (Trubek et al., 2017). Food sustainability, as stated by the High-Level Panel of Experts (2020), involves practices that ensure the regeneration of natural, social, and economic systems, meeting the food needs of present generations without compromising those of future generations. Several indices measure food security, each with different focuses. The Household Food Insecurity Access Scale (HFIAS) uses a 9-item questionnaire to classify households into four categories based on their food access experiences over 30 days, although it does not quantify actual food consumption (Manikas et al., 2023). The Household Food Security Survey Module (HFSSM) measures food insecurity over a year using 18 questions, classifying households into four categories but also focusing on food access (Bickel et al., 2000). The Latin American and Caribbean Food Security Scale (ELCSA) assesses the prevalence of food insecurity and its causes using a 15-item questionnaire (Leroy et al., 2015). The Household Hunger Scale (HHS) and Coping Strategy Index (CSI) evaluate coping mechanisms during food shortages, focusing on food access but not specifying cut points for classification.

Other methods include the Household Dietary Diversity Score (HDDS), which assesses food access by evaluating the diversity of food groups consumed, and the Food Insecurity Experience Scale (FIES), which uses an 8-item questionnaire to monitor food security over a year. The Global Hunger Index and the Suite of Food Security Indicators provide composite measures at national levels. The FAO Indicator of Undernourishment (FAOIU) and the Food Consumption Score (FCS) focus on food energy consumption as proxies for food security. This study adopts the FAO (1996) definition of food security, incorporating all dimensions except food sustainability, to assess the food security of 570 Senegalese fishermen. This comprehensive definition, developed through diplomatic negotiations at the 1996 World Food Summit, is the most complete for capturing the multifaceted nature of food security at the household level.

2.3.4. Empirical framework

As mentioned, there is no index that comprehensively captures all six dimensions of food security. Existing indicators in the literature do not fully encompass availability, accessibility, stability, utilization, agency, and sufficiency. In this study, we created a new index, the Household Food Security Access Scale (HFSAS), excluding the sustainability dimension which focuses on sustainable agricultural policies at the country level. Our index measures

food security at the household level, making sustainability inapplicable. The variables for our index are based on the literature surrounding food security concepts and their dimensions.

To construct the HFSAS, we included six dimensions: availability, accessibility (both physical and economic), stability, utilization, agency, and sufficiency. We posed the following questions to fishermen to capture each dimension: (d1) Food availability: Are all kinds of food you want to eat available in the market? (d2) Food stability: Do you eat at least three meals a day? (d3) Economic accessibility: Does your income allow you to have three meals a day? (d4) Physical accessibility: Is the market far from your location? (d5) Food utilization: Is the food you consume diversified? (d6) Measured using the FCS indicator) - Food sufficiency: Did you eat enough food? Food agency: Are you able to prepare your dish? Responses varied, with availability, utilization, and economic access having three options (always, sometimes, never), and agency, sufficiency, and physical access being binary (yes or no).

After, we give a code to each kind of answer from 0 to 3 as in the HFSAS scoring method. Using principal component analysis and min-max normalization, the index is thus comprised between 0 and 1. This approach provides a comprehensive measure of food security across multiple dimensions. For the aggregation process, we base ourselves on the fact that as mentioned by (Anand and Sen, 1997), who state that power means of order greater than one are very useful in building composite indices of food security measures that place equal weight of the four dimensions. In this study, as we include all six dimensions excluding the sustainability dimension because it is more relevant at national level and additionally, the dimension sufficiency is added in our index because as mentioned by Vhurumuku, 2014, who argues that the table of food consumption score does not take into account the quantity of food consumes.

To avoid adding dollars and meters, data should be normalized. There are several ways to do this. In this study, the min-max method is used for doing so as (The Economist Intelligence Unit, 2020) did. The formula applied to normalize data is as follows:

$$I_{qc}^{t} = \frac{x_{qc}^{t} - min_c\left(x_{qc}^{t_0}\right)}{max_c\left(x_{qc}^{t_0}\right) - min_c\left(x_{qc}^{t_0}\right)} \quad (1)$$

x_{qc}^{t}: is the value of indicator q for individual c at time t

As Obayelu (2013) describes, this study uses household food security as a dependent variable to identify factors impacting food security at the fisherman household level. The Generalized

Least Square (GLS) method as (Shah et al., 2020) did, is used to estimate this relationship. The base model is specified as follows:

$$Y_i = \alpha + \sum_{k=1}^{K} \beta X_{ki} + \mathcal{E}_i \qquad (2)$$

Here, Y is the level of food security of the household, X is the vector of independent variables, β is the vector of regression coefficients, and ε is the random error term, assumed to be normally distributed. The estimated model is specified as:

$$Y_i = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \mathcal{E}_i \qquad (3)$$

Where X_1: Marital Status, X_2: Household Size (size of the household, continuous variable), X_3: Education level of the fisherman, X_4: Boat size, X_5: Income (average daily income in FCFA), X_6: Changing in water temperature, X_7: age (age of the responder in years (continuous variables)), X_8: employ status, X_9: Second activity, X_{10}: age^2 (age of the responder multiplied par this), X_{11}: The fishing experience in years, X_{12}: districts, X_{13} : access to credit, X_{14}: overfishing, K is the number of variables include in the model, β is the vector of regression and $\mathcal{E}$ Is the error term. In this study, the gender variable is not included in the model because in Senegal especially in the study areas only fishermen. The variables included in this empirical analysis are described in Table 2. These variables have been chosen based on these studies, (Oni et al, 2011, Onya & Ejiba, 2020, Obayelu, 2012; Pauli et al 2002).

2.4. Presentation of the results and discussion

2.4.1. Descriptive statistics

This section discusses the descriptive analysis findings. Table 15 in the appendix displays the mean and the standard deviation for the variables and for the rest of the variables, the frequency and the percentage are presented in the tabulation table because they are not continuous, they are categories variables. The table below shows that 76.84% of the fishermen are married, 2.81% of them are divorced, 19.30% have never married and 1.05% are widowed. This means that most of the fishermen are married. It suggests that being a fisher is favourable to getting married at the due age. Even though the sector is collapsing the income received allows them to increase their living standards.

The table indicates that 4.39% of the fishermen are not at all educated. Most of them (48.77%) have primary education, and 11.23% and 1.93% have secondary education and tertiary education respectively. This shows that most young people who have dropped out of school join this sector, which doesn't require any experience or qualifications. This can be explained by the fact that in Senegal 80% of fishermen are Lebous whose main activity is fishing, so even before leaving school they start going out to sea just for fun or even to get a bit of money. Some of them also leave school when they reach school age and family members take them with them in search of fish. For others who have attained higher levels of education, they embrace this sector which generally does not require any experience for economic reintegration and allows them to earn money each time they return from fishing, even if this sum fluctuates.

The table of the statistic descriptive shows also that the oldest fisher man in the sample is 75 and the youngest is 17 years, living in a household composed of one to sixty members including the household head. Fishermen average daily income in these study areas fluctuate between 500 and 11500 FCFA and the mean income is 4250.395 FCFA. The size of the board is between 8 and 30 meters. Credit is an additional external income that they can use for diverse purpose but here we look at how this additional income can increase food security. Additionally, the table 1 shows that only 121 have access to credit and less than that have secondary activity (66).

Most fishermen perceived the increase of water temperature in Senegalese water, 458 responders gave a positive answer to this variable, while only 112 did not perceive it. 495 of Senegalese fishermen constate that there is overfishing.

2.4.2. Estimations results

Results for the determinants of food security from the generalized model are presented in Table 2. The seawater temperature raises threats to the production of fish. The simple linear regression model result of this study depicts that the perception of water temperature by respondents results in a decrease in the likelihood of food security. Indeed, respondents' perception of seawater temperature significantly decreases respondent’s food security by 0.174. The perception of respondents towards the change in climate in this study is similar to research reported by Mekonnen et al., (2021) in Ethiopia who showed that there was a climate change implication due to an increase in temperature. Moreover, studies conducted on the East Coast of the United States (McClenachan et al., 2019) reported that seawater temperature changes lead to fishery production and food insecurity. Authors underlined that historical

warming and cooling events affected the abundance of species targeted by fishing, the prevalence of novel and invasive species, and physical access to targeted species. Thus, fishing communities viewed colder waters to be associated with a decrease in fishing opportunities due to storminess, in contrast, warming waters can be associated with disease, reductions in abundances of target species, and shifts in distributions across jurisdictional lines. Therefore, variability in seawater water temperature perceived by fishers has a significant impact on their activities. In return, less they are willing to practice their activities less sufficient income, and food. Climate change is happening and already affecting food security in Africa. Senegal is vulnerable to climate change because its economies largely depend on climate-sensitive sectors (agriculture, fishing).

Geographic variables factors (District) were integrated to enhance location importance in implementing food security policy among fishing communities in Senegal. Living in Soumbedioun appeals to be beneficial in terms of food security relative to other districts. Disparities observed in districts and regions' vulnerability to climate change can explain this difference in Soumbedioum respondents' food security. Results reveal that living in Joal Fadiouth increases the respondents' proportion to being in severe food insecurity situations compared to Soumbedioune. According to Goujon et al., (2022), despite Dakar's (Soumbedioune) highest vulnerability to climate change compared to the Thies (Joal Fadiouth) region, the latter temperature was 0.96 higher relative to the former. This could lead to product disease. Moreover, living in other districts increases respondents' likelihood of food security compared to their counterparts in Soumbedioune. The physical vulnerabilities to climate change in 2022 for different regions integrated into the study area stand as follows: Saint-Louis; Guet Ndar district, Djiffer district; Fatick, Dakar; Soumbedioune, Hann Bel-Air, and Rufisque districts and Thies for the rest of districts.

The regression table suggest also that, fishermen without any education level are more food secure compared to educated fishermen. This can be explained by the fact that non educated fishermen practice this activity very soon and have more knowledge on this activity. Adding to the fact that they start going fishing when they were young with a member of their family. This allows them to build a network of people practicing this activity, potentially offering them job opportunities, or they can use the family board to go fishing as a family helper. This is contrary to Irohibe & Agwu`s, 2014), finding. This can be explained by the fact that fishing does not request any qualification but if you are not a boat owner boat or you did not grow up in fisher household your chance to be employed in the sector is lower compared to those who grew up in the community and were involved in fishing soon.

Table 2: Estimation results of the determinants of food security using GLS method

Variables (Xs)	GLS	Standard Error	GLS	Standard Error	GLS	Standard Error
Average daily income	**0.000*** **	0.000	**0.000*** **	0.000	**0.000*** **	0.000
Perception_ RisingWater_Temp	**-0.284*** **	0.053	**-0.196*** **	0.054	**-0.174*** **	0.050
Overfishing			**-0.198*** **	0.033	**-0.182*** **	0.025
Access Credit			**0.102*** **	0.044	**0.139*** **	0.047
Base Education level= Primary						
Tertiary					-0.047	0.042
Secondary					0.012	0.059
None					**0.197** **	0.087
Koranic					-0.058	0.131
Age					-0.007	0.009
Age2					0.000	0.000
Base Marital status= Married						
Never Married					**-0.070**	0.058
Divorced					**0.284*** **	0.107
Widowed					-0.011	0.171
Second activity					0.005	0.056
Base Employ status= Employer						
Employee					-0.001	0.044
Unemployment					-0.004	0.063
Fishing Experience					0.002	0.003
Household Size					-0.001	0.002
Boat Size					0.050	0.048
Base District = Soumbedioune						
Yarak					**-0.397*** **	0.097
Rufisque					**-0.368*** **	0.101
Kayar					**-0.514*** **	0.088
Mbour					**-0.562*** **	0.088
Joal_Fadiouth					**-0.519*** **	0.089
Guet_Ndar					**-0.506*** **	0.094
Djiffer					**-0.415*** **	0.101
Constant	**0.728*** **	0.063	**0.948*** **	0.111	**1.446*** **	0.250
R-squared	0.329		0.401		0.486	
Number of observations	570		570		570	

***Source:* Author's computation from field survey, 2023**

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Access to credit contribute positively to the food security level of the fishermen household. This is mainly due to the fact that, this credit access is an additional income that fishermen can use for different purposes including food expenses. This increases the amount of income attributed for food consumption. This additional income is important because the average daily income is the main determinant of food security but is not a fixed income and may variable significantly, especially during a day of no fishing activity due to wind, or unfavourable climate conditions or others issue. They also use this credit for their fishing fee and once back they return it before sharing the rest of money. This is in line with Osuji et al., (2017) and Onya et Ejiba., (2020) who stated that the better access a farmer has to credit the higher his/her food security. This positive relationship between credit access and food security can also be seen in the fishery sector.

The coefficient of the average daily income is positive and significant. This means that income positively influence on the food security level of the fisher's household. This is because an increase in income leads to better access to food items and, more diversified and stable food consumption. This verifies the Keynesian theory of consumption. According to him, "when income grows, so does consumption, but to a lesser extent" (1969, p. 54). Empirically, Srinivasan et al., 2010 found the same result. Thus, this result is consistent with the literature and validates our second hypothesis.

Climate change is not the only main driver of food insecurity in the fishery community. Overfishing also appears as part of the key drivers of food insecurity in Senegalese coastal zones especially in household whose main income-generating activity is fishing. Overfishing can impact entire ecosystems. It can change the size of the remaining fish, as well as how they reproduce and the speed at which they grow up. Food security is being threatened due to billions of tonnes of small fish being taken from the wild every year to feed farmed fish, a damning new report has revealed. Adding the fact that, industrial boat throughout the small fish in the sea this destroy the locale ecosystem from the reproduction to the development of fish, and this provoke also migration of some species. In other and this decrease fisher capture and reduce small scale fishermen income and decrease their level of food security. This result is consistent with findings. Indeed, Srinivasan et al., (2010) show that, in 2000, about 20 million people worldwide could have averted undernourishment and total catch in the waters of low-income food deficit countries might have been up to 17% greater than the tonnage

actually landed there. In Africa, the situation is worse. This result is confirmed by the effect of employment status on household food security.

Marital status appears to be correlated with household food security status. The coefficient associated with the variable being never married is negative and significantly correlated with the level of food security compared to married. The negative sign obtained can be explained by the fact that the never married may allocate a large part of their income to other expenses (health for example) and have a relatively higher size than unmarried households, which would decrease their chance of being food secure. This result corroborates the work of Asefach & Nigatu (2007) in Ethiopia and Yovo, & Gnedeka, (2023) in Togo.

2.4.3. Robustness test

The validation of our results is tested in two manners. First, the generalized least square regression is done using the main variables of interest such as perception of water temperature and average daily income. The results are quite the same in terms of significance and the nature of the relationship between these variable and household food security level. Indeed, average daily income has a significant and positive impact on food security in fishermen households, while perception of rising water temperature decreased it, and the coefficient is greater there compared to the general model that includes all variables used (-0.284 and -0.174). This coefficient of perception of rising water temperature while we add more variable in the model, and it is equal to -0.196 when we add overfishing and credit access. Thus, our finding is consistent compared to the general model.

2.5. Partial conclusion

This study highlights the critical impact of climate change on food security in Senegalese coastal communities, particularly those dependent on the fisheries sector. The ordinary least square model results reveal several key determinants of food security. Notably, the perception of rising seawater temperatures is associated with decreased food security, highlighting the adverse effects of climate change on fisheries production. This finding aligns with previous studies indicating that climatic changes impact fish availability, quality, and overall production, thereby affecting the livelihoods and food security of fishing communities.

Households with higher average daily incomes are less likely to be food insecure, emphasizing the need for economic stability to ensure adequate access to food. Policy implications from these findings are multifaceted. Firstly, there is an urgent need for climate

adaptation strategies tailored to the specific needs of coastal fishing communities. These strategies should focus on mitigating the impacts of rising seawater temperatures and other climate-related challenges on fisheries production. For example, investing in climate-resilient fishing practices and technologies could help sustain fish stocks and secure livelihoods. Secondly, enhancing economic opportunities and income stability is crucial for improving food security. This could involve supporting diversified livelihood options, such as aquaculture, which can provide alternative income sources for fishing communities. Additionally, promoting access to education and vocational training can equip individuals with the skills needed to pursue higher-paying jobs and reduce their vulnerability to food insecurity. Thirdly, targeted interventions are needed to address geographic disparities in food security. Policymakers should consider the specific vulnerabilities of different districts and implement location-specific measures to support the most affected communities. For example, regions experiencing higher temperatures and greater climate impacts may require more intensive support to mitigate these challenges.

Finally, strengthening community resilience through social safety nets and support systems is essential. Programs that provide financial assistance, access to healthcare, and other essential services can help buffer the impacts of climate change and economic instability on food security. Additionally, fostering community-based initiatives and cooperatives can enhance collective action and resource sharing, further strengthening resilience. In conclusion, this study underscores the complex interplay between climate change, economic factors, and food security in Senegalese coastal zones. Addressing these challenges requires a comprehensive and integrated approach that combines climate adaptation, economic development, education, and targeted support for vulnerable communities. By implementing these policy recommendations, Senegal can enhance the food security and well-being of its coastal fishing communities, ensuring their resilience in the face of ongoing climate change.

CHAPTER 3: IS SENEGALESE FISHERMEN`S MIGRATION A CLIMATE ADAPTATION STRATEGY TO INCREASE FOOD SECURITY?

RESUME

Ce chapitre vise à analyser si la migration des pêcheurs sénégalais constitue une stratégie d'adaptation au changement climatique visant à renforcer la sécurité alimentaire. Il s'appuie sur des données primaires et secondaires issues d'enquêtes menées dans 8 centres de pêche répartis dans 4 régions (Dakar, Saint-Louis, Thiès et Fatick) et sur les indicateurs de la Banque mondiale. Au total, 570 personnes ont répondu à l'enquête. Les résultats de la régression du modèle Heckman en deux étapes soulignent que le changement climatique a un impact positif sur la migration et que le niveau de sécurité alimentaire est susceptible d'avoir un impact positif sur les décisions de migration et sur le nombre de migrants. Le niveau d'éducation apparaît également comme un facteur déterminant de la migration dans ces ménages. Le gouvernement devrait développer des programmes de migration saisonnière ou circulaire et améliorer l'accès au crédit dans les communautés de pêcheurs.

Mots Clés : Changement climatique, migration, sécurité alimentaire, Sénégal, Heckman

ABSTRACT

This chapter aims to analyse whether Senegalese fishermen migration is a climate adaptation strategy to enhance food security. Using primary and secondary data from surveys in 8 fishing centres in 4 regions, such as Dakar, Saint-Louis, Thies, and Fatick, and the World Bank Indicator website. 570 fishers were part of the survey. The regression results of the two-step Heckman model highlight that climate change impacts positively on migration, and the level of food security is likely to impact positively on migration decisions and on the number of migrants. Education level also appears as a determinant of migration in these households. The government should develop seasonal or circular migration programs and improve Access to Credit in these Fishing Communities.

Keywords : Climate change, migration, food security, Senegal, Heckman

3.1. Introduction

Climate change, marine pollution, and overfishing are among the key factors that have disrupted the fisheries sector in West African coastal countries, particularly in Senegal. This sector plays a crucial role in Senegal's economy and social structure. It is the primary economic activity for approximately 86% of coastal households[23] and contributes more than 3% to the country's gross domestic product (GDP)[24]. However, the degradation of marine ecosystems due to rising sea temperatures, erratic weather patterns, and declining fish stocks has significantly undermined the livelihoods of fishing communities (Xu et al., 2024).

In response to the deteriorating conditions of the fisheries sector, many Senegalese fishermen have adopted migration as an adaptation strategy. Although often irregular and undocumented, migration is a widespread and growing phenomenon among these communities (Asiva Noor Rachmayani, 2015). Due to limited financial resources, many fishermen undertake the journey clandestinely, often using their traditional fishing pirogues to reach European shores. According to Steiner et al. (2025), this form of irregular migration is increasingly viewed as a climate adaptation strategy, as individuals seek better opportunities to support their families in the face of environmental and economic adversity.

The number of Senegalese migrants arriving in Europe has grown in recent years, particularly between 2023 and early 2025. From an economic standpoint, migration has tangible impacts on origin countries through remittances. In 2023, Senegalese migrants sent home approximately 1.842 billion CFA francs, up from 1.600 billion in 2022[25]. These remittances often serve as vital sources of income, enabling families to meet essential needs such as food, healthcare, education, and housing. Several studies (Stampini et al., 2021) have shown that remittances can improve household food security.

However, the relationship between migration and food security remains complex. While some authors argue that migration enhances food security by supplementing household income, others suggest that migration may also result in food insecurity due to the loss of labor or social capital within the household (Gero et al., 2024). This study builds on the New Economics of Labor Migration (NELM), which posits that migration is not only an individual

[23] https://books.openedition.org/irdeditions/44091?lang=fr
[24] https://www.fao.org/in-action/coastal-fisheries-initiative/activities/west-africa/senegal/ru/
[25] https://www.senenews.com/actualites/economie/economie-les-transferts-de-fonds-de-la-diaspora-senegalaise-atteignent-1-842-milliards-f-cfa-en-2023-selon-la-bceao_524735.html#:~:text=Selon%20ce%20rapport%2C%20les%20transferts,diaspora%20dans%20l'%C3%A9conomie%20s%C3%A9n%C3%A9galaise.

decision but also a household-level strategy to cope with income volatility and economic shocks, such as those caused by climate change.

Food security, as defined by the 1996 World Food Summit, exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Migration, as defined by the International Organization for Migration (IOM), refers to the movement of people across borders or within a country away from their usual place of residence, regardless of legal status, motivation, or duration.

Given the growing concerns around climate-induced migration and food insecurity, regional and national policymakers have undertaken numerous initiatives. ECOWAS and its member states, including Senegal, have adopted a variety of climate action plans and social protection programs. These include the National Adaptation Plan for Climate Change (2006), the African Union Climate and Resilience Strategy (2022–2032), the Early Warnings for All Initiative, and the Sendai Framework for Disaster Risk Reduction (2015–2030). Specific to fisheries, Senegal has introduced the National Plan for Adapting the Fisheries and Aquaculture Sector to Climate Change (Horizon 2035). In addition, Senegal has implemented several national programs aimed at combating poverty and food insecurity, such as the National Family Security Bursary Program (PNBSF), the Universal Health Coverage (CMU), and the Drinking Water Supply Program (PAEP).

In the area of migration and health, the Migration Policy Framework for Africa (2018–2030), along with its Action Plan, recommends integrating migrants into national health plans. The African Union Commission has since taken steps to better understand and address migrant health issues across the continent.

This study aims to assess whether migration among Senegalese fishing households' functions as an effective climate change adaptation strategy to enhance food security. The research focuses on eight key fishing centers, Soumbedioune, Yarakh, Kayar, Djiffer, Joal Fadiouth, Rufisque, Mbour, and Guet Ndar, which together represent over 80% of the country's fishing population. In doing so, the study contributes to the literature by focusing on a highly vulnerable and understudied population: artisanal fishing households. A key innovation of this study is the construction of a multidimensional food security index that incorporates six dimensions: availability, access, stability, utilization, sufficiency, and agency. This approach

provides a more holistic understanding of household food security than conventional indicators.

The central hypothesis of this chapter is that climate change positively influences the decision to migrate, and that fishing households with at least one migrant member are more food secure than those without. The study is further motivated by the pressing issue of irregular migration, which poses serious risks, including loss of life, and by the need to address persistent food insecurity in fishing communities. By applying a Heckman selection model to survey data from 570 fishermen, the study seeks to examine whether migration outcomes correlate with improved food security.

The remainder of this chapter is organized as follows: Section 2 presents a literature review on the interconnections between climate change, migration, and food security. Section 3 describes the econometric modelling. Section 4 discusses the empirical findings and interprets them considering the theoretical framework. Section 5 presents the partial conclusion.

3.2. Literature review

Migration is increasingly viewed as a household-level adaptation strategy in response to economic and environmental risks. This strategy can serve to diversify livelihoods and, through remittances, improve household food security. While relatively few studies explore the relationship between migration and food security, the New Economics of Labor Migration (NELM) offers a theoretical lens to examine this linkage. This section first defines the concepts of migration and food security before exploring the theoretical frameworks that underpin their interrelation.

3.2.1. Theoretical review

The decision to migrate has been explained through various economic and sociological theories. This section provides an overview of these migration theories, with a particular focus on those that link migration to household welfare and food security.

a. Neoclassical Migration Theory (Macro Level)

Neoclassical migration theory, one of the earliest frameworks, posits that migration results from geographical disparities in labor supply and demand, employment conditions, and migration costs (Sjaastad, 1962; Todaro, 1969). At the macro level, international migration is seen as driven by wage differentials: countries with labor shortages (high wages) attract

migrants from countries with labor surpluses (low wages). Migration, in this sense, is an individual response to maximize income.

Environmental factors can indirectly affect wage levels, particularly through their impacts on rural livelihoods and urban labor markets (Mueller et al., 2020). According to Harris and Todaro (1970), migration occurs even when the probability of employment at the destination is low, as long as the expected income exceeds that in the origine area.

b. Neoclassical Migration Theory (Micro Level)

At the micro level, this theory views migration as an individual rational decision based on a cost-benefit analysis. Migrants are assumed to move where they can be most productive typically where wages are highest (Lewis, 1954; Harris & Todaro, 1970). This process is also part of economic development, with labor moving from rural areas (agriculture) to urban areas (industry), leading to a convergence in wages between sending and receiving regions.

The Harris-Todaro model, a seminal contribution to this theory, introduced the concept of "expected income" as a function of both wages and the probability of employment. Later refinements of this model included migration costs, opportunity costs, risk of deportation (for irregular migrants), and psychological costs (Bauer and Zimmermann, 1998; Todaro & Maruszko, 1987; Borjas, 1989).

The neoclassical migration theory at macro and micro level is limited by the fact that they do not focus on other drivers of migration such as environmental, social, cultural, political drivers of migration. It does not explain also why migration continues even after wage gaps narrow.

c. Dual Labor Market Theory

This theory differentiates between push and pull factors that influence migration, including structural labor demands in the destination country and intervening obstacles such as costs and legal barriers (Lee, 1966). Environmental conditions (e.g., drought) can serve as both push and pull factors, influencing people's decisions to migrate (de Geest, 2001). However, not everyone will migrate; some may choose to remain and adapt in place (Moon, 1995). This theory does not consider the socio-economic motivations of the migrant itself. It overlooks push factors in origin countries.

d. New Economics of Labor Migration (NELM)

Unlike neoclassical theories that focus on individual decision-making, NELM views migration as a household strategy. Migration decisions aim to diversify income sources, manage risks, and overcome market imperfections, not only in the labor market but also in credit, insurance, and food markets (Stark and Levhari, 1982; Stark, 1991).

Remittances are seen as a key outcome of migration, helping households to cope with income shocks, reduce liquidity constraints, and improve consumption, particularly of essential goods such as food (Smith & Floro, 2019; Abebaw et al., 2020). Migration can also bring new knowledge on dietary practices. However, the departure of a household member can reduce labor availability, potentially lowering income and increasing food insecurity if remittances are insufficient (Regmi et al., 2017).

The New Economics of Labor Migration estimates that migration is a collective decision, but this idea may sometimes not be the case because a member of the household can individually take the decision to migrate.

e. World Systems Theory

This theory attributes migration to the global expansion of capitalism. The penetration of global markets into developing countries, through the search for resources, cheap labor, and new markets, disrupts traditional economies and catalyzes migration (Massey et al., 1997). Migration is viewed as a structural consequence of global economic integration. This theory overemphasis on economic determinism of migration. It underestimates cultural, political and agency-based factors.

f. Social Network Theory

Migrant networks comprised of friends and relatives facilitate the migration process by providing information, reducing costs, and offering support at the destination (Gallup, 1997). These networks lower the barriers to migration and often lead to chain migration. As the previous theory does not consider the other reason that pushes people to migrate. It focuses on the fact that people migrate because they know someone who migrates and has information about the host country.

g. Institutional Theory

This theory emphasizes the role of institutions and organizations that emerge to facilitate migration once it has begun. These include legal and illegal actors who provide services such as transportation, employment contracts, housing, and legal aid. These systems can perpetuate migration over time. This theory does not take into account the other factors that push people to migrate.

h. Cumulative Causation Theory

According to this theory, migration alters the social and economic context of sending communities, making future migration more likely. Factors such as land distribution, agricultural practices, and social norms evolve in ways that sustain or increase migration (Massey et al., 1993).

In sum, while multiple theories explain migration from different perspectives, the New Economics of Labor Migration offers the most direct theoretical link to food security. It highlights how migration, particularly through remittances, can support household welfare by increasing the consumption of essential goods like food. However, migration's effect on food security is not uniformly positive; it can also exacerbate vulnerabilities when household labor losses are not offset by sufficient remittances or income gains.

3.2.2. Empirical Review

Numerous empirical studies have explored the complex relationship between migration, remittances, and food security, employing diverse methodologies to address issues such as self-selection bias and endogeneity. This section synthesizes key findings from relevant literature.

a. Migration and Food Security

Sambo (2020) used a Heckman two-stage model to assess the impact of migration on food security in Ethiopia. The results revealed that while migration negatively affects per capita calorie intake, it improves dietary diversity. Overall, the findings indicate a net negative effect of migration on the food security status of migrant households.

However, Vo (2023) addresses the same issue in Vietnam using data from the Vietnam Household Living Standards Surveys. Applying difference-in-differences and instrumental variable estimation to address selection bias and endogeneity, the study found that domestic migration significantly increased food expenditure, calorie consumption, and dietary

diversity. The effects were mediated by household headship, number of children, and regional income levels. This study confirms the work of Nguyen and Winters (2011) who had used the same data covering the period 2004 and 2006 (the Vietnam Household Living Standards Surveys data). Using an instrumental variable approach to address endogeneity, they found that short-term migration positively affected per capita food expenditures, calorie consumption, and food diversity, thereby contributing to food security.

This positive association between migration and security is also confirmed by studies conducted by Abebaw et al. (2020) who examined the effects of rural outmigration on household food security in Ethiopia using a two-year panel dataset. Employing a combination of difference-in-differences and inverse-probability of treatment weighting (IPTW-DID), they found that outmigration increased daily calorie consumption per adult equivalent by 22% and significantly reduced the food poverty gap and severity by seven and four percent points, respectively. In addition, Onya and Ejiba (2020) confirmed that migration positively influenced food security in Nigeria. The authors employed descriptive statistics, the Foster-Greer-Thorbecke (FGT) index, and a probit model. The probit regression model includes other significant factors such as education, access to credit, farm size, and remittances. The results confirm additionally that households headed by older, less educated individuals were more likely to experience climate-induced migration.

b. Remittances and Food Security

Atuoye et al. (2017) used multivariate ordered logistic regression to study the impacts of remittances on food security in 1,438 households in eleven districts of Ghana. The findings indicated that urban remittance-receiving and rural non-remittance-receiving households were more likely to report severe food insecurity compared to urban non-remittance households. This suggests that remittance alone is insufficient to significantly improve food security. Zingwe et al. (2023) used three (03) food security indicator such as the Coping Strategy Index (CSI), Food Consumption Score (FCS), and Household Dietary Diversity Score (HDDS) to assess the impact of remittances on food security and nutrition in Malawi, using data from 7,723 households in the 5 integrated household survey (IHS5) fielded from April 2019 to March 2020 (IHS5). Results showed that remittances improved food security and nutrition only for households exposed to multiple shocks but had no impact on dietary diversity.

Mabrouk et al. (2018) explored the relationship between international remittances and the four dimensions of food security (availability, access, stability, and utilization) across African countries. Their econometric analysis found a positive association with food access, stability, and utilization, but a negative correlation with food availability, indicating a mixed effect.

Abadi et al., (2013) conducted a study on 301 farm households in the Tigray region of Ethiopia, applying propensity score matching. They found that remittances had a positive and statistically significant impact on food security. Similarly, Geeroso, (2015), using a partial proportional odds model, demonstrated that remittances positively affected food security in rural Sudanian areas of Mali and mitigated the adverse effects of intra-annual rainfall variability.

Sulemana et al., (2019) and Regmi and Paudel (2016) found that frequent remittance receipts were associated with improved food security, caloric intake, and dietary diversity in several sub-Saharan African countries. Stampini et al., (2021) observed similar findings in Venezuela, where remittances reduced food access limitations.

In South Africa, Waidler & Devereux, (2019) reported that remittances positively influenced dietary diversity but had no significant effect on food expenditures or anthropometric measures. Conversely, Babatunde (2018) found no significant impact of remittances on diet quality or child nutrition in Nigeria.

Maharjan et al. (2017) noted that in Nepal, remittances primarily supplemented agricultural income to meet basic household needs. In Bihar, India, Chaothanani (2016) found that remittances invested in agriculture improved household food security. Migration plays a significant role on improving living conditions. Franzen & Mazzucato, (2014) found that remittances in Burundi improved living standards and food security, though they had limited effect on purchasing productive assets. Antón (2010) reported a positive correlation between remittances and child nutritional status in Ecuador and Peru, while Longworthy (2011) found that in Peru, remittances could offset the negative nutritional impacts of parental migration.

De Brauw (2011) observed that during the 2007-2008 food price crisis in El Salvador, households receiving remittances experienced less deterioration in child nutritional status than those without remittances. Interestingly, Tawodzera (2010) showed that in Harare, Zimbabwe, remittance flows often moved from rural to urban areas, helping families cope with urban labor market uncertainty. This supports Stark's (1991) hypothesis that diversifying household income sources through spatial dispersion improves livelihood security.

In summary, the empirical literature presents mixed findings. While many studies show that migration and remittances can enhance household food security, particularly through increased calorie intake and dietary diversity, others caution that these strategies alone may not suffice to ensure long-term food security, especially in the face of persistent climatic and economic shocks.

3.2.3. Review of Methods for Measuring Food Security

The concept of food security was first defined during the World Food Conference in 1974 as the availability of adequate world food supplies to sustain a steady expansion of food consumption and offset fluctuations in production and prices (UN, 1975). Initially focused on availability and price stability, the definition evolved to include economic access ensuring that all people always have both physical and economic access to the basic food they need (FAO, 1983). The World Bank (1986) further refined the concept by emphasizing access to sufficient food for an active and healthy life for all people.

A major turning point came with the 1996 World Food Summit, where the Food and Agriculture Organization (FAO) defined food security as a condition in which *"all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life."* This comprehensive definition introduced four key dimensions of food security: availability, access, utilization, and stability.

Subsequent literature expanded this definition to incorporate ethical and human rights dimensions, notably the right to adequate food (FAO, 2006). Ibarrola-Rivas and Galicia (2017) further emphasized the importance of ensuring food security not only for the present but also for future generations. Among all definitions, the FAO (1996) formulation remains the most widely cited and applied in the academic literature, owing to its multidimensional nature (Webb et al., 2006; Lang & Barling, 2012; Napoli et al., 2011).

Each of the four dimensions has specific characteristics:

- **Availability** refers to the physical presence of food through production, imports, or aid.
- **Stability** ensures reliable access to food over time, despite seasonal or economic fluctuations (Swaminathan & Bhavani, 2013; Battersby & Watson, 2018; Steenkamp et al., 2021).

- **Access** involves the ability of households to obtain adequate resources (both economic and physical) to acquire appropriate foods.
- **Utilization** emphasizes the body's ability to absorb nutrients, which depends on food quality, sanitation, and health services (Clay, 2002; Webb & Rogers, 2003).

In recent years, two additional dimensions have gained prominence:

- **Food agency**, which refers to individuals' capacity to make strategic decisions about food production, preparation, and consumption within their environment (Trubek et al., 2017).
- **Food sustainability**, defined by the High-Level Panel of Experts (2020) as the ability to ensure that food systems regenerate environmental, social, and economic systems to meet the needs of current and future generations.

Several tools and indices have been developed to measure food security, each with varying emphasis:

- **The Household Food Insecurity Access Scale (HFIAS)** uses a 9-item questionnaire to classify households based on their experiences with food insecurity over a 30-day recall period. While useful for identifying food access issues, it does not quantify actual consumption (Manikas et al., 2023).
- **The Household Food Security Survey Module (HFSSM)** is an 18-item instrument primarily used in the U.S. and Canada. It assesses food insecurity over a 12-month period and categorizes households into four levels of food insecurity (Bickel et al., 2000).
- **The Latin American and Caribbean Food Security Scale (ELCSA)** employs 15 items to capture food insecurity prevalence and causes in regional contexts (Leroy et al., 2015).
- **The Household Hunger Scale (HHS)** and **Coping Strategies Index (CSI)** focus on food access during periods of shortage by examining coping behaviours. However, they often lack standard classification thresholds.

Other widely used methods include:

- **The Household Dietary Diversity Score (HDDS)**, which measures access to diverse food groups as a proxy for food quality.
- **The Food Insecurity Experience Scale (FIES)**, which tracks self-reported food insecurity using 8 standardized items, allowing for international comparisons.
- **The Global Hunger Index (GHI)** and **Suite of Food Security Indicators** provide composite national-level assessments.
- **The FAO Prevalence of Undernourishment (PoU)** and **Food Consumption Score (FCS)** assess caloric intake and dietary quality.

This study adopts the **FAO (1996)** definition of food security, as it encompasses all core dimensions, **availability**, **access**, **utilization**, and **stability,** while excluding food sustainability due to data limitations. This definition, developed through diplomatic consensus at the 1996 World Food Summit, provides the most comprehensive framework for evaluating the multidimensional nature of household food security. It is particularly appropriate for assessing food security among the 570 Senegalese fishermen surveyed in this study.

3.3. Econometric modelling

3.3.1. Study Area

This study was conducted in four coastal regions of Senegal: Dakar, Thiès, Fatick, and Saint-Louis. Senegal, located in West Africa, is bordered by the Atlantic Ocean to the west, Mauritania to the north and northeast, Mali to the east and southeast, Guinea to the southeast, and Guinea-Bissau to the southwest. The Gambia forms an enclave that penetrates 302 km into Senegal's territory. The Cape Verde Islands are situated 560 km off the Senegalese coast.

According to WACA (2016), the coastal population of Senegal is approximately 7.8 million (52% of the national population), of which 4.7 million (61%) live in urban areas. The Senegalese coastal zone spans approximately 198,000 km² and features a variety of ecosystems, including sandy and rocky shores, wetlands, mangroves, and sandy islands. It is an area of intense human and economic activity, with 60% of the population and 90% of

industrial establishments concentrated there, contributing to 68% of national GDP[26]. The coastal zone also produces 70% of the country's vegetables. The coastline extends to 718 km.

The fishery sector plays a major socio-economic role in Senegal. It is the leading source of foreign exchange, generating around CFA 200 billion annually (about 30% of export revenues), provides employment for approximately 600,000 people (15% of the active population), and supplies 75% of national animal protein needs. These results are largely due to the vibrancy of the artisanal fishing sub-sector, which accounts for more than 80% of national fish production[27] (MPEM, 2017). In 2016, fishing was the top export sector, accounting for 14.63% of export earnings. In 2022, the fisheries sector contributed 3.2% to GDP, 10.2% of exports, and generated $400 million in value (Bousso, 2022).

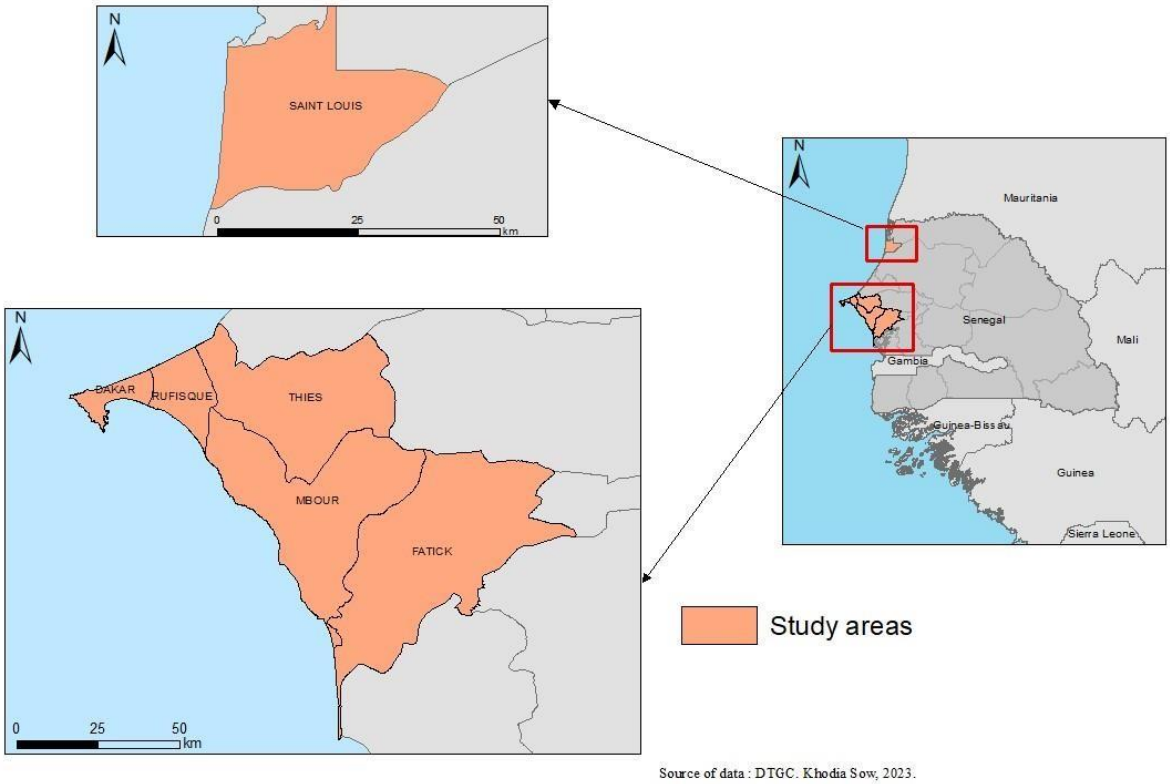
Artisanal fishing is concentrated in key centers such as Dakar, Saint-Louis, Kayar, Joal-Fadiouth, Mbour, Rufisque, and Bargny. The regions of Thiès, Saint-Louis, and Dakar account for 77% of the fishing workforce, with respective shares of 40%, 22%, and 15% (Bousso, 2022). This concentration guided the selection of fishing sites for this study: Mbour, Kayar, Joal-Fadiouth (Thiès); Guet Ndar (Saint-Louis); Rufisque, Soumbédioune, Yarakh/Hann (Dakar); and Djiffer (Fatick).

Given the strategic and economic importance of the fisheries sector in Senegal, and its vulnerability to climate change, it is critical to study the links between climate change, food security, and household well-being in these coastal fishing communities. Climate change is contributing to severe challenges, including declining livelihoods, increased migration, and heightened risks to household food security. This study seeks to understand these dynamics within the context of Senegal's major artisanal fishing centres.

[26] https://www.wacaprogram.org/country/senegal

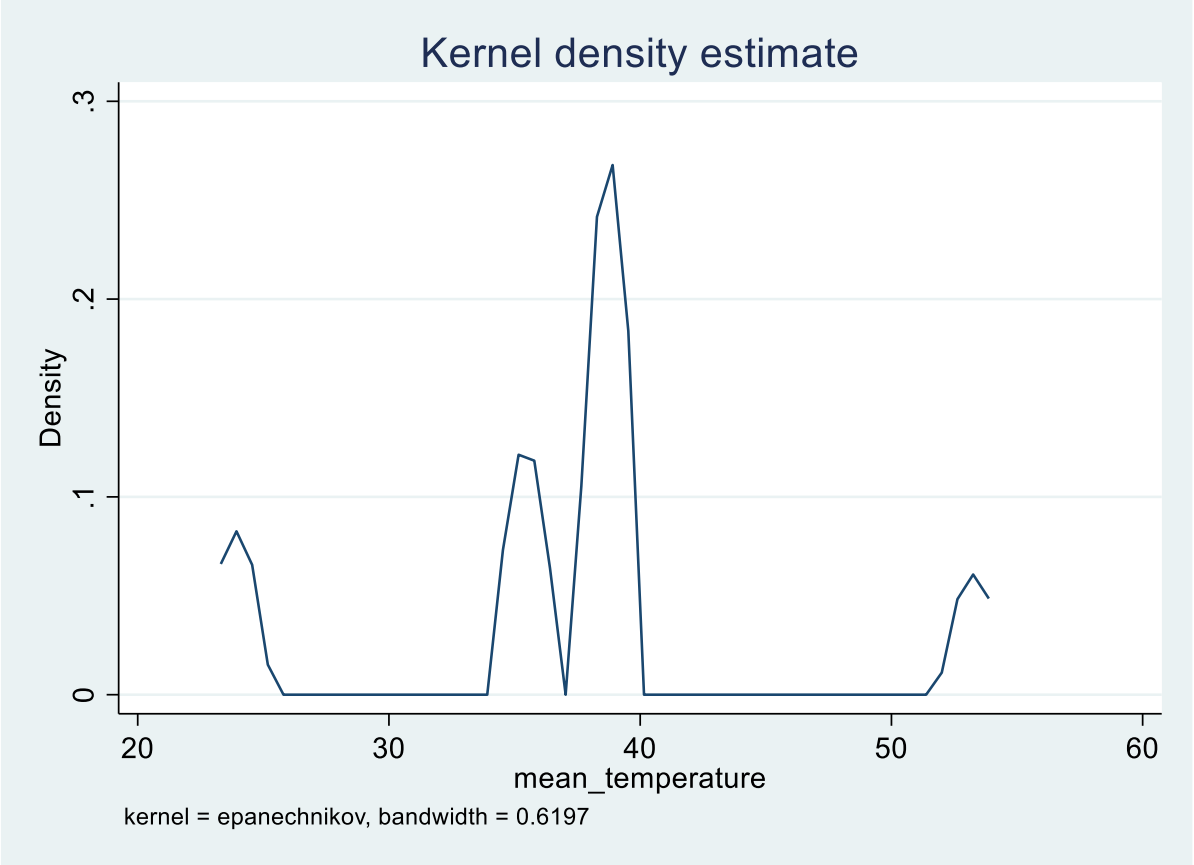
[27] https://www.leral.net/Alerte-sur-l-approche-ecosystemique-de-la-peche-senegalaise-Le-secteur-de-la-peche-est-en-crise_a354677.html

Figure 9: Study area



Source: ***Author's computation from field survey, 2023.***

Figure 10: Kernel density variation of temperature



Source: ***Author's computation from field survey, 2023.***

3.3.2. Data Collection

Primary data were collected from 570 fishermen across the eight artisanal fishing centres mentioned above. The survey was conducted in two phases. A pilot survey was first carried out in two regions to test the questionnaire, enabling refinement of the final tool. The final questionnaire included sections on: Socio-demographic characteristics, Fishing activities, Perceptions of climate change, Food security, Household well-being, Migration and remittance patterns. Interviews were conducted individually with fishermen to ensure accurate and detailed data collection.

3.3.3. Sampling Strategy

Several sampling methods were considered for determining the appropriate sample size, given the lack of an exact population figure for fishermen in the study area.

a. Probability-Based Methods

One method used was the simple random probability sampling technique, which assumes that everyone has an equal chance of being selected (Wimmer & Dominick, 2006). The following formula was applied:

$$n = \frac{N}{1 + Ne^2}$$

Where:

- n = sample size,
- N = total population,
- e = margin of error.

Another approach used was the **Krejcie and Morgan (1970)** formula:

$$s = \frac{X^2 P(1-P)}{d^2(N-1) + X^2 P(1-P)}$$

Where:

- s = sample size,
- X^2 = chi-square value for 1 degree of freedom at 95% confidence (3.841),
- P = population proportion (assumed 0.5),
- d = margin of error (0.05),
- N = total population.

b. Quota Sampling Method

Quota sampling was also used to ensure representativeness based on known population characteristics (e.g., age, gender, location, income). This approach ensures each subgroup is proportionally represented (Satin & Shastry, 1993).

c. Final Sample Size

Due to the unavailability of an exact population size for fishermen, a single population proportion formula was applied (Cochran, 1977; Tessema, 2017). Based on WACA (2016), it was estimated that fishermen represent approximately 52% of the population in the coastal

zone. Considering demographic growth between 2016 (14,799,879) and 2023 (18,032,473), the current proportion was assumed to be 56%.

Using the following formula:

$$n = \frac{Z^2 \cdot p(1-p)}{E^2}$$

Where:

- Z = 1.96 (for 95% confidence),
- p = 0.5 (assumed proportion),
- E = 0.05 (margin of error) (Agresti and Finlay, 2009).

For this method, the minimum required sample was calculated as 384. However, to increase precision, 570 fishermen were ultimately surveyed across the eight sites. The distribution is shown below:

Table 3: Sample size distribution

REGION	DEPARTMENT	DISTRICT	HOUSEHOLDS INTERVIEWED
DAKAR	Dakar	Soumbédioune	33
	Dakar	Hann Bel-Air	60
	Rufisque	Rufisque	40
THIÈS	Thiès	Kayar	85
	Mbour	Mbour	90
	Mbour	Joal-Fadiouth	111
FATICK	Djiffer	Djiffer	64
SAINT-LOUIS	Saint-Louis	Guet Ndar	87
TOTAL			**570**

***Source:** Author's computation from field survey, 2023.*

3.3.4. Empirical Framework

To date, no index comprehensively captures all six key dimensions of food security: availability, accessibility, stability, utilization, agency, and sufficiency. Most used indicators only cover a subset of these dimensions. To address this gap, we developed a new composite index, the **Household Food Security Access Scale (HFSAS),** adapted specifically to the household level. We exclude the sustainability dimension, which typically applies to national-level agricultural policy and long-term environmental goals.

The HFSAS incorporates six household-level dimensions of food security, each derived from theoretical literature and previous studies:

- **(d1) Availability** – "Are all the types of food you want available in the market?"
- **(d2) Stability** – "Did you eat at least three meals per day?"
- **(d3) Economic Accessibility** – "Does your income allow you to afford three meals per day?"
- **(d4) Physical Accessibility** – "Is the market far from your location?"
- **(d5) Utilization** – "Is the food you consume diversified?" (captured using the Food Consumption Score – FCS)
- **(d6) Sufficiency** – "Did you eat enough food?"
- **(d7) Agency** – "Are you able to prepare your meals yourself?"

Responses were collected using binary (Yes/No) or ordinal scales (Always/Sometimes/Never). To construct the index, responses were normalized using the min-max method, which rescales variables to fall between 0 and 1:

$$I_{qc}^{t} = \frac{x_{qc}^{t} - \min_{c} x_{qc}^{t_0}}{\max_{c} x_{qc}^{t_0} - \min_{c} x_{qc}^{t_0}}$$

Where:

- x_{qc}^{t}: Value of indicator q for individual c at time t

Normalization ensures comparability across dimensions and prevents adding dollars and meters. We then applied Principal Component Analysis (PCA) to assign weights and aggregate the normalized responses into a single index score ranging from 0 (high insecurity) to 1 (high security).

a. Model Specification

To estimate the effect of migration on food security, we use a Heckman Selection Model (Heckman, 1979) as (Sambo, 2020). This approach corrects for potential selection bias arising from the fact that the number of migrants in a household is only observed for households that have at least one migrant.

The model is estimated in two stages:

First Stage: Migration Decision

Let M_i^* be the latent (unobserved) propensity for household i to have at least one migrant. The selection equation is modelled as a probit:

$$M_i^* = \theta_0 + \theta_1 X_i + \theta_2 Z_i + \varepsilon_i$$

$$M_i = \begin{cases} 1 & if\ M_i^* > 0 \\ 0 & Otherwise \end{cases}$$

Where:

- X_i: vector of socio-economic characteristics
- Z_i: instrumental variable(s), affecting migration but not food security (e.g., average rainfall)
- M_i: observed migration status (1 = has at least one migrant, 0 = none)

- X_i: vector of socio-economic characteristics
- Z_i: instrumental variable(s), affecting migration but not food security (e.g., average rainfall)
- M_i: observed migration status (1 = has at least one migrant, 0 = none)

From this probit estimation, we derive the **Inverse Mills Ratio (IMR)** to correct for selection bias in the second stage:

$$\lambda = \frac{\varphi(\theta_0 + \theta_1 X_i + \theta_2 Z_i)}{\phi(\theta_0 + \theta_1 X_i + \theta_2 Z_i)}$$

Second Stage: Impact of Migration on Food Security

Conditional on having migrants, the second step estimates the effect of migration on the household's food security index:

$$M_i = \beta_0 + \beta_1 X_i + \beta_2 FS_i + \beta_3 \lambda_i + \mu_i$$

Where:

- FS_i: food security index (HFSAS)
- M_i: number of migrants in household i;
- X_i : vector of other explanatory variables
- λ_i: IMR from the first step
- μ_i: error term

This approach accounts for selection effects and provides consistent estimates of migration's effect on food security.

b. Variables and Data Description

The study sample includes only artisanal fishing households.

Dependent Variables

The dependent variable in this study is **migration**, which is represented in two forms to correspond to the two stages of the Heckman selection model.

c. Migration Dummy Variable (Selection Equation)

This binary variable indicates whether a household has at least one member who has migrated. It takes the value of 1 if the household has at least one migrant member, and 0 otherwise. This variable is used in the first step of the Heckman model to estimate the **probability of migration** using a probit (or logit) specification. The question posed to households is: *"Does your household have a member who has migrated?"* This reflects a yes/no response.

d. Number of Migrants (Outcome Equation)

This is a continuous variable used in the second step of the model, conditional on the household having a migrant member. It measures the total number of migrants in the household, particularly those who are fishermen. This variable helps to analyse the extent of migration among fishing households.

Independent Variables

The two key explanatory variables of interest are climate change perception and food security level, in addition to a set of control variables based on literature and data availability.

1. Climate Change Perception

This is a binary variable capturing whether the household head perceives changes in climate. It equals 1 if the respondent perceives climate change (e.g., rising sea temperatures, changes in rainfall), and 0 otherwise. The rising sea temperature is considered an economic stressor, as it affects fish availability and pushes fishermen to migrate.

2. Food Security Level (Household Food Security Access Scale - HFSAS)

To measure food security, we construct a composite index inspired by literature on food access. The HFSAS assesses multiple dimensions of food access at the household level. The index is built based on responses to specific questions on food availability, utilization, and access. Its construction and justification are presented in the methodological section.

Other Control Variables

Several socio-demographic and economic variables are included in the model, drawing from the migration and food security literature.

- **Age and Age Squared**

Age is expected to positively influence migration, while age squared is expected to have a negative effect, indicating a nonlinear relationship (Vo, 2023). Younger individuals are more likely to migrate, but this tendency decreases with age.

- **Education Level**

Education is categorized into five levels: no education, Koranic, primary, secondary, and tertiary. Higher levels of education are generally associated with a greater likelihood of migration (Docquier et al., 2017; Belot & Hatton, 2012).

- **Marital Status**

Marital status is categorized as married, divorced, never married, and widowed. Studies show that single individuals are more likely to migrate than married ones (Schiff & Morrison, 2007).

- **Household Size**

This refers to the total number of individuals in the household. Larger households may have a higher propensity to send migrants (Sadiddin et al., 2019).

- **Fishing Experience**

This variable captures the number of years the head of household has been engaged in fishing. More experienced fishermen are often better connected and knowledgeable about routes and networks, potentially facilitating migration (especially via fishing boats).

- **Employment Status**

This variable is categorized as employer, employee, or unemployed, where *Employer* means "Owns a boat and hires others", *Employee* represents "Works on someone else's boat", and *Unemployed* corresponds to "Not engaged in fishing or boat-related employment".

This variable influences migration based on the stability and nature of employment (Smith & Floro, 2019).

- **Average Daily Income**

This continuous variable reflects the income of the household head, measured in local currency. It is expected to affect migration both positively and negatively, depending on whether income facilitates or substitutes the need for migration (Smith and Floro, 2019).

- **Access to Credit**

A binary variable (1 = has access to credit; 0 = no access). Credit access may increase migration by providing the means to finance migration, but it can also reduce migration if used for other livelihood improvements.

- **Land Tenant**

Binary variable indicating whether the household has his own home, or he is paying rent.

Instrumental Variable (IV) for Heckman Model

A key requirement of the Heckman selection model is the inclusion of an instrumental variable that affects the selection equation (i.e., the decision to migrate) but not directly the outcome equation (i.e., the number of migrants).

Following Sambo (2020), we use average annual rainfall as an instrument. Annual rainfall data from 2018 to 2022 were averaged at the regional level, under the assumption that climatic instability during this period has influenced migration decisions. Rainfall variability affects agricultural and fishing productivity and thereby serves as a credible instrument for migration decision-making.

Table 4: Definition of Variables

VARIABLE	DESCRIPTION
DEPENDENT VARIABLES	
MIGRATION (BINARY)	1 if the household has at least one migrant; 0 otherwise
MIGRATION (COUNT)	Number of migrants in the household
INDEPENDENT VARIABLES	
FOOD SECURITY INDEX	Household Food Security Access Scale (HFSAS)
AGE	Age of household head (17–75 years)
AGE²	Square of age to capture non-linear effects
MARITAL STATUS	Dummy: 1 if single (includes divorced/widowed), 0 if married
EDUCATION LEVEL	Dummy: 1 if any schooling (including Quranic), 0 if none
CLIMATE CHANGE	Perception of climate change (1 if yes, 0 if no)
HOUSEHOLD SIZE	Number of people sharing meals in the household
AVERAGE DAILY INCOME	In FCFA
EMPLOYMENT STATUS	Dummy: 1 if boat owner, 0 if employee
ACCESS TO CREDIT	1 if household has credit access, 0 otherwise
LAND TENANT	1 if household has house, 0 otherwise
FISHING EXPERIENCE	Number of years practicing fishing
AVERAGE RAINFALL	Regional average from 2000 to 2022 (instrumental variable)

***Source:* Author's computation from field survey, 2023.**

- **.4 Justification of Key Variables**
- **Food Security Index (HFSAS)**: Our main outcome variable, based on a multidimensional understanding of food security.
- **Climate Change Perception**: Captures local awareness of changing environmental conditions, hypothesized to influence migration.
- **Rainfall (Instrument)**: Used as an instrument in the selection model, based on its link with migration but not directly with food security at the household level (Sambo, 2020).
- **Household Size, Age, and Income**: Frequently cited in migration literature as determinants of migration and food security outcomes (Smith & Floro, 2019; Sadiddin et al., 2019).
- **Education:** Posited to increase migration aspirations through access to information and opportunities (Belot and Hatton, 2012; Docquier et al., 2017).

3.4. Presentation of the results and discussion

3.4.1. Descriptive Statistics

The data used in this study come from a survey of 570 artisanal fishing households in coastal Senegal. The descriptive statistics provide an overview of the key socio-economic and demographic characteristics of the sample.

Table 5: Descriptive statistics

Variables	Modalities	Frequences	Percent	Cum
Credit Access	Non	75	13.16	13.16
	Oui	495	86.84	100
Prob Migrant	Non	202	35.44	35.44
	Oui	368	64.56	100
Employment Status	Employer	225	39.47	39.47
	Employee	345	60.53	100
Climate change	Non	366	**64.21**	64.21
	Oui	204	35.79	**100**

Source: Author's computation from field survey, 2023.

Out of the 570 fishermen surveyed, 391 households (68.6%) reported having internet access, while 179 (31.4%) did not. 495 households (86.84%) had access to credit, while only 75 (13.16%) lacked such access. Migration is a common livelihood strategy in these communities. 368 households (64.56%) had at least one member who migrated, indicating that migration is a major coping mechanism for fishing households. The number of migrants per household ranges from 1 to 15, with a mean of approximately 1.69 migrants per household. Fishermen in the study are engaged in two main roles: 225 respondents (39.47%) are boat owners (referred to as “employers”), while the remaining 345 (60.53%) work as employees on others’ boats. In some cases, family members of the boat owner act as unpaid helpers; for analytical purposes, these individuals are included in the "employer" category.

Regarding Climate Change Perception, 204 respondents (35.79%) reported perceiving changes in climate conditions. The majority, 366 fishermen (64.21%), did not perceive any significant changes. Household Demographics shows that Household size ranges from 1 to 60 members, with an average of 15.58 people per household. This reflects the communal living style common in fishing communities. The age of respondents varies between 17 and 75 years, with a mean age of 39.36 years. Fishing experience ranges from 1 year to 60 years, with an average of 20.57 years of practice. Average daily income varies between 500 FCFA and 11,500 FCFA, with a mean of 4,250 FCFA. Mean annual precipitation, based on regional long-term averages (2000–2022), ranges from 23.93 to 53.26 mm, with an overall mean of 37.34 mm. The food security variable is not presented in the table below because it is a composite numerical index, the Household Food Security Access Scale (HFSAS), which ranges from 0 (high insecurity) to 1 (high security). This index is discussed in detail in the methodology section.

Table 6: Summary Statistics of Key Numerical Variables (n = 570)

VARIABLE	MEAN	STANDARD DEVIATION	MIN	MAX
FISHING EXPERIENCE (YEARS)	20.57	11.08	1	60
HOUSEHOLD SIZE (MEMBERS)	15.58	9.56	1	60
AGE OF RESPONDENT (YEARS)	39.36	12.35	17	75
AVERAGE DAILY INCOME (FCFA)	4,250.40	1,785.64	500	11,5
MEAN PRECIPITATION (MM)	37.34	7.60	23.93	53.26
NUMBER OF MIGRANTS	1.69	2.10	0	15

***Source:** Author's computation from field survey, 2023.*

3.4.2. Estimation results

Instrument Validation: Mean Temperature as an Exogenous Variable

To validate the use of mean temperature as an instrument in the Heckman selection model, we examined the correlation between the Inverse Mills Ratio (IMR) and the instrumental variable (mean temperature). The table shows a near-zero correlation (r = -0.3327), suggesting that mean temperature is not correlated with the IMR, which represents the error term in the outcome equation after correcting for selection bias.

Table 7: Validation test

	IMR	MEAN TEMPERATURE
IMR	1.000	
MEAN TEMPERATURE	-0.3327	1.000

***Source:** Author synthesis*

This lack of correlation confirms the validity of the instrument, as it influences the probability of household migration (selection equation) but does not directly affect the number of migrants in the household (outcome equation). Therefore, mean temperature satisfies the exclusion restriction and is a valid instrument in this model.

3.4.2. Main Findings from the Heckman Two-Step Model

Table 8: Heckman Two-Step Regression Results – Determinants of Migration Among Senegalese Fishermen

VARIABLES	MIGRATION PROBABILITY (SELECTION EQUATION)		MIGRATION SCORE (OUTCOME EQUATION)	
	Coefficient	**Std. Error**	**Coefficient**	**Std. Error**
FOOD SECURITY	0.340	1.294	1.227**	0.535
AVERAGE DAILY INCOME	0.000	0.000	-0.000	0.000
SECONDARY_ ACTIVITY	-0.531**	0.263	-0.140	0.124
AGE	0.005	0.057	-0.015	0.029
AGE SQUARED	-0.000	0.001	0.000	0.000
HOUSEHOLD SIZE	0.048**	0.015	0.014**	0.006
FISHING EXPERIENCE	0.048**	0.016	0.002	0.008
EDUCATION LEVEL	1.077*	0.574	-0.182	0.265
MARITAL STATUS	0.360	0.383	0.244	0.152
LAND TENURE	0.152	0.137	0.123*	0.071
CLIMATE CHANGE	0.607**	0.247	0.130	0.114
CREDIT ACCESS	-0.460***	0.176	-0.047	0.083
MEAN TEMPERATURE	—	—	0.022***	0.008
CONSTANT	-0.598	1.830	-1.380	0.842
INVERSE MILLS RATIO (Λ)	1.300			1.344
RHO				0.599
SIGMA				**2.172**
WALD TEST				48.630***
OBSERVATIONS				570

***p < 0.01**, **p < 0.05**, *p < 0.1

Source: ***Author's computation from field survey, 2023.***

Migration and Food Security

The Heckman estimation results indicate that the probability of having at least one migrant in the household is positively associated with food security. Households with migrants are significantly more food-secure than those without. This finding supports the hypothesis that migration contributes to improving household food security, likely through remittances. The result implies that migration acts as a climate adaptation strategy, particularly among Senegalese fishing households facing declining fish stocks and income instability.

Approximately 10% of the variation in food security is explained by whether the household has a migrant, highlighting the importance of migration in coping with climate-induced livelihood challenges. These findings validate our first research hypothesis: "*Households with at least one migrant member have a higher level of food security than households with no migrant members."* However, it is important to underline that much of this migration is irregular and risky, as many fishermen use their own pirogues to cross to the Canary Islands without proper documentation. They often report that the risk of dying at sea is preferable to seeing their families go hungry, as daily catches continue to decline due to climate change and overfishing (Abebaw et al., 2020; Hasanah et al., 2017).

Climate Change as a Push Factor

The results further show that the perception of climate change has a significant and positive effect on the number of migrants per household. This confirms that climate change is a major driver of migration among Senegalese fishermen. As fish resources become scarcer and some species disappear, fishing becomes less viable. This pushes fishermen to migrate in search of better livelihoods, validating our second hypothesis: "*Senegalese fishermen migrate in response to climate change, using migration as a survival and adaptation strategy.".*

Other Key Determinants of Migration

- Access to Credit: Negatively associated with the number of migrants. Households with credit access are less likely to send members abroad, as credit helps them bridge income gaps locally and reduces the financial motivation to migrate.
- Household Size: Positively associated with both the probability of having a migrant and the number of migrants. Larger families are more likely to send members abroad, aligning with literature showing that migration decisions are often collective strategies to diversify income and reduce household risk.
- Education Level: Positively associated with the number of migrants. Educated fishermen are more likely to migrate, possibly due to limited skilled job opportunities locally, leading to a form of brain drain.
- Fishing Experience: Positively associated with the number of migrants. Experienced fishermen often act as captains or organizers of migration journeys, using their knowledge of maritime routes and often charging others to join.

- Land tenant: Positively correlated with migration. Fishermen that have their own home access to the internet may be better informed about the risks and realities of migration, reducing their likelihood to migrate. This is consistent with findings from other contexts (e.g., Niger).

3.5. Partial conclusion

This study examined how the level of food security can act as a push factor for migration among Senegalese fishing households in the context of climate change, using data from eight major artisanal fishing centres and applying the Heckman two-step model.

Our results reveal that both climate change and the level of food security significantly drive migration decisions. Households facing environmental and economic hardship often send one or more family members abroad as a survival and adaptation strategy. Specifically, we find that the probability of having a migrant in the household is positively associated with food security, suggesting that remittances play a key role in improving household well-being. This confirms that migration is not only a response to environmental stress but also a livelihood strategy to enhance resilience.

Furthermore, higher levels of education are positively associated with the number of migrants, possibly reflecting the limited job opportunities available for educated individuals in coastal areas. However, it is important to note that much of this migration is irregular and dangerous, often involving the use of fishing pirogues to reach the Canary Islands. This exposes migrants to significant risks, including death at sea.

To address the root causes of irregular international migration among Senegalese fishermen and enhance household resilience, the policy actions should be oriented in these senses. First, promote Safe and Legal Migration Channels. Indeed, the government should develop seasonal or circular migration programs for the fishery community, especially during periods when fishing is unprofitable, allowing fishermen to migrate legally for temporary employment.

Secondly, improve Access to Credit in Fishing Communities by Expanding access to microcredit can help fishermen smooth income shocks and reduce the financial pressure that leads to migration. Thirdly, support the Development of Income-Generating Activities. For instance, policymakers should encourage investment in fish processing, preservation, and marketing activities that add value to fishery products. This would not only stabilize income but also reduce over-reliance on fishing. Finally, strengthen Climate Adaptation Programs.

These Programs aimed at sustainable fisheries management, alternative livelihoods, and community-based adaptation can help mitigate the adverse effects of climate change on fishing communities.

While this study provides valuable insights into the link between food insecurity, climate change, and migration, it should be interesting to include direct information about the migrants themselves, such as their current occupation, income, or well-being in the destination country. Future research should collect such data to better assess the full impact of migration by comparing pre- and post-migration conditions and evaluating long-term outcomes on household welfare.

CHAPTER 4: FOOD INSECURITY IN WEST AFRICAN COASTAL AREAS IS A DRIVER AND OUTCOME OF CLIMATE CHANGE RELATED MIGRATION : CASE STUDY OF SENEGAL

RESUME

Dans cette étude, nous avons utilisé le modèle SVAR pour estimer la relation bidirectionnelle entre migration et insécurité alimentaire dans le contexte du changement climatique au Sénégal, à partir de données chronologiques couvrant la période 2000-2020. Les résultats soulignent que les chocs migratoires ont un effet significatif et immédiat sur l'insécurité alimentaire. Parallèlement, l'insécurité alimentaire est affectée négativement par les chocs pluviométriques. Chaque variable du modèle s'explique positivement par sa valeur précédente. En termes de politique, le gouvernement sénégalais devrait aider les agriculteurs à pratiquer une agriculture intelligente face au climat et à migrer de manière saisonnière.

Mots clés : Changement climatique, insécurité alimentaire, migration, Sénégal, SVAR

ABSTRACT

In this study, we used the SVAR model to estimate the bidirectional relation between migration and food insecurity under climate change in Senegal, employing time series data from 2000 to 2020. The results indicate that international migration stocks have a significant and immediate effect on food insecurity. Meanwhile, food insecurity is impacted negatively by rainfall shocks. Each variable in the model is explained positively by its previous value. In terms of policy, Senegal government should help farmers to practice climate smart-agriculture, and seasonal migration.

Keywords : Climate change, food insecurity, migration, Senegal, SVAR

4.1. Introduction

Food insecurity is one of the most pressing development challenges in sub-Saharan Africa, where a significant portion of the population lacks regular access to sufficient, safe, and nutritious food. Indeed, according to the 2022 global report on food crisis, no priority is more pressing than addressing food insecurity to safeguard the calorie and nutrition needs of Africa's one billion people and protect their human development[28]. The repot state that at least one in five Africans goes to bed hungry, and an estimated 140 million people in these regions face acute food insecurity. In Senegal, this issue is exacerbated by persistent economic constraints, population growth, and environmental degradation. In 2023, the country has faced repeated food crises linked to droughts, declining agricultural productivity, and rising food prices, which caused 1.26 million people, about 7 percent to faced acute food insecure during the lean season, (World Food Programme, 2022). Therefore, in 2024, the number of Senegalese facing acute food insecurity is 519000, about 3 percent of the population, during the same period[29].

Despite national and international efforts, a considerable share of the population remains vulnerable to hunger and malnutrition in the country due to natural hazards[30]. One of the defining features of Senegal's recent socioeconomic landscape is the increasing impact of climate change. The country's reliance on rain-fed agriculture makes it particularly susceptible to climate variability, including irregular rainfall patterns, prolonged dry spells, and rising temperatures (Nguru et al., 2023). These environmental stressors not only threaten food production but also contribute to the erosion of rural livelihoods, prompting many to migrate in search of alternative opportunities. Migration, both internal (from rural to urban areas) and international, has therefore emerged as a significant demographic and socioeconomic dynamic in response to climate change, but also increases livelihood, (Jha et al., 2018), (Mcdowell and Haan, 1997), (de Haas, 2007).

This climate change also causes significant loss for the country in terms of revenue, leading to poverty. Indeed, according to (World Bank, 2024) if anything is done, the country will lose annually 3 to 4% of its GDP as soon as 2030 and further increase to 9.4% by 2050 wiping away years of per capita income growth and eroding any important human capital accumulation, which will lead two million Senegalese into poverty by mid-century.

[28] https://www.worldbank.org/en/news/immersive-story/2022/10/17/putting-africans-at-the-heart-of-food-security-and-climate-resilience
[29] https://www.fao.org/giews/countrybrief/country.jsp?code=SEN
[30] https://www.acaps.org/en/countries/senegal

Climate change is a determining factor in the fight against and improvement of both food security and migration. This change is leading to a loss of housing, particularly due to coastal erosion, which poses a serious threat to the coastline, infrastructure, and local communities (Fiawotoafor et al., 2025). The sea level rise in Senegal, for example, is a phenomenon that has become recurrent, especially during the rainy season, leading to economic, social, and demographic instability[31]. From a social perspective, it has resulted in the loss of homes for some households. Indeed, many houses are flooded by seawater, even leading to the disappearance of some cultivated areas[32]. In August 2024, the phenomenon also occurred in other areas, such as Rufisque, Mbao, and Bargny, where at least 30 houses were engulfed by the sea in August[33]. Residents are thus forced to leave their homes to rent or buy new housing, or to relocate to other areas. This can lead to the dispersal of the family if the household is unable to reunite the entire family under one roof. Floods are also very frequent, further increasing the vulnerability of the Senegalese population. Thus, when these climate migrants change their place of residence, it can affect their jobs, their income, and their well-being [34] also.

From a migratory perspective, as mentioned above, climate change can be the primary driver of migration through coastal erosion. However, it is important to note that even if one is not directly impacted by coastal erosion, other factors can push people towards migration, notably declining agricultural yields and reduced fishing income due to decreased fish availability. Thus, poor harvests push people to migrate. Globally, environmental stress may force people to migrate (Bernzen et al., 2019).

Migration, however, plays an ambivalent role in the context of food security. On the one hand, it can act as a coping strategy, allowing households to diversify income sources and access remittances that can be used to purchase food, invest in agriculture, or smooth consumption during periods of stress. On the other hand, migration can also have adverse effects, such as removing labour from farming households, increasing dependency on uncertain external income, or contributing to the depopulation of rural areas (Pinilla et al., 2008).

[31] https://www.preventionweb.net/news/rising-sea-levels-are-driving-faster-erosion-along-senegals-coast
[32] https://www.aljazeera.com/features/2023/3/23/a-vanishing-coast-deserted-fields-and-the-search-for-solutions-senegal
[33] https://www.iisd.org/articles/explainer/climate-change-impacts-women-senegal-nature-based-solutions
[34] https://www.amnesty.org/fr/latest/campaigns/2025/10/when-people-are-displaced-by-climate-change-what-rights-do-they-have/

The relationship between migration and food insecurity is further complicated by structural factors such as GDP growth, inflation, employment, and international trade. These elements interact with climatic shocks and population dynamics in complex ways. Yet, few empirical studies have explored these interactions in a systematic, data-driven way, particularly in the West African context.

This study aims to fill that gap by analysing the interlinkages between migration and food insecurity under the influence of climate change in Senegal from 2000 to 2020. Using a Structural Vector Autoregression (SVAR) model, the research examines the dynamic responses of food insecurity to shocks in migration, climate-related variables (e.g., cereal yields, food production), and macroeconomic indicators (e.g., GDP, inflation, remittances). The SVAR framework enables the identification of causal relationships and the decomposition of variance in food insecurity outcomes over time.

This research is about the interlink between migration and food insecurity in Senegal under climate change constraints. The hypothesis that this study focuses on is that food insecurity is a driver of migration under climate change firstly. Secondly, food insecurity is an outcome of climate change related migration. For doing so, the SVAR regression model is used to verify our hypothesis.

This chapter is structured as follows: section 2 presents the literature review. Section 3 highlights the conceptual framework. Section 4 presents the econometric modelling. Section 5 deals with the results and discussion and the last section, which is section 6, concludes the study.

4.2. Literature review

4.2.1. Theoretical review of migration and food security

Several theories have attempted to explain food security. Among these theories, the most prominent is the availability approach, which explains food security as a phenomenon as a disequilibrium between population growth and the main of subsistence. Meanwhile, other schools of thought have tried to explain migration. Regarding these theories, the approach that suited best to our study is the theory of new classical economics, which argues that migration is a collective decision made by family members to diversify their sources of income and cope with risks, whether environmental, social, or political instability. In this section, we present the theories of migration and food security because each of these variables is represented as a

dependent variable. Therefore, we present the different reasons that drive migration, as well as the factors or variables that explain food security, and the interaction between these variables and climate change.

Food availability approach or the Malthusian theory

The oldest theory of food security is the food availability theory. This theory was popularized by Malthus (1798). According to him, population grow geometrically, but the livelihoods growth mathematically. Therefore, there is a disequilibrium between population and food, so to maintain this equilibrium the rate of growth of food availability should not be lower than the rate of growth of population. Consequently, from this point of view, food security is merely a matter of aggregate (per capita) food availability which depends mainly on food production and stocks. According to him, the disequilibrium between population and food caused famine. This famine happens during the period of climate events. In other words, this approach argues that food insecurity is due to changing climate. As we are looking at the impact on climate change on food security, we will focus on the first theory of food security. This theory is limited because it focusses only on the physical presence of food, not its accessibility to people.

Basic need approach

In the second half of the 1970s, the International Labor Organization (ILO) developed a new theory of food security to incorporate also non-economic dimensions of development. (ILO,1976). The defenders of this theory of basic needs view development as a process aiming to ensure that all people satisfy their basic needs composed of material and non-material elements (Stewart, 1985). The list of these materials differs between authors but in most case, it includes food, together with shelter and clothing (Denton, 1990). For Magrabi et al., (1991) food is a basic need and probably the most basic need of all. A similar conclusion was drawn by Maslow (1943) in psychology. (Kent, 2005) concludes that adequate food is the primary component of human rights.

The Basic Needs approach completes this by expanding the focus to include access and utilization, recognizing that food security depends on a household's ability to acquire and use food through economic access, rights, and overall livelihood. Critics argue it prioritizes subsistence over fairness and may not account for non-material needs like political freedom or cultural identity, potentially leading to a consumption-oriented model rather than one that builds sustainable economic growth.

Sustainable livelihoods approach

Chambers, (1983) had introduced the concept of emphasis on livelihood which mainly focuses on rural development and poverty, but later on he and other authors expanded the meaning of the concept. It focuses on gaining a living (Chambers and Conway, 1992), that is the necessities of life, rather than on human development in a broader sense. This approach of food security mostly concerns the tangible and intangible assets commanded by a household, which is very close to the concept of endowments in the entitlement approach. These are classified in five groups, which are natural capital, physical capital, human capital, financial capital, and social capital. The important theory of the sustainable livelihood frame is the "sustainable livelihood" defines as the competences, material, activities and social assets that are essential for a means of alive (Chambers and Conway, 1992). This theory states that a life is livelihood and livelihood is supportable the time it can adjust to intimidations, and it can uphold or develop its talents and possessions, and it does not cooperation extra livelihoods at nearby and more extensively for at the present and in the future (Chambers and Conway 1992). However, its theoretical underpinning has been questioned, and some have pointed to the weak representation of important dimensions such as power, including its link to globalization, and culture, with the latter including faith. This paper explores the various ways that these issues have been addressed by using faith as a lens, and makes a case for a 'Sustainable Living Approach' (SLivA) to provide a stronger dovetailing with the capabilities/functions approach of Amartya Sen.

Entitlement approach

For a long time, the debate on hunger and famine has been heavily affected by the food availability approach rooted in Malthus' thought. Only at the beginning of 1980s Amartya Sen's entitlement approach contributed to challenge this perspective and shifted the focus from national food availability to people's access to food. "The entitlement approach concentrates on each person's entitlements to commodity bundles including food, and views starvation as resulting from a failure to be entitled to any bundle with enough food" (Sen 1981: 434). Entitlements depend on two elements: 1) the personal endowments, which are the resources a person legally owns such as house, livestock, land, and nontangible goods (Osmani 1995); 2) the set of commodities the person can have access to through trade and production, i.e., the "exchange entitlement mapping" (Sen 1981: 435). Starting from a situation in which an individual has just enough means of subsistence, a decline of endowments can obviously lead the person to starvation. However, with the same

endowments, a person can still fall into the hunger trap because of a decline in the exchange entitlement mapping; for instance, a sharp reduction of the price of the commodity that the individual produces, due to external causes, reduces its capacity to buy food. Moreover, the entitlement failure takes different forms. Given an economy in which each group produces one commodity, including labour commodity, and a given food exchange rate (commodity price divided by food price), any group risks to starve due to an entitlement failure either because of reduction of food production for personal consumption or because of fall in the food exchange rate (Sen, 1981). In the first case, there is a direct entitlement failure; in the second case, a trade entitlement failure. The direct entitlement failure belonged to food-producers due to a decline in their production.

Income based approach

As explained by Burchia & DeMuro, (2015), the long-lasting view of food security as a problem of food availability has been partly re-visited within a more macroeconomic approach. The focus on the food sector initially only agricultural production, and food trade later on has been criticized by economists for being too concentrated on one single economic sector. Recognizing that the economy is composed of many interdependent sectors, food security cannot be viewed as an exclusive problem of the agricultural/food sector. That is why the first attempt to broaden the discipline was actually an attempt to shift the analysis towards national economies as a whole. This meant bringing in the analysis variables such as Gross Domestic Product (GDP), economic growth, and, eventually, but not necessarily, highly dependent on food production. In a market economy, a stronger economic system can allow the import of goods, such as food. This macro-economic framework was also more consistent with old and very influential economic theories such as Ricardo's comparative advantages, according to which each country must specialize in the sector in which it has an advantage given by the abundance of a specific productive asset or by lower costs of production. This whole approach might be considered to include within the food security framework the national "means" to increase aggregate food availability. However, the most important shift was from food availability at macro-level to income at micro-level (Reutlinger & Selowsky 1976; Haq 1976; Griffin and Khan 1977). The approach is very similar to the one traditionally used to assess poverty. While poverty was conceived as a lack of enough income necessary to buy a bundle of goods to guarantee the survival (or minimum standard of living) of a person, food insecurity is implicitly assumed as a sub-category of poverty (often referred to as "food poverty"), i.e. lack of enough income necessary to buy at the given conditions the amount of

food required (Sibrian et al. 2007; Sibrian 2008). In particular, the different foods are converted into calories (characteristics of the food): if people's calorie availability is lower than a threshold identified by international nutritionists, they are considered food insecure. Through household surveys providing information on income, it is theoretically possible to estimate the amount of food consumed, under the assumption that poorer households use a larger proportion of their income to buy food.4 Food is, then, converted in calories: if household calorie availability is lower than the "required" minimum one, some or all the members are food insecure. The specific problem related to this method consists in the assumption of a given income-calorie elasticity. Taking, for example, an elasticity measured in the same country in previous studies requires making very strong hypotheses.

Finally, this method could better suit an ideal market economy in which nobody works in subsistence agriculture. Given the fact that these measurements are often realized in rural areas of low-income countries, where the dominant part of the population is in subsistence agriculture, the method is not highly reliable. As also argued by Frankenberger (1992: 96) "expenditure surveys tend to underestimate expenditures on food because the value of food produced at home or gathered locally is often not recorded".

Human development and capability approach

This theory was primarily developed in 1989 by Drèze & Sen in their pioneering book "Hunger and Public Action". Although, the authors do not make any reference to the concept of food security. They developed a general analytical framework for studying chronic hunger and transitory hunger, and all related aspects, based both on the capability approach of (Sen, 1985, 1999) and his entitlement approach. Their starting point for this new theory is that, according to them, the entitlement theory is not sufficient for a general approach to hunger problems. Therefore, it is important to move beyond the theory of entitlement towards nutritional capabilities. This change of perspective derives from the crucial differentiation between means and ends of development emphasized by Sen (1989) can also be applied to the study of hunger. The capability theory approach refers to have the capability to avoid undernourishment and escape deviation associated with hunger (Drèze & Sen, 1989), i.e., the capability to be free from hunger. By switching the focus from command over food to nutritional capability, this approach goes beyond the access dimension of food security, which is the main concern of the basic needs, entitlement, and the SL food security theories and the food utilization dimension. Defenders of this theory, Drèze & Sen (1989) argue that food access is insufficient, and utilization is very important. They add that the relationship between

food intake and nutritional achievement can vary greatly depending on features such as sex, age, pregnancy, metabolic rates, climate conditions, activities and also on access to complementary inputs. These features of the capability approach to hunger make it the one that better takes into account the three dimensions of food security. This theory has two recent developments that allow the framework proposed by the authors to be expanded and complemented. The first development is about the agency component of the capability approach; it's means that the person`s ability to pursue and achieve goals. The second component concerns security. The approach to food security includes the fourth dimension of food security, as defined by the World Food Summit, which is stability that is more than just food price stability.

Food access and climate change

Cox (1981) related this theory to the concept of "famine belt" in with he linked directly climate condition to food security. This theory argues that at the national and local level, climate linked phenomena, such as droughts, floods and others are major factor causing food insecurity. The defender of this approach such as Huscher (1959) said that droughts cause serious hydrological imbalance in affected areas and impacts adversely crop production (Rosenberg,1981).

Neoclassic migration theory at macro level

This is the first theory that explained labour migration. According to this theory, migration is a result of geographical differences between supply labour and demand labour, employment conditions, and on migration costs. It's considered migration as an individual decision to maximize income. This difference can be observed it the international level or at the internal (national) level. International migration is a function of global supply and demand labour (Sjaastad, 1962; Torado, 1969). For neoclassic, countries with high wages due to the fact that demand labour is greater than supply labour which attract immigrants from countries with a surplus of labour. The main assumption for neoclassic theory of migration is explained by two key factors which are the wage differentials and the probability of obtaining job. Countries characterized by a high initial endowment labour relative to capital have a low equilibrium market wage, while countries with a limited endowment of labour relative to capital have contrarily high market wage equilibrium (Massey et al.,1993). Environmental factors can indirectly cause this wage difference, through impacts on rural livelihoods or urban wage rates. Where wage may be construed as income from livelihoods that are sensitive to climate

variability and change (Mueller et al., 2020). Face in this context, people will move from countries with low income and where the probability of having job is low to countries where the expected income is high, even the probability to obtain job (Harris & Torado, 1979). This theory considers migration as an individual decision to maximize income.

Neoclassical migration theory at micro

It is the earliest theoretical framework to explain labour migration in the process of economic development. This theory argues that international migration is mainly to by the geographical difference in wage levels between countries and labour markets. Thus, wage differential pushes workers to move from a state characterize by low wages and a surplus of labour to a region with high wages and labour scarce. This process will cause labour to become less scared at the destination and scarcer at the sending end. Capital will also move in the opposite direction through remittances that migrants send to their family, friends and so one. This growing process will eventually cause convergence between wages in the sending and receiving states. This is what we will observe in a perfect neoclassical world: this situation of "factor price equalization" in a perfectly neo-classical world, this process of "factor price equalization" (the Heckscher-Ohlin model) (Harris & Todaro 1970; Lewis 1954; Ranis & Fei 1961; Schiff 1994; Todaro & Maruszko 1987). In the long run, this process would stop migration patterns.

The neoclassical migration theory at macro and micro level is limited by the fact that they do not focus on other drivers of migration such as environmental, social, cultural, political drivers of migration. It does not explain also why migration continues even after wage gaps narrow.

Dual Labor Market theory

This theory distinguishes between push and pulls factors and intervening obstacles that can impact the decision to migrate, such as costs to move and legal barriers (Lee, 1966). Network forces assist in the move, broadly serving as pull factors. This theory is very amenable to the case of environmentally induced migration. Indeed, environmental conditions can be both pull and push factors. Indeed, Geest (2001) suggests that drought in sending areas could push migrants, while more favourable environmental conditions could act as a pull factor for improving their living conditions. But a corollary is that not all people want to migrate, and

thus the concept or mooring suggests that non migrants are also able to maximize their physical, psychological, and emotional well-being in place (Moon, 1995). This theory can be grouped with neoclassical migration theory. This theory does not consider the socio-economic motivations of the migrant itself. It overlooks push factors in origin countries.

The new economics of migration theory

Contrarily to the neoclassic, this theory argue that the decision to migrate is not by individual but is the result of a collective decision to maximize income and employment opportunities and to minimise risks and to loosen constraints associated with a variety of market failures, apart from those in the labour market (Stark and Levhari, 1982; Stark, 1984; Katz and Stark, 1986; Lauby and Stark, 1988; Taylor, 1986; Stark, 1991). Hence, migration is a strategy to diversify risks. The main incentive to migrate is not only to raise income but also to diversify risks. International migration may occur alongside increases in local employment and production. It does not have to stop when wage differentials disappear. This theory also introduces the notion of relative deprivation: migration can alter income distribution within a community and therefore lead to more people deciding to migrate. This theory states that remittances are important for household welfare in overcoming liquidity constraints and unbinding insurance. Particularly, migration has a positive influence on consumption expenditure through spending remittances on basic needs products like food. Migration might expose migrants to newfound knowledge about nutrition and dietary diversity. The loss of a family member to migration can improve the food security of other members by reducing the demand for precautionary savings and lessening the mouths to feed. In the other hand, migration may reduce a household`s food security status if the family`s loss of labour is inadequately replaced by remittances. In this situation, the impact of migration includes loss of employment, reduced income, and decreased spending on food and nutrition products. The New Economics of Labor Migration estimates that migration is a collective decision, but this idea may sometimes not be the case because a member of the household can individually take the decision to migrate.

World systems theory

According to this theory, the world marked is a determinant of migration. This theory argues also that migration is caused by a capitalist market formation in the developing world, in which the penetration of the global economy into peripheral regions catalyses migration (Massey et al., 1997). Due to globalisation, owners and managers of firms from developed countries enter the poor countries in search of land, raw materials, labour, and new consumer markets to make profits and generate wealth. This theory sees migration as a natural outgrowth of disruptions and dislocations that inevitably occur in the process of capitalist development. It underestimates cultural, political and agency-based factors.

Social Network theory

The flow of information has been considered important for migration before it was a major concern for the rest of the economics (Gallup, 1997). Family and friends give important information on the destination area. So, the bond between migrants and their family or friends in the origin areas motivates new migration routes. This network minimises the cost and risk of migration for newcomers, thus encouraging potential migrants. It focuses on the fact that people migrate because they know someone who migrates and has information about the host country.

Institutional theory

This theory argues that once international migration has started, institutions and voluntary organisations develop to support the movement of migration. These can be legal or illegal migration circuits which facilitate migration that persists over time and increase migration by providing transport, labour contracting, housing, and other legal services, many of which have proven not easy for governments to control. This theory does not take into account the other factors that push people to migrate.

Cumulative causation theory

This theory pronounces that each action of migration outcomes in alteration of the social context in which subsequent migration decision are taken, making new movements more likely, the distribution of income and land; the organisation of agriculture; culture; regional distribution of human capital; and the social meaning of work are the factors that are affected by this cumulative tendency (Massey et al., 1993).

In sum, the various migration theories and the reasons to migrate differ from one theory to another, but theories that try to link migration and food security can be traced back to the new economics of labour migration. This theory argues that remittances are important for household welfare in overcoming liquidity constraints and unbinding insurance (Abebaw et al., 2020). Particularly, migration positively can influence consumption expenditure by spending remittances on basic needs products like food. Migration might also expose migrants to newfound knowledge about nutrition and dietary diversity (*Smith and Floro*, 2019). The loss of a family member because of migration can improve the food security level of other members of the household by decreasing the demand for precautionary savings and lessening the mouths to feed. On the other hand, migration may endanger a household`s food security level if the family`s loss of labour is inadequately replaced by remittances (Regmi et al., 2017). In this situation, migration creates loss of employment, reduced income, and decreased spending on food and nutrition products.

4.2.2. Empirical revue

Empirically, Mugambiwa & Makhubele (2023) rethink the nexus of climate change, food insecurity, and migration in the developing world. Their results suggest that most of the world`s poor communities rely on subsistence farming for their livelihood, that is why their industry is particularly vulnerable to the effects of climate change. They also argue that adverse shocks to agricultural productivity due to climate change significantly increase emigration from developing countries, but this impact is more significant in low-income countries and a smaller one in middle-income countries.

Carney (2024) analyses the climate food migration nexus using critical perspectives. He argues that there has been surprisingly limited scholarship and policy attention to the structural conditions underlying this relationship. Using a participatory method, Andrea & Ruanob (2013) investigate the impact of rainfall variability, food insecurity, and migration in four rural mountain communities in the Western Highlands of Guatemala. Authors consider the importance of rainfall on local livelihoods because in these communities, the most important source of food is the yearly harvest of a rain-fed corn-based crop sub-system called milpa. Most of the participants in the survey report that climatic conditions have worsened in the last 20 years and are affecting their food production. They also noticed that the profitability of in situ diversification options is decreasing and associated with decreasing migration opportunities.

Nawrotzki *et al*., (2016) are interested in the link between food security and migration in 164884 and 57052 households in Burkina Faso and Senegal, respectively. They find that international migration increases under beneficial climatic conditions and decreases when conditions become less favourable. Indeed, when climate adversely impacts agricultural production and livelihoods, the resource base of households may degrade, making it difficult to finance an expensive international move when they consider marginalized departments, but in areas with good food security conditions, climate adversity can foster migration. They employed multilevel logit models to estimate the odds of a move to an international destination from a household i located within a province/department j.

(Etzold et al., 2014) present empirical evidence on changing rainfall patterns in Kurigram district in northern Bangladesh, on the local people's perception of these changes, and on their decision to migrate, or not, to cope with rainfall variability and food insecurity. This research is part of the 'Where the Rain Falls' project, and both qualitative and quantitative data were collected in October 2011. For quantitative data, it has been collected through a structured questionnaire survey where 150 households selected randomly in four (4) study villages Kurigram Sadar Upazila namely Khanpara, Khamar Holokhana, Arazi-Kodomtola, and Doalipara were interviewed. The qualitative data were collected through 33 focus group discussions, where several participatory action research tools were used, such as a comprehensive well-being analysis, livelihood risks rankings, timelines on agro-ecological changes and migration patterns, seasonal calendars, impact diagrams of rainfall variability, Venn diagrams on food security and migration networks, or mobility maps. Results show that,

instead of climate change, social inequality and food insecurity, as well as structural economic differences, are the strongest drivers of migration inside Bangladesh.

In rural Savannah communities in Northern Ghana, Rademacher-Schulz et al., (2014) examine the interrelationships between rainfall variability, livelihood/food security, and migration. Their study addresses the question of how strongly dry season migration is pronounced and whether the recent dominant migration type is a coping or adaptation mechanism. Based on empirical research analysis conducted in four communities of the Nadowli district (Upper West Region), using a mixed methods approach with a sample of 158 households. The findings suggest that the households are highly dependent on rain-fed subsistence agriculture and livestock rearing, showing a low degree of economic diversification. Study participants in general complained about the unpredictability of the weather and linked changes in rainfall to declining crop yields and livestock possession as well as to increasing food prices. Additionally, they state that a common livelihood strategy used by households is dry-season migration to more suitable farming areas and to mining sites. Research in 2011 revealed that most migrants were forced to migrate during the rainy season to feed their household members. This observation may indicate a shift in seasonal migration patterns with potentially harmful consequences for household livelihood security in the future.

Using the same approach as combines expert interviews, household survey of 165 and Participatory Research Approach (PRA) sessions with the communities (Rademacher-Schulz et al., 2012; Afifi et al., 2014) addresses the interrelation between rainfall variability, food insecurity and human mobility in three villages located in the Same District, Kilimanjaro, Tanzania, namely the villages Vudee, Bangalala and Ruvu Mferejini which are of distinct elevation and precipitation levels. It runs a comparison between the three villages and shows that there is a positive relationship between rainfall shortage and out-migration, after taking other important demographic and socioeconomic factors into account, such as age, wealth, and education. The article further argues that the mechanism through which rainfall variability affects human mobility in the research site is food insecurity for humans and livestock.

(Murali & Afifi, 2014) investigate the impacts of rainfall variability on agriculture, food security, livelihoods, and human mobility in the Janjigir-Champa district of Chhattisgarh. The research tests the hypothesis that human migration is a major coping mechanism against climate variability. The field research combined expert interviews (government officials, environmental and migration scholars, meteorological specialists and non-governmental

organization representatives), a household survey of 180 and PRA sessions with the communities The findings confirm that a coordination mechanism exists between rainfall changes (i.e. erratic rainfall patterns in terms of delayed monsoons, seasonal shifts, drought and floods) and livelihood and food security of a number of farmers and farm labourers in the research site. Because there is only a single annual harvest of paddy rice (practiced as monoculture) in the research site, which is partly due to the non-availability of water for a second crop, marginal farmers and farm labourers are left with very few options in finding sufficient employment in and around their villages. Some people cope with the situation by seeking assistance from their relatives, friends, and the government. However, seasonal and permanent migrations are the most opted-for coping strategies in the study area.

Migration has become a key component in the livelihood strategies of an increasing number of households across the developing world, and remittances have expanded dramatically in the last decade. This has come at a time when an increased emphasis has been placed on reducing malnutrition to achieve Millennium Development Goal (MDG) targets. While this is the case, there has been little attention paid to the interface between migration and nutrition, even though migration can influence nutrition through several channels. The objective of this special issue is to present state-of-the-art analyses of the link between migration and nutrition in developing countries. In this paper, an overview of the conceptual and empirical issues in identifying the link between migration and nutrition are considered. Further, the results from seven country case studies are synthesized and policy implications are drawn (Zezza et al., 2011).

Crush, (2013) argues that the issue of food security is strikingly absent from current debates about the relationship between migration and development. The current international food security agenda displays similar disregard for migration. There thus appears to be a massive disconnect between these two global development agendas. The reasons are hard to understand since the connections between migration and food security seem obvious. This article addresses possible reasons for the disconnect and then presents and discusses the implications for linking migration and food security of a recent survey in 11 African cities. The results show a consistent pattern of difference between urban migrant and non-migrant households in relation to levels of food insecurity, sources of income, food procurement strategies, and participation in urban agriculture. This article therefore seeks to initiate a conversation between the separate worlds of migration and development on the one side, and food security on the other.

4.2.3. Conceptual framework

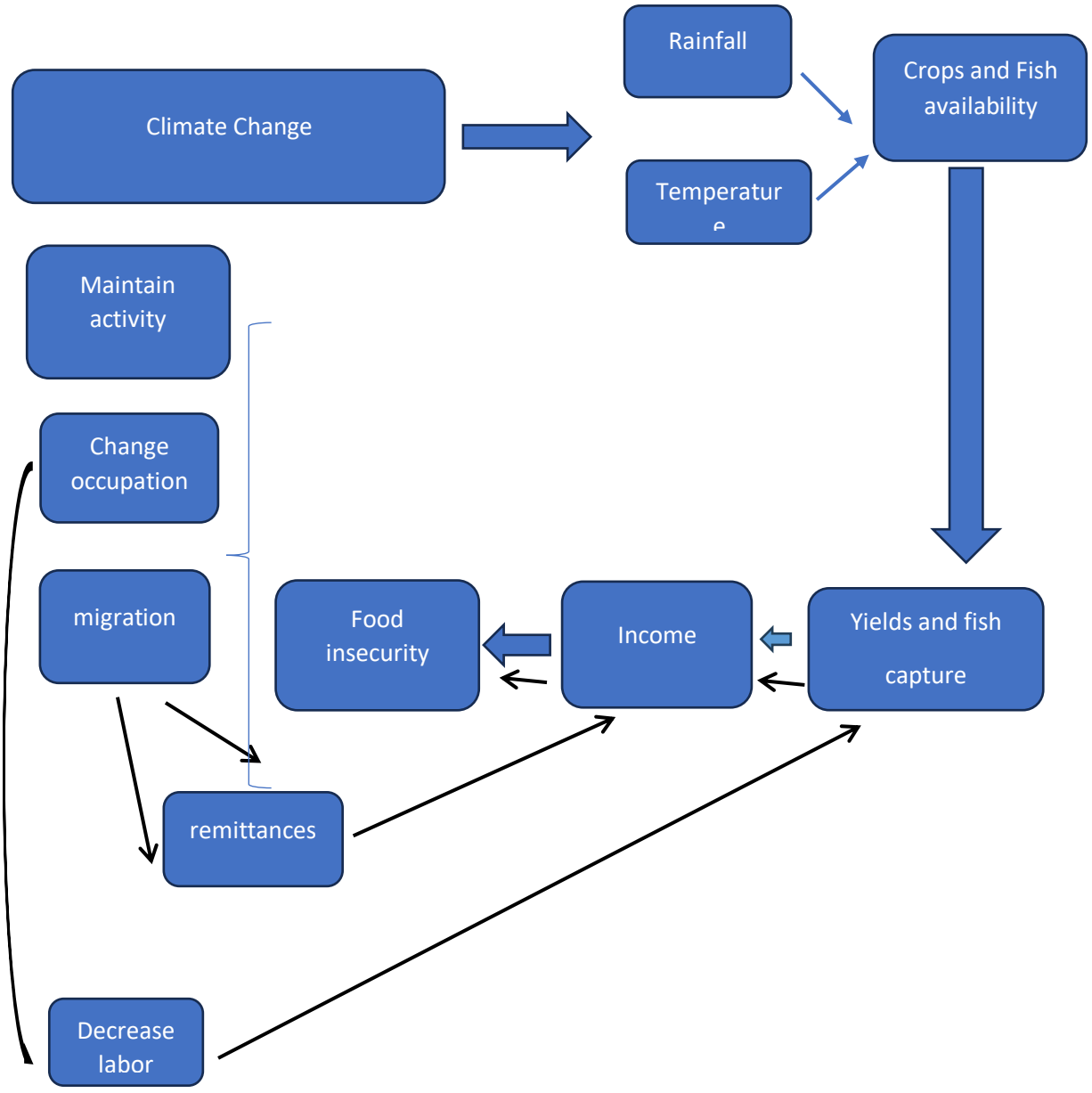
In this section, we would like to present how the variables, namely climate change, migration, and food security, are interlink. With migration leading to a loss of labour and declining harvests, some farmers and fishermen are leaving these sectors, some to travel and others to pursue other activities. This has caused a decline in labour in these sectors, which in turn has led to a decline in production. As a result, those who do not have the means to migrate or change activities will remain in the village to practise agriculture, which is often subsistence farming. In other words, they simply practise agriculture for their own consumption because they do not have enough strength to cultivate large fields and do not have a high level of education to practise innovative agriculture in the face of climate change. Even if they can sell part of their harvest, it is still insufficient or just enough to buy other food products such as oil, fish, meat, and other products. As a result, their diet remains limited due to insufficient income and a lack of agricultural labour. All these factors combined will push people to migrate according to the New Theory of Labor Migration, (Stark & Levhari, 1982; Stark, 1984). People therefore migrate because of food insecurity. When a family member migrates, the family hopes to have more income from the remittances, which are used, among other things, to improve the household's consumption basket. Migration thus improves food security through remittances.

From another perspective, migration due to climate change will lead to food insecurity for migrants in their destination areas. When people migrate, they do not have all the information about the host country. This means that they may experience food shortages in the early days in that country. There is also the fact that migrants do not have the income to meet their basic needs, such as food, healthcare, and clothing. Migrants are faced with a precarious situation that can affect their level of consumption and, therefore, their food security. Indeed, the theory of consumption has shown that when income decreases, consumption also decreases, (Thakur and Aditya, 2024).

Migrants also face food insecurity because the cultures and consumption habits are not generally the same between the country of origin and the host country, so even if they have an income that allows them to feed themselves, it may not coincide with their food preferences, so they are in a situation of food insecurity because the food agency pillar is not valid. They eat, but not the type of food they prefer in their consumption basket.

Migration also leads to food insecurity in the country of origin or family of origin when considered on an individual basis. Indeed, the migrant in the family may be among the youngest members of the family and able to finance their journey, or family members may help them financially in this venture. This means that the household's overall income decreases.

Figure 11: Conceptual framework



***Source* : Theoretical framework that capture the interlink between climate change, migration and food insecurity in Senegal, author compilation, 2025**

This decrease in income leads to a decrease in household consumption according to Keynesian theory.

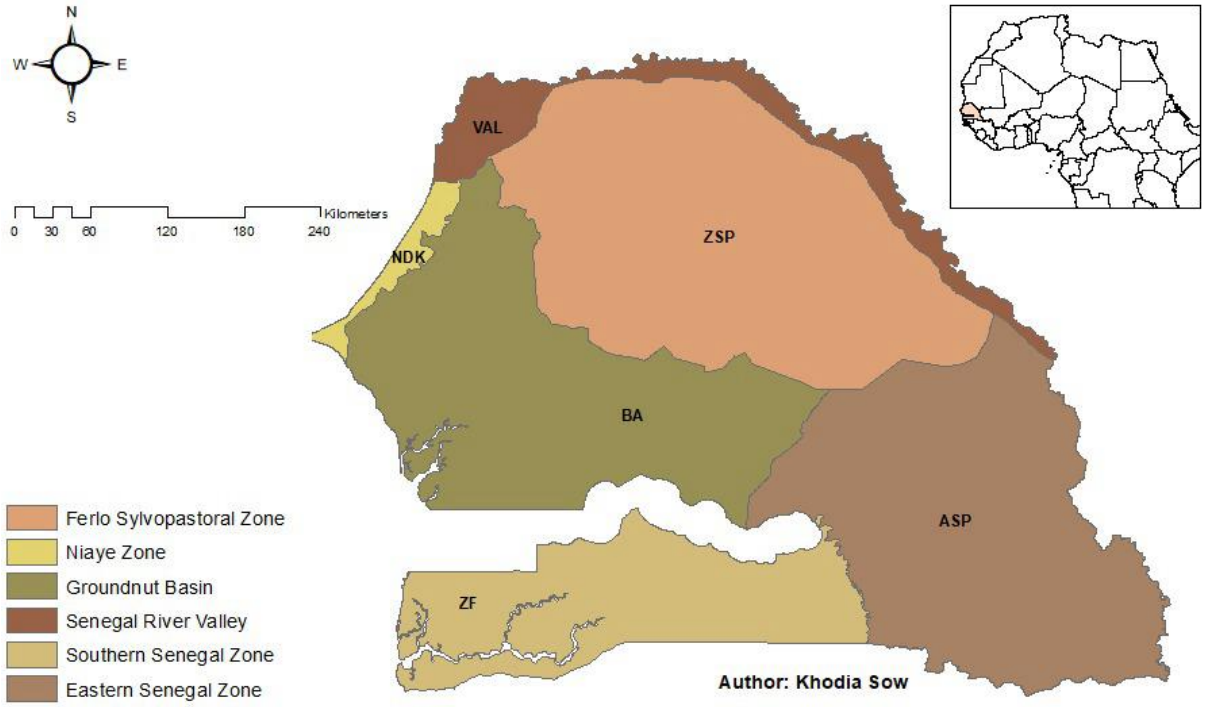
When considering an agricultural household where all family members are involved in this activity, the departure of one or more family members leads to a decrease in agricultural labour. If the family does not replace this lost agricultural labour, it will lead to either an increase in working hours to maintain production levels.

Or, if the family does not have the financial means to maintain its level of production, it will be forced to reduce its agricultural production, which will lead to lower harvests. This leads to food insecurity in this family and at the national level as well.

4.3. Econometric modelling

4.3.1. Study area

Figure 12: Study area



Senegal is located in the western part of the African continent, more precisely in the Sudano-Sahelian zone of West Africa. The country is bordered to the west by the Atlantic Ocean, to the north by Mauritania, to the east by Mali, and to the south by Guinea, Guinea-Bissau, and The Gambia. Senegal covers an area of 196,722 km². In 2024, Senegal's population is estimated at 18,593,258 inhabitants.

4.3.2. Data source and description of the variables

Our study employed time series data from 1990 to 2020. In this study, time series data are used to estimate the interlink between migration and food insecurity under climate change. The migration stock was acquired from the World Bank Indicator, and annual mean precipitation data was acquired from the climate change knowledge portal, and the prevalence of moderate or severe food insecurity in the total population by three years average is obtained from the FAO database. This indicator of chronic hunger captures the evolution of fundamental elements that drive the long-term nutrition condition in a country. It is intended to capture the evolution of fundamental elements that drive the long term nutrition condition in a Country (Cafiero and Gennari, 2015). And Migration stock represents the number of Senegalese emigrants abroad. It is a continuous variable.

Prevalence of moderate or severe food insecurity in the total population or Prevalence of undernourishment (percent) (3-year average) is an estimate of the percentage of people in the population who live in households classified as moderately or severely food insecure. The assessment is conducted using data collected with the Food Insecurity Experience Scale or a compatible experience-based food security measurement questionnaire (such as the HFSSM). The probability of being food insecure is estimated using the one-parameter logistic Item Response Theory model (the Rasch model), and thresholds for classification are made cross country comparable by calibrating the metrics obtained in each country against the FIES global reference scale, maintained by FAO. The threshold to classify "moderate or severe" food insecurity corresponds to the severity associated with the item "having to eat less" on the global FIES scale. In simpler terms, a household is classified as moderately or severely food insecure when at least one adult in the household has reported to have been exposed, at times during the year, to low quality diets and might have been forced to also reduce the quantity of food they would normally eat because of a lack of money or other resources. It is an indicator of lack of food access. Confidence intervals at 90% level are also available. They are computed considering both sampling and measurement variability[35].

4.3.3. Model specification

As we are looking for the interlink between climate change, migration, and food insecurity in Senegal, one of the best methods is the var structural or the simultaneous equations method. In this study, we chose the var structural. This model is firstly developed by (Watson, 1994).

[35] https://www.gafs.info/dataviz/indicator/FAO_FS_210091

The basic form is as follows:

$$AY_t = \gamma + \sum_{i=1}^{p} \beta_i Y_{t-i} + \mu_t \qquad (1)$$

The reduce form is given by:

$$Y_t = A^{-1}\gamma + \sum_{I=1}^{P} A^{-1}\beta_i Y_{t-1} + A^{-1}\mu_t \qquad (2)$$

Generally, the model can be written as follows:

$$Y_t = \pi + \sum_{i-1}^{p} \varphi_{iY_{t-i}} + \varepsilon_t \qquad (3)$$

Where: $\pi = A^{-1}\gamma$; $\varphi_i = A^{-1}\beta_i$; $\varepsilon_t = A^{-1}\mu_t$

The elements of A are not modified randomly; economic theory or experience (observation of facts) is used. Modifying A also exposes us to the risk of under-identification of the SVAR, which will make it difficult to estimate the reduced form. To address the identification problem, restrictions must be imposed on the SVAR.

In our case, in structural form, our SVAR (1) is written as:

$$\begin{bmatrix} 1 & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & 1 & \alpha_{21} \\ \alpha_{31} & \alpha_{21} & 1 \end{bmatrix} \begin{bmatrix} FI_t \\ Migstock_t \\ Rainfall \end{bmatrix} = \begin{bmatrix} \alpha_{10} \\ \alpha_{20} \\ \alpha_{30} \end{bmatrix} + \begin{bmatrix} \mathrm{b}_{11} & \mathrm{b}_{12} & \mathrm{b}_{13} \\ \mathrm{b}_{21} & \mathrm{b}_{22} & \mathrm{b}_{23} \\ \mathrm{b}_{31} & \mathrm{b}_{32} & \mathrm{b}_{33} \end{bmatrix} \begin{bmatrix} FI_{t-1} \\ Migstock_{t-1} \\ Rainfall_{t-1} \end{bmatrix} + \begin{bmatrix} {\mu_t}^{FI} \\ {\mu_t}^{Migstock} \\ {\mu_t}^{Rainfall} \end{bmatrix} \qquad (4)$$

The reduce form is describe as :

$$AY_t = \beta_0 + \beta_1 Y_{t-1} + \varepsilon_t \qquad (5)$$

Identification or restriction of the model SVAR

To determine the number of restrictions the formula followed is applied: $= \frac{k(k-1)}{2}$,

In our case k is equal to the number of equation or number of endogenous variables; k=3

n=3(3-1)/2=3. Thus, we should at least have 3 restrictions in the short term, and the matrix A has 3*3=9 unknowns. It is equal to:

$$\mathrm{A}=\begin{bmatrix} \mathrm{b}_{11} & 0 & 0 \\ \mathrm{b}_{21} & \mathrm{b}_{22} & 0 \\ \mathrm{b}_{31} & \mathrm{b}_{32} & \mathrm{b}_{33} \end{bmatrix}$$

We are using Cholesky recursive.

The most important thing in the SVAR is to check first the stationarity, and the variables should be stationary or be stationary at the first difference:

Here the variables are stationary at the first difference. The number of lag optimal in the model is 2 **(see table 22).**

4.4. Presentation of the results and discussion

4.4.1. Descriptive statistics

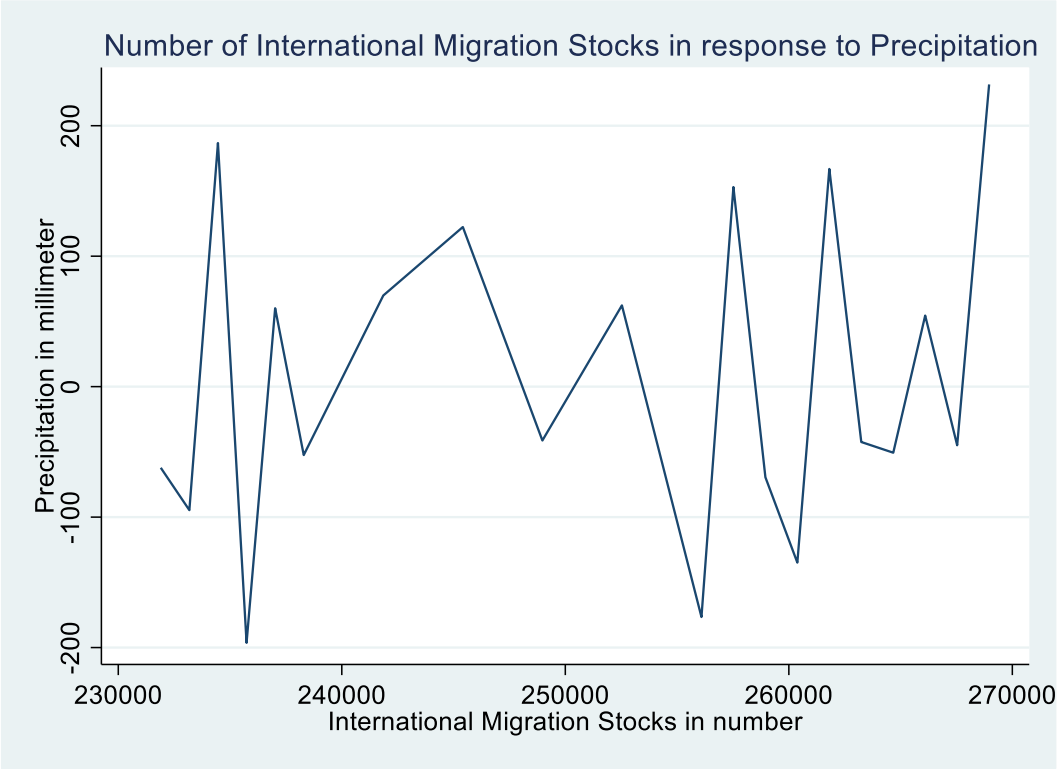
The table below presents the results of the descriptive statistics. The table 11 shows that on average, about 252145 of Senegalese migrate internationally. Additionally, the table demonstrated that per year at least 231901 Senegalese migrate. The higher number of migrants for the country during the period of study is 270392. For the food insecurity variable, which is the prevalence of moderate and severe food insecurity of the country, the percentage of Senegalese who experience moderate, or severe food insecurity yearly is 0.18, which a minimum equal to -4.1 and the maximum is 3.8 percent. Finally, the table captures the average rainfall variation in Senegal from 2000 to 2020. It suggests that some time, the country face to rarity of precipitation that cause drought and less rainfall. The maximum precipitation that the country has experience is 639.6 mm.

Table 9: Descriptive statistics

Variables	Mean	Std.Dev	Min	Max
Food_Insecurity	0.18	3.132277	-4.1	3.8
Migration_stock	252144.7	13252.91	231901	270392
Average_Rainfall	-46.55158	474.2997	-1193.54	639.6

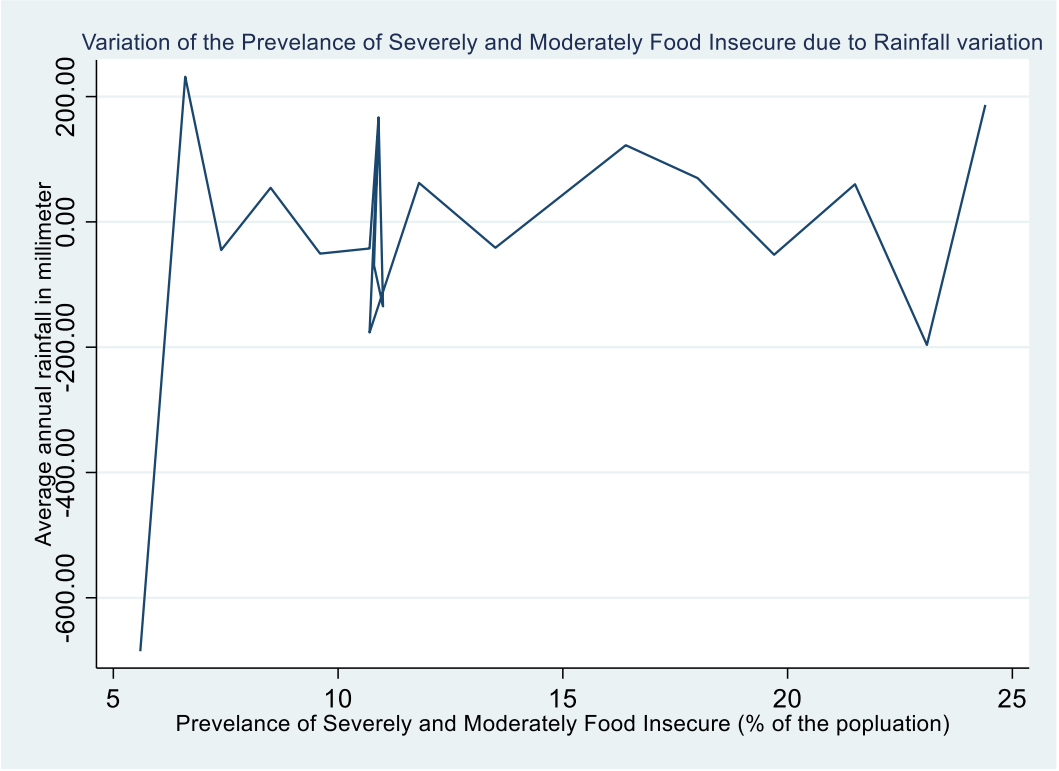
***Source*: Autor compilation, 2025**

Figure 13 : Link between climate change and migration



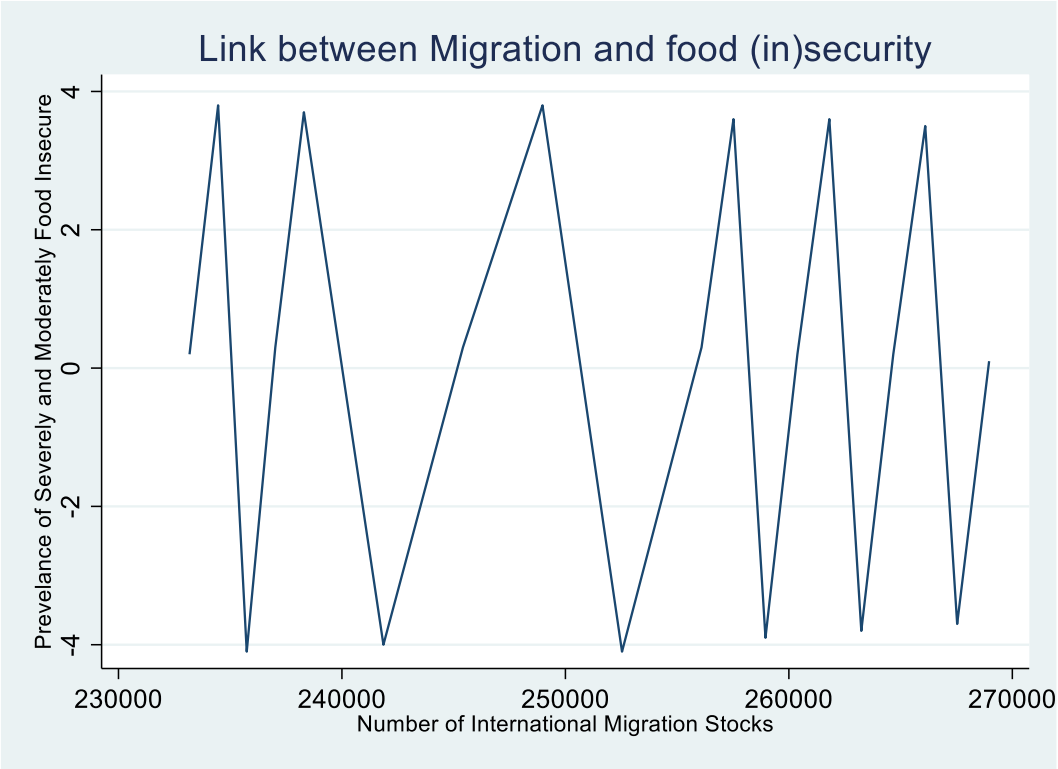
Source: ***Autor compilation, using WDI and ANACIM data, 2025***

Figure 14 : Link between climate change and food insecurity



Source: ***Autor compilation, using WDI and FAO data, 2025***

Figure 15 : Link between food insecurity and migration



Source: ***Autor compilation, using WDI and FAO data, 2025***

1.1.Stationary test

In the SVAR model, the stationary test must be tested, and variables should be stationary at the level or at the first difference if not, this model cannot be employed. To validate this model, the stationarity is run for each variable, and the test of Dickey-Fuller shows that no variable took individual is not stationary at the level. Then, the first difference is run at the test of Dickey-Fuller demonstrate that all the variables are stationary at the first difference. Thus, the SVAR is usable with our data.

Stationary test of the 3 variables, namely Food Insecurity or prevalence of moderate and severe food insecurity, international migration stock and average annual rainfall.

- Test of stationarity of variables

Table 10 : Stationary test at level of the variables

	Test	1%	5%	10%	MacKinnon p-value	Number of obs
Food_Insecurity Z(t)	-0.173	-3.750	-3.000	-2.630	0.9417	21
Inter_Migration_Stock	-1.718	-3.750	-3.000	-2.630	0.4219	21
A_Annual_Rainfall	-1.273	-3.750	-3.000	-2.630	0.6415	21

Conclusion of the test: The variables are not stationary at the level because the Z(t) is greater than all critical values, thus the Null hypothesis is rejected, and the variables are not stationary.

- Test of stationary of the variables at first difference

Table 11: Stationary test of the variables at the first difference

	Test	1%	5%	10%	MacKinnon p-value	Number of obs
A_Annual rainfall	-9.669	-3.750	-3.000	-2.630	0.0000	20
Inter_Migration _Stock	-4.124	-3.750	-3.000	-2.630	0.0009	20
Food_Insecurity	-6.791	-3.750	-3.000	-2.630	0.0000	20

Conclusion of the test: The variables are stationary at the first difference because all the Z(t) are lower than all critical values, thus the Null hypothesis is not rejected, and the variables are stationary at the first difference.

- SVAR models consist only of endogenous variables

4.4.2. Estimation results

Table 12 : SVAR (1) estimation results

Variables	Coef	Sd.Err	P>Z
1-1	0.041***	0.007	0.000
2-1	-203.5***	46.25	0.000
3-1	0	0	0
1-2	0	0	0
2-2	135.0***	23.15	0.000
3-2	251.2	156.7	0.109
1-3	0	0	0
2-3	0	0	0
3-3	621.0***	106.5	0.000
Number of observations	19		
Prob>Chi(2)=0.000			

Source: ***Author's computation, 2025***

Table 13 : Meaning of the number in the SVAR (1) model as variables

Variables	Reference number	Interactions	Meaning
Food Insecurity	1	1-1	Impact of Food Insecurity on its own variable
	1	1-2	Effects of Food Insecurity on migration stocks
	1	1-3	Impacts of Food Insecurity on Average Annual Rainfall
International Migration Stock Migration	2	2-2	Impacts of International Stocks on its own variable
	2	2-1	Impacts of International Migration Stocks on Food Insecurity
	2	2-3	Impacts of International Migration Stocks on Average Annual Rainfall
Average Annual Rainfall	3	3-3	Impacts of Average Annual Rainfall on its own variable
	3	3-1	Impacts of Average Annual Rainfall on Food Insecurity
	3	3-2	Impacts of Average Annual Rainfall on International Migrations Stocks

Source: Autor compilation, using regression table

Consider the matrix 1-1 that captures the impact of food insecurity on itself. The result suggests that an increase of one unit of food insecurity has positively impacted the food insecurity level of the next year. In other words, the level of food insecurity is linked positively with the level of food insecurity of the previous year in Senegal. This result shows that when you are food insecure in a year, you are at risk of being food insecure the next year. It can be because when, for instance, a household or a community experiences food insecurity in one year, they try to cope by depleting assets (selling livestock, tools, or land), borrowing money, or reducing food intake. This situation may take time before the household, or the

community returns in their normal situation. In a sense, where they are incapable to recover quickly, they become more vulnerable the next year.

In the agricultural pathway, low food insecurity can decrease agricultural productivity, e.g., due to lack of money, farmers cannot afford seeds, fertilizers, or labour force, such that they may plan less or get a lower yield the next season. This extends food shortages and decreases the level of food security. In addition, climate shocks like droughts and floods in some regions lead to repeated food insecurity because damage to soil, infrastructure, and water systems may take years to rebuild. In Senegal, rising waters of the Senegal River due to rainfall have destroyed 120 hectares of rice in Ndouloumadji Dembe, and Woudourou, two villages in the commune of Nabadji Civol in 2024[36] , and before farmer rebuild their land in the culturable sense that can take years. These results are in line with the literature. Indeed, (Villacis et al., 2022) find that food insecure families in Nigeria have been shown to have less agricultural output value than food-secure households.

The matrix 2-1 measures the effect of migration stock on food insecurity. The table of estimation results suggests that there is a negative association between migration and food insecurity. It means that an increase of one unit of migration in one year decreases the level of food insecurity in Senegal the next year by 203.5 units. These results highlight the fact that when people migrate, there is a decrease in labour force that impacts negatively the agricultural, fisheries sector. This causes a decrease in crop production and fish capture when the work time is stable, and this sector does not have any new workers. That affects worsen the food insecurity.

This finding means that, when people migrate the level of food insecurity can be decreased if the member of the household who migrate send money back i.e., remittances. This additional income can improve the level of food security of the household by the way reduce the food insecurity level of this household. Therefore, the food security level of the household decreases. This relationship between hunger or food insecurity and migration has been debated in the literature, which found that food insecurity is one of the dimensions influencing migration (FAO, 2016; Black et al., 2011).

[36] https://www.senenews.com/en/senegal/senegal-river-more-than-120-hectares-of-rice-engulfed-in-ndouloumadji-dembe-and-woudourou-1814.html

The results show also a positive effect of migration on its own variable of the next year. This result is in line with the literature related to network. When the number of international migrants is important in one year, it's associated with a higher number of migrants the next year due to the presence of a country mate in the new destination. These networks give information to the non-migrants. This motivates them to want to migrate as well and discover new things and migrate also. Furthermore, this network can serve as a guide, but also as a means of encouraging others to come, because, although they are embarking on a new adventure, they will be supported by this network. One of the most important effects of the migrant networks is that they attract new migrants (Boyd, 1989; Massey et al., 1993).

In terms of remittances, when a neighbour travels and information about their standard of living and that of their family is well known, if after this migration there is a noticeable improvement in the family's standard of living, potential migrants will want to migrate to improve their family's standard of living as well. If the presence of a migrant is the only factor that has changed in this household. In other words, when a family member migrates, people compare the situation before and after migration, and if the situation after migration is significantly better, other members of the family or community or even the country will also want to migrate.

Average annual rainfall influences positive on migration decisions and food insecurity. The result also suggests that rainfall impacts positively on migration stock in Senegal. A shock in rainfall increases migration by these results is shown in the literature. Indeed, found this positive link between rainfall and migration. The explanation belongs to this finding is that for instance, rainfall destroy crop, and buildings which that impact socially and economically the community. That`s why changing climate is positively associated with migration**.** Several studies highlight that favourable rainfall conditions can have a positive effect on migration by improving household resources and enabling migration as a strategic investment. In rural economies that rely heavily on rain-fed agriculture, such as in Africa, adequate rainfall enhances agricultural productivity and household income, which in turn provides the financial means to cover the high costs of migration (Yahaya, 2022). This aligns with the New Economics of Labor Migration (NELM), which views migration not only as a response to shocks but also as a planned decision to diversify income sources and improve long-term welfare (Taylor, 1999). For instance, in Senegal, years with above-average rainfall have been associated with increased international migration because families leverage agricultural surpluses to finance the departure of household members (Dia, 2020). Thus, good rainfall can

indirectly encourage migration by improving economic stability and reducing credit constraints.

Adequate average annual rainfall generally reduces food insecurity by improving agricultural production, stabilizing food prices, and enhancing rural incomes. In rain-fed agricultural economies, such as Senegal and other Sahelian countries, rainfall is a critical determinant of crop yields and household food availability (FAO, 2021). When rainfall is sufficient, cereal production increases, reducing the prevalence of undernourishment and dependence on food imports. This positive relationship is also linked to improved livestock health, fishing opportunities, and agricultural employment, all of which enhance household purchasing power and food access (Brown et al., 2021). Studies have shown that favourable rainfall conditions contribute to lower food insecurity levels by decreasing both the incidence and severity of food crises (Ouédraogo et al., 2020). Thus, consistent rainfall plays a vital role in strengthening food systems and ensuring that households maintain adequate and stable food consumption.

Table 14 : Results of SVAR (2)

Variables	Coef	Std.Err	P>z
1-1	0.041***	0.007	0.000
2-1	577.6***	168.4	0.001
3-1	0	0	0
1-2	0	0	0
2-2	656.7***	112.6	0.000
3-2	116.2**	50.60	0.022
1-3	0	0	0
2-3	0	0	0
3-3	191.8***	32.89	0.000

Number of observations= 19

Prob>chi(2)=0.000

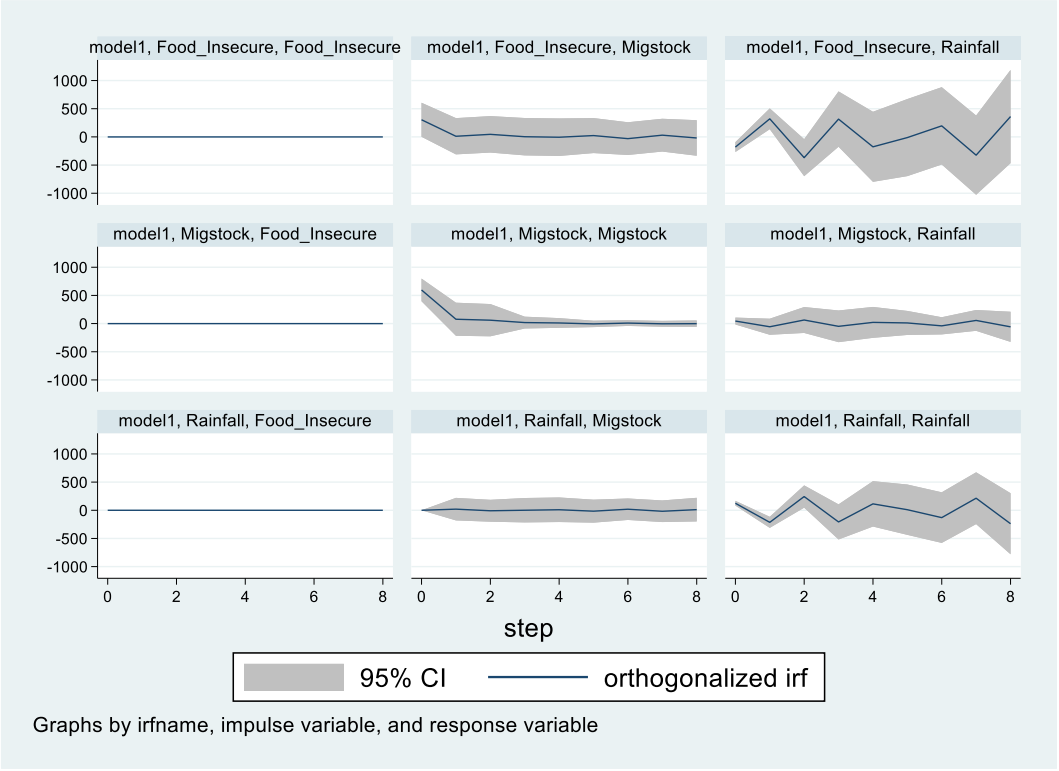
Source: ***Authors compilation, 2025***

The effect of food insecurity in migration is not captured by our first regression because it appears a constraint. To have this effect, we run the second model where food insecurity is still the first variable, but rainfall is the second variable, and migration stock is the third variable. This table of regression shows a negative link between rainfall and food insecurity. Shocks of rainfall decrease food insecurity by 203.5 units. Consistent and moderate rainfall is crucial for agricultural productivity. This result was shown by (Hamadjoda Lefe et al., 2024) who argue that precipitation and CO_2 emissions influence food security positively. Niles et al (2018) investigate the relationship between climate shocks and food insecurity among smallholder farmers across 15 countries of Latin America, Africa, and South Asia. Their results highlight that rainfall variability, in particular, leads to unpredictable agricultural yields, which in turn exacerbates food insecurity.

Food insecurity is positively linked to climate change or environmental degradation. Indeed, when people are food insecure, they adapt survival strategies that cause environmental degradation due to overexploitation of the environment, (Frankenberger, 1990). For example, in the fishery sector fishers overexploit fish for increasing their capture increase also their income and increase their level of food security. Food insecurity often pushes households to adopt short-term survival strategies aimed at ensuring immediate access to food, even when these strategies undermine their long-term livelihood sustainability. When agricultural yields decline due to climatic shocks or market instability, rural populations frequently intensify land use, expand cultivation into marginal lands, or reduce fallow periods, (Azadi et al., 2018). These adaptive responses may temporarily increase food availability, but they accelerate soil exhaustion, loss of soil organic matter, and fertility decline. That impact more climate variables like rising temperature and changing rainfall. Thus, when people are food insecurity, several strategies can be favoured, which can advantageously lead to environmental degradation, notably through deforestation to expand cultivated land and the unrestricted use of fertilizers to boost harvests, which degrades the land. In the fishing sector, food insecurity pushes fishermen to overexploit fish stocks, negatively impacting marine ecosystems according to (Pauly et al., 2005, Pomeroy et al., 2016). Garcia et al., (2010) had found this conflict between fish exploitation and conflict on marine ecosystem.

One of the specific features of the SVAR model is the variance decomposition table and impulse response functions. The variance decomposition measures the contribution of each variable to fluctuations in the other variables. But the impulsive response function analyses the interactions between variables over time after a shock.

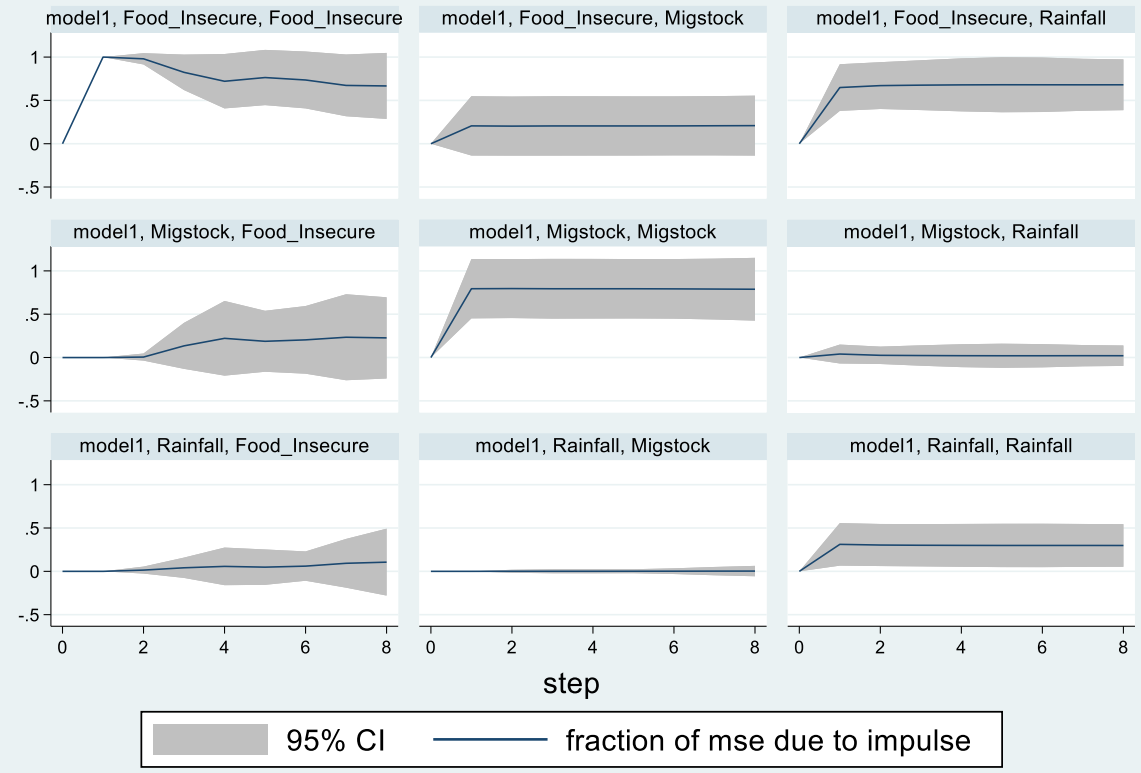
Figure 16 : Function of impulsive response



Source : ***Author, using regression results***

The impulse response functions (IRFs) reveal that shocks to migration stocks have a modest but negative effect on food security, suggesting that an increase in migration tends to alleviate food insecurity in Senegal over the forecast horizon. This negative impacts of migration on food insecurity is mainly due to remittances. Thus, migration plays a positive effect on food systems. This link is explained by the fact that through remittances that migrants send back home. It increases the income of the household. This additional income increases also the level of food security of the household. This result aligns with the Keynesian theory of consumption. Furthermore, rainfall appears largely unaffected by shocks in migration or food insecurity, reflecting its exogenous nature. Overall, these results highlight that while migration plays a role in mitigating food insecurity, climatic shocks such as rainfall have less predictable impacts.

Figure 17 : Decomposition of the variance



Source : ***Author, using regression results***

The figure shows a forecast error variance decomposition. It indicates how much of the forecast error variance of each variable is explained by shocks to itself or the other variables over time. in the graphs, the time is set to 8 horizons over which the variance is decomposed. The forecast error variance decomposition (FEVD) results indicate that food insecurity is largely self-driven, with its own shocks explaining most of its forecast error variance across all forecast horizons. This suggests a high level of persistence in food insecurity, where past fluctuations strongly influence future outcomes. Rainfall shocks, however, account for a notable share of the variance (up to approximately 30 to 40%), highlighting the importance of climate variability as a driver of food insecurity dynamics. Migration stock shocks contribute only marginally to the variance of food insecurity, but their influence shows a slight upward trend over time, pointing to potential indirect effects of migration on food availability and access. Overall, these findings emphasize that while food insecurity is persistent, external shocks such as rainfall variability remain significant factors.

The variance decomposition results also show that migration stock is predominantly explained by its own shocks, with self-contributions accounting for nearly all the forecast error variance across all time horizons. This suggests that migration dynamics are largely self driven, with limited influence from food insecurity or rainfall shocks. The impact of food insecurity shocks on migration stock remains minimal and statistically uncertain, as reflected by the narrow range around zero. Similarly, rainfall shocks explain an insignificant portion of migration variance, indicating that climatic factors exert little direct influence on migration stock in the short and medium term. Overall, migration appears to be relatively exogenous within the system compared to the other variables."

"Rainfall variance is also strongly self-determined, with its own shocks accounting for nearly all the forecast error variance across all steps. The effects of food insecurity and migration stock shocks on rainfall are negligible, suggesting that rainfall patterns are largely exogenous to socioeconomic dynamics in the model. The decomposition confirms that rainfall variability is driven primarily by climatic factors rather than by feedback from migration or food insecurity. This reinforces the interpretation of rainfall as an external driver, whose influence on the other variables, particularly food insecurity, is more pronounced than the reverse."

Likelihood Ratio Test

- LR test ($\chi^2 = 17.76$, $p = 0.000$):

This confirms that our identification structure (the zero restrictions) fits the data well; so our assumptions about contemporaneous causal ordering are statistically supported.

The estimated structural impact matrix (Table 14) indicates that migration shocks have a significant and immediate effect on food insecurity: a one-unit migration shock raises food insecurity by approximately 577.65 units ($p < 0.01$). Similarly, food insecurity shocks significantly increase both food insecurity itself (656.74) and climate-related stress (116.21) in the same period. Climate shocks primarily affect the climate variable contemporaneously (191.76) but do not have direct effects on migration or food insecurity. The likelihood ratio test strongly rejects the null hypothesis of invalid restrictions ($\chi^2(1) = 17.76$, $p < 0.001$), confirming that the imposed recursive structure is consistent with the data.

4.5. Partial conclusion

The final chapter of this thesis examines the link between migration, food insecurity, and climate change in Senegal. The data used in this study comes from the World Bank for the international migration stock variable, climate data captured by average rainfall levels comes from ANACIM, 2023, and data on food insecurity, which is measured here by the prevalence of moderate and severe food insecurity in Senegal. The study period is from 2000 to 2020. The structural VAR model is used. After estimation, the results show that variables such as the international stock of Senegalese migrants, average precipitation levels, and food insecurity are primarily explained by their own past values but also interact with each other. Migration thus has a positive impact on food insecurity. Therefore, food insecurity in Senegal is due to migration in the context of climate change. There is also a positive link between average rainfall and migration. However, food insecurity is negatively linked to rainfall variation. To combat food insecurity and moderate the level of migration in Senegal, the government must implement integration policy addressing these three phenomena: food insecurity, migration, and climate variation. To do this, it is necessary to implement climate adaptation strategies, practise smart agriculture to ensure a resilient agricultural sector in the face of climate shocks, and pursue full-time, non-seasonal agriculture that is not overly dependent on the weather. This will boost harvests and increase food production, which could also help achieve food sovereignty. In terms of income, it will increase farmers' incomes, which could reduce migration levels. It would also be appropriate to carry out seasonal migration, especially during the lean season (raining season) when food insecurity is high.

GENERAL CONCLUSION

This study highlights the interlinkages between climate change, migration, and food (in)security in Senegal. The first chapter presents an overview of our main variable of interest in Senegal, such as migration, food security, food insecurity, and climate change. It also presents policy related to these phenomena to enhance food insecurity, and migration especially irregular migration, and to be resilient to changing climate. The second chapter focuses on the impact of climate change on food security in Senegalese fishery households using primary data collected from fishers. The results from the generalized least squares model suggest a negative link between climate change and food security. While income is very important to ensure food security. Households with higher average daily incomes are less likely to be food insecure, emphasizing the need for economic stability to ensure adequate access to food. Employment status also plays a significant role, with employer respondents more likely to be food secure compared to employees and the unemployed. This suggests that stable and well-paying jobs are essential for enhancing food security. Education emerges as another vital determinant. Living in certain districts, such as Soumbedioune, appears to be beneficial for food security compared to other districts. This may be due to variations in climate change impacts and the availability of resources across different districts. For instance, regions with higher temperatures may face more severe challenges related to fish disease and reduced catch, exacerbating food insecurity. The results also suggest that overfishing impact negatively on fishermen households, but credit access has a positive effect on food security.

The third chapter aims to analyse the effect of migration as a climate adaptation strategy to enhance food security in Senegalese fishers' household. Using the Heckman model, the results indicate that climate change influences positively fishers` migration, but food security impacts negatively migration. Other variables such as fishing experience, household size, and education level, are also positive determinant of migration and the average annual rainfall. The fourth chapter analyses the interlink between migration, and food insecurity using secondary data.

The Svar was employed. The findings show a positive association between migration and food insecurity. Additionally, there is a negative link between rainfall and food insecurity, migration has a positive link on itself, while food insecurity at the same time. This finding aligns with previous studies indicating that climatic changes impact fish availability, quality,

and overall production, thereby affecting the livelihoods and food security of fishing communities, leading to migration as a climate adaptation strategy.

For a country like Senegal, where the fishery sector is very important in terms of job creation, food security, and its weight of Senegalese exportations. Therefore, it is important to establish policies to strength this sector and stop the phenomenon of irregular migration.

POLICY IMPLICATIONS

Policy implications from these findings are multifaceted. Firstly, there is an urgent need for climate adaptation strategies tailored to the specific needs of coastal fishing communities. For example, investing in climate-resilient fishing practices and technologies could help sustain fish stocks and secure livelihoods. These programs should focus on implementing a sustainable fisheries management, respect the exclusive economic zones and finally control catches in terms of type of fish. Secondly, enhancing economic opportunities and income stability is crucial for improving food security. This could involve supporting diversified livelihood options, such as aquaculture, which can provide alternative income sources for fishing communities. Thirdly, targeted interventions are needed to address geographic disparities in food security. Policymakers should consider the specific vulnerabilities of different districts and implement location-specific measures to support the most affected communities. For example, regions experiencing higher temperatures and greater climate impacts may require more intensive support to mitigate these challenges. In addition, the government must also focus on these policies when it`s come to create a fishery sector resilient to shocks and stop the phenomena of irregular migration.

- Promote Safe and Legal Migration Channels: The government should develop seasonal or circular migration programs, especially during periods when fishing is unprofitable, allowing fishermen to migrate legally for temporary employment but select the most vulnerable community and practicing illegal migration therefore fishermen. The time to practice this circular migration should be specially during breeding season.

- Improve Access to Credit in Fishing Communities: Expanding access to microcredit can help fishermen smooth income shocks and reduce the financial pressure that leads to migration. This credit can be also used to finance other activities like market gardening and aquaculture. Since secondary activity is linked negatively with migration.

- Support the Development of Income-Generating Activities: Policymakers should encourage investment in fish processing, preservation, and marketing activities that add value to fishery products. This would not only stabilize income but also reduce over-reliance on fishing.

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APPENDIX

Appendix 1

Table 15 : Descriptives statistics of the variables

Variables acronym	Variable meaning	Types of measure	Mean	Std	Min	Max
Dependent variable						
Household food security access scale index (HFSAS)	Level of food security of the fisherman	Continuous: from 0 to 1	0.445265	0.13549	0.19181	1
Independent Variables						
Age	Age of the household head	in years	39.36316	12.3541	17	75
Household size (Hhsz)	Number of people living in the same household including the household head	Continuous	15.58246	9.5573	1	60
Average Daily income (ADI)	Daily income of the Fisher	Continuous in FCFA	4250.395	1785.64	500	11500
Fishing Experience (FE)	Number of years practicing fishing as main activity	in years	20.57193	11.0771	1	60
Boat size (BS)	Size of the fishing boat	in meters	16.33914	9.244769	8	30

Table 16 : Descriptive statistics

Variables acronym	Variable meaning	Types of measure		Frequence	Percentage	Cum
Perception of Rising water temperature	Whether the fisherman perceive	Dummy:	1 if Yes	458	80.35	80.35
			0 Otherwise	112	19.65	100.00
Marital Status	Matrimonial status of the fisherman	4 categories:	Married	438	76.84	76.84
			Divorced	16	2.81	79.65
			Widowed	6	1.05	80.70
			Never Married	110	19.30	100.00
Education Level	Highest degree attends by the fishermen	5 categories:	None	25	4.39	4.39
			Koranic	192	33.68	33.68
			Primary	278	48.77	86.84
			Secondary	64	11.23	98.07
			Tertiary	11	1.93	100
Employment status	Occupation of the fisherman	3 categories:	Employer	225	39.47	39.47
			Employee	342	60	99.47
			Unemployed	3	0.53	100.00
Secondary activity	Whether the fisher has secondary Activity or not	Dummy:	1 if Yes	66	11.58	11.58
			0 Otherwise	504	88.42	100.00
Disticts	Geographic location of the fisher	7 categories:	Soumbedioun	33	5.79	5.79
			Yarakh	60	10.53	16.32
			Rufisque	40	7.02	23.33
			Kayar	85	14.91	38.25
			Mbour	90	15.79	54.04
			Joal Fadiouth	111	19.47	73.51
			Djiffer	64	11.23	84.74
			Guet Ndar	87	15.26	100.00
Access to credit	Whether the fisher has access to credit or not	Dummy:	1 if Yes	121	21.23	21.23
			0 Otherwise	449	78.77	100.00
Overfishing	Whether there is overfishing or not	Dummy: 1 if Yes		495	86.84	86.84
		0 otherwise		75	13.16	100.00

Table 17 : Descriptive statistics for education level

Education Status	Frequency	Percentage
None	25	4.39
Koranic School	192	33.68
Primary	278	48.77
Secondary	64	11.23
Tertiary	11	1.93
Total	570	100.00

Table 18 : Description of statistics for marital status

Marital status	Frequency	Percentage (%)
Divorced	16	2.81
Married	438	76.84
Single	110	19.30
Widowed	6	1.05
Total	570	100

Table 19 : Regression results of the GLS model

Linear regression	Number of obs = 570				
	F(26, 543) = 10.66				
	Prob > F = 0.0000				
	R-squared = 0.4854				
	Root MSE = .40495				
	Robust				
Food_security	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]

Increase_Water_Temperature	-.1692563	.0579753	-2.92	0.004	-.2831397	-.0553729
Avairage_daily_incmoe |	.0001724	.0000134	12.83	0.000	.000146	.0001988
age	-.0055257	.0093422	-0.59	0.554	-.0238771	.0128256
age2	.0000402	.0001085	0.37	0.711	-.000173	.0002533
Distrits (Base_district=Soumbedioune)						
Hann Bel-air	-.3970649	.1282869	-3.10	0.002	-.6490643	-.1450655
Rufisque	-.371613	.1425347	-2.61	0.009	-.6516	-.091626
Kayar	-.5159076	.1040392	-4.96	0.000	-.7202761	-.3115391
Tefess	-.5712184	.1002802	-5.70	0.000	-.7682031	-.3742338
Jaol	-.6204195	.104762	-5.92	0.000	-.8262079	-.4146312
Djiffer	-.5103533	.1045368	-4.88	0.000	-.7156995	-.3050072
Guet Ndar	-.4173137	.1156983	-3.61	0.000	-.6445847	-.1900426
Marital (Base_Marital_Status=Marie)						
Jamais Marié	-.0721892	.0550232	-1.31	0.190	-.1802736	.0358951
Divorcé	.2918696	.1719469	1.70	0.090	-.0458931	.6296322
Veuf	-.0080001	.0947007	-0.08	0.933	-.1940247	.1780244
Education (Base_Education_Primary)						
Secondary	-.0462325	.0421123	-1.10	0.273	-.1289555	.0364904
Tertiary	.0119709	.063103	0.19	0.850	-.111985	.1359267
None	.2012271	.1000556	2.01	0.045	.0046837	.3977705
Koranic	.0531045	.2008748	0.26	0.792	-.3414824	.4476913
Employment (Base_employement _status=Employer)						
Employé	-.0062594	.0474083	-0.13	0.895	-.0993856	.0868667
Chômeur |	.3380998	.4788587	0.71	0.480	-.6025426	1.278742

Moyenne |	.0518135	.0569245	0.91	0.363	-.0600058	.1636327
Board_size	-.0268728	.0571885	-0.47	0.639	-.1392106	.085465
Secondary_activity	.0087973	.0534652	0.16	0.869	-.0962267	.1138213
Overfishing	-.181563	.0336718	-5.39	0.000	-.2477059	-.1154201
Credit_access	.1409049	.0435169	3.24	0.001	.0554229	.226387
_cons	1.416961	.2321777	6.10	0.000	.960884	1.873037

Table 20 : Heckman selection model estimation

Heckman selection model -- two-step estimates Number of obs = 570

(regression model with sample selection) Selected = 368

Nonselected = 202

Wald chi2(13) = 48.63

Prob > chi2 = 0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Migration						
FoodSecurity	-.3396551	1.294276	-0.26	0.793	-2.876389	2.197079
Avairage_daily_incmoe	.0000125	.000089	0.14	0.888	-.0001619	.0001869
Householdsize	.047771	.0146119	3.27	0.001	.0191322	.0764099
climate_change	.6069747	.2473782	2.45	0.014	.1221224	1.091827
age	.0049253	.0565336	0.09	0.931	-.1058785	.1157291
age2	-.0002772	.0006346	-0.44	0.662	-.001521	.0009667
Land_tenancy	.152109	.1365066	1.11	0.265	-.115439	.419657
FishingExpirience	.0477491	.0163019	2.93	0.003	.015798	.0797002
Secondary_activity	-.5308229	.262537	-2.02	0.043	-1.045386	-.0162599

Employment_status	.2074245	.3517422	0.59	0.555	-.4819775	.8968266
Credit_Access	-.4598021	.1760688	-2.61	0.009	-.8048906	-.1147136
Education_level	1.076687	.5741621	1.88	0.061	-.0486502	2.202024
Marital_status	.3597834	.3831401	0.94	0.348	-.3911574	1.110724
_cons	-.5984865	1.830298	-0.33	0.744	-4.185806	2.988833

ProbMigrant

FoodSecurity	1.227289	.535356	2.29	0.022	.1780108	2.276568
Avairage_daily_incmoe	-.0000462	.0000387	-1.19	0.233	-.000122	.0000297
Householdsize	.013738	.0062136	2.21	0.027	.0015596	.0259165
climate_change	.1303715	.1144849	1.14	0.255	-.0940148	.3547578
age	-.015388	.0293011	-0.53	0.599	-.0728172	.0420411
age2	.000266	.0003282	0.81	0.418	-.0003772	.0009093
Land_tenancy	.1231689	.0705091	1.75	0.081	-.0150265	.2613643
FishingExpirience	.0020558	.0082203	0.25	0.803	-.0140558	.0181674
Secondary_activity	-.1397996	.1244332	-1.12	0.261	-.3836842	.1040851
Employment_status	-.0411193	.1721333	-0.24	0.811	-.3784944	.2962557
Credit_Access	-.0469362	.0828683	-0.57	0.571	-.2093551	.1154827
Education_level	-.1820278	.2654058	-0.69	0.493	-.7022137	.3381581
Marital_status	.2435578	.1518868	1.60	0.109	-.0541348	.5412503
mean_temperature	.0222855	.0084991	2.62	0.009	.0056276	.0389433
_cons	-1.380358	.8419705	-1.64	0.101	-3.03059	.2698738

/mills |

lambda 1.300363 1.34362 0.97 0.333 -1.333083 3.93381

---

rho | 0.59882

sigma | 2.1715497

Table 21 : Eigenvalue stability condition of the SVAR

Eigenvalue	Modulus
-.8588429 + .5045598i	.996088
-.8588429 - .5045598i	.996088
-.4960382 + .8620548i	.994581
-.4960382 - .8620548i	.994581
.3756727	.375673
-.2543259	.254326

All the eigenvalues lie inside the unit circle

Table 22 : Determination of the optimal lag

Selection-order criteria

Sample: 2002 - 2020 Number of obs = 19

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-306.027				1.2e+12	36.3561	36.3707	36.5031
1	-295.831	20.392	9	0.016	1.1e+12	36.2154	36.2738	36.8035

| 2 | -209.026 173.61* 9 0.000 1.3e+08* 27.0619* 27.1642* 28.0912* |

+--+

Endogenous: Food_Insecure Migstock Rainfall

Endogenous: foodinsecure mig_stoc2 Averageannuellrainfall

Exogenous: _cons

Table 23 : VAR estimation result satisfies stationarity condition

Vector autoregression

Sample: 2002 - 2020 Number of obs = 19

Log likelihood = -209.0262 AIC = 27.06191

FPE = 1.33e+08 QIC = 27.16422

Det(Sigma_ml) = 9604001 BIC = 28.09117

Equation	Parms	RMSE	R-sq	chi2	P>chi2
Food_Insecure	.054097	0.9998	90002.41	0.0000	
Migstock	873.423	0.2157	4.674003	0.5863	
Rainfall	292.355	0.7581	53.28328	0.0000	

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Food_Insecure						
Food_Insecure						
L1.	-.9945887	.0048663	-204.38	0.000	-1.004127	-.9850509
L2.	-.9855548	.0044363	-222.16	0.000	-.9942497	-.9768599

h

Migstock

L1.	3.39e-06	.0000148	0.23	0.819	-.0000257	.0000324
L2.	.0000625	.0000148	4.24	0.000	.0000336	.0000914

Rainfall

L1.	.000065	.0000504	1.29	0.197	-.0000338	.0001638
L2.	.0000513	.0000507	1.01	0.311	-.0000481	.0001507
_cons	-.0341293	.0101192	-3.37	0.001	-.0539625	-.0142961

Migstock

Food_Insecure

L1.	113.4159	78.56927	1.44	0.149	-40.57708	267.4088
L2.	113.6464	71.62595	1.59	0.113	-26.73787	254.0307

Migstock

L1.	.1170865	.2393346	0.49	0.625	-.3520006	.5861736
L2.	.0864063	.238161	0.36	0.717	-.3803808	.5531933

Rainfall

L1.	.1588481	.8140269	0.20	0.845	-1.436615	1.754312
L2.	.1770051	.8188836	0.22	0.829	-1.427977	1.781987
_cons	36.48977	163.3791	0.22	0.823	-283.7274	356.707

Rainfall

Food_Insecure|

L1.	42.67426	26.29899	1.62	0.105	-8.870811	94.21934
L2.	16.64545	23.9749	0.69	0.488	-30.34448	63.63539

Migstock						
L1.	.0350645	.0801109	0.44	0.662	-.12195	.192079
L2.	.0150175	.0797181	0.19	0.851	-.1412272	.1712621
Rainfall						
L1.	-1.710913	.272474	-6.28	0.000	-2.244953	-1.176874
L2.	-.9857981	.2740997	-3.60	0.000	-1.523024	-.4485727
_cons	-25.87639	54.68685	-0.47	0.636	-133.0607	81.30788

Table 24 : Results of the SVAR(1)

Sample: 2002 - 2020 Number of obs = 19

Overidentified model Log likelihood = -217.9071

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]
/A					
1_1	1	(constrained)			
2_1	0	(constrained)			
3_1	0	(constrained)			
1_2	0	(constrained)			
2_2	1	(constrained)			
3_2	0	(constrained)			
1_3	0	(constrained)			
2_3	0	(constrained)			
3_3	1	(constrained)			

/B

1_1	.0414905	.0071156	5.83	0.000	.0275442	.0554367
2_1	577.6474	168.4347	3.43	0.001	247.5214	907.7734
3_1	0 (constrained)					
1_2	0 (constrained)					
2_2	656.741	112.6302	5.83	0.000	435.99	877.4921
3_2	116.2106	50.59936	2.30	0.022	17.0377	215.3835
1_3	0 (constrained)					
2_3	0 (constrained)					
3_3	191.7617	32.88686	5.83	0.000	127.3047	256.2188

LR test of identifying restrictions: chi2(1) = 17.76 Prob > chi2 = 0.000

Table 25 : Regression results of the SVAR(2)

Sample: 2002 - 2020 Number of obs = 19

Overidentified model Log likelihood = -210.9861

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]
/A					
1_1	1 (constrained)				
2_1	0 (constrained)				
3_1	0 (constrained)				
1_2	0 (constrained)				
2_2	1 (constrained)				
3_2	0 (constrained)				

1_3	0 (constrained)					
2_3	0 (constrained)					
3_3	1 (constrained)					
/B						
1_1	.0414905	.0071156	5.83	0.000	.0275442	.0554367
2_1	-203.4736	46.24566	-4.40	0.000	-294.1134	-112.8338
3_1	0 (constrained)					
1_2	0 (constrained)					
2_2	134.9747	23.14797	5.83	0.000	89.60553	180.3439
3_2	251.1953	156.6556	1.60	0.109	-55.84395	558.2346
1_3	0 (constrained)					
2_3	0 (constrained)					
3_3	621.0047	106.5014	5.83	0.000	412.2658	829.7437

LR test of identifying restrictions: chi2(1) = 3.92 Prob > chi2 = 0.048

Table 26 : Test of stationary of the prevalence of moderate and severely food insecure (at level)

Dickey-Fuller test for unit root Number of obs = 21

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
		---------- Interpolated Dickey-Fuller ---------		
Z(t)	-0.173	-3.750	-3.000	-2.630

MacKinnon approximate p-value for Z(t) = 0.9417

Table 27 : Test of stationary of the prevalence of moderate and severely food insecure (at first difference)

Dickey-Fuller test for unit root Number of obs = 20

---------- Interpolated Dickey-Fuller ---------

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-6.791	-3.750	-3.000	-2.630

MacKinnon approximate p-value for Z(t) = 0.0000

Table 28 : Test of stationary of the international migration stock (at level)

Dickey-Fuller test for unit root Number of obs = 21

---------- Interpolated Dickey-Fuller ---------

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-1.718	-3.750	-3.000	-2.630

MacKinnon approximate p-value for Z(t) = 0.4219

Table 29 : Test of stationary of the international migration stock (at first difference)

Dickey-Fuller test for unit root Number of obs = 20

---------- Interpolated Dickey-Fuller ---------

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-4.124	-3.750	-3.000	-2.630

MacKinnon approximate p-value for Z(t) = 0.0009

Table 30 : Test of stationary of the Average rainfall (at level)

Dickey-Fuller test for unit root Number of obs = 21

---------- Interpolated Dickey-Fuller ---------

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-1.273	-3.750	-3.000	-2.630

MacKinnon approximate p-value for Z(t) = 0.6415

Table 31 : Test of stationary of the Average rainfall (at first difference)

Dickey-Fuller test for unit root Number of obs = 20

---------- Interpolated Dickey-Fuller ---------

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-9.669	-3.750	-3.000	-2.630

MacKinnon approximate p-value for Z(t) = 0.0000

Appendix 2

Questionnaire

Questionnaire – Enquête auprès des ménages de pêcheurs sénégalais

I. Informations générales

1. Point GPS du district : .....

2. Date de l'enquête : .....

3. Heure de début : .....

4. Heure de fin : .....

5. Langue principale du chef de ménage : .....

6. Groupe ethnique du chef de ménage : .....

7. Âge du chef de ménage : .....

8. Sexe du chef de ménage : Homme / Femme

9. Situation matrimoniale : Marié(e) / Célibataire / Divorcé(e) / Veuf(ve)

II. Caractéristiques du ménage

10. Nombre total de membres du ménage : .....

11. Nombre d'enfants : .....

12. Tous les enfants en âge scolaire sont-ils scolarisés ? Oui / Non

13. Si non, pourquoi ? .....

14. Statut d'occupation du logement : Propriétaire / Locataire / Gratuit

15. Nombre de membres pratiquant la pêche : .....

16. Niveau d'éducation du chef de ménage : Aucun / Coranique / Primaire / Secondaire / Supérieur

17. Statut professionnel : Employeur / Employé / Sans emploi

18. Années d'expérience dans la pêche : ..... années

III. Perception et impact du changement climatique

19. Avez-vous l'impression que le climat change ? Oui / Non

20. Votre localité est affectée par : Inondation / Érosion / Élévation de la mer / Salinisation / Température / Précipitations / Autres

21. Précisez les conséquences observées : .....

22. Nombre de personnes ayant quitté le secteur : .....

23. Nombre de déplacés forcés : .....

IV. Pratiques de pêche

24. Méthodes de pêche utilisées : .....

25. Outils de pêche utilisés : .....

26. Moyen de transport utilisé : .....

27. État du moyen : Bon / Moyen / Mauvais

28. Avez-vous une licence de pêche ? Oui / Non

29. Avez-vous accès au crédit ? Oui/Non

29. Votre moyen est-il licencié ? Oui / Non

30. Méthode de conservation du poisson : .....

31. Impact du climat sur vos activités : .....

V. Revenus et effort de pêche

32. Jours de pêche par mois : .....

33. Était-ce le même avant le changement climatique ? Oui / Non

34. Si non, cela a : Diminué / Augmenté

35. Revenu journalier minimum (FCFA) : .....

36. Revenu journalier maximum (FCFA) : .....

37. Était-ce le même montant avant ? Oui / Non

38. Si non, cela a : Augmenté / Diminué

39. Évolution du revenu de pêche (2000–2023) : Inchangé / Fluctue

VI. Activités secondaires et satisfaction

40. La pêche est-elle votre seule activité ? Oui / Non

41. Si non, seconde activité : .....

42. Pourquoi avez-vous une autre activité ? .....

43. Êtes-vous heureux dans votre métier ? Oui / Non / Pas mal

44. Le revenu couvre-t-il vos dépenses primaires ? Oui / Non

45. Permet-il de couvrir les dépenses alimentaires ? Oui / Non

46. Disposez-vous de temps de loisir ? Oui / Non

47. Aimez-vous votre métier ? Oui / Non / Pas mal

48. Si non, pourquoi ? Trop de temps / Revenu insuffisant / Autres

VII. Sécurité alimentaire

49. Sécurité alimentaire garantie ? Chaque jour / Parfois / Jamais

50. Les stocks sont-ils aussi abondants ? Oui / Non

51. Si non, les stocks ont : Augmenté / Diminué

52. Accès aux trois repas ? Oui / Non

53. Alimentation diversifiée ? Oui / Non

54. Qualité et nutrition adéquate ? Oui / Non

VIII. Migration

55. Y a-t-il migration saisonnière ? Oui / Non

56. Si oui, quand ? .....

57. Où vont-ils ? Intérieur / Côte / Autres

58. Souhaitez-vous migrer ? Oui / Non

59. Avez-vous des membres ayant migré ? Oui / Non

60. Migration légale ou illégale ? Légale / Illégale

61. Continent de destination : Afrique / Amérique / Asie / Europe / Océanie

62. Était-il pêcheur ? Oui / Non

63. Recevez-vous des transferts ? Oui / Non

64. Ces transferts couvrent les besoins ? Oui / Non

65. Améliorent-ils vos conditions ? Oui / Non

66. Permettent trois repas/jour ? Oui / Non

67. Quantités suffisantes ? Oui / Non

68. Repas diversifiés ? Oui / Non

69. Qualité et protéines adéquates ? Oui / Non

IX. Score de consommation alimentaire

Groupes d'aliments	**Poids**
Céréales/tubercules	2
Légumineuses	3
Légumes	1
Fruits	1
Viande/Poisson	4
Lait/Produits laitiers	4
Sucre	0.5
Huile	0.5
Total Maximum	**16**