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博士論文

International Doctoral Degree Program in Climate Change and Sustainable Development
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Doctoral Dissertation

糧食系統對氣候災害的脆弱性和抵禦能力：

海地農民的應對和適應策略

Food System Vulnerability and Resilience to Climate Disasters: Farmers Coping and Adaptation Strategies in Haiti.

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ABSTRACT

The food system in Haiti faces challenges due to small-scale farming, inadequate infrastructure, and climate change impacts like droughts, floods, and hurricanes. These factors undeniably play a crucial role in the food system's inability to fulfill its primary objective of ensuring food security, particularly in rural regions where the majority of the population depends on agriculture for sustenance. Furthermore, these circumstances give rise to concerns regarding the ability of the food system to meet the projected high demand for food in the years 2030-2040 and 2050. Thus, this doctoral thesis focuses on the examination and analysis of the vulnerability and resilience of the food system, with a specific emphasis on food production, to climate-related disasters in Haiti. It also investigates not only the farmers' willingness to adapt to climate change but also their perceptions and the existing adaptive measures they have already implemented to mitigate the impacts of climate change. In order to fulfill this objective, a comprehensive analysis has been conducted on four specific food crops and cash crops that are predominantly consumed in Haiti.

The research focuses on communities situated in the Artibonite region of Haiti and aims to achieve three main objectives. Firstly, we evaluate and analyze the projected food demand for the years 2030 – 2050, using two scenarios: Business as Usual and Stratified Society. The findings of both scenarios reveal that the selected crop yields will remain low and fail to meet the increasing local food demand. In this case, we assessed the willingness of 488 farmers to adopt crop rotations as an adaptive strategy to enhance yields. The findings reveal that less than half of the surveyed population is inclined to implement this adaptation measure on their plots to cope with climate change impacts. This suggests a

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potential challenge in achieving higher crop yields and meeting the growing food demand in the years 2030-2040 and 2050. Crop rotations are considered a beneficial agricultural practice as they can help improve soil fertility, control pests and diseases, and enhance overall crop productivity. It is crucial to address these challenges and promote sustainable agricultural practices to ensure an adequate food supply in the coming decades.

As we have seen the selected crop yields are likely to remain low and climate change poses the greatest challenge to crop productivity, the second objective of this research is to evaluate the agricultural drought risk by incorporating all the relevant components of risk, namely vulnerability, hazard, exposure, and adaptive capacity, along with their respective influencing indicators. The assessment of drought risk is conducted in two stages, following the risk equation. Firstly, the risk equation is applied without considering the adaptive capacity, and secondly, the adaptive capacity is included as an additional component in the risk equation. The analysis of both approaches reveals that the first method yields a higher percentage (45.8%) of moderate to very-high drought risk compared to the second approach (30.7%). This indicates that approximately 30.7% of the land area exhibits a moderate to very high agricultural drought risk, posing a significant risk to both the existing food supply and the future productivity of the selected crops. This situation raises concerns regarding the ability to meet the escalating food demand in the coming years.

Enhancing crop productivity and addressing the rising food demand in the future necessitates the implementation of climate change adaptation measures. However, it is imperative to recognize that achieving this goal is contingent upon the active participation and involvement of farmers. Hence, the third objective of this research is to investigate the

variations in climate change perceptions among farmers based on their socioeconomic status and gender. Additionally, this section of the research seeks to explore the existing adaptation strategies that have been implemented to foster resilience in the face of climate change. Data for this investigation were collected through surveys administered to 670 farmers residing in two distinct regions of Haiti that are drought-prone areas. By utilizing structural modeling equations, the results indicate that farmers with lower incomes had a higher level of climate change perception compared to their higher-income counterparts. Additionally, female farmers demonstrated a greater level of climate change perception compared to male farmers. The analysis of adaptation strategies revealed that low-income farmers primarily relied on off-farm activities, such as securing off-farm employment, leasing lands, and household migration, as methods of coping with the impacts of climate change. Conversely, female farmers primarily focused on on-farm activities to adapt to climate change, including modifying the farming calendar, altering crop varieties, and adjusting the irrigation system. So, addressing the climate change perceptions and adaptation strategies of farmers, particularly those with lower incomes and female farmers, is crucial for improving crop productivity and meeting future food demand. By providing targeted support, promoting climate-resilient farming techniques, and adopting gender-specific approaches, agriculture can become more resilient and sustainable in a changing climate.

Key words

Food systems, vulnerability, resilience, climate change, adaptation, farmers, Haiti.

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ABBREVIATIONS

NTU : National Taiwan University
IPCS : Inter Degree Program in Climate Change and Sustainable Development
DPSIR : Driver-Pressure-State-Impact-Response
WB : World Bank
FAO : Food and Agriculture Organization
USD : United State Dollar
GDP : Gross Domestic Product
PNCC : National Climate Change Policy
ME : Ministry of Environment
NCCAP : National Climate Change Adaptation Plan
BAU : Business As Usual
SSS : Stratified Societies
IPCC : Intergovernmental Panel in Climate Change
NOAA : National Oceanic and Atmospheric Administration
GHG : Green House Gaz
CO_2 : Carbone Dioxide
NO_2 : Nitrogen Dioxide
NH4 : Ammonium
AGGI : Annual Greenhouse Gaz Index
MTCO2e : Metric Ton CO_2 emission
WFP : World Food Program
UNICEF : United Nations International Children's Emergency Fund
GEC : Global Environmental Change
GECAFS : Global Environmental Change And Food Systems
SPF : Stochastic Production Frontier
CARICOM : Caribbean Community and Common Market

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SRES	Special Report on Emissions Scenarios
MARNDR	Ministry of Agriculture
LAC	Latin America and Caribbean
CNSA	National Food Security Council
MT	Metric Ton
Kg	Kilogram
Kg/ha	Kilogram per Hectare
MT/ha	Metric Ton per Hectare
FEWSNET	Famine Early Warning Systems Network
SDG	Sustainable Development Goal
UNDRR	United Nations Office for Disaster Risk Reduction
MCDM	Multiple Criteria Decision Methods
AHP	Analytic Hierarchy Process
FAHP	Fuzzy Analytic Hierarchy Process
GIS	Geographic Information System
SPI	Standardized Precipitation Index
AC	Adaptative Capacity
WGS84	World Geodetic System 1984
UTM	Universal Transverse Mercator
NDVI	Normalized Difference Vegetation Index
LULC	Land Use Land Cover
PAWC	Plant Water Available Capacity

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1. Chapter 1: Introduction

1.1.Overview

Climate change poses a unique and pressing challenge to food security, particularly in developing nations (Shukla et al., 2019). The global agricultural systems are currently experiencing strain and are unable to produce an adequate supply of food to meet the demands of both local and global populations (Sachs, 2015). Consequently, climate change is recognized as a significant threat to food systems, with alarming repercussions for food security, livelihoods, and overall well-being, particularly among impoverished and vulnerable communities in developing countries. The main objective of this research is to investigate the vulnerability and resilience of food systems to drought and explore the coping strategies employed by male and female farmers in the context of Haiti. By doing so, this research aims to provide valuable insights and potential pathways for implementing adaptation strategies within the agricultural sector. To achieve this, a mixed methods approach has been employed, encompassing: (i) a comprehensive analysis of crop yield and Farmers' Willingness to Adapt to Climate Change in Haiti; (ii) a thorough assessment of agricultural drought risk, which incorporates all relevant components (vulnerability, hazard, exposure, and adaptive capacity) along with their respective parameters crucial for plant growth and development; and (iii) an examination of the socio-economic backgrounds and gender dimensions in relation to climate change perception and the coping strategies employed in two distinct farming regions in Haiti.

This research study offers site-specific evidence to guide interventions aimed at enhancing farm productivity and proposes equitable adaptation strategies within the local

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context for Haitian farmers, particularly those residing in Anse-Rouge and Dessalines. Additionally, this thesis addresses the existing research gap by incorporating multiple factors such as climate change, farmers' willingness to adapt, agricultural drought assessment in the Caribbean region from a Haitian perspective, and the socio-economic and gender dimensions in climate change perception and adaptation strategies. The ultimate objective is to provide policymakers with evidence-based research that can inform initiatives to ensure food security in Haiti amidst the ongoing challenges of climate change.

1.2.Research rational

The pursuit of long-term solutions to achieve food security and combat global hunger has been a primary concern for policymakers and practitioners. However, it is widely recognized that the failure of food systems to ensure food security has undermined these efforts (Haddad et al., 2016). The recent food crisis has likely contributed to this failure, with the number of individuals suffering from severe food insecurity increasing from 135 million in 2019 to 345 million in June 2022, across 82 countries, predominantly in developing nations (WB, 2022).

Previous research has documented that rising temperatures and decreased precipitation in certain regions are expected to diminish crop yields (Lobell et al., 2008). According to Shukla et al. (2019), the escalation of temperatures, changes in precipitation patterns, and the intensification of extreme weather events, including droughts, floods, and cyclones, have already had adverse effects on agricultural production and disrupted food supply chains. In this context, we assume that climate-related disasters in developing countries are a major cause of the failure of food systems to delivering food security. For instance, the FAO (2021a) reported that between 2008 and 2018, there was a significant economic

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impact due to reduced crop and livestock production following various disasters. Billions of dollars (of which USD 29 billion in Latin America and the Caribbean) were lost during this period. Agriculture bore the brunt of the damage and loss caused by drought, accounting for 82% of the total during that period. Unfortunately, it is the farmers in developing countries like Haiti who bear the brunt of these agricultural losses because they rely heavily on agriculture.

Approximately two-thirds of the population in Haiti rely on agriculture, livestock, and fishing as their primary sources of income[1]. Presently, around 6.8 million individuals, constituting a significant portion of the total population, are experiencing inadequate food consumption. Furthermore, acute malnutrition affects approximately 6% of children under the age of five, while chronic malnutrition[2] affects approximately 22.7% of the same age group. The country boasts a population of around 1 million farmers, with the agricultural sector employing approximately 60% of the working population, as reported by the Ministry of Agriculture, Natural Resources and Rural Development. Agricultural output accounts for about 45% of the country's overall food consumption, and typically consists of several small-sized plots (averaging 0.62 hectares per plot). Many of these plots are owned and operated by their respective owners, with limited access to production resources. Approximately 90% of these farms heavily rely on rainfall, while the remaining 10% are situated within irrigated perimeters, which face challenges related to water supply and the accumulation of sediment in irrigation canals. Although Haiti heavily depends on rainfall for food production, it is recognized as one of the most vulnerable countries worldwide

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[1] https://shorturl.at/iFHY2
[2] https://hungermap.wfp.org/

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when it comes to natural hazards[3]. This vulnerability is largely attributed to environmental degradation resulting from deforestation and inadequate farming practices. The devastating 2010 earthquake, prolonged drought during the El Niño event from 2014 to 2016, and recurring tropical storms since 2000 exemplify the natural hazards that have severely impacted the Haitian economy and exacerbated the issue of food insecurity.

According to recent research by Masson-Delmotte et al. (2021), climate change is expected to intensify globally in the next decade, leading to changes in precipitation patterns. Subtropical regions are projected to experience decreased rainfall, while high latitudes will likely see increased precipitation. These changes will also impact the monsoon season, albeit with regional variations. Consequently, droughts and floods, which play a crucial role in short-term fluctuations in food production in semiarid and sub-humid areas, are anticipated to become more frequent and severe as climate oscillations become more extreme and widespread. In this context, Haiti as a tropical country, is likely to experience decreased rainfall. This reduction in precipitation can have detrimental effects on agricultural activities, as water availability is critical for crop growth and sustenance. Reduced rainfall can lead to soil moisture deficits, hinder plant growth, and result in yield losses. The combination of decreased precipitation and increased frequency and severity of droughts can exacerbate the vulnerability of Haiti's agricultural sector, making it more challenging for farmers to maintain consistent food production.

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[3] https://www.worldbank.org/en/country/haiti/overview

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Studies, such as McCarthy et al. (2001) have found that droughts can have a significant negative impact on food yields, livestock numbers, and overall productivity including water scarcity, thereby intensifying food shortages and exacerbating existing challenges related to poverty and malnutrition. This implies that countries such as Haiti, which are suffering from high levels of chronic malnutrition, will be particularly vulnerable to the detrimental effects of climate-induced food production instability. In other words, drought is expected to exacerbate the prevalence and severity of food insecurity in Haiti, affecting both the capacity of the food system to delivering sufficient food security and the ability of households to access an adequate food supply.

Presently, there exists a scarcity of information regarding the attributes of the food system, specifically concerning food production in Haiti amid the impact of natural hazards such as drought. Furthermore, there is a lack of understanding regarding the willingness of farmers to adjust to climate change, encompassing their attitudes and adaptive measures formulated to confront these obstacles. Therefore, conducting assessments of food production under recurring climate change can assist policymakers in identifying suitable policy options to support farmers in building resilience to drought on their farms, improving the productivity of food and cash crops, and ultimately reducing household food insecurity.

Slette et al. (2019) indicate that drought that extensively examined as a crucial catalyst of ecosystem dynamics, is anticipated to undergo a global increase in frequency and severity. Widely recognized as one of the more costly natural hazards (FAO, 2021a), drought exerts substantial and diverse impacts, affecting multiple populations and economic sectors concurrently. Specifically, it can lead to a decrease in crop yield (Santini

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et al., 2022), a reduction in livestock numbers (Bahta & Myeki, 2022), and a decline in GDP, thereby constraining economic growth (Amarasinghe et al., 2020). Although some studies based on national-level data contend that floods and droughts do not have significant effects on long-term economic growth (Cavallo et al., 2013; Hertel & Liu, 2016), various other research findings highlight a wide range of consequences on income growth (Loayza et al., 2012; Shabnam, 2014). Nevertheless, it is evident that the frequency and intensity of climatic disasters, particularly droughts, are increasing at the sub-national level (Pachauri & Meyer, 2014; Parker et al., 2019). The lack of adequate information on drought at the sub-national level presents a challenge in formulating effective adaptation and mitigation plans. Notably, a previous study emphasizes that in the absence of adaptation measures, intensifying disasters could impact millions of people, impeding regional economic development and human progress (Padli et al., 2018).

Field observations indicate that physical water scarcity is already widespread in various regions of Haiti, where the existing water supplies are inadequate for facilitating the establishment of new water infrastructure. Furthermore, it is evident that the severity of water scarcity will escalate in the future. The increasing water scarcity will adversely affect agricultural development and exacerbate the socio-economic conditions of the most vulnerable groups. However, to the best of the author's knowledge, there is currently no comprehensive assessment of drought risk in Haiti, particularly in relation to agricultural drought. Such an assessment is crucial for the formulation of effective adaptation and mitigation plans, as well as efficient water resource management in drought-prone provinces. It would enable stakeholders and policy-makers to identify locations that are most susceptible to drought. This study addresses this knowledge gap by focusing on the

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agricultural drought risk assessment in Haiti, considering all relevant risk factors and associated indicators of crop growth.

The detrimental effects of climate change on developing countries have been extensively demonstrated and acknowledged in the literature (McCarthy et al., 2001). It is widely recognized that impoverished populations are particularly vulnerable to and less equipped to cope with these changes (Swart et al., 2003). Countries lacking resources, adequate infrastructure, and stable institutions exhibit limited capacity to adapt and are highly susceptible to the impacts of climate change (Smit & Pilifosova, 2003). In the context of food systems, it is crucial to ensure that food production, distribution, and consumption are adjusted to address climate-related disasters, thereby supporting rural livelihoods and promoting equitable access to a nutritious diet for all, regardless of social group and income growth. At the agricultural level, the adaptation process must consider shifting growing conditions, water scarcity, and other climate-related disasters, particularly drought, to achieve food security in countries like Haiti. However, it is important to recognize that strategies aimed at addressing climate change cannot be gender neutral, given that its impacts are not uniform. Men and women may possess differing perspectives and coping mechanisms, as well as varying degrees of access to and control over resources. Gender disparities within families and communities, which influence decision-making, financial control (especially in relation to agricultural resources), and access to technology and knowledge, pose a threat to individuals' ability to successfully adapt to climate change's effects. Women, in particular, face amplified challenges in sustaining themselves through agriculture due to these barriers, which are further exacerbated by climate change. Consequently, to mitigate the impacts of climate change and enhance the adaptive capacity

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of food systems, urgent adaptation measures, including the implementation of public policies and interventions, are required (Howden et al., 2007; Kumar et al., 2020).

However, several studies suggest that farmers' awareness of climate change is a crucial factor in motivating them to undertake adaptation measures (Meldrum et al., 2018; Silvestri et al., 2012). It has been found that farmers' behaviors regarding climate change, such as adjusting their farming calendar and adopting adaptation strategies, are significantly influenced by their perception of local climate change (Meldrum et al., 2018). Therefore, understanding farmers' perspectives on climate change is essential for the development and effective implementation of agricultural adaptation programs (Hansen et al., 2004; Silvestri et al., 2012). However, it is important to note that Haiti is characterized by significant social inequalities. A recent study on climate change and social inequality within the country (Islam & Winkel, 2017) highlights three main ways in which climate change exacerbates inequality: (i) by increasing the exposure of disadvantaged groups to the adverse effects of climate change; (ii) by heightening their vulnerability to climate-related damages; and (iii) by reducing their capacity to cope with and recover from such damages. Consequently, the impacts of climate change may be disproportionately felt within countries. As a result of their marginalized status, poor farmers and female farmers are likely to be more severely affected by climate change impacts than other social groups. The perception and coping behavior regarding climate change might also vary across different gender-based social groups. Therefore, it is necessary to integrate people from diverse socio-economic backgrounds into the processes of adaptation to climate change.

In 2019, the Haitian government introduced the National Climate Change Policy (PNCC), which outlined a long-term objective to steer Haiti towards green growth by 2030.

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The policy aimed to develop socio-economic sectors that are less susceptible to climate change impacts, possess the capacity to respond effectively to unfavorable climatic conditions, and embrace low-carbon technologies, particularly renewable energies. These measures were intended to enhance competitiveness while simultaneously fostering wealth creation, job opportunities, and the emergence of new professions Ministry of the Environment (ME, 2019).

Subsequently, in 2022, the Haitian government officially published the National Climate Change Adaptation Plan (NCCAP) (ME, 2022). This plan established four primary objectives: (i) the implementation of gender-sensitive programs and projects at a large scale to enhance resilience in priority sectors against adverse climatic conditions; (ii) the strengthening of human capital, with a specific focus on women and girls, to facilitate adaptation planning at the local level, particularly in areas most vulnerable to climate change; (iii) the improvement of the institutional and legal framework pertaining to the adaptation of priority economic sectors to climate change; and (iv) the formulation and implementation of communal climate change adaptation plans for at least half of the country's communes.

However, insufficient attention has been directed towards within-country inequality regarding the impact and perception of climate change, including the coping mechanisms employed. Initial discussions primarily revolved around the physical effects of climate change within the country. Despite the intention of the NCCAP to incorporate scientific and traditional knowledge while being sensitive to gender and the most vulnerable groups (ME, 2022), no active research has been conducted to explore gender perspectives on climate change and coping mechanisms among smallholder farmers in Haiti. Therefore,

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this research aims to address this gap by examining social disparities in the perception of climate change and the related coping strategies between male and female farmers in Haiti. The findings of this study aim to provide valuable insights to support the NCCAP.

1.3. Research objectives

The main objective of the food system is to ensure food security, as stated by (Ericksen, 2008) and (Ingram, 2011). Food security encompasses various aspects, one of which is food production, as highlighted by (Ingram, 2011). The production of food is inherently influenced by climate change, with factors such as the presence or absence of drought risk playing a significant role, as indicated by Schmidhuber and Tubiello (2007). This particular research focuses specifically on food production. Its primary purpose is to offer a comprehensive characterization and critical evaluation of future food production in Haiti. This evaluation also includes an examination of farmers' willingness to adapt to climate change, an assessment of agricultural drought risk, and an analysis of climate change perception and adaptation strategies based on dimensions such as gender and socio-economic background. The ultimate aim of this research is to generate valuable insights and knowledge that can be utilized to inform future studies, policies, and interventions aimed at enhancing the resilience and sustainability of food production in Haiti in the face of climate disasters.

This study takes an exploratory approach rather than being driven by specific hypotheses, aiming to generate hypotheses and contribute to the understanding of Haiti's food production. The primary goal is to provide a comprehensive characterization and critical evaluation of Haiti's food production. To accomplish this objective, the study has outlined the following specific objectives:

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- Investigate the future trend of food production in Haiti within the context of ongoing climate change, while also assessing the willingness of smallholder farmers to adapt and cope with these changes.
- Evaluate the level of agricultural drought risk in the study area by utilizing a risk formula and considering various risk factors and their corresponding indicators.
- Examine smallholder farmers' perceptions of climate change and their strategies for managing and adapting to ongoing drought events within their communities.

1.4. Thesis structure and overview of chapters

This thesis comprises six chapters, including three empirical manuscripts, and follows a general conclusion. The first chapter serves as the introduction, outlining the rationale behind the thesis and presenting the proposed objectives with corresponding explanations. The second chapter delves into the research approach, encompassing an extensive review of pertinent academic literature and defining the study population. Given the thesis's purpose, this chapter is divided into two sections. The first section focuses on the framework used, the research approach, theories, and existing academic literature concerning food systems and global climate change. It explores the intricate relationship between food systems and climate change, emphasizing how the food system contributes to environmental degradation and how climate change poses threats to the overall agricultural system. This section culminates with an examination of the impacts of climate change on postproduction activities.

The second section of this study undertakes an assessment of the vulnerability and resilience of Haiti's food systems in the context of climate change. Initially, it offers a comprehensive overview of climate vulnerability, followed by an in-depth understanding

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of the concept of resilience in the face of climate change. Subsequently, a meticulous geographical analysis is conducted to evaluate Haiti's food supply, taking into consideration the spatial distributions of climate change within the country. Finally, the section concludes by providing a detailed description of the inherent vulnerability that exists within Haiti's food system.

In Chapter 3, an extensive examination is conducted on the correlation between food production in Haiti and the projected population growth for the years 2030, 2040, and 2050. This chapter focuses mostly on evaluating the projected food demand associated with four main crop types predominantly consumed in the country. Previous studies and available data are reviewed to identify the limitations and challenges faced by these crop productions. While acknowledging that climate change is not the sole factor influencing crop yields; two scenarios namely Business As Usual (BAU) and Stratified Society (SSS), incorporating various indicators including climate change are used in this study. These two scenarios are developed and used by FAO (2018) to investigate and predict the yield per hectare (yield/ha) of different crop types around the world for 2030 – 2040 and 2050. The data pertaining to Haiti reveal that the projected production of the four major selected crops will fall short of meeting the expectations necessary to address the daily per capita requirements and nutritional needs of the Haitian population between the years 2030 and 2050.

Considering that climate change poses significant challenges to crop production through direct, indirect, and socio-economic effects (Raza et al., 2019), and given the substantial evidence from numerous scientific studies supporting the essentiality of both adaptation and mitigation in effectively addressing climate change (Kongsager, 2018;

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Schipper, 2020), as well as the crucial role of farmers in the agricultural system to provide food security, this chapter concludes by testing and evaluating farmers' willingness to adapt (such as using crop rotations) to climate change as a means to enhance future crop production.

Chapter 4 discusses the assessment of agricultural drought risk in Haiti using geospatial techniques. This study integrates various risk factors, including vulnerability, hazard, exposure, and adaptive capacity, along with relevant plant development-related parameters, to conduct a comprehensive evaluation of agricultural drought risk. To generate agricultural drought risk maps, a set of 18 comparable spatial indicators is defined. Fuzzy logic is employed to standardize multiple drought features within a range of 0-1, allowing the aggregation of drought vulnerability, hazard, exposure, and adaptive capacity indicators. Two separate analyses of drought risk are conducted: one without considering adaptive capacity as a risk component, and another with adaptive capacity incorporated into the risk equation.

Chapter 5 focuses on the socio-economic analysis and gender perspectives of climate change and coping mechanisms in Haiti. This manuscript compares the perceptions of climate change and coping mechanisms between low-income farmers and female farmers in two distinct farming regions in contrast to high-income and male farmers, respectively. The findings reveal that low-income and female farmers exhibit a greater awareness of climate change compared to their high-income and male counterparts, respectively. These findings align with similar previous research in the sociology of science field. Overall, the surveyed population employs similar coping mechanisms to mitigate the impacts of climate change. However, low-income farmers tend to rely more on off-farm strategies, such as

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off-farm jobs, land leasing, or relocation, whereas female farmers are more inclined to utilize on-farm strategies, such as altering the farming calendar, changing crop varieties, or modifying the irrigation system. Despite having fewer educational opportunities, land, and resources compared to male farmers, female farmers demonstrate higher levels of climate change awareness and engagement in seeking new alternatives to cope with this imminent threat.

Chapter 6 presents the overall conclusion and the policy implications of the study. This chapter provides a summary and synthesis of the key findings from the preceding chapters, highlighting the main contributions and implications of the research. The conclusion also discusses the limitations of the study and suggests avenues for future research in the field. Furthermore, it offers recommendations for policymakers and stakeholders based on the insights gained from the research. Overall, it presents a comprehensive understanding of the research outcomes and their significance in addressing the research objectives and broader scientific context.

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2. Chapter 2: Framework, Research Approach and Background

In this pivotal chapter, we delve into the core framework of this research, which comprises the DPSIR model, the chosen research approach, and the essential background. With a comprehensive exploration, we begin by analyzing the intricate interplay between food systems and their impacts on climate change. Subsequently, we investigate the reciprocal effects of climate change on these very food systems. Finally, we thoroughly discuss the vulnerability and resilience of the HAITI food system in the face of climate change, shedding light on crucial insights for sustainable development and adaptation strategies. The chapter sets the stage for a profound understanding of the complex dynamics that underpin the critical relationship between climate change and food security.

2.1. The DPSIR framework

The DPSIR model represents a socio-economic framework that establishes connections between changes in ecosystems and the underlying social, economic, and political forces (Mandić, 2020). Originally conceived by the Organization for Economic Co-operation and Development (OECD), this model has been embraced by esteemed organizations such as the United Nations and the European Environmental Agency (Tscherning et al., 2012). By discerning and elucidating processes and interactions within human-ecological systems (Nguyen et al., 2019; Rodrigues, 2015), the DPSIR framework aligns closely with the ecosystem-based management approach. As a widely recognized tool, it holds significant promise and value in research, offering policymakers a coherent and substantive elucidation of cause-and-effect relationships. Gebremedhin et al. (2018) assert that the DPSIR model serves as an effective means of succinctly summarizing and visually

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representing the cause-and-effect dynamics within lake ecosystems, rendering complex relationships more accessible and understandable.

In fact, DPSIR stands for Driver-Pressure-State-Impact-Response, and it is an acronym that represents the key components of the framework. Each component describes a different stage in the cause-and-effect chain of environmental issues. It is used by researchers, policymakers, and environmental professionals to assess and manage various environmental challenges. It is a flexible tool that can be adapted to different scales, from local to global, and applied to various environmental issues, such as air and water pollution, climate change, biodiversity loss, and more.

2.1.1. The framework and its components

DPSIR is described as Driver-Pressure-State-Impact-Response. This framework helps in understanding the linkages between human activities, environmental changes, and their effects on society. By using this framework, decision-makers can develop targeted and effective policies to tackle environmental problems and achieve sustainable development goals. Below is defined the different components and their corresponding indicators for this research (Figure 1).

I. **Drivers**: The "Driver" represents the underlying forces that lead to human activities. These can be economic, social, demographic, or technological factors that influence human behavior and decision-making. In this research, some of the drivers might include:

  - Population growth: The increasing population in Haiti is a significant driver of food demand, putting pressure on the food system to produce more.

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- Climate change: Ongoing climate change is a primary driver, affecting agricultural production, water availability, and overall food security.
- Land degradation: The degradation of agricultural land due to various factors, including deforestation and soil erosion, impacts crop yields and resilience;
- Socio-economic factors: Income disparities and the economic situation of farmers play a role in their ability to cope with and adapt to climate change

II. **Pressure:** The "Pressure" phase refers to the activities and processes that directly impact the food system and its vulnerability. In this research, these could include: Extreme weather events, such as hurricanes, floods, and prolonged droughts, exert pressure on Haiti's food system. These events especially droughts damage crops, infrastructure, and agricultural land, leading to reduced agricultural productivity. It also includes:

- *Intensive agricultural practices*: Unsustainable farming methods, such as monoculture and excessive use of chemical inputs, may weaken the resilience of agricultural ecosystems and increase susceptibility to climate impacts.
- *Deforestation*: Land degradation and deforestation can lead to soil erosion, reducing the capacity of land to cope with extreme weather events.
- *Lack of access to resources and technology*: Limited access to resources, such as seeds, irrigation systems, and climate information, can hinder farmers' ability to adapt effectively to changing climate conditions (Figure 1).

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III. **State**: The state represents the current condition or state of the environment and society. With regards to this research, it is addressed in chapter 3 assessing the agricultural drought risk condition of the study site. In this case, extreme weather events and climate change have led to decreased agricultural productivity in Haiti. Crop losses and damage to farmland result in food shortages and increased food insecurity in the country (Figure 1).

IV. **Impact**: This component is linked to chapter 4 of the thesis. The "Impact" phase signifies the consequences of the environmental state on human well-being, ecosystems, and other aspects. These impacts can be both positive and negative and can include effects on human health, biodiversity loss, climate change, ecosystem services, and economic implications. For example, the reduced agricultural productivity and food insecurity have a significant impact on farmers in Haiti. They become more vulnerable to economic instability, food shortages, and livelihood disruptions (Figure 1).

V. **Response**: The final component, "Response," refers to the actions taken to address the identified environmental issues. These responses can be policy measures, regulations, technological advancements, educational initiatives, or any other intervention aimed at mitigating or adapting to the environmental challenges. In this research, the responses are based on actions developed by farmers to cope with climate change impacts which are addressed in chapter 5 (Figure 1).

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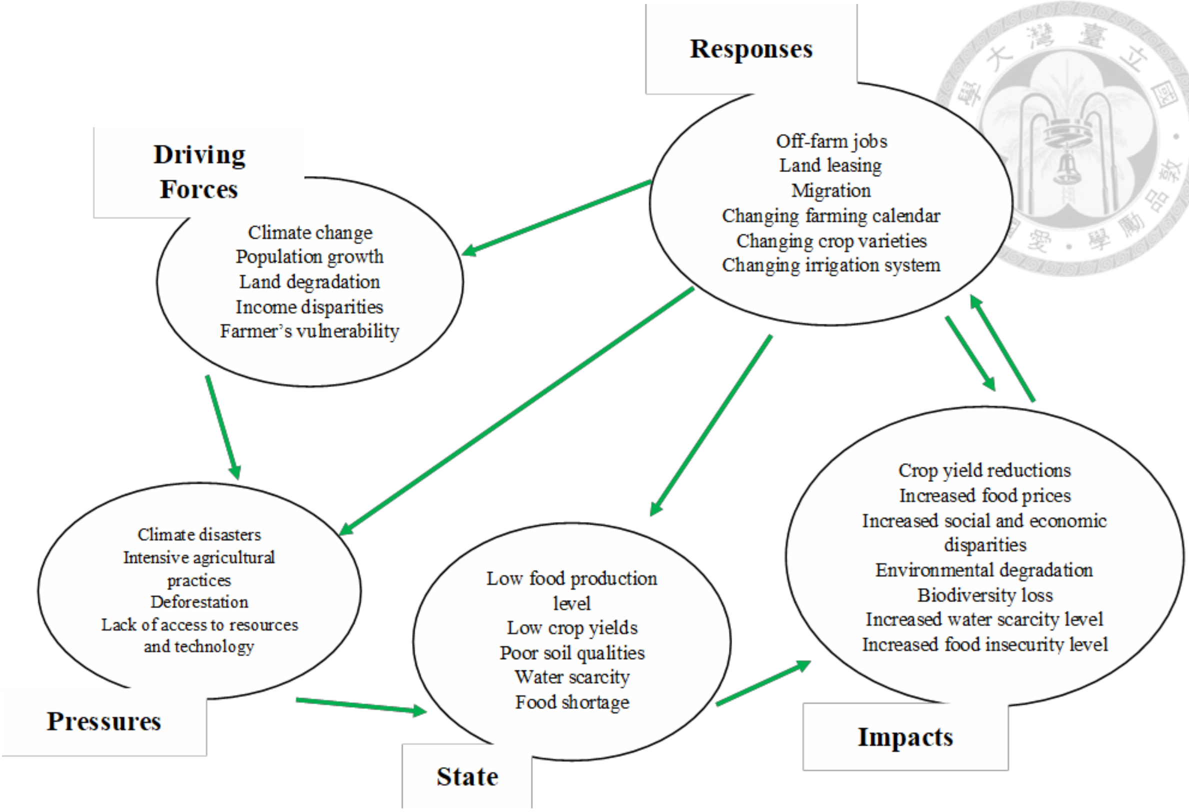

Figure 1 A generic DPSIR framework for this research

2.2. Research approach: Theories and key concepts

Food systems and climate change are topics of significant importance in global policy debates and research. The Intergovernmental Panel on Climate Change (IPCC) was established to provide policymakers with regular scientific assessments on climate change, its impacts, and potential risks. The IPCC also offers alternative strategies for adaptation and mitigation. Climate change refers to enduring and widespread changes that persist for several decades or longer. It should be distinguished from climate variability, which pertains to year-to-year, multi-year, and decadal fluctuations in climate variables' mean conditions. Climate change encompasses substantial temporal shifts in interconnected features and patterns of the global climate system, including precipitation and temperature (Brini, 2021). Over the past decade, climate change has been recognized as one of the most pressing issues. For instance, the National Centers for Environmental Information of the National Oceanic and Atmospheric Administration (NOAA) reported that the Earth's temperature has increased by an average of 0.08°C per decade since 1880. Moreover, the rate of warming has more than doubled to 0.18°C per decade in recent times. As of 2022, the surface temperature was 1.06°C warmer than pre-industrial levels and 0.86°C above the 20th-century average of 13.9°C (1880-1900). Based on NOAA's temperature data, 2022 was the sixth-warmest year on record, where cooler-than-average years are represented by blue bars and warmer-than-average years are depicted by red bars (Dahlman, 2023).

According to recent research (Yong et al., 2022), human activities have led to an increase in greenhouse gases (GHGs), such as carbon dioxide (CO_2), methane (NH4), and nitrous oxide (NO2), in the atmosphere, resulting in an intensified greenhouse effect. The annual GHG index (AGGI) reached a value of 1.49 in 2021, indicating a 49% increase in the warming effect of GHG since 1990. It is noteworthy that the AGGI took over 200 years to progress from 0 to 1 (representing a 100% increase) following the onset of the Industrial Revolution in 1750. However, it took merely 30 additional years for the AGGI to reach nearly 1.5, reflecting an additional 50% increase in the warming effect. Consequently, the current atmosphere absorbs approximately 3.22 watts of energy per square meter of Earth's surface more than it did during pre-industrial periods (Lindsey, 2022). Haiti has other developed nations have contributed to the GHG emission into the atmosphere. According to the data presented in Figure 2, the country's emissions amounted to over 10 MtCO$_2$e in 2019, a significant increase from the level of below 6 MtCO$_2$e observed in 1990. Since 1991, the emissions trend in Haiti has shown a consistent upward trajectory.

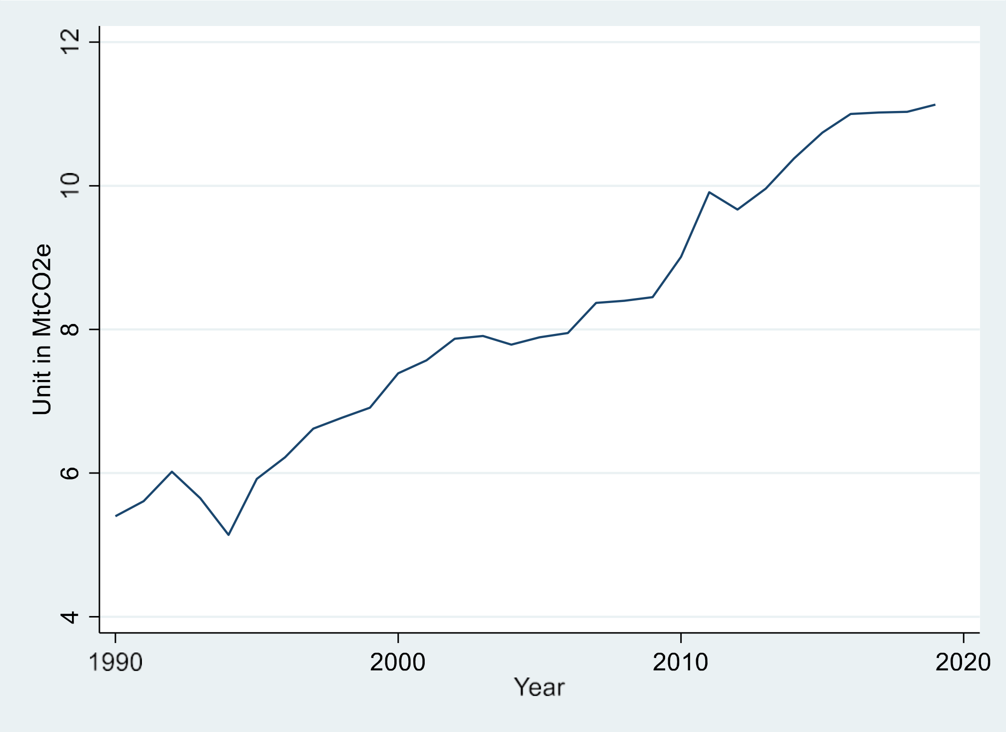

Figure 2 Contribution of Haiti of GHGs trend from 1990 to 2019.
Source : Author’s production based on data from Climate Watch. 2022. Washington, DC: World Resources Institute. Available online at: https://www.climatewatchdata.org/

The capacity of the atmosphere to hold water vapor, another GHG, increases as a consequence of global warming. The IPCC concludes that human influence has most likely been the primary driver of observed global warming since the mid-20th century (Stocker et al., 2014). It is evident that climate change is occurring, necessitating society's long-term adaptation to changing temperature and precipitation patterns. While complete mitigation is lacking, it is crucial to take ambitious and expeditious action to adapt to climate change while simultaneously making significant reductions in GHG emissions. This approach is imperative to prevent further loss of life, biodiversity, and infrastructure (Pörtner et al., 2022).

Previous research suggests that the impacts of climate change on food systems are expected to occur through both direct and indirect means (Pielke Sr et al., 2007). In this context, the term "food systems" encompasses various activities and consequences such as production, processing, packaging, distribution, retail, and consumption. It also encompasses social, economic, political, and environmental aspects and elements (Ericksen, 2008). The execution of these activities leads to various outcomes, including environmental concerns and other social welfare issues, in addition to contributing to food security (Ingram, 2011), as exemplified in Figure 3.

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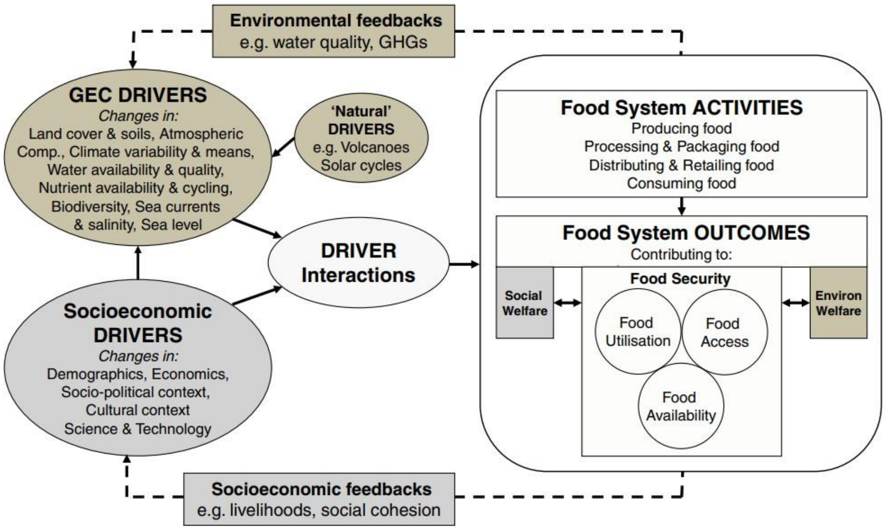

Figure 3 Food system activities, outcomes, drivers and feedbacks

Sources : Adapted from Ingram (2011)

The graph depicts the various activities involved in the food system, ranging from food production to consumption, and highlights their diverse outcomes, such as food security. The visual representation demonstrates that the advantages of the food system extend beyond solely ensuring food security. It also encompasses environmental well-being by preserving the stocks, flows, and services of ecosystems, while additionally generating benefits like revenue and employment. However, these activities and outcomes are reportedly impacted by global environmental changes, particularly climate change, which may have adverse effects on both food security and the future performance of the food system (Ericksen, 2008).

Previous research indicates that the primary goal of food systems is to ensure food security, which is defined as "all individuals, at all times, having physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences, enabling them to lead an active and healthy life" (FAO, 2005). However, it is widely acknowledged that food systems worldwide fall short of achieving this objective, given that an estimated 702 and 828 million people were affected by hunger in 2021 (WFP & UNICEF, 2022), and approximately 193 million people faced acute food insecurity and required immediate assistance across 53 countries/territories (Vos et al., 2022).

Understanding the shortcomings of food systems in achieving food security cannot be attributed solely to global-scale environmental changes. In order to assess food security adequately, it is crucial to consider a broad range of socioeconomic factors known as "drivers" (Ingram, 2011; Kearney, 2010) as well as the interactions between these drivers and the Global Environmental Change (GEC) (Ericksen, 2008; Ingram, 2011). The functioning of the food system and the manifestation of outcomes, including food security, are determined by the interplay between these two sets of drivers (Figure 2). It is imperative to comprehend these food system drivers as an initial step towards enabling policymakers at various levels to formulate and implement suitable policies and interventions.

While several scholars have proposed frameworks for analyzing food systems, Sobal et al. (1998) noted that most of these models inadequately capture the entirety of the system, often focusing on a single disciplinary perspective or system component. They identified four main categories of models: (i) food chains, (ii) food cycles, (iii) food webs, and (iv) food contexts. Additionally, Dixon (1999) introduced a cultural economy model for understanding power dynamics in commodity systems, emphasizing the vulnerability of food systems to future shocks based on the principles of landscape ecology (Fraser et al., 2005). However, these approaches fail to emphasize the importance of examining the two-way interactions between the complete spectrum of GEC characteristics and the various activities and outcomes of the food system. Thus, a new approach called Global Environmental Change and Food Systems (GECAFS) has been developed. Its purpose is

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to facilitate discussions about adaptation choices throughout the entire range of food system operations and to provide a systematic framework for considering trade-offs and synergies that are balanced across diverse societal goals (Ingram, 2011). However, it is worth noting that this study does not analyze food systems from the perspective of global environmental change alone but rather in relation to the interactions with climate change.

2.2.1. Food system effects on climate change

The food system, encompassing the entire process from farm to fork, includes various stages such as input supply, manufacturing, production, harvesting, processing, packaging, marketing, and consumption. Previous research, Garnett (2011) has highlighted that some of these activities contribute to the emission of GHGs and other climate change forcing agents, including aerosols and changes in albedo. However, certain agricultural practices, such as specific agroforestry systems, can effectively sequester carbon when applied to degraded soil. While there have been numerous studies examining the impact of climate change on agricultural production and crop yields, limited attention has been given to how changes in food systems may influence the climate. Nevertheless, Davis et al. (2016) assessed the environmental footprints of water, nitrogen, carbon, and land to quantitatively evaluate future agriculture's resource requirements and GHG emissions. They also explored different dietary scenarios to assess the potential for mitigating the environmental burdens associated with food production. Their findings indicated that expected improvements in production efficiency would not be sufficient to meet future food demand without significantly increasing the overall environmental burden.

Based on an analysis of existing peer-reviewed research on food systems and climate change, including the potential for mitigation and the benefits of adaptation,

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Vermeulen et al. (2012) concluded that food systems have substantial adverse effects on climate change, with approximately one-third of all anthropogenic GHG emissions originating from agri-food systems (Crippa et al., 2021). However, these studies lack detailed insights into how altered food systems contribute to climate change. To address this knowledge gap, a potential approach is to understand the various drivers influencing food systems. Kearney (2010) and Ericksen (2008) have identified socio-economic and natural resources and environmental factors as key drivers of food systems, respectively. These drivers connect food systems to the climate system, as different stages of the food system, such as production, processing, marketing, and distribution, release distinct GHGs. For example, transportation plays a significant role in linking the entire food supply chain, while energy-intensive processes like processing, packaging, and fertilizer manufacturing rely on electricity, heat, and substantial energy inputs. Overall, the production, harvesting, processing, consumption, transportation, and disposal of food result in GHG emissions. Inputs are transferred to farms, where they are transformed into outputs, as highlighted in a prior study (Vermeulen et al., 2012).

Table 1 illustrates the quantity of GHG emissions produced through the consumption of food mostly consumed in Haiti. These emissions were computed utilizing the food calculator provided by BBC. The calculations were performed for three different frequency levels: once to twice a week, three to five times a week, and once a day. For the purpose of this analysis, it was assumed that the standard portion size remained consistent across all individuals worldwide. The British United Provident Association and the British Dietetic Association were consulted to obtain this standardized portion size. Additionally, the emissions resulting from the transportation of food were taken into consideration during

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the calculation process. The European Environment Agency served as the source for data on the distance traveled by food. According to the agency, a conventional diesel vehicle emits approximately 220 g of CO_2 equivalent per kilometer over its entire lifespan, encompassing emissions from vehicle production, fuel production, and exhaust emissions per kilometer. The average distance was determined through a comprehensive survey involving 40,000 farms and 16,000 processors, ensuring a representative estimation on a global scale.

Table 1 Climate change food calculator: Diet's carbon footprint

	Frequency		
Food Items	**Once a day**	**Once a week to twice**	**Three to five times a week**
Banana	25	5	14
Avocado	72	15	41
Beans	36	7	20
Potatos	16	3	9
Tomato	60	13	34
Bread	21	4	12
Rice	121	26	69
Milk (dairy)	229	49	131
Coffee	155	33	89
Beef	2820	604	1611
Chicken	497	106	284
Eggs	202	43	115
Pasta	43	9	25

Source: Calculate from BBC Food Calculator (2019)[4]

Based on empirical evidence, it has been found that vegetarian food products exhibit significantly lower GHG emissions compared to non-vegetarian diets. To illustrate, according to the data presented in Table 1, the consumption of beef three to five times a week is projected to result in the emission of approximately 1611 kg of GHG into the atmosphere. Conversely, opting for a combination of bananas, beans, potatoes, and tomatoes would emit only 118 kg of GHG. This finding suggests that adopting a vegetarian

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[4] https://www.bbc.com/news/science-environment-46459714

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diet can lead to a substantial reduction in GHG emissions, particularly when compared to a non-vegetarian diet that includes beef consumption. Furthermore, selecting plant-based foods over meat and dairy products offers an effective strategy for mitigating the environmental impact associated with our dietary choices.

During the food processing stage and packaging, GHGs, CO_2 and NH4, are released into the atmosphere. According to Ericksen (2008) and Ingram (2011), the terms "processing and packaging" encompass the various transformations that raw food materials, including grains, vegetables, fruits, and animals, undergo before being distributed and sold in the retail market. This process involves the active involvement of managers and employees in processing and packaging companies, trade organizations responsible for establishing standards, as well as intermediaries involved in purchasing from producers and supplying to processors. All these entities play crucial roles in the processing and packaging of food.

Based on FAO statistics (FAO, 2023a), in 2020, Haiti made notable contributions to GHG emissions throughout various stages of the food system. Assessing the NH4 emissions, the country's involvement can be observed across multiple sectors. Within food processing, Haiti accounted for 10.62 kilotons of NH4 emissions. Additionally, in the realm of food packaging, their contribution amounted to 0.8912 kilotons. The country's impact on GHG emissions related to food waste was substantial, with an estimated 85.15 kilotons being attributed to Haiti. In terms of food retail, their contribution stood at 0.0293 kilotons, and for food transportation, it was 0.09 kiloton. Similarly, Haiti's role in CO_2 emissions is significant. Within food processing, their contribution was recorded as 100.64 kilotons, and for food packaging, it was 8.5 kilotons. Food waste emissions were notably higher, with

428.27 kilotons being associated with Haiti. The country's impact on CO_2 emissions in food retail was substantial, accounting for 1,544 kilotons, while in food transportation, it stood at 110.55 kilotons. These figures emphasize the considerable role Haiti plays in contributing to GHG emissions within the food system, thereby underlining the need for targeted efforts to mitigate and reduce these emissions.

In general, the food system plays a significant role in contributing to GHG emissions released into the atmosphere. According to Crippa et al. (2021), approximately one-third of global GHG emissions originate from various stages of the food system, including agricultural production, transportation, processing, packaging, and waste disposal. Each stage within the food system has its own contribution to GHG emissions as well as the different sectors. For example, among all sectors generating GHGs into the atmosphere in Haiti, agriculture remains the most important sector with highest emission rate in 2019 as showing in the Figure 4.

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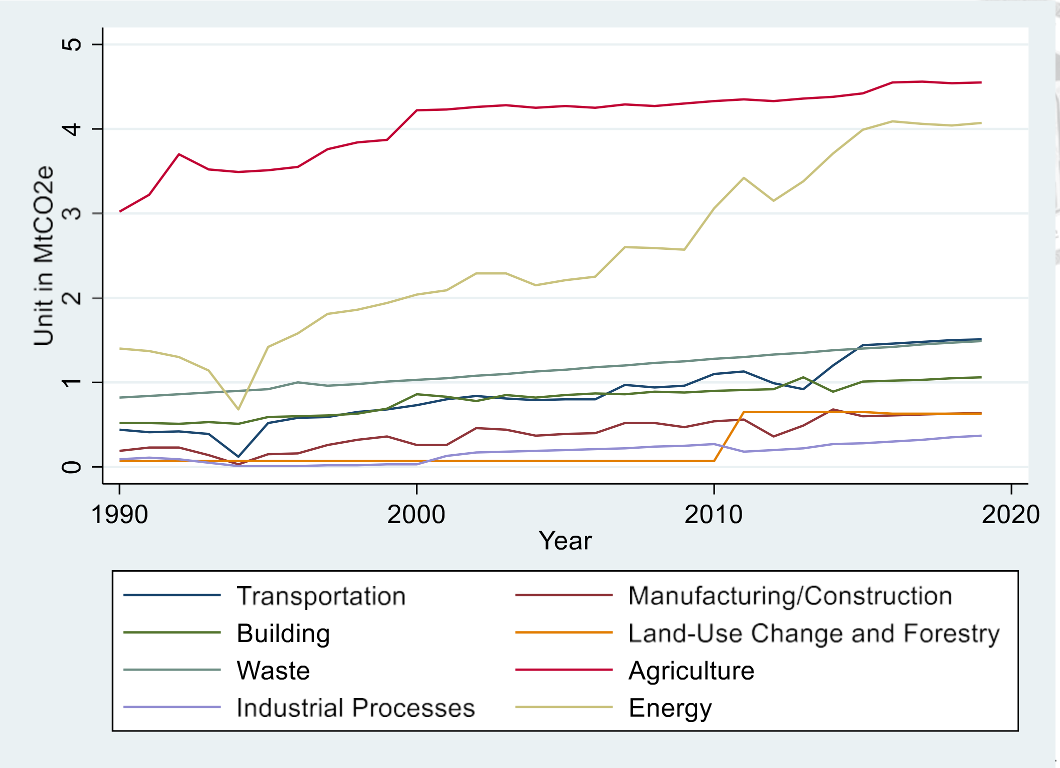

Figure 4 Contribution of green house gas by sector in Haiti.

Source: Author's calculation and production based on data from

2.2.2. Climate change effects on food systems

The relationship between climate change and food systems is intertwined and creates a negative feedback loop. This loop is expected to have far-reaching, intricate, and diverse effects on food systems. Additionally, these impacts are strongly influenced by current and developing social and economic circumstances, as well as varying by location and time. A recent study undertaken by Owino et al. (2022) highlighted that the different levels of food systems have been impacted by climate change including changes in soil fertility and crop yield, composition, and bioavailability of nutrients in foods, pest resistance, and risk of malnutrition. It is globally accepted that crop production is the core component of the food system, and climate change poses significant challenges to it. Changing weather patterns,

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including climate relate – disasters such as extreme heat, droughts, and floods, might negatively affect crop yields and quality. Zhao et al. (2017) examined the effect of temperature on the productivity of four major crops (wheat, rice, maize, and soybean) by collecting and analyzing numerous published research findings using four different analytical approaches. The methods included global grid-based and local point-based models, statistical regressions, and field-warming experiments. The results obtained from these different methods consistently demonstrated that the impact of temperature on crop yields was negative at a global level, and this was supported by similar effects observed at the country and site levels. Another similar study also found that the global production of wheat, rice and rice is expected to decrease by 9% in 2030 and by 23% in 2050 (Haile et al., 2017). So, the significance of temperature in the growth of plants cannot be overstated, as alterations in weather conditions are anticipated to exert an influence on plant development and subsequently result in a reduction in crop productivity.

Several scholars such as Chakraborty and Newton (2011); Bender and Weigel (2011), and Challinor et al. (2009) indicated that climate change can have both positive and negative impacts on crop growth, affecting factors such as timing of growth stages, heat and water stress, and increase in pests and diseases. Researchers have attempted to estimate the global effects of climate change on crop production, with Funk and Brown (2009) predicting a decrease in per capita food production using general circulation models. Nelson et al. (2009) also used these models to predict yield changes for key staples in developing and developed nations, considering the potential for carbon fertilization effects. Their findings suggest a wide range of yield changes from a significant decrease to a considerable increase by 2050. Lachaud et al. (2022) used a random parameter stochastic

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production frontier (SPF) model to analyze the effects of climate variability on agricultural productivity in 28 Latin American and Caribbean countries over a 52-year period (1961-2012). Their findings indicate that climatic variability has a negative impact on crop production in 20 of the 28 countries, with the greatest impact observed in Central America and the Caribbean. On average, the reduction in crop yields attributed to climatic variables in the region ranges from 0.02% to 22.7% over the past decade compared to the period from 1961-1999. Thus, the Caribbean region, where Haiti is located is highly vulnerable to climate change (Table 2), and this vulnerability has direct effects on crop yields.

Table 2 Climate change impacts in Caribbean.

Study	Summary
Mimura et al. (2007)	In 2004, Hurricane Ivan had a significant impact on Grenada's agricultural sector, resulting in a loss that was equivalent to 10% of the country's GDP. This natural disaster also caused a delay of approximately 10 years in the production of two of Grenada's primary crops, cocoa and nutmeg, which have a significant economic value for the island.
Cashman et al. (2010)	New forms of susceptible pests and diseases may arise due to changes in climatic variables
Simpson et al. (2012)	According to this study, a sea level rise of 2 meters or more could result in the loss of over 3% of agricultural land globally. This loss of agricultural land could have significant implications for food supply, security, and rural livelihoods. The impact of such a sea level rise would be particularly severe in some countries, such as The Bahamas (12% agricultural land lost), St. Kitts and Nevis (8% agricultural land lost), and Haiti (5% agricultural land lost).
Simpson (2010); (Simpson et al., 2012)	For CARICOM countries the biological effects of 2050 climate relative to 2000 climate are yield declines ranging from 3% to over 8% for rice, maize, and cowpea
Simpson (2010)	Sea-level rise will increase the risk of saltwater intrusion into coastal aquifers, particularly those that are already at risk from over abstraction.
Cashman et al. (2010)	Most small Caribbean islands will experience extreme water stress regardless of SRES scenario
Lachaud et al. (2022)	In 20 out of the 28 countries analyzed, crop production is adversely affected by climatic variability, with Central America and the Caribbean experiencing the most substantial repercussions. Over the past decade, the average decline in crop yields due to changing climate in this region has varied from 0.02% to 22.7% compared to the period spanning 1961 to 1999.

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This being said that climate change represents the most significant threat for crop yield production in the Caribbean region. However, there is considerable evidence indicating that climate change will have an impact not only on the yields of crops but also on the quality and safety of food, as well as the reliability of its delivery. As a result, both food production activities (including crops, livestock, fisheries, food safety, and the overall agricultural systems) and post-production activities (such as harvests, storage, transportation, marketing, retail, and consumption) are likely to be affected by climate change.

In the case of marine life, for example, climate change represents one of the greatest threats. Perry et al. (2005); (Pörtner, 2008) highlighted that fluctuations in temperature have significant effects on fish reproductive cycles, growth rates, sexual maturity, and spawning timing warming of surface water reduces oxygen levels, leading to reduced maximum body weight and lower catch potential of fish species worldwide. Species intolerant to hypoxia, such as tuna, will experience a decrease in habitat size and productivity (Stramma et al., 2012). Many fish species are already moving towards the poles, causing a rapid 'tropicalization' of mid- and high-latitude systems. Predictive models based on environmental conditions, habitat types, and phytoplankton primary production suggest a significant redistribution of global marine fish catch potential, with a 30 to 70 percent increase in high-latitude regions and a drop of up to 40 percent in the tropics (Cheung et al., 2010). But the impact is expected to be more severe in devloping nations as Pachauri et al. (2014) reported that small-scale fisheries in economically poor, tropical, and less developed regions are especially vulnerable to the impacts of climate change.

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2.2.3. Climate Change Impact on Postproduction Activities

Vermeulen et al. (2012) suggest that climate change will impact the postproduction activities of food commodities, including storage, primary processing, secondary processing, transport, retail, and consumption. Parfitt et al. (2010) report that climate change could result in postharvest losses of up to 80% in rice and 55% in vegetables. Projected scenarios indicate that mean precipitation will increase, especially in the tropics and subtropics, leading to higher humidity levels and accelerating the chemical and biological deterioration of food commodities. This, in turn, will result in higher postharvest losses (FAO, 2008; Stathers et al., 2013).

In eastern and southern Africa, recent data show that the highest proportion of food waste is due to postharvest losses on or near the farm. Yield losses for different cereals, with maize being the highest, range from 5% to 35%, resulting in an aggregate loss of 15% of production value each year (Hodges et al., 2011). In Kenya, research has shown that storing maize that contains dangerous levels of aflatoxin can lead to prolonged and widespread exposure to the surrounding community. This is because farmers sell the maize to local markets and buy it back throughout the season (Lewis et al., 2005). Conversely, temperate regions may benefit from an increase in humidity as it creates ideal conditions for storing harvested grains (FAO, 2008). However, in countries with inadequate infrastructure such as poorly maintained roads and bridges, the risk of extremes events such as floods can pose significant threats to food distribution in rural areas. This is particularly true for low-income countries where transport infrastructure is already limited, as the impacts of floods are likely to be exacerbated (FAO, 2008).

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For example, in South Asia, Ingram (2011) found that increased frequency of floods also disrupted food distribution systems in rural areas. Additionally, regions with inadequate transport infrastructure that experience high frequency and intensity of precipitation are likely to face challenges in effectively distributing food, as shown by previous studies (Hendrix & Salehyan, 2012). Similarly, sophisticated food supply chains that operate with low inventory levels and rely on just-in-time delivery are vulnerable to disruptions caused by changes in weather patterns (Waters, 2011). While temperate countries may benefit from reduced transportation costs during certain times of the year due to less maintenance needed and longer opening of river and sea routes, developing countries will need to focus on improving transport logistics and storage to minimize losses caused by weather-related disruptions (Waters, 2011). Food chains in high-income countries often have seasonal markets based on demand rather than supply. Studies have shown that consumer behavior can be influenced by weather variables such as temperature and sunshine, which could affect patterns of food consumption in response to future climate trends. Therefore, it is important for these sophisticated food chains to be aware of the potential impact of climate change on their operations and take steps to adapt to mitigate any negative effects.

Overall, climate change poses a significant threat to global food systems, particularly for vulnerable populations who are at risk of hunger and malnutrition (Vermeulen et al., 2012). The impact of climate change on agriculture is expected to affect all four components of food security, namely availability, access, utilization, and stability over time (Schmidhuber & Tubiello, 2007; Ziervogel & Ericksen, 2010). The poor are likely to be more vulnerable to the adverse effects of climate change on agriculture due to

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reduced consumption resulting from food price increases, reduced income generation, and diminished adaptive capacity (Hertel & Rosch, 2010). Rural areas dominated by smallholder agriculture are home to an estimated 2.3 billion people, and in many countries, the majority of poor rural households are marginal net food purchasers who buy and sell different foods at different times (Aksoy & Isik-Dikmelik, 2008). Extreme weather events can severely affect households' ability to maintain their assets or reinvest in agriculture, leading to chronic food insecurity, poor health, and decreased economic productivity (Alderman, 2010). Longitudinal household survey research in Malawi highlights the impact of climate shocks on food security and how households secure food through labor, trade, and transfers from family and social networks, as well as on their agricultural production (Devereux, 2007). A summary of the main challenges facing the post harvest activities in Haiti is given in Table 3.

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Table 3 Main challenges of post-harvest activities in HAITI

Post-Harvest	Challenges
Product at Harvest	- Poor product quality at harvest - Consumer preferences favor varieties susceptible to disease - Increased frequency and intensity of extreme events may further damage processing equipment and products
Processing	- Old and poorly maintained processing equipment, such as mills - Poor processing practices leading to damages and losses - Undeveloped processing industry - Increased temperatures may accelerate perishability
Packaging	- Limited access to quality packaging - High perishability
Storage	- Lack of storage facilities - Poor condition of storage facilities - Poor storage practices resulting in shorter shelf life - Increased frequency and intensity of extreme events and coastal flooding may further damage facilities
Transportation	- High transportation costs - Poor transportation and road infrastructure - Limited transportation options due to product bulkiness - Increased frequency and intensity of extreme events and coastal flooding may further damage and inhibit access to roads
Distribution	- Inefficient aggregation and distribution - Challenges in improving distribution processes due to a large number of actors - Increased frequency and intensity of extreme events and coastal flooding may further disrupt distribution

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2.3. The Vulnerability and Resilience of the HAITI Food System to Climate Change

2.3.1. Understanding climate vulnerability

In academic literature, vulnerability is commonly defined as the state of being at risk of harm or damage, whether physical or psychological, due to internal or external factors. The Intergovernmental Panel on Climate Change (IPCC) provided a widely referenced definition of vulnerability in its Third Assessment Report (IPCC, 2001). According to the IPCC, vulnerability refers to the extent to which a system is susceptible and unable to cope with adverse effects arising from climate change, including climate variability and extremes. It encompasses the characteristics, magnitude, and rate of climate change and variation to which a system is exposed, as well as its sensitivity and adaptive capacity.

However, in the context of social vulnerability, Cutter et al. (2003) defined vulnerability as the potential for loss, damage, or harm to individuals, infrastructure, and the environment resulting from the interaction between hazards and conditions of exposure, susceptibility, and coping capacity. This definition aligns with other studies that emphasize social vulnerability to climate change and other global environmental changes as the inability to effectively manage external pressures or alterations, leading to unfavorable outcomes (Adger, 2006; o’Brien et al., 2004).

Thus, vulnerability to climate change can affect various systems, such as individuals or communities, and is a dynamic and multidimensional characteristic influenced by intricate interactions among social, economic, and environmental factors. (Marshall, 2010) highlighted the dominance of human activities in agricultural systems, indicating that the vulnerability of agriculture and food systems to climate change is contingent not only upon the physical impacts of climate change but also on human adaptive responses aimed at mitigating those impacts.

Consequently, the vulnerability of a system is determined by its level of exposure and sensitivity to hazardous conditions, which are moderated by its ability to cope, adapt,

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or recover from those conditions. Smit and Wandel (2006) emphasized the critical role of adaptive capacity or resilience in determining the vulnerability of a system. For instance, Figure 5 illustrates a schematic diagram depicting the social and environmental dimensions of food system vulnerability. The figure illustrates that vulnerability to environmental changes arises from exposure to environmental hazards, which are influenced by social factors and institutions that shape the adaptive capacity and overall vulnerability of the food system (Ingram & Brklacich, 2002).

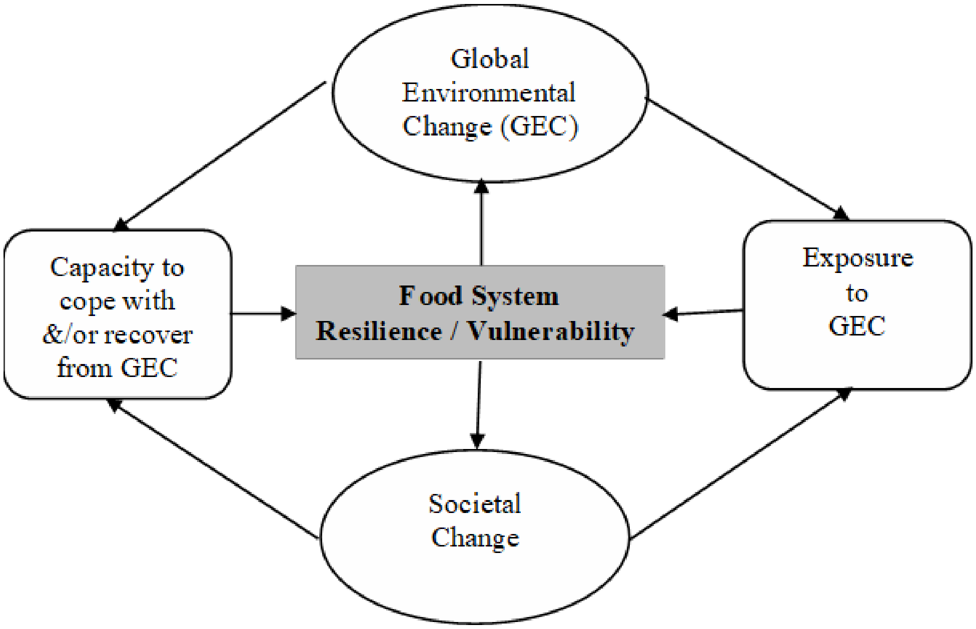

Figure 5 Food System Vulnerability

Source: Author’s production based on Ingram and Brklacich (2002).

Global Environmental Change (GEC) refers to significant modifications in the Earth's physical, chemical, and biological systems resulting from both human activities and natural processes. GEC can profoundly impact the susceptibility of food systems at various levels. Firstly, climate change entails a gradual rise in the Earth's surface temperature due to the emission of greenhouse gases from activities such as fossil fuel combustion and deforestation. This phenomenon leads to alterations in rainfall patterns, heightened

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frequency and severity of extreme weather events like droughts and floods, as well as changes in the distribution and abundance of pests and diseases. Consequently, these changes can adversely affect crop yields, diminish water availability for irrigation, and heighten the risk of crop failure, resulting in food scarcity and price escalation.

Secondly, land degradation represents a crucial factor that can compromise the resilience of the food system and render it more vulnerable. Land degradation encompasses the deterioration of soil quality, water resources, and vegetation on land, stemming from natural or human-induced processes such as deforestation, overgrazing, and erosion. This degradation can reduce agricultural land productivity, deplete water resources available for irrigation, and increase the susceptibility of crops to pests and diseases. As a consequence, it can lead to reduced crop yields, food scarcity, and price increases.

Thirdly, the loss of biodiversity refers to the decline in the variety and abundance of plant and animal species within an ecosystem. This loss can impair the capacity of ecosystems to provide crucial services like pollination, pest control, and soil fertility. Consequently, it can result in decreased crop yields, heightened vulnerability of crops to pests and diseases, and diminished nutritional quality of food.

Fourthly, water scarcity denotes the insufficient availability of water resources to meet the demands of human activities and ecosystems. Water scarcity can curtail the accessibility of water for irrigation and domestic use, thereby causing reduced crop yields, food scarcity, and price increases. Furthermore, the utilization of unsustainable irrigation practices can exacerbate water scarcity and contribute to the deterioration of freshwater ecosystems.

Lastly, energy insecurity refers to the absence of reliable and affordable energy

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sources, which can impact the production, storage, processing, and transportation of food. Energy insecurity can lead to disruptions in the food supply chain, spoilage of perishable food items, and increased prices due to elevated production costs. Moreover, the reliance on fossil fuels for energy generation contributes to climate change, thereby further intensifying the vulnerabilities of the food system

As illustrated in Figure 5, societal change also plays a role in contributing to the vulnerability of the food system, which refers to its susceptibility to disruption and failure. Various societal change factors can influence and elucidate the vulnerability of food systems in several ways, including:

(i) Demographic changes: With the continuous growth and urbanization of the global population, the demand for food increases, exerting pressure on food systems to produce more. This demand can lead to the overexploitation of resources such as land and water and can exacerbate the impact of climate change on food production.

(ii) Economic changes: Alterations in economic systems can result in heightened competition for resources like land and water, making it more challenging for small-scale farmers to access these vital resources. Economic globalization can also amplify the vulnerability of food systems to price shocks and disruptions in the supply chain, as food is transported over longer distances and relies on intricate distribution networks.

(iii) Technological changes: The adoption of new technologies can enhance food production and efficiency. However, it can also contribute to the consolidation and industrialization of food production, leading to biodiversity loss, increased use of chemicals and fertilizers, and heightened vulnerability to climate change.

(iv) Political changes: Political decisions, such as modifications in agricultural policies and

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trade agreements, can have significant impacts on food systems. For instance, policies that prioritize large-scale agriculture or favor exports over local food production can impede the ability of small-scale farmers to compete. Additionally, trade agreements can expose food systems to competition from cheaper imports, undermining local food systems.

(v) Cultural changes: Shifts in cultural norms and values, such as a preference for high-meat diets or convenience foods, can escalate the demand for resource-intensive food production systems. Consequently, this can lead to further environmental degradation and vulnerability to climate change.

Overall, societal change factors interact with environmental change factors to create intricate challenges for food systems. Addressing these challenges necessitates the development of more resilient and sustainable food systems capable of adapting to changing conditions and meeting the needs of a growing global population while reducing their environmental impact. This entails implementing various strategies, including promoting local food production, supporting small-scale farmers, and investing in sustainable agricultural practices and technologies.

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2.2.3. Understanding Resilience to climate change

In the context of climate change adaptation, resilience is characterized by a social or ecological system's ability to absorb disturbances while maintaining its structure, self-organization capacity, and adaptability to stress and change. In other words, when a food system can handle unexpected changes and still continue to function properly, it can be referred to as resilient. This definition is supported by Pingali et al. (2005) and Schipanski et al. (2016). Resilient systems are associated with high adaptive capacity, which is demonstrated by response capacity, recovery capacity, and transformation capacity. A system with high adaptive capacity is considered resilient, and vice versa (Walker & Salt, 2012). The context in which decisions are made shapes adaptive actions, including the quality and availability of natural, human, social, financial, and physical capital, social norms, nonclimate stressors, and government policy and programs, as well as access to effective adaptation options, and individual capability to take adaptive action. The adaptive capacity of a system moderates the potential impact of climate change by taking actions to protect the system from damaging climate effects, recover from damages, or transform into a more climate-resilient system (Berkes & Jolly, 2002). According to Eakin (2005) adaptive capacity requires long-term changes in behavior and livelihood strategies to ensure income or food security in the foreseeable future in the face of upcoming changes). While coping capacity involves more than just access to resources, requiring active strategies to manage resources in the face of risk Barrett and Carter (2000). Coping capacity is best understood as a short-term response to current stresses. The distinction between coping and adaptive capacity is not always clear (Table 4); however, coping capacity is typically reactive, while adaptive capacity should refer to the potential to adapt to future uncertain changes without increasing vulnerability and is proactive.

Adger and Kelly (1999) argued that the capacity to cope and adapt is influenced significantly by access to entitlements or resources. According to Sen (1982)' s entitlement theory, food insecurity is determined not only by the availability of food but also by the possession of assets, including physical, social, and political resources. Generally, those with greater endowments of resources and entitlements can withstand stresses and shocks better. Nonetheless, the institutional and policy frameworks are also essential as they shape people's agency to act (Eakin et al., 2013). Multiple stressors and intricate interactions within the system and with environmental changes result in vulnerability. Thus, managing other stressors may limit the system's adaptive capacity.

Table 4 Differences between coping and adaptation

Coping	**Adaptation**
The capacity of a system to react to the onset of detrimental events and avert their prospective ramifications (Kelly & Adger, 2000).	The inherent capability of a unit to undergo progressive alterations in its structure, functioning, or organization in order to ensure its survival in the face of existential hazards (Kelly & Adger, 2000).
The mechanisms for adaptation and persistence within the established frameworks of governing principles (Gore, 1993).	Alteration of the institutions (comprising cultural norms, laws, and habitual behavior) embodied in livelihoods (Gore, 1993).
The spectrum of available measures to address perceived risks associated with climate change within a specific policy framework (Yohe & Tol, 2002).	Modification of the array of accessible inputs that determine the capacity to cope with adverse conditions (Yohe & Tol, 2002).
The process by which established practices and underlying institutions are mobilized in response to the impacts of climate change (Pelling & Dill, 2010).	The process by which an actor engages in introspection and implements changes in the practices and underlying institutions that generate fundamental and immediate causes of risk, shape the capacity to cope, and facilitate subsequent cycles of adaptation to climate change (Pelling & Dill, 2010).

Moreover, the climatic shift susceptibility, reactivity, and adjustive ability are determined by the local context. The likelihood and reactivity levels differ within the Haiti regions and are impacted by the feedback mechanisms of manufacturing, production, and allocation systems to the regional climate impacts. The ability to adjust is reliant on the location and associated with the food system's capability to react, recuperate, and restructure in the local context of operation. That is why certain researchers believe that studies on the resilience of the food system should be conducted at two levels: the local level and the global level. On a local level, Béné et al. (2016) highlighted that investigations into the resilience of food systems have primarily concentrated on case studies pertaining to disaster response and comprehensive assessments of infrastructure, governance, and social networks. While at the global level, the research on resilience has a distinct emphasis, primarily assessing economic patterns and interconnections instead of individual or household food security. The examination of resilience on a global scale involves studying the propagation of shocks across international boundaries within the food system, as observed in studies by Marchand et al. (2016). This means, In the context of studying food system resilience in Haiti, the local level refers to analyzing the specific dynamics and factors within the country itself. This includes investigating how the food system responds and adapts to disruptions at a local or regional scale, such as natural disasters, infrastructure challenges, governance structures, and social networks within Haiti. On the other hand, the global level pertains to examining the broader economic patterns and relationships that affect the food system in Haiti on an international scale. This involves assessing how external factors, such as global market dynamics, trade policies, and international shocks, impact the resilience of Haiti's food system.

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Nevertheless, since food security, with its four essential pillars (food availability, food access, food utilization, and stability), is the principal objective of the food systems, Vallée (2007) proposed four dimensions of resilience in food system resilience research. These dimensions include ecological resilience, economic resilience, consumption resilience, and social resilience, with each dimension being associated with a specific pillar of food security (Table 5). Below is provided a table summarizing the different types of resilience, their descriptions, and their link to food system resilience research in Haiti:

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Table 5 Resilience dimensions in food system research

Resilience Dimension	Description	Link to Food System Resilience Research in Haiti
Ecological Resilience	Associated with land-use changes, efficient resource utilization, waste reduction, and maintaining ecological sustainability. Linked to the pillar of food availability.	Focuses on assessing the impact of land-use changes, resource management practices, and ecological conditions on food availability in Haiti. Aims to maintain or enhance natural ecosystems and resources for sustainable food production.
Economic Resilience	Connected to the financial wealth, economic growth, diversity, productivity, and market integration of the food system. Primarily associated with the pillar of food access.	Examines market dynamics, income levels, employment opportunities, and the efficiency of the food provision chain in the Haitian food system. Aims to understand how the system can withstand economic shocks and ensure access to food for all segments of the population.
Consumption Resilience	Relates to individual nutritional status and its position within the adaptive cycle and food regime level of the system. Can differ from overall household food security.	Focuses on assessing the nutritional status of individuals and households, examining intra-household dynamics, and identifying vulnerabilities and disparities in food access and utilization in Haiti. Aims to inform interventions and policies to address individual-level food security within food-insecure households.
Social Resilience	Represents a mixed dimension of both slow and fast processes and encompasses the human, political, and cultural wealth of the food system. Linked to the pillar of food security in terms of stability.	Explores socio-political and cultural aspects influencing food security in the Haitian food system. Examines safety nets, educational programs, institutional stability, and social cohesion. Aims to enhance social cohesion, strengthen institutions, and promote equitable access to food resources in Haiti.

Sources : Vallée (2007)

2.2.4. The geography of the HAITI food supply

Haiti's primary food crops include plantains, rice, maize, wheat flour, tubers (sweet potatoes, cassava (yuca), and yams), pulses (dry beans & peas), and sorghum. For this research purpose, more attentions will be given to the following crop types:

Rice holds significant importance in the Haitian diet as the most consumed staple, yet its cultivation area at the national level is limited to just 5 percent (Giordano, 2016). The Artibonite Department stands as the primary rice producer in Haiti, accounting for approximately 70 – 88 % of the total cultivated land dedicated to rice production. Although rice is also cultivated in South, North, Northeast, and Centre regions, their contribution to the overall cultivated land is relatively smaller, ranging from 1 to 5 % (MARNDR, 2017). While rice cultivation mainly relies on irrigation methods (Giordano, 2016), rainfed production occurs in the humid mountains of North, Northwest, and Northeast regions (MARNDR, 2015).

The yield of paddy rice in Haiti is relatively low, ranging from 1.75 to 3.50 metric tons per hectare (MT/ha). The national average stands at 3.00 MT/ha, which is comparably lower than other rice-producing regions in the Latin America and Caribbean (LAC) area, such as the Dominican Republic (6.55 MT/ha) and Colombia (5.90 MT/ha) (CNSA, 2013). From 2012 to 2016, the average production of paddy rice was 156,864 MT, which is equivalent to 91,258 MT of milled rice, assuming an extraction rate of 0.6. Production levels vary annually, primarily influenced by climatic events. While rice cultivation occurs in all three seasons in the main producing areas, other regions, such as the Centre region, have only one season, and some, including North, Northeas, Northwest, and Grand'Anse

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regions, have two seasons. Approximately 36 % of the total production is attributed to the spring season (CNSA, 2013; MARNDR, 2015).

Maize holds the position of being the second most consumed cereal in Haiti, while also being the predominant crop grown throughout the country. The current estimated annual consumption of maize per person in Haiti stands at an average of 20 kg, as reported by CNSA in 2014. However, consumption rates tend to be higher in regions where maize production is prevalent. Maize cultivation is widespread across Haiti, encompassing approximately 25 % of the total cultivated land. Most agricultural producers, constituting 75 %, engage in maize cultivation, often in rainfed conditions and in conjunction with other crops like beans, peas, banana, and tubers. Farmers typically produce their own maize seeds through harvest (Giordano, 2016). Notably, the departments of West, Artibonite, Centre, and South contribute to more than 60 % of the total maize production in Haiti (MARNDR, 2017).

Regrettably, maize yields in Haiti are characterized by low productivity, ranging from 0.5 to 3.0 MT/ha. The national average yield is estimated at 1.0 MT/ha, which falls significantly short when compared to the neighboring Dominican Republic's average of 3.5 MT/ha, according to CNSA (2013). Over the period of 2012 to 2016, the average maize production amounted to 174,256 MT. However, production levels have demonstrated variability, particularly due to the impact of climatic events. In 2009, which serves as the reference year, maize production reached a total of 353,785 MT (CNSA, 2013).

Sorghum, ranking as the third most significant cereal produced in Haiti, exhibits the lowest consumption levels among all cereals, with an average annual consumption of 5 kg per person, as reported by CNSA (2013). At the national level, approximately eight

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percent of the cultivated land is allocated to sorghum production, as noted by Giordano (2016). Notably, the regions of West, Artibonite, Centre, and South contribute to over 80 % of the total sorghum production in Haiti, as indicated by MARNDR (2017). Sorghum is cultivated throughout the year, although the timing of planting and harvesting varies depending on the region and the variety employed. While the spring season accounts for approximately 40 % of the total output, recent years have witnessed year-to-year variations in production levels, as reported by CNSA (2013).

Sorghum yields in Haiti are characterized by their low productivity, ranging between 0.50 and 1.50 MT/ha, with an average of 1.00 MT/ha. This performance is considerably lower when compared to other sorghum-producing regions in the LAC (Latin America and the Caribbean) region, such as the Dominican Republic (3.22 MT/ha) and Colombia (3.04 MT/ha), according to CNSA (2013). Between 2012 and 2015, Haiti's average annual sorghum production stood at 57,934 MT. However, since 2014, total production has experienced a considerable decline, maintaining a downward trend. Generally, Haiti is deemed self-sufficient in terms of sorghum for human consumption, with no documented formal imports in this regard.

Haitian individuals have a diverse consumption pattern when it comes to pulses, with black beans, red beans, pigeon peas, and groundnuts being the most consumed varieties. The average annual consumption of pulses is estimated to be 25 kg per person. Pulses occupy approximately one-third of the cultivated land in Haiti, and their production is widespread across the country, particularly in mountainous regions and irrigated plains. Among the pulses grown, beans (black, red, white, yellow, and pinto), peas (pigeon pea, cowpeas, and others), and groundnuts are the primary ones, with beans dominating in terms of cultivated area.

In terms of yields, beans average around 600 kg/ha, while peas average around 800 kg/ha. These levels of productivity are comparatively low when compared to the yields observed in the Dominican Republic, where beans yield between 1.50 and 2.28 MT/ha, and peas yield 2.45 MT/ha, as reported by CNSA (2013) . It is worth noting that these yield levels of 600 kg/ha for beans and 800 kg/ha for peas are repeated in the original text and likely represent a duplication error. Nonetheless, they still indicate low yields in comparison to the Dominican Republic. More information is provided in the table below on these crop types and the major constraints related to their productions. A summary of these crop types is provided in Table 6, Figure 6 depicts the geographical distribution of livelihood zones in Haiti along with the corresponding food crops.

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Table 6 Most consumed staples in Haiti, production zones and constraints

Crop Types	Production Zones	Total Production (2012-2015)	Main Constraints
Dried beans	- Artibonite, - Centre, - Ouest, Grand'Anse	Average of 150,764 MT/year	- Availability and affordability of quality seeds - Lack of access to irrigation - Traditional cropping techniques with low input usage - Adverse effects of climatic events
Maize	Grown in all regions of the country	Average of 174,256 MT/year	- Unfavorable climatic factors (erratic rains, drought) - Lack of access to irrigation - Limited availability and access to production inputs - Incidence of pests and diseases - Use of traditional cropping practices - Lack of access to financial capital for investment - Lack of organization of producers
Rice	- Artibonite - South - North - Northeast - Centre	Average of 156,864 MT/year	- Lack of financial resources for investment - Lack of technical support - Increasing price of fertilizers - Untimely access to inputs - Lack of availability of quality inputs - Lower availability of labor and its increasing cost - Deterioration of irrigation infrastructure - Incidence of pests and diseases - Impacts of climatic factors
Sorghum	- Artibonite - Centre - Nippes - South	Average of 57,934 MT/year	- Adverse climatic factors (late rains, drought) - Incidence of pests and diseases - Use of low-yielding varieties - Lack of use of production inputs - Lack of improved crop management techniques

Author’s production
Source: Ministry of Agriculture

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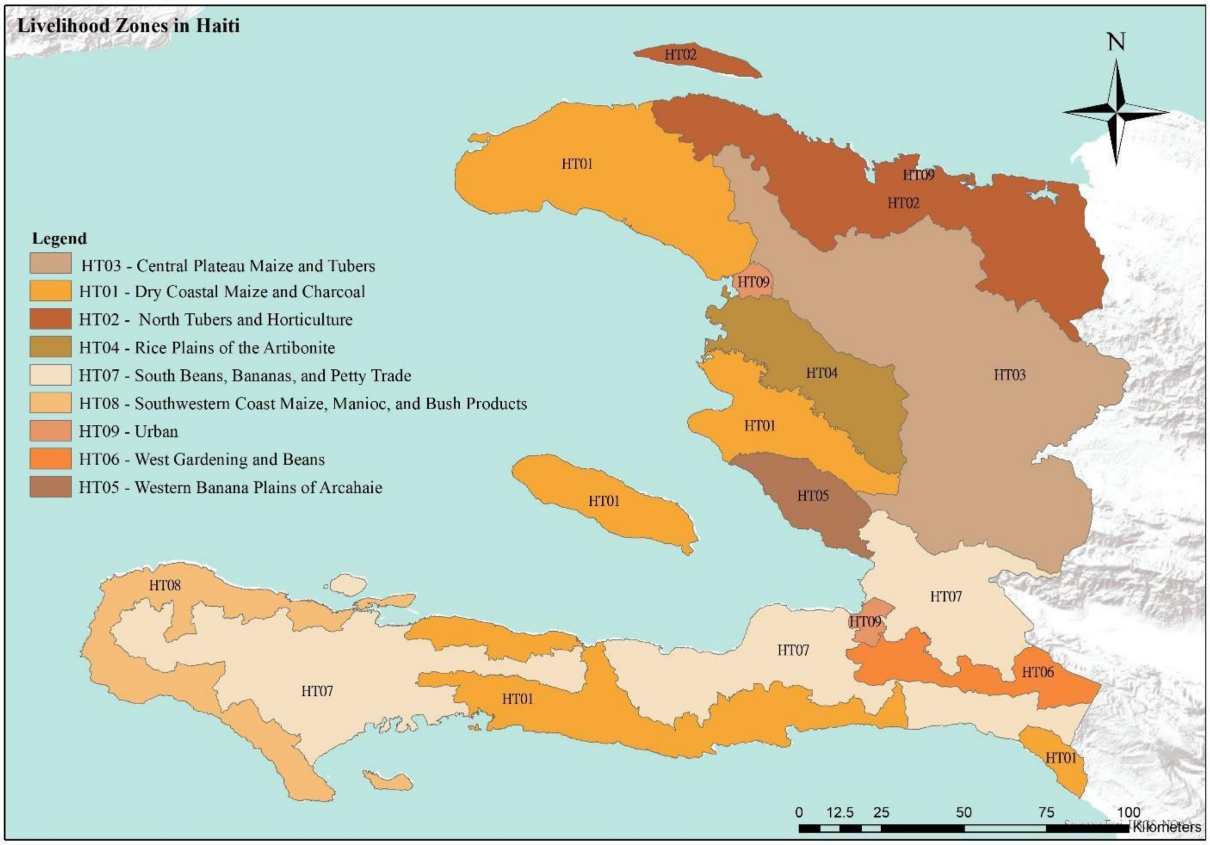

Figure 6 Livelihood zones in Haiti

Source: Author's production based on data from https://rb.gy/je4az

With regards to food processing industry throughout the country, it consists of a few large-scale facilities and many small-scale operations as presented in figure 7. Large-scale processing of imported grains into various products takes place near Port-au-Prince, while vegetable oil processing focuses on blending and bottling imported refined oil. Sorghum processing into alcoholic and non-alcoholic beverages is mainly carried out in the capital city and other regions of Haiti. Small-scale processing is done locally by numerous small mills throughout the country. However, the use of outdated and poorly maintained equipment in these small mills compromises the quality of the final product and the extraction rate (FEWSNET, 2017).

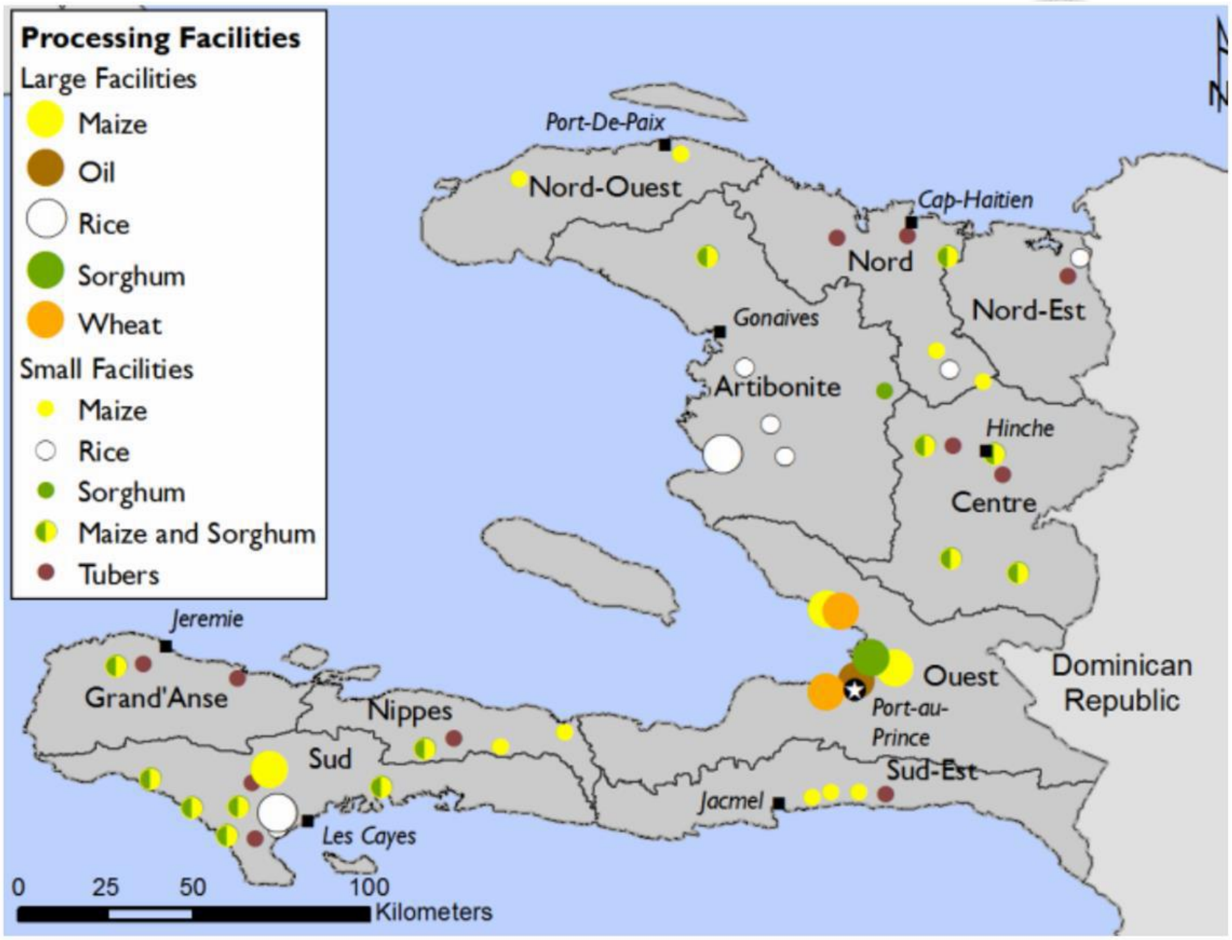

Figure 7 Geographical distribution of food processing facilities
Source: Adapted to FEWSNET (2017)

2.2.5. The geography of climate change in Haiti

Haiti has a tropical climate, with the central departments generally classified as equatorial savannah, and the north and southwestern departments generally classified as equatorial rainforest and equatorial monsoon. In Haiti, daily temperatures typically range from 18°C–29°C in the winter and 22°C–32°C in the summer as illustrated in Figure 8– 9. Through these figures, though that the distribution of the temperature is not uniform, but we observed an increase in the maximum temperature across the three periods presented in the maps. But it was hotter in the Artibonite region than in all other regions. While the

Artibonite region is characterized by vast fertile plains that are ideal for food production. The Artibonite is indeed the main rice-producing region in Haiti, registering between 70–88 percent of total land under its cultivation (FEWSNET, 2018). The region also produces other crops such as corn, cassava, vegetables, fruits, coffee, and cocoa. This variation at the temperature level has direct effect on crop production and therefore result in food shortage since according to Adams et al. (1998), agricultural productivity is responsive to variations in climatic conditions and is affected by both favorable effects (such as higher levels of atmospheric CO_2 leading to increased productivity) and unfavorable impacts (such as elevated temperatures shortening the grain-filling period and increasing rates of evapotranspiration).

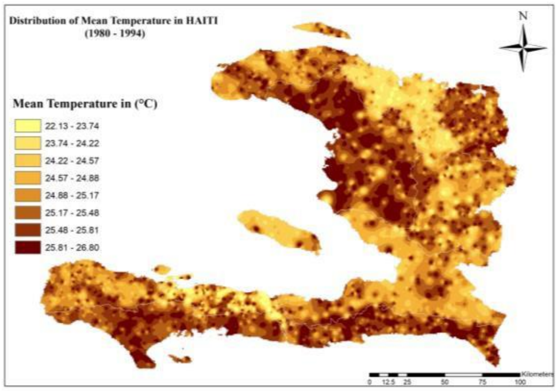

Figure 8 Temperature trend 1980 – 1994

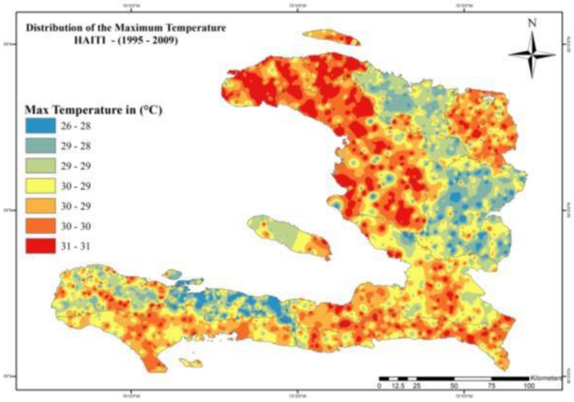

Figure 9 Temperature trend 1995 – 200

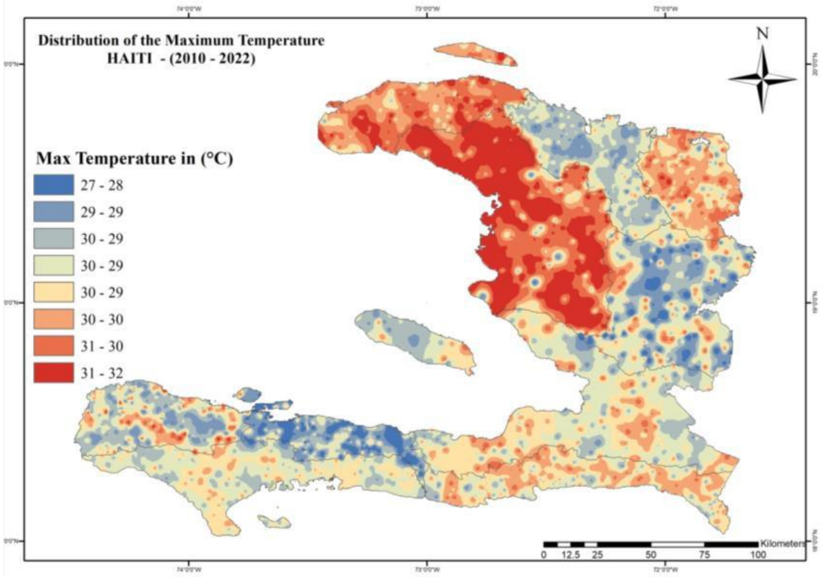

Figure 10 Temperature trend 2010 – 2022
Source : Author’s calculation and production based on data from Abatzoglou et al. (2018)

Climate change impacts vary across Haiti due to the interplay between local topography and the global climatic system, leading to regional differences in the effects of climate change. For instance, Figure 10 illustrates that the Artibonite division has undergone greater warming compared to other regions in the country; however, from around 1980, all regions of the country began to warm up. The periods of 1980-1994 and 2010-2022 have been warmer than the preceding periods analyzed across the country, with the Artibonite, North, and North-west regions encountering higher temperatures while a reduction in temperature was observed in the South division (as described in Figure 11 – 13). These rising temperature trends are discernible in climate data pertinent to agricultural production. These alterations in daily and seasonal temperature patterns hold the potential to disturb agricultural production because of the of crop sensitivity, livestock, and pests to seasonal temperature patterns and temperature extremes.

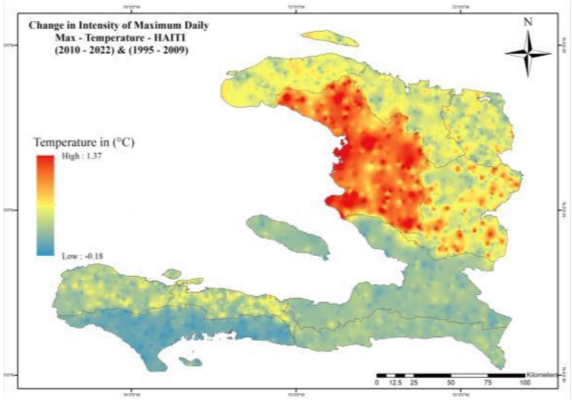

Figure 11 Temperature change (1995 – 2009)

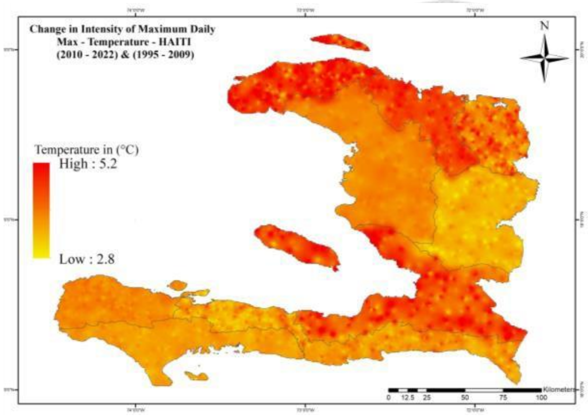

Figure 12 Temperature change (2010 – 2022) vs (1995 – 2009).

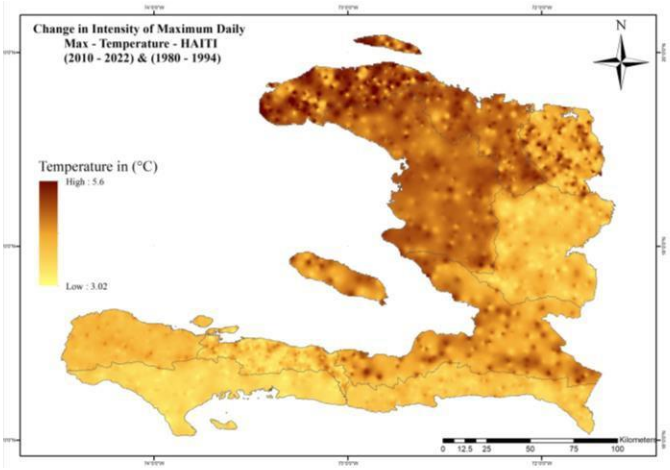

Figure 13 Temperature trend (1980 – 1994) vs (2010 – 2022)

Source : Author’s calculation and production based on data from Abatzoglou et al. (2018)

Similarly, the data on rainfall shows a decrease in average precipitation throughout Haiti over the studied period (as shown in Figures 14 – 15 and 16). However, when considering the lowest amount of rainfall received during this time, the departments of North-west, North-east, South-east, and South stand out. Conversely, the distribution of rainfall was relatively consistent across the other departments, as depicted in Figures 14, 14, and 15. But according to Figure 15, the period from 2010 to 2022 experienced the least amount of rainfall across the whole region, with around 21000 mm recorded. This is lower than the amount recorded between 1995 and 2009, which was about 24000 mm, and the period between 1980 and 1994, which saw a slightly higher amount of rainfall at 25000 mm

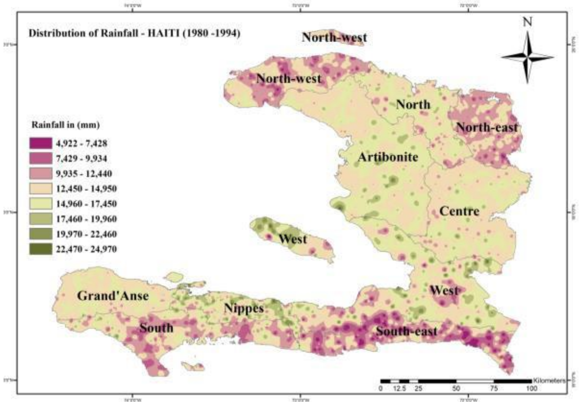

Figure 14 Rainfall distribution (1980 – 199

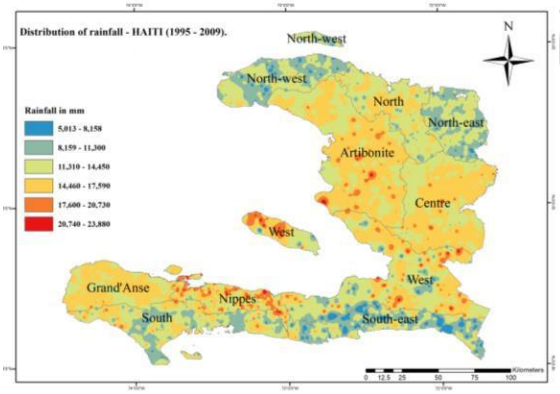

Figure 15 Rainfall distribution (1995 - 2009)

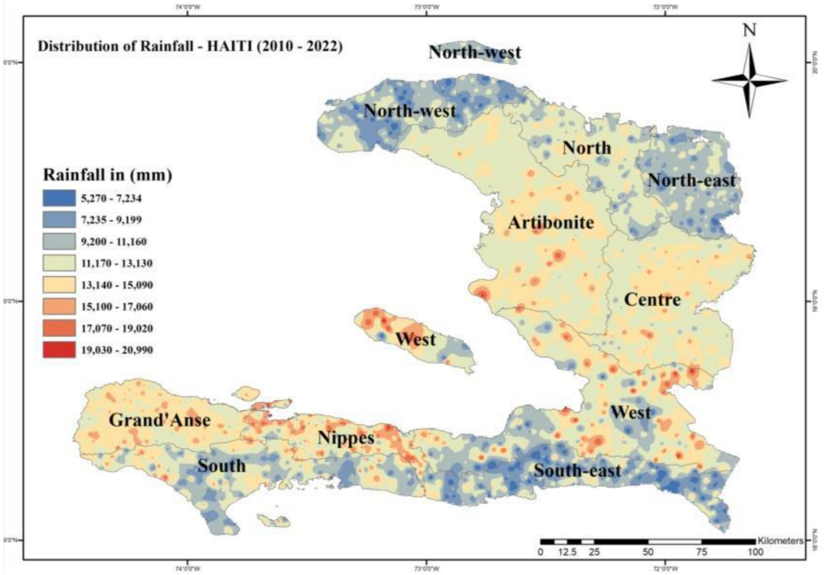

Figure 16 Distribution of rainfall (2010 - 2022)

Source : Author’s calculation and production based on data from Abatzoglou et al. (2018)

Regarding variations and changes in the distribution of rainfall across the territory, it is noteworthy that these variations and changes significantly vary depending on the geographic region of the country and the season. Nonetheless, there are general trends that have been observed at the national level.

As demonstrated in figures 17 – 18 and 19, during the period from 1980 to 2022, many places in Haiti have experienced an increase in the intensity and frequency of extreme precipitation events, while others have experienced a decrease in average annual precipitation. This trend is associated with climate change and global temperature increase. In some regions of the country, such as the Northwest, North, Northeast, and West, there has been a decrease in average annual precipitation during the periods of 1995-2009 and 1980-1994, which has had significant impacts on agriculture and food security.

Other regions, such as Grand'Anse, Nippes, South, Southeast, and Central, have experienced an increase in average annual precipitation. Overall, and according to figures 17 and 18, the distribution of rainfall was not uniform, and the amount of rainfall gradually reduced year after year. Variations and changes in the distribution of precipitation across the territory are complex and vary significantly depending on the geographic region and season. However, the general trends observed at the national level are associated with climate change and global temperature increase.

Regions that have experienced an unfavorable change in rainfall distribution may face a scarcity of water accessible for crops, which could lead to a decline in agricultural productivity and potentially lower crop yields, particularly for general rain-fed agriculture. The negative trend change in rainfall over time also suggests that the country also experienced drought conditions, which could have had severe impact on food production and food security. And in regions where there has been a positive change in rainfall distribution, there might be an increase of water availability for crops, which could lead to

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higher agricultural productivity and potentially higher yields of crops. However, if the increase in rainfall is too much, it could lead to flooding, which could also have a negative impact on crop production. So, in certain regions, such as coastal areas, precipitation tends to occur in the form of torrential rain, which can cause floods and landslides. According to the international disaster database, from 1980 to 2022, Haiti has experienced sixty cases of floods, which have had considerable effects on the food system in general.

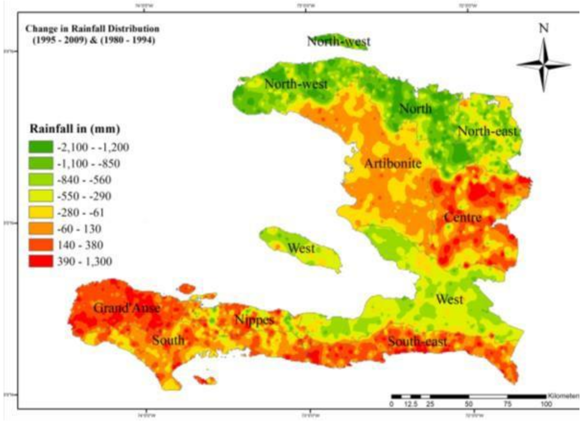

Figure 17 Rainfall changes (1995 - 2009) vs (1980 – 1994)

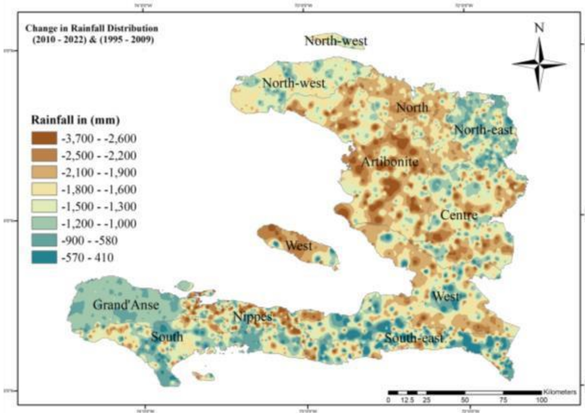

Figure 18 Rainfall changes (2010 - 2022) vs (1995 – 2009)

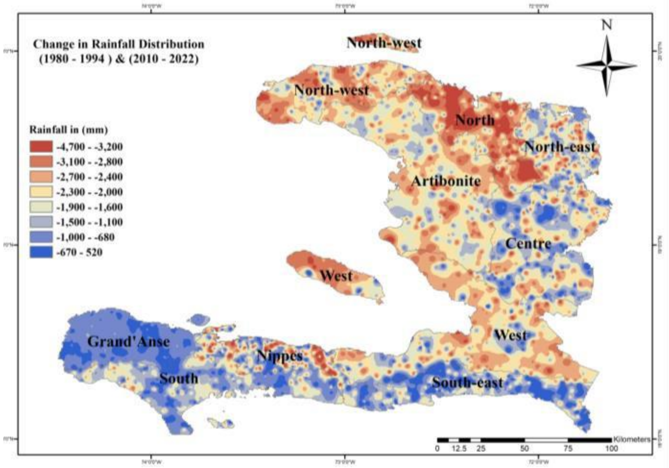

Figure 19 Rainfall changes (2010 - 2022) vs (19980 – 1994)

Source : Author’s calculation and production based on data from Abatzoglou et al. (2018)

2.2.6. The vulnerability of the HAITI food system

Resilience and vulnerability are indeed two interconnected concepts that describe different aspects of systems, including the food system. Resilience refers to the ability of a system to withstand shocks, disturbances, or stresses, and maintain its basic functions and structures. Vulnerability, on the other hand, refers to the susceptibility of a system to these shocks and its inability to cope or recover from them. Within the community focused on disaster risk, resilience has traditionally been regarded as the antithesis of vulnerability. In other words, the greater the resilience, the lower the vulnerability (Pelling, 2010). However, this simplistic understanding fails to acknowledge the intricate conceptual connection between these terms, which have also been conceptualized as interdependent. Specifically, vulnerability is influenced by resilience (Manyena, 2006), and some argue that resilience encompasses adaptive capacity (Gallopín, 2006). The resilience of a food system involves its capacity to adapt and recover from various challenges, such as climate change, natural disasters, economic fluctuations, and social disruptions. A resilient food system can withstand these disturbances, absorb their impacts, and bounce back to its normal functioning, minimizing the adverse effects on food production, distribution, and access. When a food system lacks resilience, it becomes vulnerable to various threats. For instance, a lack of diversity in crop varieties increases the vulnerability of agriculture to pests, diseases, and adverse climate conditions (Díaz et al., 2019). Similarly, inadequate infrastructure, such as poor transportation networks or storage facilities, can make a food system more vulnerable to disruptions in supply chains (HLPE, 2017). Social factors like poverty, inequality, and conflicts also contribute to the vulnerability of food systems (FAO, 2020). Cutter et al. (2008) also highlight research that ascribes resilience and associated

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measures to various systems, including ecological systems (such as biodiversity), social systems (such as social networks), economic systems (such as wealth generation), institutional systems (such as participation), infrastructure systems (such as design standards), and community competence (such as risk perception) (Folke, 2006; Paton & Johnston, 2017; Rose, 2004). In this case, we based the analysis of food system vulnerability in Haiti on the four food system resilience dimensions, i-e., ecological resilience; economic resilience; consumption resilience, and social resilience which each of them is associated to a food security dimension.

2.2.6.1. Ecological resilience and vulnerability

Haiti's food systems face significant challenges in terms of ecological resilience. Several factors contribute to this lack of resilience: (i) Land-use changes: Published studies indicate that Haiti has experienced extensive deforestation and land degradation, resulting in the loss of natural ecosystems and agricultural land. Deforestation has contributed to soil erosion, reduced water retention capacity (Khodadadi et al., 2021), and therefore increased vulnerability to natural hazards such as hurricanes and floods. These land-use changes have negatively impacted the ecological conditions necessary for sustainable food production, (ii) Resource management practices: The agricultural system in Haiti exhibits unsustainable farming methods, encompassing improper land stewardship, insufficient irrigation practices, and excessive or insufficient utilization of chemical inputs. These practices have resulted in the depletion of soil fertility and the deterioration of land quality. According to FAO (2023b), the lack of proper resource management practices diminishes the capacity of the land to support food production over the long term, (iii) Ecological sustainability: Published information indicates that Haiti's food systems face challenges related to ecological sustainability. In addition to the aforementioned aspects, the farming system in Haiti is further marked by the overexploitation of natural resources. The overexploitation of natural resources, such as forests and fisheries, has undermined the resilience of these ecosystems and compromised their ability to provide essential food resources; and (iv) Impact on food availability: The loss of natural ecosystems, combined with unsustainable resource management practices, has negatively affected food availability in Haiti. Reduced agricultural productivity and increased vulnerability to climate-related events have resulted in fluctuating food production levels and limited access to diverse and nutritious food sources for the population. Addressing these challenges requires interventions focused on sustainable land-use practices, natural resource conservation, and enhancing the capacity of ecosystems to support food production in a resilient and environmentally sustainable manner.

2.2.6.2.Economic resilience and vulnerability

The food systems in Haiti are also lacks economic resilience which undermines the system capacity to respond to eventual shocks. Several factors contribute to this vulnerability: firstly, market dynamics: Studies indicate that Haiti's food system is highly dependent on imported goods (Vansteenkiste, 2022), making it susceptible to price fluctuations and disruptions in global markets. Limited domestic production and reliance on imports for essential food items render the system vulnerable to changes in trade policies, currency fluctuations, and international market conditions. These dynamics pose challenges to maintaining a stable and resilient food supply chain. At the income levels and poverty, available data show that a significant proportion of the Haitian population lives in poverty[5]

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[5] The World Poverty Clock provides real-time estimates until 2030 for almost every country in the world. It

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and experiences low income levels (WorldPovertyClock, 2023). Persistent poverty and income disparities limit individuals' purchasing power and their ability to access sufficient and nutritious food (Siddiqui et al., 2020). The lack of economic resources within the population hinders their resilience to food insecurity and makes them more vulnerable to shocks and disruptions in the food system. Employment opportunities is also another factor that might contribute to the vulnerability of food system in Haiti: Haiti faces challenges in providing adequate employment opportunities, particularly in the agricultural sector. Limited access to productive and secure employment affects farmers' livelihoods and their capacity to invest in sustainable farming practices. Insufficient employment opportunities contribute to the vulnerability of the food system by hampering economic growth and reducing the overall resilience of the population. Lastly, the efficiency of the food provision chain is crucial to economic resilience to ensure food security within a country because it argued that resilience in agri-food supply chains is an area of significant importance due to growing supply chain volatility (Stone & Rahimifard, 2018). The food provision chain in Haiti faces inefficiencies, including inadequate infrastructure, limited storage facilities, and challenges in transportation and distribution. These inefficiencies contribute to post-harvest losses, food waste, and increased costs throughout the supply chain.

The lack of a well-functioning and efficient food provision chain undermines the system's ability to respond effectively to shocks and disturbances. Collectively, these factors demonstrate that the food system in Haiti is vulnerable and lacks economic resilience. The country's heavy reliance on imports, low-income levels, limited employment opportunities, and inefficiencies in the food provision chain contribute to its

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monitors progress against Ending Extreme Poverty. 2481 haitian pople living in extreme poverty in June 2023. https://worldpoverty.io/map

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vulnerability to shocks and disruptions. Addressing these challenges requires interventions that promote economic growth, enhance domestic agricultural production, improve employment opportunities, and strengthen the overall resilience of the food system to ensure access to affordable and nutritious food for all segments of the population.

2.2.6.3. Consumption resilience and vulnerability

The food systems in Haiti are vulnerable and lack consumption resilience. Several factors contribute to this vulnerability: First, the nutritional status and disparities: Available data indicate that Haiti faces significant disparities in nutritional status among individuals and households. Food insecurity and malnutrition persist, with a considerable portion of the population experiencing inadequate access to nutritious food. Approximately 6.9 million[6] people with insufficient food consumption. These disparities highlight the vulnerability of the food system to meet the individual nutritional needs of its population. Second, the intra-household dynamics: Research suggests that intra-household dynamics play a crucial role in determining individual-level food security within food-insecure households (Lutomia et al., 2019). Factors such as gender inequality, unequal distribution of resources, and intra-household power dynamics can affect the allocation and utilization of food resources. These dynamics contribute to the vulnerability of certain individuals within food-insecure households, as they may experience food insecurity despite overall household food security. Third, vulnerabilities and disparities in food access: Food access in Haiti has been a subject of concern due to vulnerabilities and disparities that impact people's ability to secure an adequate and sustainable food supply. Factors such as geographic location, socioeconomic status, and social inequalities can limit individuals' access to affordable and nutritious food.

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[6] https://hungermap.wfp.org/

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Vulnerable populations, including women, children, and marginalized communities, face particular challenges in accessing adequate food, exacerbating the vulnerability of the food system in Haiti.

Fourth, the measurement of food security: Measurement and assessment of food security at the individual level are critical to understanding consumption resilience. Studies indicate the need to consider individual food utilization and intra-household allocation rules and processes when evaluating food security (Jones et al., 2013). This nuanced understanding is necessary to differentiate between the food secure, the vulnerable to food insecurity, and the food insecure. It highlights the vulnerabilities within households and the limitations of the current food security measurement approaches in capturing the full extent of consumption resilience in Haiti. Overall, these factors demonstrate that the food systems in Haiti are vulnerable and lack consumption resilience. Disparities in nutritional status, intra-household dynamics, vulnerabilities in food access, and limitations in measuring food security contribute to the vulnerability of the system. Addressing these challenges requires interventions that promote equitable access to nutritious food, address intra-household disparities, and enhance the consumption resilience of vulnerable populations.

2.2.6.4. Social resilience and vulnerability

The food systems in Haiti are lack of social resilience and therefore highly vulnerable to specific hazard. Several factors might explain this vulnerability: (i) Safety nets and institutional stability: Haiti's food systems face challenges in terms of safety nets and institutional stability. Limited social protection programs and weak institutional structures hamper the ability of the food system to provide support during times of shocks or

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disruptions. Insufficient safety nets and fragile institutions undermine the resilience of the system to effectively address food security concerns, (ii) levels of education and political coherence: Levels of education and political coherence might be areas of concern for the social resilience of Haiti's food systems. Limited access to education and low literacy rates might hinder individuals' ability to adopt and implement sustainable agricultural practices and understand their rights and entitlements within the food system. Similarly, political coherence and stability are crucial for the effective governance of the food system and the implementation of policies that address food security and resilience. Without a formal education, many Haitian farmers may have limited access to information, modern agricultural techniques, and best practices. This hinders their ability to adopt innovative farming methods, improve productivity, and respond effectively to challenges such as climate change, pests, and diseases. Likewise frequent changes in government, lack of continuity, corruption, and weak governance structures can hinder the establishment of robust institutions capable of effectively coordinating and implementing agricultural policies and programs. This instability affects the long-term planning and implementation of strategies to address food security challenges.

(iii) Social cohesion and improvements in living standards: Social cohesion and improvements in living standards is important for the social resilience of food systems. Social cohesion, characterized by trust, cooperation, and collective action, is essential for addressing food security challenges collectively. Improvements in living standards, including access to basic services and infrastructure, might contribute to the overall well-being and resilience of the population, and lastly (iv) Equitable access to food resources: research emphasizes the need for equitable access to food resources to enhance social

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resilience in food systems, especially in the Haitian context. Social inequalities, including gender disparities and marginalization of certain groups, can hinder equitable access to food. Addressing these inequalities and promoting social inclusivity are vital for building resilient food systems that prioritize the well-being of all segments of the population. Limited safety nets, weak institutional stability, low levels of education, political challenges, and social inequalities contribute to Haiti’s food system vulnerability. Addressing these challenges requires interventions that strengthen social protection programs, improve educational opportunities, foster political stability, promote social cohesion, and ensure equitable access to food resources.

2.3. Limitations and conclusions for data collection

The research on "food system vulnerability and resilience to climate disasters in Haiti: farmers' coping and adaptation strategies in Haiti" faced several constraints during data collection, which impacted the reliability of both primary and secondary data.

The primary data for this research was collected through a two-wave survey from households in October 2020 to April 2021. These surveys aimed to capture demographic, socioeconomic, and biophysical attributes of farmers. Additionally, the primary data included valuable insights into farmers' perceptions of temperature and rainfall patterns over the past decade and the adaptive strategies they developed to cope with climate change impacts. To gather these data, various methods were employed, such as survey questionnaires, focus group discussions, and field observations. However, due to the complexity of the research topic and the need for further information, a second wave of data collection was necessary. This second questionnaire focused primarily on farmers'

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willingness to adapt to climate change, specifically their practices, like crop rotations, to improve future crop yields. The primary data obtained from these field surveys were essential for understanding farmers' experiences and responses to climate disasters.

Nevertheless, accessing accurate and up-to-date data in Haiti posed significant challenges. At the time of the research, the most recent population census data available were from 2017, and no annual surveys were conducted at the municipal level. This lack of current data limited the ability to assess recent changes and trends in farmers' coping and adaptation strategies. Moreover, Haiti's complex security situation further hindered data collection efforts. The presence of armed gang groups occupied all regions of the research site, making certain agricultural zones inaccessible. Insecurity levels also affected women's participation, as they were more reluctant to express themselves and provide their opinions and perceptions, especially on climate change. In some cases, women may have deferred to their husbands, impacting the gender representation and accuracy of the data collected.

So, for this thesis journey, I encountered various challenges in obtaining accurate and specific data relevant to my research objectives. The primary obstacle I faced was the lack of comprehensive research in Haiti, with most available data being sourced from international organizations operating in the country and on the global scale. Moreover, the presence of gang activity and security issues in certain regions hindered researchers and data collectors from accessing farms and agricultural areas. The inadequate infrastructure and limited funding further compounded the difficulties.

In the context of climate disasters, the timely and precise data on agricultural production, crop losses, and farmers' responses played a critical role in understanding the

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vulnerability and resilience of the food system. Regrettably, the constraints in resources and funding posed significant obstacles to establishing a robust data collection infrastructure and conducting comprehensive surveys following climate events in Haiti. Consequently, information regarding farmers' coping and adaptation strategies was scarce, or completely unavailable. Political instability in Haiti was another significant concern affecting data continuity. Changes in government or administrative structures could shift the focus of agricultural data collection, leading to inconsistencies and gaps in the data. Such interruptions hindered the ability to assess changes in farmers' coping strategies and resilience over various climate disasters, making it challenging to identify long-term trends. A further challenge was the absence of regular annual data collection. Climate disasters do not occur every year, and without continuous data gathering efforts, it becomes difficult to establish baselines and monitor changes in food production and farmers' resilience over time. The lack of data also limited the identification of successful strategies and best practices, impeding the formulation of targeted interventions. Another crucial aspect that required attention was data quality and verification. Collecting data on food production, farmers' coping and adaptation strategies during climate disasters demanded careful methodologies to ensure data accuracy. However, the constrained conditions often hindered the verification process, particularly when resources were scarce and access to farms was restricted. This raised concerns about the reliability of the collected data and its potential impact on the overall findings of my thesis.

Chapter 3

Meeting the food demand challenge for fourteen million Haitian people in 2050.

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3. Chapter 3 Meeting the food demand challenge for fourteen million Haitian people in 2050.

3.1. Introduction

Feeding the Caribbean population, especially in Haiti, poses a significant challenge, as evidenced by the country's current population of approximately 12 million, with an annual growth rate of 140 thousand individuals. Haiti is beset by ongoing social, economic, and environmental crises, worsened by the COVID-19 pandemic and the 2021 earthquake, resulting in a severe food crisis in terms of both supply and demand. The implications extend beyond food security, negatively affecting economic growth, social cohesion, and the right to adequate food and nutrition. The Food and Agriculture Organization (FAO) reported that around 4.4 million Haitians experienced food crises in the March-June 2021 period, largely due to economic shocks, the COVID-19 pandemic, and resulting job and income losses (FAO, 2021b). Although the total food production in 2020 was estimated at approximately 370 thousand tons (FAO, 2022), it fell short of meeting the local food demand of 12 million people. Haiti's vulnerability stems from rapid population growth, limited agricultural land, erratic rainfall patterns, and recurrent climate-related disasters. With only 0.17 hectares of agricultural land per person (FAO, 2022), increasing food production to meet the demands of the projected population of 7.66 million aged 25 to 64 by 2050 (UN, 2015) becomes a formidable challenge.

Climate change exacerbates the food security challenge in Haiti. Studies indicate that the country's future climate projections indicate a significant decline in the suitability of growing crops such as dry beans, maize, and sorghum. Observations predict a potential reduction of up to 30% in suitable cultivation areas for maize and sorghum by 2050

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(Eitzinger et al., 2013). Furthermore, sorghum, a vital crop for food consumption and businesses, faces extinction due to poor harvests resulting from plant diseases. These climatic changes pose significant threats to agricultural production, thereby jeopardizing food security and livelihoods. Haiti is not alone in facing these challenges; neighboring countries in the Caribbean region also confront similar issues. El Salvador, Guatemala, Honduras, and Nicaragua are projected to witness up to a 34% decline in maize yield by 2025 due to climate change impacts (Schmidt et al., 2012). Furthermore, according to Tzul et al. (1997) Belize is expected to experience a 17% to 22% decrease in maize yield between 2060 and 2100. The Caribbean region, including Haiti, is estimated to face a 12% decline in crop yields, excluding rice, by 2050 (Hutchinson et al., 2013).

The data presented clearly indicate that climate change presents a significant and escalating hazard to the well-being of Caribbean inhabitants, particularly the people of Haiti. The decisions made today will determine how well the Haitian population can adapt and how nature will respond to the increasing climate-related risks. It is anticipated that countries with weak economies, poor governance, social inequalities, inadequate infrastructure, political instability, and conflicts will likely experience a higher degree of risk. Consequently, it remains uncertain whether Haiti will be able to meet the rising food demand of its population of 14 million people by 2050, considering the limited agricultural resources available per person. Because Ackerman et al. (2009) found that the economic cost of climate change impacts on Haiti's agricultural sector could amount to 10% of the country's per capita GDP in 2025.

One possible approach to address these concerns is the formulation of a new food policy framework that considers both population growth and income growth, alongside a

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climate change adaptation plan aimed at enhancing climate resilience. Climate change adaption refers to actions undertaken to build resilience or exploit beneficial opportunities (Lobell, 2014; Parry et al., 2007). However, the realization of this vision is uncertain due to several factors. Firstly, there is a decline in cropland per capita, compounded by geopolitical concerns associated with food policies in Haiti. Presently, Haiti has a population density of 339 people per square kilometer, and the UN's medium fertility scenario predicts a further increase of nearly 50% by 2040. Such a scenario would lead to the expansion of urban areas, resulting in the conversion of agricultural lands for non-agricultural purposes. Consequently, the availability of cultivated land is likely to decrease, negatively impacting food supply in relation to demand. Secondly, Haiti heavily relies on food imports, such as cereals, instead of prioritizing local production, which could provide financial security for smallholder producers. Such a policy not only hampers the development and devaluation of local production, but also contributes to the financial vulnerability of the majority of farmers. Thirdly, climate change acts as a multiplier of hunger risk and has already affected all four dimensions of food security, including food production. Adapting to climate change is one of the options available to mitigate its impact. Climate change adaptation entails implementing actions to enhance resilience or exploit beneficial opportunities. However, individual farmers have the autonomy to decide how and when to implement adaptation measures. Some adaptation options that could offer significant benefits for certain cropping systems (Howden et al., 2007) may be underestimated by farmers who rely on traditional farming practices. Their willingness to adapt at this level is therefore uncertain. However, there is limited research on this issue, particularly in developing countries like Haiti, where most farmers lack formal education.

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Current research on climate change adaptation in developing countries often focuses on topics such as educating people about climate change, understanding how people perceive climate change, examining gender-based factors that influence adaptation, and analyzing the factors that affect adaptation to climate change. However, the research tends to overlook an important aspect: people's willingness to adopt measures that can help them adapt to climate change. Understanding people's willingness to adopt climate change adaptation strategies is crucial for ensuring food security, increasing income, and promoting climate change adaptation in developing countries. If individuals and communities are not willing to adopt or implement climate change adaptation measures, the effectiveness of such measures will be limited. Therefore, it is important to consider factors such as social, cultural, economic, and political aspects that influence people's decision-making processes and their willingness to adopt climate change adaptation strategies.

By addressing people's willingness to adapt to climate change, decision-makers and policymakers can better understand the barriers and opportunities for implementing effective adaptation measures. This knowledge can support the development of policies and strategies that align with the needs, values, and aspirations of the local communities. It can also help in promoting inclusive and participatory approaches to climate change adaptation, empowering individuals, and communities to actively engage in decision-making processes related to farming practices and other relevant sectors. Considering people's willingness to adopt climate change adaptation measures can contribute to achieving food security by promoting sustainable agricultural practices that are resilient to changing climatic conditions. This, in turn, can increase agricultural productivity, improve

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livelihoods, and enhance income generation opportunities in developing countries. Additionally, addressing people's willingness to adapt can foster a sense of ownership and empower individuals to take proactive measures to mitigate and adapt to the impacts of climate change. Consequently, our initial step involved an examination of the correlation between the overall population and the food demand and supply in Haiti during three distinct time periods: 2021-2030, 2031-2040, and 2041-2050. Subsequently, we proceeded to evaluate and gauge the extent to which farmers are inclined to modify their agricultural methods to facilitate adaptation strategies for climate change. This investigation aimed to ascertain the potential for enhancing both the yield per hectare and the income of farmers.

3.2. Methodology

In this study, we focused on four main crops: maize, dried pulses (dry bean, pulses), sorghum, and paddy rice for the following periods: for 2030; 2040 and 2050. These crops were selected for their significant usage and consumption in Haitian cuisine, as well as their dual roles as food and cash crops. Additionally, these crops have been previously evaluated by the Food and Agriculture Organization (FAO) for their report "Alternative Pathways to 2050," which examines the future of food and agriculture (FAO, 2018). The FAO assessment considered three scenarios: Business as Usual (BAU), a Stratified Society (SSS), and Toward Sustainability (TSS). The BAU scenario represents current socio-economic, technological, and environmental patterns that inadequately address various challenges related to food access, utilization, and sustainable availability. Despite efforts to achieve Sustainable Development Goal (SDG) targets, the BAU scenario exhibits moderate global economic growth (per capita) of around 1.5 percent per year, with uneven distribution across countries. While there are some fiscal policies promoting within-country redistribution, incentives for transitioning towards sustainability are limited. Education quality remains subpar, and reliance on fossil fuels as the primary energy source persists, albeit with a slow emergence of renewable alternatives. The SSS scenario portrays a society divided into distinct strata, where an elite class primarily utilizes their decision-making power to safeguard their own interests, disregarding the urgency of conserving natural resources or mitigating climate change. Concurrently, increased poverty, food insecurity, and malnutrition contribute to the overexploitation of natural resources and uncontrolled urbanization. Under the SSS scenario, both equity and sustainable production face more severe challenges compared to the BAU scenario. In contrast, the TSS scenario embodies a virtuous cycle of social, environmental, and economic dynamics, ensuring a reasonably widespread equity in terms of basic service access and universal, sustainable availability of sufficient, safe, and nutritious food. This scenario relies on resource-efficient food production systems and inclusive societies, resulting in lower challenges regarding access, utilization, and sustainable food stability and availability compared to the BAU scenario.

The TSS scenario displays universal progress towards achieving SDG targets, with continued efforts beyond 2030. More details about the different scenarios can be found here FAO (2018). However, our analysis primarily focuses on the BAU and SSS scenarios due to the considerable inequality, poverty, low education levels, lack of access to basic services, and reliance on traditional farming practices without mechanization observed in Haiti. The analysis conducted reveals that Haiti is projected to encounter a scarcity of food based on its domestic agricultural output during the specified study years. Consequently, we expanded our focus beyond local production of the selected crops to also incorporate

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food imports, as the current level of local production falls short of meeting the country's demand for food. To address this concern, we considered the overall quantity of food required for each crop, considering both the annual per capita requirements and the projected total population for the years 2030, 2040, and 2050. To calculate this, we simply multiplied the daily per person requirement for each type of crops by the estimated total population for the given period.

The Intergovernmental Panel on Climate Change-IPCC indicates that climate change will increasingly put pressure on food production and access, especially in vulnerable regions, undermining food security and nutrition (Pörtner et al., 2022). As such, tropical countries such as Haiti, are expected to experience increase in frequency, intensity and severity of droughts, floods that will increase risks to food security. The crops may encounter challenges posed by the impacts of climate change, rendering them incapable of generating a yield that would be sufficient to meet the annual per capita needs of the entire population. It is estimated that climate change will reduce global crop yields by between 5 and 30% by 2050 without adaptation (Schellnhuber et al., 2013). However, Challinor et al. (2014) argued that using adaptation techniques such as changing farming calendar, crop varieties, and managing water supplies could probably increase yields by 7 to 15% compared to present production rates. But it is important to note that as the planet continues to warm (between 1 to 2°C in temperate regions and 1.5 to 3°C in tropical regions), adaptation becomes more difficult and creates fewer benefits (Challinor et al., 2014). Face with these obvious threats, intervention measures must be developed to adapt Haitian agriculture to changing climate and ensure a sustainable improvement in the well-being of agricultural households. Adaptation measures to this pressure are imperatively needed to neutralize its potentially adverse effects (Hassan & Nhemachena, 2008), and subsequent impacts.

From this perspective, a survey was conducted among farm households to evaluate the extent to which farmers are willing to modify their crop choices (crop rotations) between seasons as a strategy to address the effects of climate change. The existing literature presents a wealth of evidence highlighting the numerous benefits associated with crop rotations. Firstly, empirical studies have demonstrated that crop rotations play a crucial role in enhancing soil water storage capacity and improving crop water use efficiency (Han et al., 2012; Wang et al., 2021). Secondly, crop rotations have been shown to effectively reduce surface water runoff (Adiku et al., 2008; Baumhardt et al., 2012; Carroll et al., 1997). Moreover, crop rotations contribute significantly to soil health by improving both its physical and chemical properties (N'Dayegamiye et al., 2017; Sarwar et al., 2008; Wright et al., 2015). These enhancements create a favorable environment for optimal plant growth, characterized by improved nutrient availability, moisture retention, soil structure, pH balance, and enhanced disease and pest control. Consequently, these improvements result in healthier plants, better root development, increased yields, and overall enhanced plant development and productivity.

Furthermore, the implementation of crop rotations has been found to increase soil enzyme activity, facilitating nutrient activation and utilization (HONG et al., 2019; C. Zhang et al., 2020). Additionally, crop rotations positively influence the soil's micro-ecology by reducing the population of pathogenic bacteria while promoting the proliferation of beneficial bacteria (Adhikari & Basnyat, 1998; Bezdicek & Granatstein, 1989; Guo et al., 2005; Zhao et al., 2020). Lastly, crop rotation contributes to weed control through two mechanisms: enriching the diversity of weed species, thereby reducing the dominance of any single weed (Cheng et al., 2013; Ouda et al., 2018), and increasing the overall biodiversity within the crop system, thereby dispersing the risk of yield reduction (Degani et al., 2019).

It is important to recognize that the involvement of farmers is crucial in the development of adaptation measures, as they are the primary stakeholders. The study area was selected using a multistage sampling technique, with particular emphasis on the Artibonite region in Haiti due to its vulnerability to drought and its significant potential for food production. To gather relevant data, a structured questionnaire comprising four modules was designed and administered through face-to-face interviews with 488 local farmers on their respective farms. The questionnaire encompassed inquiries on (i) household demographic characteristics, (ii) farm characteristics, (iii) perception of the local climate, and (iv) adaptation to climate change. Stata was employed as the data management tool, while descriptive analysis served as the chosen method for data examination More details are provided in the appendix.

3.3.Results and Discussions

The study aims to evaluate the potential yields of four crop types most consumed in Haiti and their implications on food supply and demand under two different scenarios BAU and SSS respectively. The BAU scenario represents a continuation of current socio-economic, technological, and environmental patterns, while the SSS scenario reflects a society structured into separate social strata. This analysis assesses the yield projections for 2030, 2040, and 2050. The findings suggest that while the BAU scenario shows higher crop yields production in terms of yield per hectare, the SSS scenario raises concerns about

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equity and sustainable production due to socio-economic disparities and overexploitation of resources.

3.3.1. Crop yield projection under the BAU and SSS scenarios.

Table 6 and 7 present the projected yield of dried pulses, maize, sorghum, and paddy rice respectively under the BAU and SSS scenarios. According to the results, the BAU scenario projects an increasing trend in these crop yields over time (Figure 20). For example, in the case of grain maize, by 2030, the projected yield is 1.04 t/ha, which rises to 1.22 t/ha in 2040 and 1.38 t/ha in 2050 (Table 7). This scenario considers socio-economic, technological, and environmental factors but fails to adequately address challenges related to food access, utilization, and sustainable food stability. In contrast, the SSS scenario projects lower maize yields compared to the BAU scenario. The projected yield is 0.96 t/ha in 2030, 1.07 t/ha in 2040, and 1.15 t/ha in 2050 (Table 8). This scenario describes a society with significant socio-economic disparities, leading to increased poverty, food insecurity, and poor nutrition. The over-exploitation of natural resources and unmanaged agglomerations further contribute to the challenges of equity and sustainable production. But, both BAU and SSS scenarios are anticipated to yield consequences for the future food supply and demand in Haiti during the periods spanning from 2030 to 2040 and 2050.

Firstly, the higher crop yields projected under the BAU scenario suggest a potential increase in food supply. Improved productivity may help meet the growing demand for these four crop types in Haiti, supporting food security and stability. However, this scenario may not adequately address broader issues such as equitable distribution and sustainable production practices. Secondly, the lower crop yields projected under the SSS scenario raise concerns about food demand and supply. Insufficient yields may exacerbate food insecurity and nutritional deficiencies, particularly among marginalized populations. The overexploitation of natural resources and unmanaged agglomerations threaten the long-term sustainability of food production, further challenging the achievement of food security goals. The findings of this analysis highlight the importance of considering equity and sustainable production practices when projecting crop yields and addressing food demand and supply in Haiti.

Table 7 Project crop yields under the BAU scenario

BAU Scenario				
Year	Dried Pulses	Grain Maize	Sorghum	Paddy rice
2030	0.94	1.04	1.07	2.7
2040	1.01	1.22	1.16	2.87
2050	1.08	1.38	1.24	3.02

Unit: Tons/ha

Table 8 Projected crop yields under the SSS scenario

SSS Scenario				
Year	Dried Pulses	Grain Maize	Sorghum	Paddy rice
2030	0.88	0.96	0.97	2.59
2040	0.9	1.07	0.98	2.67
2050	0.92	1.15	0.99	2.72

Unit : tons/ha

Table 9 Baseline: Crop production (2013)

Crop types	Yield/hectare	National Average yield/ha
Dried Pulses	1400kg/ha	
Grain Maize	0.5 - 3 t/ha	1 t/ha
Sorghum	0.5 - 1.50 t/ha	1 t/ha
Paddy rice	1.75 - 3.5 t/ha	3 t/ha

Baseline: Crop production (2013)

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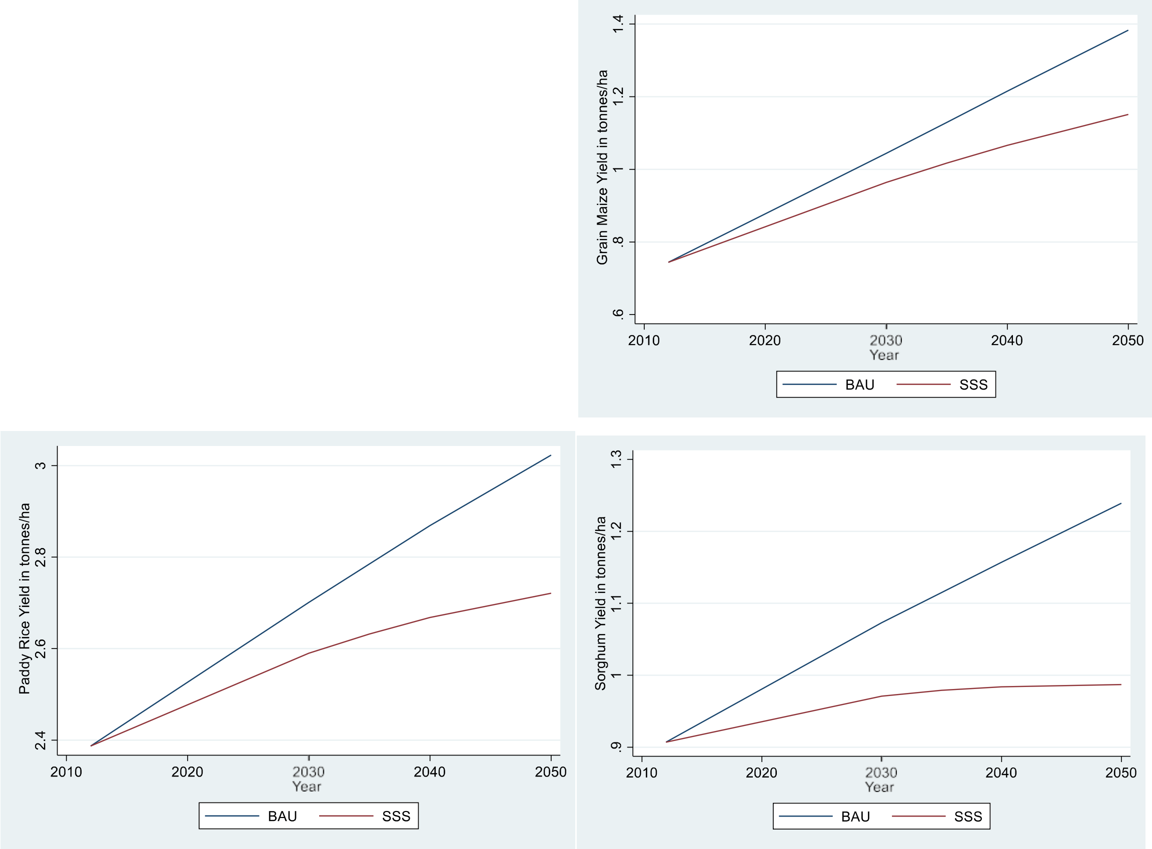

Figure 20 Crop yield of selected crops based on the scenarios BAU and SSS.

Source: Author's calculation and production based on data from FAO (2018). Crop yields reflect changes in crop yields arising from technological progress, climate change, and price effects. Aggregate values are weighted by harvested area.

An essential matter of inquiry revolves around the discrepancy observed in crop yields between the SSS scenario and the BAU scenario. In the SSS scenario, the projected crop yields are lower compared to the BAU scenario due to several factors inherent in the societal structure and dynamics described in the scenario. First, socio-economic disparities: The SSS scenario suggests the presence of separate social strata, including self-protected elite classes and marginalized populations. The decision-making power primarily resides with the elite, who may prioritize their own interests over sustainable resource management and climate change mitigation. This exacerbates socio-economic inequalities, with limited access to resources and opportunities for most of the population, including small-scale farmers.

Second, poverty and food insecurity: Increased poverty levels in the SSS scenario contribute to food insecurity (Siddiqui et al., 2020; Wight et al., 2014). Limited access to financial resources, inputs, and technology impedes farmers' ability to invest in improved agricultural practices and infrastructure. This leads to lower productivity, affecting for example maize yield. Third, lack of sustainable practices: The SSS scenario suggests that sustainable production practices are not prioritized. Without sufficient emphasis on conservation of natural resources, such as soil and water, and the adoption of sustainable farming techniques, agricultural productivity suffers (FAO, 2023b). Over time, this can lead to soil degradation, reduced fertility, and lower crop yields. Fourth, over-exploitation of resources: The scenario highlights the over-exploitation of natural resources, which includes land, water, and forests. Unmanaged agglomerations and unsustainable agricultural practices, such as excessive use of chemical inputs, contribute to environmental degradation. This degradation, coupled with the absence of proper resource management, negatively impacts the crop yields, and firth limited technological advancements: The SSS scenario may not prioritize technological advancements and innovation in the agricultural sector. Lack of access to modern farming techniques, improved seeds, and efficient irrigation systems hinders productivity gains and limits the potential for higher crop yields. Overall, the lower crop yields projected in the SSS scenario reflects the consequences of socio-economic disparities, over-exploitation of resources, and a lack of sustainable practices. These factors compromise both equity and sustainable production, ultimately affecting food demand and supply in Haiti.

The Food Security Council (referred to as CNSA in French) in Haiti has reported that the production levels of dehydrated legumes in the region are typically around 600 kg/ha for beans and 800 kg/ha for peas. Similarly, sorghum yields are also relatively low, ranging from 0.50 to 1.50 MT/ha, with an average of 1.00 MT/ha. Furthermore, the national average yield for maize is estimated to be 1 1M/ha (CNSA, 2013), underscoring the urgent requirement for enhancements in agricultural productivity in Haiti. As indicated, the predicted yields per hectare of these crops exhibit a slight increase compared to the actual yields observed on the field. These observations provide a baseline for comparing the projected yields under the BAU and SSS scenarios. The difference between the observed low yields and the projected yields can be explained by several factors:

First of all, the observed low dry bean yield for example represent the current state of dry bean productivity in Haiti (CNSA, 2013). This yield is influenced by a range of factors, including limited access to resources, availability and affordability of quality seeds, inadequate infrastructure, poor farming practices, and environmental constraints mainly droughts (Giordano, 2016). The observed yields serve as a starting point for understanding the existing challenges in dried pulse production. In contrast, the BAU and SSS scenarios are hypothetical scenarios that make certain assumptions about the future trajectory of socio-economic, technological, and environmental factors. These assumptions might include improvements in farming techniques, investments in agricultural infrastructure, policy interventions, or changes in climate conditions. The scenarios consider different drivers and dynamics that could affect crop yields in the future.

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Moreover, the BAU scenario assumes a continuation of current patterns, including potential interventions and investments aimed at improving agricultural productivity. These interventions could include the introduction of improved seeds, adoption of modern farming techniques, expansion of irrigation systems, or enhanced access to credit and inputs. The BAU scenario incorporates efforts to address the challenges identified in the observed low yields. Further, the SSS scenario introduces a different societal structure, characterized by socio-economic disparities, over-exploitation of resources, and limited sustainability practices. These dynamics, as described in the scenario, contribute to lower crop yields compared to the BAU scenario. The socio-economic disparities and unsustainable practices in the SSS scenario hinder equitable access to resources and impede sustainable agricultural development. It's important to note that the observed low yields and the projected yields under the BAU and SSS scenarios cover different timeframes. The observed low yields represent the current situation, while the scenario projections extend to 2030, 2040, and 2050.

The projected yields consider potential changes and developments over these time periods, including technological advancements, policy shifts, and evolving socio-economic conditions. It is noteworthy that the disparity between the crop yield observed in the field (as a baseline) and the projected yield under different scenarios is not significant. However, it is important to acknowledge that the current maize yield is insufficient to meet the demand and supply requirements of grain maize for the existing population. Moreover, the slight increase in projected maize yield under the various scenarios would still be inadequate to satisfy the demand and supply of grain maize, especially considering the additional 140 thousand people per year being added to Haiti's population.

To confront these challenges and attain a higher yield per hectare to adequately address the escalating demands and supply requirements resulting from the exponential population growth, the Haitian government should adopt a holistic approach that encompasses various aspects of food security. To this end, the following policy suggestions are proposed:

i. *Technology transfer and innovation* (Flórez Gómez et al., 2023; Lau & Yotopoulos, 1989): There is a need to enhance the transfer of technology and innovation to the farming communities in Haiti. This can include the introduction of new crop varieties, mechanization, and digital agriculture tools that can improve productivity, reduce post-harvest losses, and enhance market access.

ii. *Rural infrastructure development* (Omotoso et al., 2022)*:* The lack of adequate infrastructure in rural areas is a major constraint to agricultural productivity in Haiti. Investments in rural infrastructure, including roads, storage facilities, and market infrastructure, can enhance access to markets and reduce post-harvest losses.

iii. *Policy support* (Hayami & Ruttan, 1971)*:* There is a need for policy support that can enhance agricultural productivity and reduce food insecurity in Haiti. This can include policies that promote smallholder agriculture, improve access to credit and inputs, and enhance market access. Because it is argued that in politically and institutionally challenged areas, governments and institutions frequently face limitations in terms of their capacity and willingness to efficiently execute measures aimed at curbing deforestation for the purpose of land expansion. This holds true even when external initiatives offer economic incentives (Karsenty & Ongolo, 2012; Osaghae, 2007).

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iv. *Sustainable food systems*: Building sustainable food systems that prioritize equity, resilience, and environmental sustainability can enhance food security in Haiti. This can include promoting local food systems, reducing food waste, and enhancing the management of natural resources.

v. *Cross-sectoral collaboration*: Addressing the complex challenges of food insecurity in Haiti requires collaboration across sectors, including agriculture, health, education, and social protection. Cross-sectoral collaboration can enhance the impact and sustainability of food security interventions.

vi. *Climate-smart agriculture:* Given the vulnerability of Haiti to climate-related disasters mainly drought, it is important to firstly advocate for the implementation of a climate change adaptation policy because it has been contended that in order to safeguard crop production and ensure the continuity of food supply, farmers need to undertake adaptive measures and explore alternative approaches to mitigate the unavoidable and lasting consequences inflicted by climate change (Alam et al., 2011), and secondly promote climate-smart agriculture practices that can enhance the resilience of the farming systems (Saran et al., 2022). This can include the use of drought-tolerant crops, improved water management, agroforestry, and conservation agriculture. However, the feasibility of this relies on farmers' willingness to adapt to climate change, which may involve relinquishing their traditional practices, as policies pertaining to climate change adaptation cannot remain impartial to farmers.

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3.3.2. Farmers’ willingness to adapt to climate change.

3.3.2.1. Farmers’ willingness to use crop rotations.

A total of 488 participants were included in this study, with 57.38% identified as male and 42.62% as female. Among the respondents, 30.48% expressed their willingness to transition to crop rotation, while 69.52% stated their resistance to adopting crop rotation practices as described in Table 9. Among the surveyed individuals engaged in agricultural activities, a majority of 78.28% were found to practice crop cultivation; however, only 26.7% of them were open to shifting their crop rotation between seasons. This finding suggests that while a significant portion of farmers in the surveyed population are involved in crop cultivation, there is a notable resistance among them when it comes to adopting changes in crop rotation practices between seasons. This implies that there may be various factors or barriers influencing farmers' reluctance to shift their crop rotation, such as traditional farming practices, lack of awareness about the benefits of crop rotation, or concerns about potential risks and uncertainties associated with the change.

Table 10 Description of household characteristics

Variable		Number of respondents	Not Willing To Shif		Willing To Shift	
			Number of Respondents	(%)	Number of Respondents	(%)
Gender	Male	280	177	71.08	72	28.92
	Female	208	115	67.25	56	32.75
Activity	Agriculture	382	280	73.3	102	26.7
	Manufacturing/Service	35	11	31.43	24	68.57
Education	No formal education	111	73	72.28	28	27.72
	Primary school	225	142	71.72	56	28.28
	High school	126	70	67.31	34	32.69
	Vocational school	10	4	40	6	60
	University	12	3	42.86	4	57.14
Rainy season	Early	60	35	64.81	19	35.19
	On time	29	18	85.71	3	14.29
	Late	381	239	69.48	105	30.52
Farming system	Ongoing cropping	95	51	64.56	28	35.44
	Mixed cropping	319	233	73.97	82	26.03
Land tenure	Own land	323	229	73.87	81	26.13
	Renting land	82	54	66.67	27	33.33
Climate Observation	Less rain	55	29	58	21	42
	Raining late	30	7	31.82	15	68.18
	Rainy season ends early	162	93	72.09	36	27.91
	More hot days	218	152	75.25	50	24.75
	Less hot days	18	11	64.71	6	35.29

Source: Author’s calculation and production based on data from the surveyed population

When considering educational background, 46% of the respondents had received only basic education (primary school), 25.82% had completed high school, and 22.75% had no formal education. It was observed that respondents with higher levels of education (university or vocational background) exhibited greater willingness to adopt crop rotation compared to those with primary or high school education, including the uneducated respondents (refer to Table 3 for detailed findings). The results suggest that there is a correlation between educational background and the willingness to adopt crop rotation practices. Respondents with higher levels of education, such as those with a university or vocational background, were more inclined to embrace crop rotation compared to those with only primary or high school education, as well as those with no formal education. This implies that education plays a role in shaping farmers' attitudes and openness to implementing innovative agricultural practices like crop rotation (Feinstein & Mach, 2020). Farmers with a higher educational background may have a better understanding of the potential benefits and long-term sustainability associated with crop rotation, leading to their increased willingness to adopt this practice. On the other hand, farmers with lower educational levels may require targeted educational and awareness programs to enhance their knowledge and encourage them to adopt new farming techniques.

Among the survey participants, 81 out of 488 respondents (16.67%) reported a delayed onset of the rainy season over the past decade, but only 30.52% of them expressed their readiness to modify their crop rotation practices. The findings suggest that although a significant number of survey participants experienced a delayed onset of the rainy season in the past decade, only a relatively smaller proportion of them were willing to adjust their crop rotation practices accordingly. This implies that while some farmers recognize the changing climate patterns and its impact on the agricultural seasons, there might be hesitancy or resistance in adapting their farming practices to align with these shifts. The reasons for this reluctance could vary and may include factors such as ingrained traditional practices, concerns about potential risks or uncertainties associated with changes in crop rotation, lack of awareness about suitable alternatives, or perceived challenges in implementing new approaches. Addressing these barriers and providing support, education, and incentives to farmers may be crucial in encouraging a greater uptake of modified crop rotation practices in response to changing climate patterns.

The farming system analysis, as presented in Table 3, revealed that 65.37% of the respondents engaged in mixed cropping, a farming method involving the simultaneous cultivation of multiple crop types on the same agricultural plot. Within this subgroup, only 26.03% expressed their willingness to alter their crop rotation patterns. This suggests that while mixed cropping is a prevalent farming method among the respondents, a significant portion of them are not open to altering their current crop rotation patterns. This resistance to change could be due to various reasons such as familiarity with the existing practices, concerns about potential risks or uncertainties associated with altering crop rotation, or perceived benefits of the current system. The low percentage of respondents willing to modify their crop rotation patterns within the mixed cropping subgroup may indicate a need for targeted interventions or strategies to encourage and educate farmers about the potential benefits of altering their crop rotation. These interventions could focus on promoting sustainable agricultural practices, increasing crop diversity, improving soil health, reducing pests and diseases, or enhancing overall productivity and profitability.

The assessment of land ownership also reveals that many of the surveyed farmers (66.18%) operate on their own land. However, within this group, a significant majority (73.87%) demonstrated reluctance to change their crop rotation practices adapting to climate change. This implies that despite owning their land, a substantial number of farmers are resistant to altering their crop rotation practices for climate change adaptation purposes. This reluctance could stem from various factors such as a lack of awareness or understanding about the potential impacts of climate change on their farming operations, skepticism about the effectiveness of changing crop rotation, concerns about potential risks or uncertainties associated with adopting new practices, or limited access to resources and

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support for implementing alternative crop rotation strategies. The findings suggest that there may be a need for targeted education and outreach climate change adaptation programs to raise awareness about the importance of adapting agricultural practices to climate change. It may also be necessary to address the specific barriers or challenges that prevent farmers from changing their crop rotation practices, such as providing financial incentives, technical assistance, or access to climate-resilient crop varieties. Overall, the reluctance of most farmers who own their land to change their crop rotation practices highlights the importance of understanding and addressing the specific concerns and constraints faced by farmers in adopting climate-smart agricultural strategies.

What are the implications of the identified findings, specifically the reluctance of farmers to change their crop rotation practices, for food production in the country, particularly under ongoing climate-related disasters like drought?

i. *Limited Adaptation*: The reluctance of most farmers to change their crop rotation practices suggests that they may be less prepared to adapt to climate-related disasters, such as drought. As a result, their agricultural systems may be more vulnerable to the impacts of water scarcity and reduced rainfall, leading to potential decreases in crop yields and overall food production.

ii. *Reduced Resilience*: Without altering crop rotation patterns, farmers may have limited diversity in their agricultural systems, which can impact the resilience of their production. Crop rotation plays a crucial role in managing soil health, pests, diseases, and nutrient balance. By not adapting their practices, farmers may face greater challenges in maintaining soil fertility, managing pests, and adapting to changing climatic conditions, ultimately affecting their ability to sustain food production.

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iii. *Increased Risk*: Climate-related disasters, particularly drought, can exacerbate the challenges faced by farmers who are not willing to change their crop rotation practices. Drought conditions can intensify water scarcity, reduce crop yields, and increase the risk of crop failure. Farmers who rely on a single or limited set of crops without adapting their practices may face higher risks of production losses and economic hardships.

iv. *Need for Supportive Measures*: The findings highlight the importance of implementing supportive measures to assist farmers in adapting their crop rotation practices and enhancing their resilience to climate-related disasters. This can include providing access to climate information, promoting sustainable farming techniques, offering financial incentives for adopting climate-smart practices, and improving access to resources and technologies that support climate resilience.

3.4. Conclusion

This research firstly evaluates and forecasts the potential yields of primary food crops and cash crops in Haiti, specifically for the years 2030 and 2050, to determine whether they can sustain the growing food demands of the Haitian population. Two scenarios are considered. The first scenario, known as "Business As Usual (BAU)," represents the current socio-economic, technological, and environmental patterns that inadequately address food-related challenges. It incorporates indicators such as economic growth, policy, conservation practices, and yields. The projected yield ranges for specified crops under the BAU scenario are: dry legumes (0.9 to 1.08 ton/ha), maize (1.04 to 1.038 ton/ha), sorghum (1.07 to 1.24 ton/ha), and paddy rice (2.7 to 3.02 ton/ha). These projections are subject to the influence of climate change and socio-economic factors. The second scenario, called

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"Stratified Society" (SSS), depicts a society with distinct strata and decision-making power concentrated in an elite class. The SSS scenario incorporates the same indicators as BAU, with the addition of population growth and inequality. Results show that crop yields under the SSS scenario are lower than BAU, making them insufficient to meet local food demand. For example, projected yield ranges for dry pulses are estimated to be between 0.88 and 0.92 tons/ha from 2030 to 2050, 0.96 to 1.15 tons/ha for maize, 0.97 to 0.99 tons/ha for sorghum, and 2.59 to 2.72 tons/ha for paddy rice. These figures are not significantly different from the current national average yields per hectare for these crops. Proactive measures and sustainable agricultural practices are crucial to ensure future food security in Haiti, considering the potential variation in crop productivity influenced by climate change and other socio-economic factors.

Secondly, the research also tests and evaluates farmer's willingness to apply adaptation measures on their farms to face climate change impacts. The results show that that there is a varied level of willingness among farmers to adapt to climate change, especially using crop rotations. The willingness to adopt specific adaptation practices also differs among farmers (78.28%) engaged in agricultural activities. Factors such as educational background and experience of climate change impacts play a role in shaping farmers' willingness to adapt. Farmers with higher levels of education, such as those with a university or vocational background, demonstrate greater openness to adopting adaptive measures like crop rotation. This suggests that education equips farmers with knowledge and awareness about the benefits of adaptation practices, making them more receptive to change.

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However, when it comes to specific adaptation practices like shifting crop rotation or modifying crop types, the willingness of farmers diminishes. Only a minority of farmers express a willingness to make such changes, indicating that there may be barriers or challenges hindering their adoption. These barriers might include attachment to traditional practices, concerns about potential risks or uncertainties, and limited awareness of suitable alternatives. Additionally, the statistics reveal that farmers who have experienced a delayed onset of the rainy season are not universally inclined to adjust their crop rotation practices. Despite perceiving the climate change impact, a significant proportion of farmers do not express readiness to modify their agricultural practices accordingly. In short, while some farmers demonstrate a willingness to adapt to climate change impacts, there are significant barriers and variations in their readiness. Addressing these barriers, such as providing education, raising awareness, and offering support and incentives, can play a pivotal role in enhancing farmers' willingness and capacity to adapt to climate change, especially drought which constitutes one of the major problems of agricultural production in Haiti. More details will be given in the following chapter which is focused on agricultural drought.

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Chapter 4

Agricultural Drought Risk Assessment in HAITI

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4. Chapter 4. Agricultural Drought Risk Assessment in HAITI

4.1. Introduction

Droughts are complex natural hazards (Bachmair et al. 2015). Existing studies have documented that this climate hazard results from lack of rainfall or a significant change of normal precipitation, leading to a deficit of water availability (Vogt & Somma, 2013). Droughts are recognized as the most complex and severe type of climate disaster affecting the entire food system with wide-ranging cascading impacts. Some previous studies have found that droughts are the most detrimental of all-natural disasters (Cook et al., 2007; Mishra & Singh, 2010), especially in terms of economic impacts (Wilhite, 2000). Recent studies have estimated that annual worldwide economic losses due to drought range from 6 to 8 billion dollars (Zeng et al., 2019; Zhang et al., 2015), with disproportionate losses centered on the agricultural sector. Droughts generate long-term social, economic and environmental impacts, affecting many people and regions, with about half of the world's land area at chronic risk of drought (Kogan, 1997). While the influence process of droughts are slow to materialize (Vogt et al. 2011), they can cover extensive areas and last for many years, with devastating impacts on the agriculture sector, the environment and water management (Sheffield & Wood, 2012). Droughts have become recurrent in many parts of the world, including the Caribbean region, where agriculture plays a central role in the economy. For example, from 1992 to 2016, Haiti experienced nine drought episodes including one in 2016 which affected 3.6 million people. Haiti’s economy is largely agrarian, and these drought events have had a severe impact on crop production and livestock farming. The World Food Program (WFP, 2016) reported that the 2016 drought affected 70% of Haiti’s staple crops, leading to long-term negative economic suffering among the rural population. Similarly, the Food and Agriculture Organization (FAO) (2020) found that the 2018-2019 drought in Haiti resulted in a 12% year-on-year decline in local crop production. These events resulted in significant direct and indirect income losses for smallholder producers and also restricted their access to food due to rising food prices.

Drought frequencies and intensities are increasing (Li et al., 2019; Mohsenipour et al., 2018) and this trend is projected to continue in the future with climate change and increased water demand (Jiao et al., 2019; Pei et al., 2019). As evidence, under the climate change scenario, it is found in a recent study on the influence of climate change-induced drought propagation on wetland in South Korea from 2021 to 2060, meteorological and hydrological conditions, including agricultural drought duration, severity, and frequency, were projected to increase throughout the study area (Jehanzaib & Kim, 2020). In response, disaster scholars are urging the formulation and implementation of effective adaptation and mitigation policies (Wijitkosum & Sriburi, 2019). Drought-coping capacity measures refer here to various types of specific actions that contribute to the mitigation of drought impact at different scales to limit social, economic and environmental vulnerability. The impacts of natural disasters, including those related to drought, can be reduced through mitigation and preparedness (Wilhite 2003). This calls for addressing drought triggers and the spatial pattern of drought risk, including associated factors (Belal et al., 2014; Hoque et al., 2020). Drought risk mapping is a key component of such mitigation measures. Risk mapping is frequently used for risk analysis in risk management frameworks. Several previous studies have stressed that drought risk mapping provides spatial information on hazard characteristics (e.g., location, intensity, frequency and probability) and incorporates this

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information in the mapping of the risk components including the risk itself to clearly present spatial drought distribution information (Pei et al., 2019; L. Zhang et al., 2020).

Risk herein is defined as the probability of damage and losses resulting from interactions between hazards and vulnerable conditions (UNDRR, 2009). In other terms, risk is the interchange between different risk components (vulnerability, hazard, and exposure, including adaptive capacity) (Gu et al., 2017). “Hazard” is defined as a physical event or phenomenon that may cause harmful effects in a given area or a system, whilst vulnerability is the degree to which a system acts adversely to the occurrence of the hazardous event (Timmerman, 1981). Exposure represents people, livelihoods, systems or other elements present in the hazardous zone that are thereby subject to potential losses. Adaptive capacity has to do with alleviation measures that are defined and taken to minimize the hazard effects (Khan, 2008). Risk maps can be used by policy makers to develop countermeasures to reduce drought impacts (Belal et al., 2014). Drought risk assessment calls for analyzing the risks that threaten food production and strategies for reducing those eventual risks. In this specific context, large spatial and non-spatial datasets are needed (Hao et al., 2012; Hoque et al., 2020). Several scholars have stressed the need for spatial analysis techniques for effective assessment, including remote sensing (Zeng et al., 2019). Through they can be performed separately, hazard and vulnerability assessments together form a major part of the overall risk analysis. However, the difference between risk analysis, hazard analysis and vulnerability analysis remain poorly defined. "Risk" and "vulnerability" are applied quite loosely, with some overlap, where most vulnerability assessments incorporate a wider risk analysis, whilst "risk assessment" centers on vulnerability (Twigg, 2015). Existing literature describes approaches for drought risk

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mapping (Guo et al., 2016; Hoque et al., 2020; Zeng et al., 2019). However, multicriteria-based mapping methods are recognized as being indispensable for providing comprehensive information on drought risks, owing to their inherent complexity and intrusiveness (Ajaz et al., 2019).

In mapping various natural hazards, previous studies used multiple criteria decision methods (MCDM) such as the analytic hierarchy process (AHP), fuzzy analytic hierarchy process (FAHP) approach, fuzzy logic (Hategekimana et al., 2018; Hoque et al., 2020; Hoque et al., 2021; Jun et al., 2013), statistical models (Bui et al., 2011), and machine learning (Dayal et al., 2017). For example, to map landslide hazards, Gorsevski et al. (2006) developed a heuristic approach integrating fuzzy logic with AHP. Similarly, AHP has been used to determine criteria weights for mapping landslide susceptibility in Bostan Abad, Iran (Feizizadeh et al., 2011). Multi-criteria decision analysis and GIS techniques have also been used to perform landslide hazard zone mapping elsewhere in Iran (Othman et al., 2012). These models are considered to be among the most important hazard assessment tools (Dayal et al., 2018b). However, multi-criteria decision-making is more accurate and subjective when using fuzzy logic because it reduces imprecision and subjectivity (Al-Abadi, 2017).

The Caribbean region, including Haiti, is frequently affected by multi-decadal droughts (Lane Chad S., 2014). The region accounts for seven of the world's top 36 water-stressed countries (FAO, 2016). While numerous drought studies have been carried out in this region where agriculture is particularly vulnerable to climate change (Beharry, 2019; FAO, 2016), very few studies have applied agricultural drought risk mapping. Agriculture is also the sector most vulnerable to the seasonal nature of regional drought (FAO, 2016).

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A recently study (Herrera, 2020) analyzing the dynamic characteristics of drought in the Caribbean fails to properly emphasize specific risk components, i.e., vulnerability, hazard, exposure, and coping capacity. In addition, Herrera's (2019) drought study simply applied the Standardized Precipitation Index (SPI) to build a baseline scenario for meteorological droughts. A study on agricultural drought assessment carried out in Australia used some limited indicators through machine learning approaches without taking into account the required risk parameters (Feng et al., 2019) or geospatial techniques while considering all the risk factors (Hoque et al., 2021). Similarly, a component of the risk equation (hazard) was also used with some corresponding variables to map agricultural risk through machine learning approaches (Rahmati et al., 2020). In this study, as the disaster bearing body is agriculture, more corresponding variables for the different risk components to represent the real agricultural drought conditions have been used. Few related studies have sought to integrated all risk parameters with these relevant indicators in drought risk mapping.

Mapping accurate and detailed information about agricultural drought risk requires selecting the appropriate risk components and their applicable indicators (Belal, 2014).It is also necessary to incorporate specific criteria related to coping capacity in the appropriate drought risk assessment procedure to obtain the most up-to-date drought risk information (Hoque, 2018) for management purposes. In this study, using the risk equation, the agricultural drought risk is evaluated: (i) without including the adaptive capacity in the equation, and (ii) including the adaptive capacity as a risk component in the risk equation. Effectively managing the risks of agricultural drought in the Caribbean region requires a detailed assessment incorporating all risk components and their corresponding criteria, especially for countries that are drought prone (e.g., Haiti) (Singh & Barton-Dock,

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2015). Although the region has been exposed to severe and long-term drought episodes, no previous study has conducted a detailed and exhaustive agricultural drought risk assessment incorporating all risk components with their relevant indicators using the fuzzy logic approach. The application of this mapping method is completely new to the Caribbean region including Haiti. This study addresses this knowledge gap, taking a broader perspective to account for the overall risk level because it is argued that for reliable drought-related decision-making, accurate monitoring, forecasting, and comprehensive assessments are essential (Kim & Jehanzaib, 2020). Geospatial techniques are applied to evaluate Haiti's agricultural drought risk, including various risk components with their appropriate indicators.

4.2. Materials and Methods

This study conducts exhaustive agricultural drought risk mapping using fuzzy logic-based MCDM techniques by integrating different risk components such as vulnerability (V), hazard (H), exposure (E) and adaptive capacity (AC). A variety of studies point out that MCDM is a very effective way to analyze vulnerability, susceptibility, and the impact of certain hazards (Mullick, 2019; Sahana & Patel, 2019). The resampling technique from Arc Toolbox in ArcGIS was used to obtain a similar pixel size (10 meters) to prepare each risk component criterion. Which are subsequently ranked based on their respective influence on agricultural drought risk. The resampling in ArcMap modifies the spatial resolution of a raster dataset and sets rules for assembling or interpolating values across new pixel sizes. The ArcGIS's toolbox fuzzy membership function is then applied as a possible basis for an application of fuzzy overlay to obtain the different risk components maps (Figure 21).

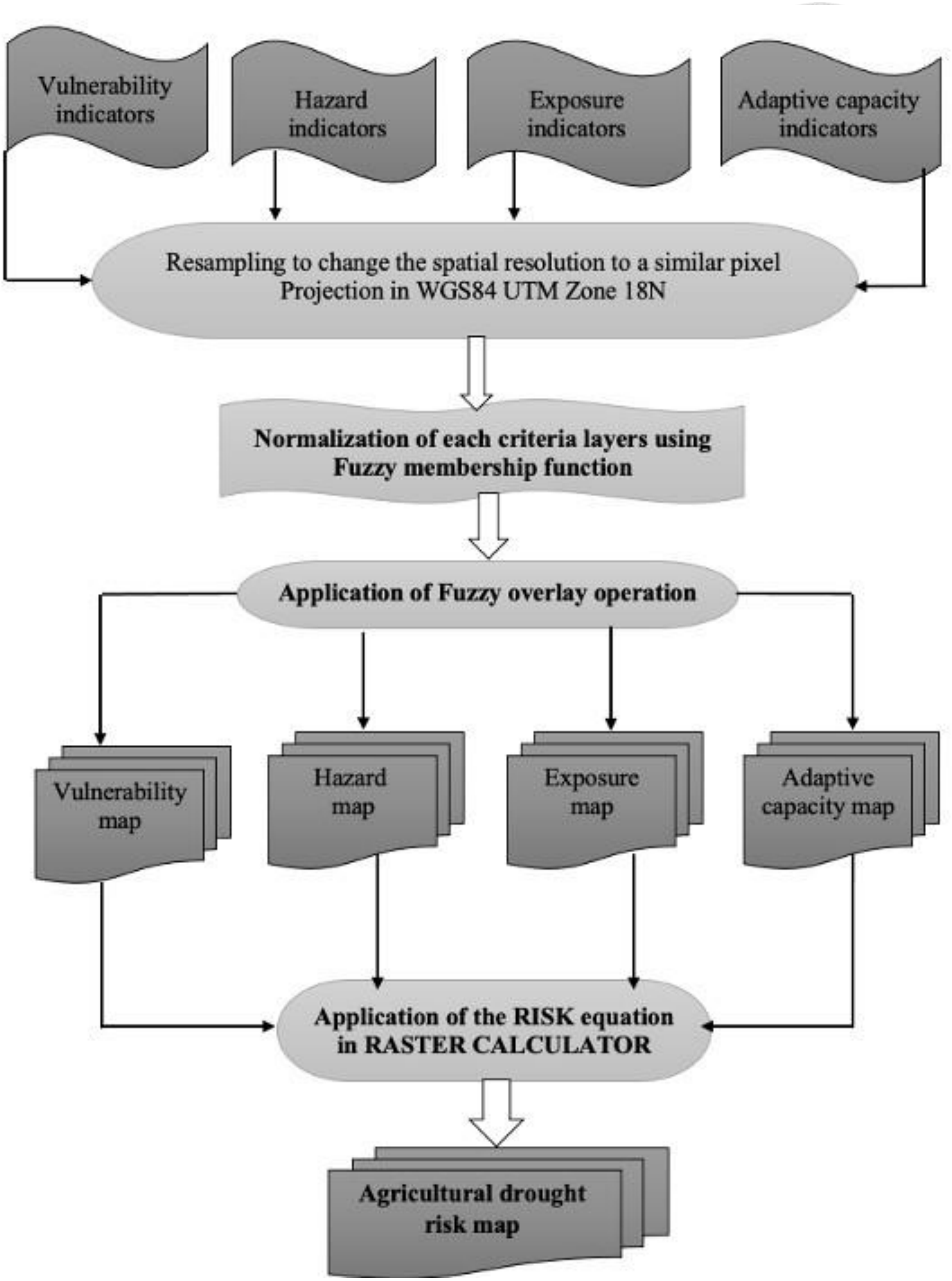

Figure 21 Basic processing flowchart of the mapping technique
Source : Author's production

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4.3. Study area and data

Haiti takes up the eastern part of the island of Hispaniola in the northern Caribbean (18° 32' 21" N and 72° 20' 11" W). The country is divided into ten regions that collectively present an area of approximately 27,750 km^2 (Figure 22). Haiti has a tropical savanna climate, according to the Köppen Classification. Average annual temperatures vary between 25°C and 30°C, and between 26°C and 29°C in coastal areas. There are three production cycles: the spring season, which extends from March to July; the summer/fall season, from July to November; and the fall/winter season, which takes place between November and March (MARNDR, 2014). Spring is considered the main production season since it contributes about half of total annual production of cereals, pulses, and tubers (CNSA, 2014). The livelihoods of more than 80% of Haiti's 12 million people depend on agriculture, which accounts for 60% of the labor force and contributes 25% of the gross domestic product. In general, agricultural yields are low throughout the country, mainly due to extreme climatic conditions, especially drought. Haiti's staple crops include bananas (plantain), rice, maize, wheat flour, tubers, dry beans, peas, and sorghum. Rice is the most important cereal crop, followed by maize and sorghum. More than 70% of the current food crops are harvested from rainfed farming. Over the past decade, the annual crop production growth rate was only 2% (Assouline & Dicko, 2019). This low productivity was the result of poor agricultural practices, low inputs, low mechanization, and climate related disasters mainly droughts. The country's terrain is also characterized by steep slopes and impoverished soils, and only 27.75% of Haiti's land is classified as cultivable.

Haiti is prone to climatic hazards such as floods and particularly droughts which are endemic in most of the country's regions (Figure 22). Drought events have a direct impact on the farming calendar, agricultural practices and main crop yields. During dry seasons, riverbeds dry up, but flood during the rainy season. Whereas Haiti's rainy season used to last from January to March, today it begins in late March. This dramatic shift has deeply disrupted agricultural planning and hinders the planting of rainfed crops such as maize and dry beans. As a result, seasonal crop yields are dramatically reduced, thus impacting farmers' ability to cope with episodic food insecurity.

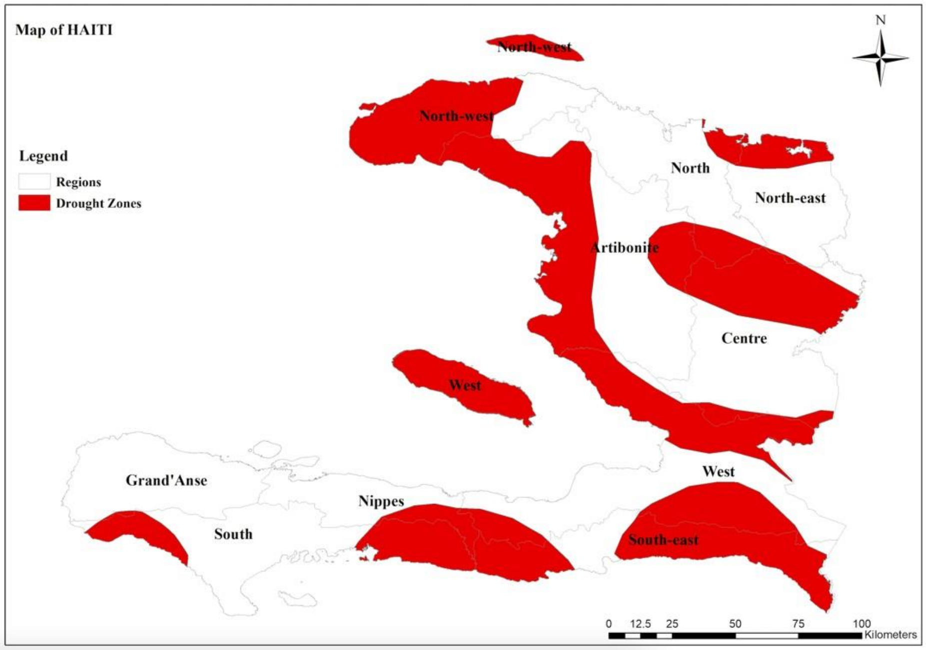

Figure 22 Map of Haiti with observed drought prone-areas

Source: Author's production based on data from https://shorturl.at/lpJNU

4.4. Data

Agricultural drought is defined as an insufficient amount of moisture in the soil that hampers plant growth or crops yields (Hong et al., 2021; Huang et al., 2015). Agricultural drought is induced by mostly climatic as well as socio-economic factors. Increased frequency and severity of extreme weather events under climate change can increasing the incidence of agricultural drought (Ahmad, 2016). Other studies have found that low levels of soil moisture can result in agricultural drought, significantly damaging crop yields. Thus,

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various soil moisture-based indicators such as Crop Moisture Index, Soil Moisture Percentile (Sheffield et al., 2004), Standardized Soil Moisture Index (Hao et al., 2014), and Soil Water Deficit Index (Martínez-Fernández et al., 2016) have been generated to measure agricultural drought. For the present study, all relevant and available parameters that could influence agricultural drought frequency are used to determine the various risk components alongside available adaptation options to generate risk maps. Based on previous work (Baik et al., 2019; Dayal et al., 2018b; Pei et al., 2018; Zeng et al., 2019), we define and attribute four separate indicators to each risk component from various sources for a total of sixteen dynamic indicators. Data characteristics are summarized in Table 11. All the indicators are chosen based on previous studies and their relevance to agricultural drought risk studies (Baik et al., 2019; Dayal et al., 2018b; Hao et al., 2012; Pei et al., 2018; Zeng et al., 2019). ArcMap is used to prepare the thematic layer of the risk component for each variable. The following sections describe the mapping techniques of each criterion and their relevance to this study.

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Table 11 Data types and relevant sources

No.	**Indicators (Owning component) a**	**Format**	**Period**	**Source**
1	Soil depth (V)	GeoTIFF	2017	ISRIC World Soil Information
2	Soil moisture (V)	GeoTIFF	1958 – 2020	TerraClimate (Abatzoglou et al., 2018)
3	Clay (V)	GeoTIFF	2017	ISRIC World Soil Information
4	Sand (V)	ASCII	2017	ISRIC World Soil Information
5	Elevation (V)	ASCII	N/ A	FAO Soils Portal (Fischer et al., 2008)
6	Slope (V)	GeoTIFF	2017	Author’s calculation using the elevation
7	Rainfall (H)	ASCII	1958-2020	TerraClimate (Abatzoglou et al., 2018)
8	Temperature (H)	GeoTIFF	1958 – 2020	TerraClimate (Abatzoglou et al., 2018)
9	Evaporation (H)	GeoTIFF	1958 – 2020	TerraClimate (Abatzoglou et al., 2018)
10	Relative humidity (H)	ASCII	1980 – 2020	NASA POWER data
11	LULC(E)	Shapefile	2020	Esri Land Cover Sentinel-2
12	Population density (E)	GeoTIFF	2020	WorldPop (Bondarenko, 2020)
13	NDVI (E)	GeoTIFF	2021	https://earlywarning.usgs.gov/fews/product/447
14	Crop prod. harvest area (E)	GeoTIFF	2010-2016	Havard Dataverse
15	River distance (AC)	GeoTIFF	N/A	HydroRIVERS Version 1(Lehner, 2019)
16	River density (AC)	GeoTIFF	N/A	Author’s calculation
17	Distance to road (AC)	GeoTIFF	N/A	Author’s calculation
18	Plant Av. Water Cap. (AC)	GeoTIFF	2017	ISRIC World Soil Information

a. Refer to section 2.2.1.

4.5. Risk mapping

The present agricultural drought risk analysis is based on the classic risk-assessment approach defined by IPCC (Cardona et al., 2012) where risk is a function of the components of vulnerability, hazard and exposure. Preparation of risk maps involves analyzing several variables and parameters that can be broken down into these three components. Obviously, this process is important in preparing risk maps for the management and reduction of drought risk for farming. We use the following equation for this purpose: Risk = Vulnerability (V) * Hazard (H) * Exposure (E) (Eq. (1)). This equation has been used in several past studies such as mapping spatial drought risk in a drought-prone region (Dayal et al., 2018b). Several previous studies (Belal et al., 2014; Hoque et al., 2018) stressed the minimize eventual agricultural draught impacts by incorporating available adaptation options into the appropriate drought risk assessment procedure. This implies the importance of incorporating the AC into the equation to access the latest drought risk information. Thus, we therefore integrate the adaptive capacity (AC) into Eq, (1) to obtain the actual drought risk details, which is corresponded to a related study on agricultural drought risk assessment in Australia (Hoque et al., 2021). Hence, Risk = V* H * E / AC (eq (2)). Based on this formula, four maps for each component are projected to be produced. Socio-economic, environmental and physiographic factors (see section 2.2.3) are used to produce these risk components due to their ability to influence drought intensity. The process includes four stages as defined in Eq. (2) in mapping and subsequently analyzing each component using their related criteria to finally generate risk maps by applying the raster calculator of the ArcMap's toolbox function.

4.5.1. Vulnerability mapping

The term "vulnerability to natural hazards" refers to a set of conditions and processes caused by physical, social, economic, and environmental factors which increase a community's susceptibility to the effects of certain hazards. We mapped drought vulnerability using the criteria of soil depth, soil moisture, soil clay percent, sand percent, elevation and slope (Figure 23 & Figure 24). These elements are crucial in assessing agricultural drought vulnerability. Clays and sands play a significant role by holding mineral nutrients and retaining water in the soil for plant growth (Ceballos et al., 2002; Jain et al., 2015). The higher the soil's clay content, the higher its water retention capacity, and the lower its hydraulic conductivity (Kutılek & Nielsen, 1994). In addition to increasing water storage, clays also provide a large number of micropores promoting free drainage of water, aeration, evaporation and gas exchange in the soil profile (Easton, 2021).

In the same way, sand percent also regulates water holding capacity, but it works in the inverse and has the opposite effect on drought (Pandey et al., 2012). The soil depth differences have a significant impact on soil moisture retention. Deeper soil provides more root space, allowing for growth competition among plants. Shallow soils experience greater evaporation and thus provide lower nutrient concentrations for plants (Schimel et al., 1985; Turner, 2019), while deeper soils may reduce the effect dimensions of drought on plants and soil properties (Schwinning & Sala, 2004). Lastly, soil moisture is a parameter widely used to assess and analyze agricultural drought vulnerability (Hoque et al., 2021; L. Zhang et al., 2020) because higher soil moisture levels correspond with reduced agricultural drought vulnerability (Hoque et al., 2020). Also, high-elevation and slope region cropland resources are more exposed to drought hazard due to their low water holding capacity (Dayal et al., 2018b; Zeng et al., 2019).

4.5.2. Hazard mapping

Climate variables are well-known as climate hazards. Thus, as illustrated in Figure 25, this study maps the hazard component using four climatic variables: mean rainfall, maximum temperature, mean humidity and evaporation. Previous studies (Dahal et al., 2016) have indicated that agricultural drought is highly influenced by these sub-factors. For example, it is widely acknowledged that rainfall scarcity and humidity enhance drought conditions. Therefore, areas experiencing rainfall shortage and low humidity are recognized as drought-prone areas (Esfahanian et al., 2017). In contrast, drought conditions are less likely to develop in areas with low temperatures and low evaporation (Karamouz et al., 2015).

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4.5.3. Exposure mapping

Exposure entails population, infrastructure, and built surfaces prone to hazards. Vegetation index has been taught of as an important criterion by numeral scientists for mapping agricultural fields, predicting weather impact, crop yields including drought condition assessment (Chakraborty & Sehgal, 2010; Dabrowska-Zielinska et al., 2002; Sruthi & Aslam, 2015). NDVI (Normalized Difference Vegetation Index) is the most commonly used, simplest, and most efficient of the vegetation indices (Liu & Huete, 1995). Consequently, these two variables (crop production harvest area and NDVI) in conjunction with land use land cover (LULC) and population density have been applied to generate the exposure map (Figure 26). Based on the LULC, Haiti is largely dominated by scrub/shrub (description can be found here: https://shorturl.at/mzKOV). However, in terms of weighting, croplands are ranked highest while water bodies, snow, flood vegetation, cloud including bare ground were ranked negatively (masking) because the present study is primarily concerned with cropland.

4.5.4. Parameters for adaptive capacity mapping

Agricultural drought resilience and vulnerability are affected by actions taken to mitigate drought impacts and increase drought preparedness (Solh & van Ginkel, 2014). Agricultural risk mitigation is a strategy to prepare for and lessen the effects of the drought threats. Similar to risk reduction, implementing adaptation strategies minimizes the negative effects of drought on crops. To map adaptive capacity, this study uses parameters including plant water available capacity (PAWC), distance to river and river density, and distance to roads (Figure 27). Agricultural droughts are more likely to occur in places far from river channels, and it is easier to mitigate drought conditions if river channels are

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located near cropland (Thomas et al., 2016). Similarly, regions with high river density are less vulnerable to drought impact than those with low river density (Pandey et al., 2012). Road networks are also a key agricultural infrastructure component and are critical in providing disaster aid and relief as well as facilitating manual irrigation. In disaster response, roads are indispensable in building resilience by connecting farmers (Gajanayake et al., 2020). Most of the data used herein are available at a global scale. We used GIS techniques to extract data for the study area. Euclidean distance has been used to create raster layers reflecting distance to roads and rivers, while line density was applied to generate a raster layer related to drainage density. PAWC is a key determinant of potential yields in dryland agriculture. PAWC is the maximum amount of water stored in a soil profile that can be used by plants. Different soils have different PAWC values. Increasing soil PAWC would decrease the frequency and the impact of future agricultural droughts. Likewise, an increase of PAWC will reduce agricultural drought vulnerability by enhancing local mitigation capacity against agricultural drought (Stone & Potgieter, 2008). It has been used as one of the mitigation capacity indicators to assess agricultural drought in Northern Australia (Hoque et al., 2020); whereas it has been chosen as a vulnerability indicator for agricultural risk assessment in Southwest China (Zeng et al., 2019). In this study, it is selected as an indicator of adaptive capacity because in the context of climate change, adaptive capacity means "deployed to adapt to perturbations in growing or living conditions or shocks brought on by climate change". It has been known as the second important property that refers to the responsiveness of agri-food systems when faced with

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extreme conditions[7]. In other words, it is the amount (whether small or large) of water available that could be used by plants in case of drought event.

4.5.5. Assigning weight to the criterion

The ArcMap reclassification tool was used to classify all the parameters (raster layers) according to their contributions to soils for plant growth and agricultural drought. A scale of 5 to 25 was defined, with 5 (very low), 10 (low), 15 (moderate), 20 (high), and 25 (very high). Following that, fuzzy-large/small/linear from the fuzzy membership function were used for each indicator. Details for using these functions are provided by (Mullick et al., 2019). The fuzzy membership function expresses the degree of similarity between the data value at a specific location and the prototypical value of its class, or its centroid, with a value between zero and one (Goldszal & Pham, 2000). Table 14 (Appendix 2) provides details for each indicator and its associated fuzzy membership function (e.g., the fuzzy linear function is used for the population density parameter).

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[7] https://shorturl.at/aoT07

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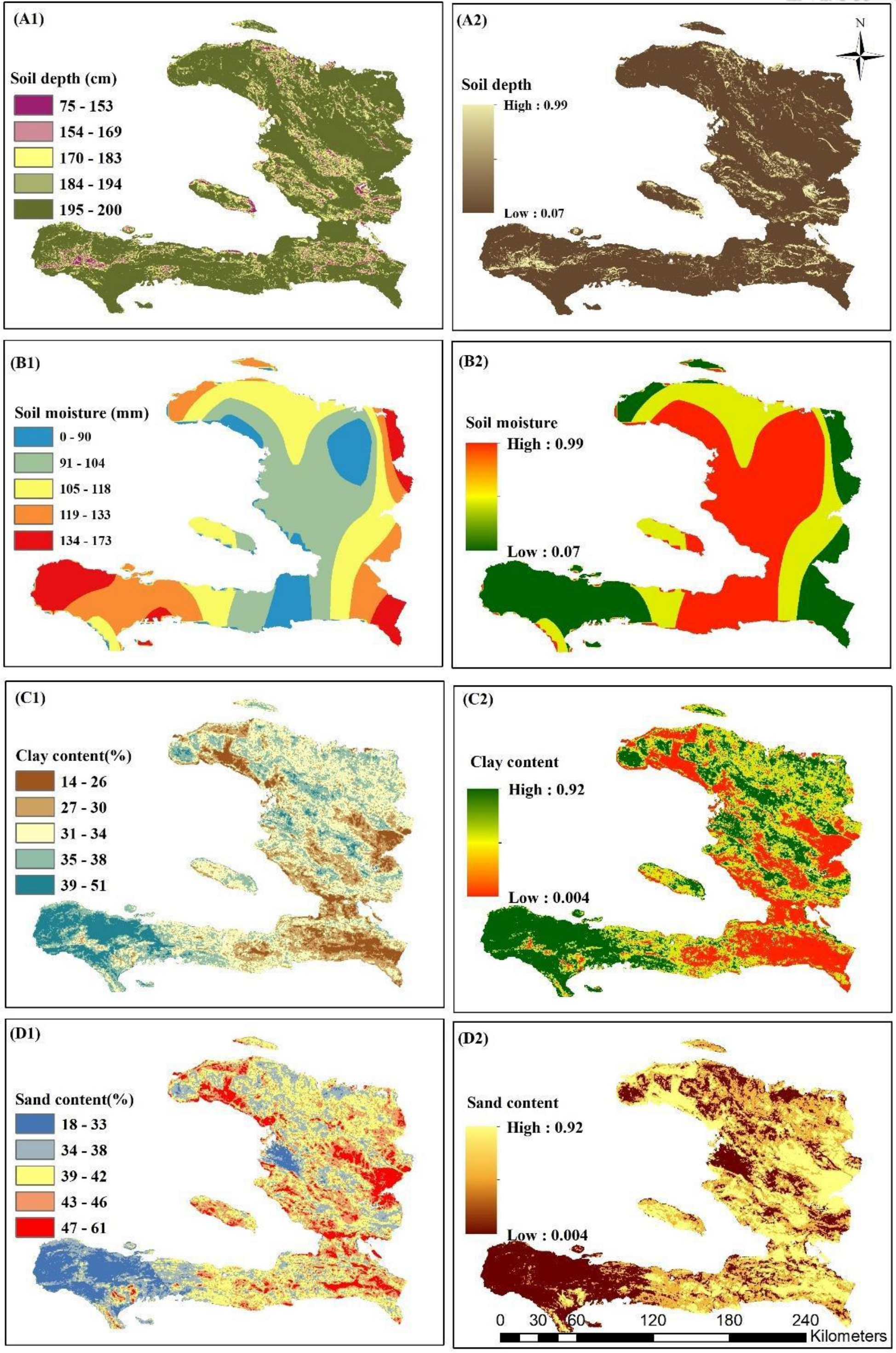

Figure 23 Original drought vulnerability indicators (a)

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Note : The maps are produced by the Autor using a mix of geospatial techniques (a) Original drought vulnerability factors in absolute units (left): (A1) soil depth, (B1) soil moisture, (C1) clay content, (D1) sand content and corresponding standardized vulnerability factors (right) using fuzzy membership

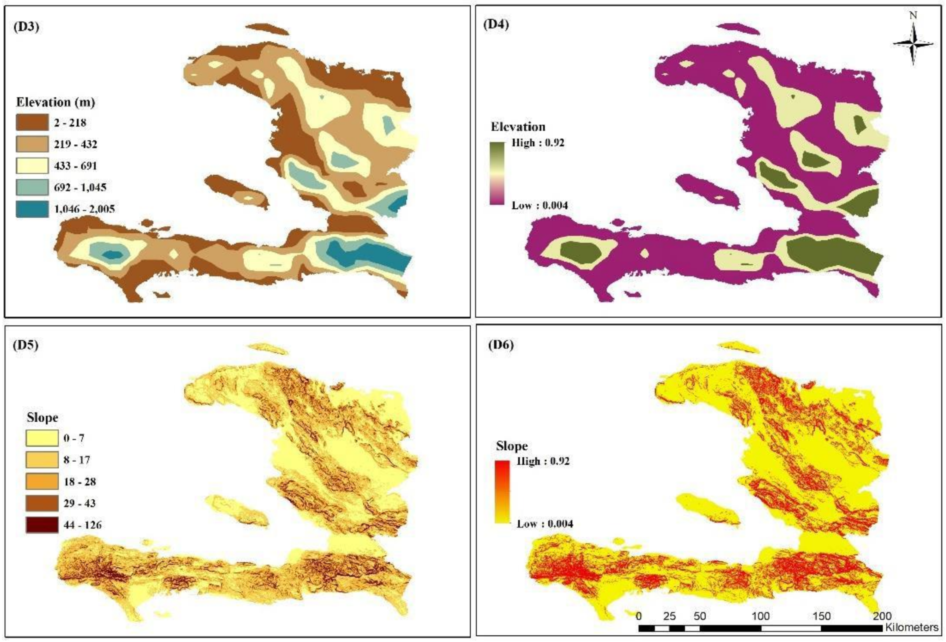

Figure 24 Original drought vulnerability factors in absolute unit (a)

Note : The maps are produced by the Autor using a mix of geospatial techniques (left): (D3) elevation and (D5) slope with their corresponding standardized vulnerability factors (right) using fuzzy membership

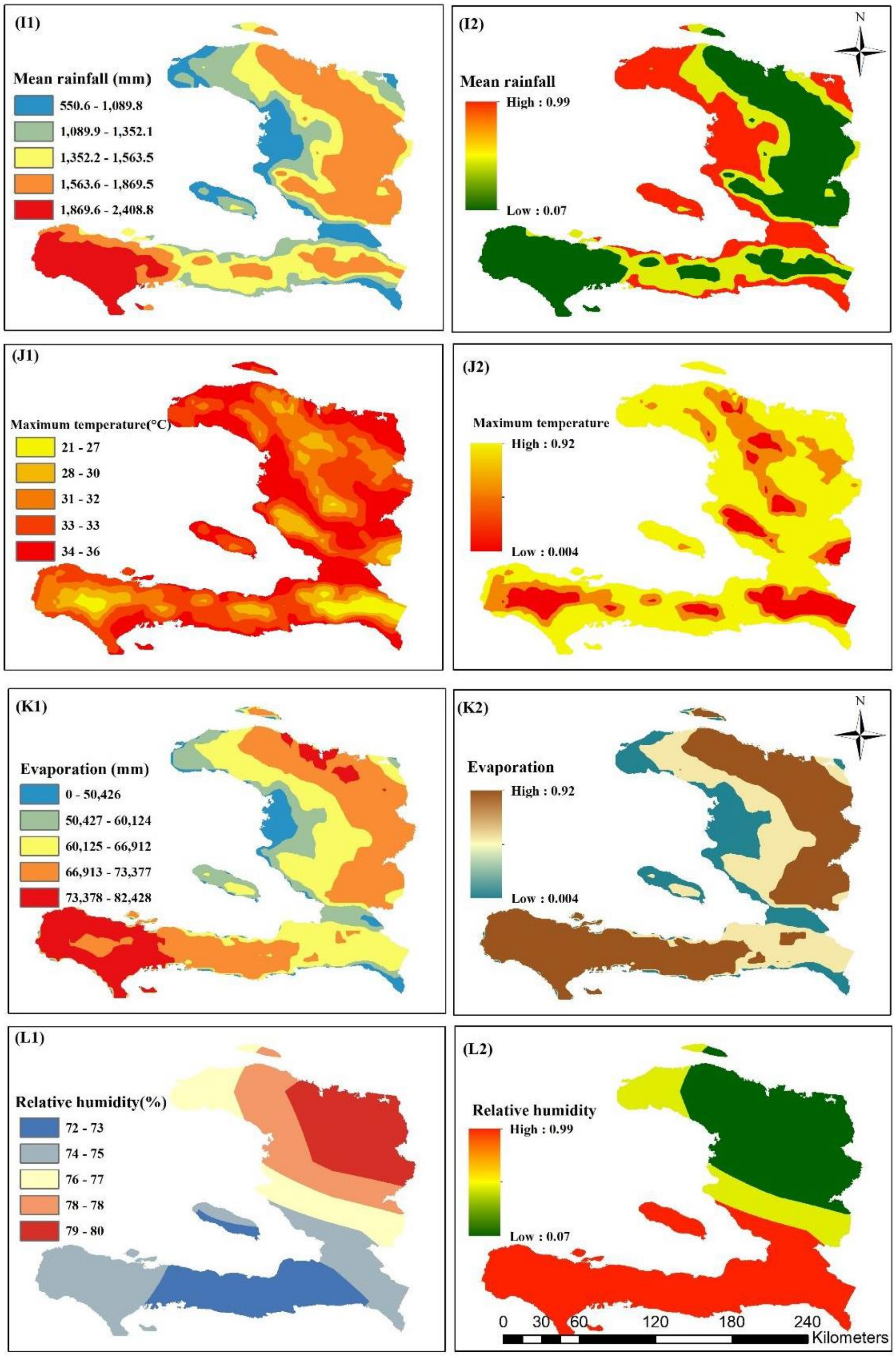

Figure 25 Original drought hazard factors in absolute unit

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Note : The maps are produced by the Autor using a mix of geospatial techniques. The panel at the left side represents: (I1) rainfall, (J1) temperature, (K1) evaporation, (L1) relative humidity and their corresponding standardized hazard factors using fuzzy membership are at the right side.

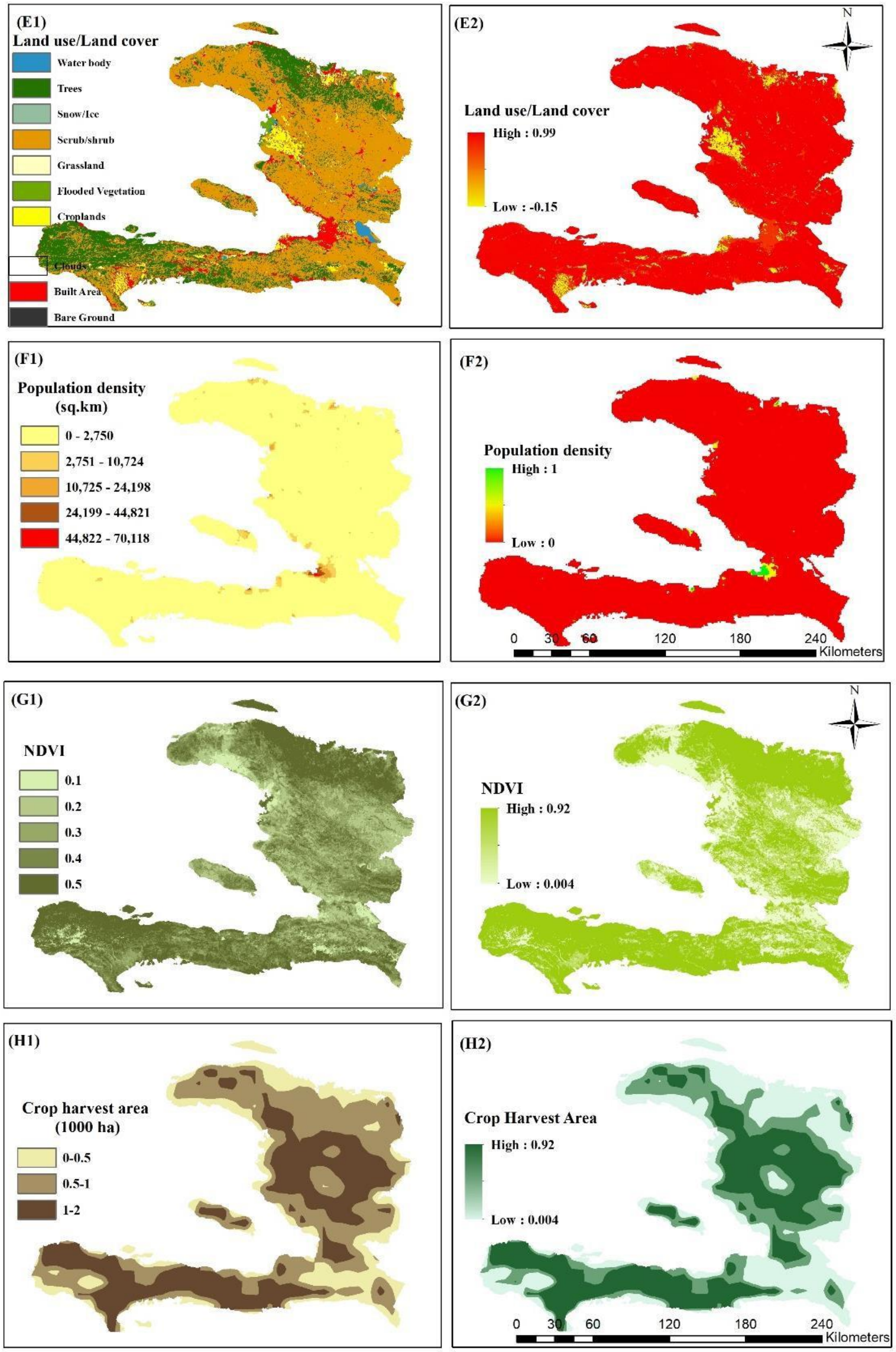

Figure 26 Original drought exposure factors in absolute unit

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Note : The maps are produced by the Autor using a mix of geospatial techniques. The panel at the left side represents: (E1) LULC, (F1) Population Density, (G1) NDVI, (H1) crop production harvest area and corresponding standardized exposure factors using fuzzy membership at the right corner.

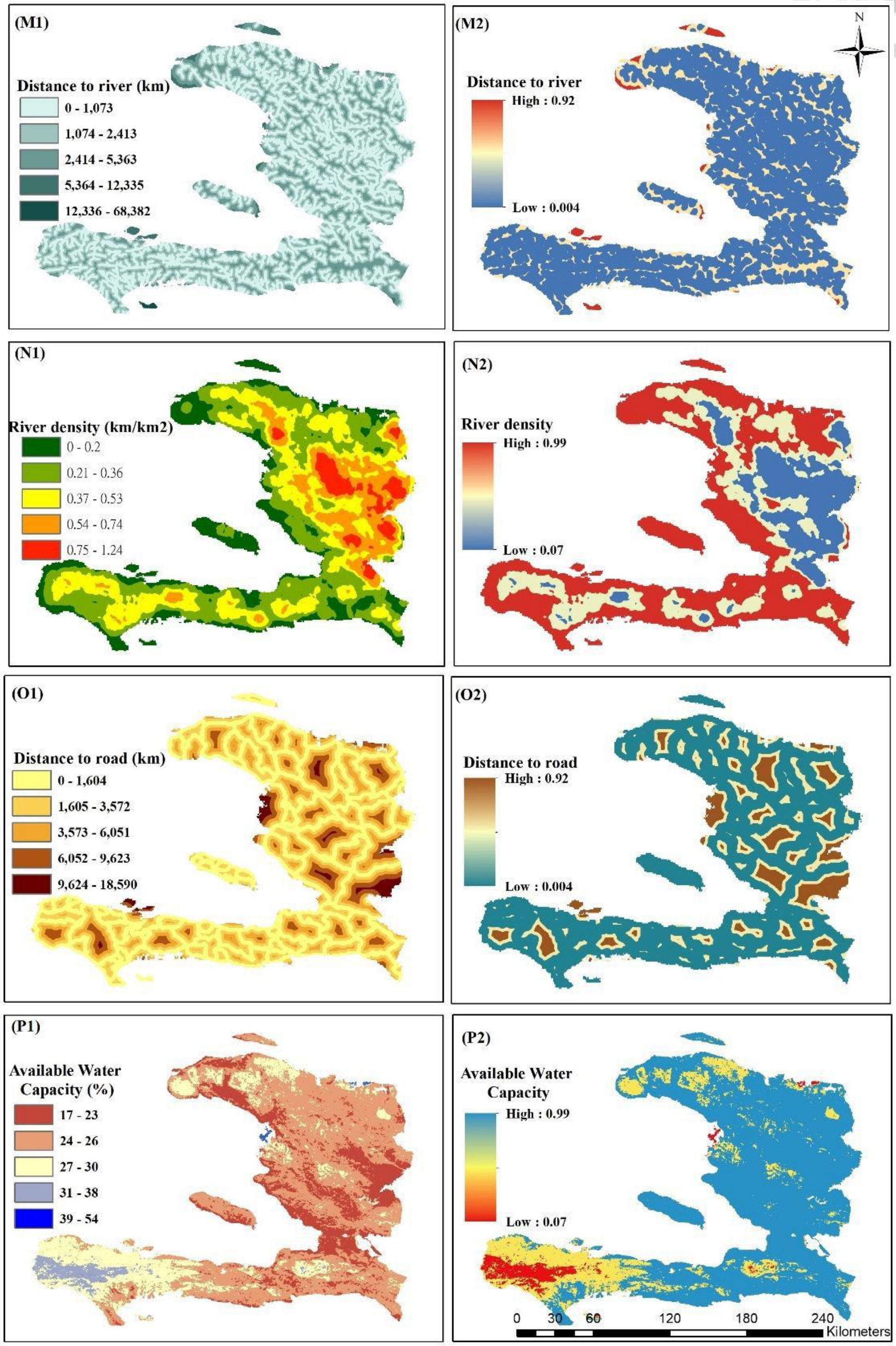

Figure 27 Original drought adaptive capacity factors in absolute unit

Note : The maps are produced by the Autor using a mix of geospatial techniques. The panel at the left side represents: (M1) distance to river, (N1) river density, (O1) distance to road, and (P1) available water capacity including the corresponding standardized mitigation capacity factors figure at the right side.

4.5.6. Risk assessment

Agricultural drought risk was calculated using the Eqs. (1) and (2), respectively representing without and with the adaptive capacity. First, a fuzzy overlay operation is carried out for each risk component incorporating their assigned weights after rating normalization. With the Fuzzy Overlay tool, we can determine whether a phenomenon might belong to more than one set in a multicriteria overlay analysis. Moreover, Fuzzy Overlay analyzes the relationship between memberships of the multiple sets in addition to identifying the set to which the phenomenon belongs. Among the five types of available operation methods of Fuzzy Overlay in the ArcGIS toolbox, Fuzzy GAMMA is used in this study to calculate each risk component. Fuzzy GAMMA was chosen because it applies the algebraic product of the "increasing" fuzzy SUM and "decreasing" fuzzy PRODUCT effects, both raised to the power of gamma, and also to avoid bias on the risk equation. More details can be found in this on the using of Fuzzy GAMMA overlay (Dayal et al., 2018b). Once all the risk components were prepared, we applied the risk formulas (eq (1) and (2)) in the raster calculator from the spatial analyst toolbar menu of ArcGIS to produce the final risk maps, which are then classified into five classes to describe the drought severity.

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4.6. Results

This study is the first attempt to use MCDM with a focus on fuzzy logic to monitor agricultural drought in the Caribbean region (specially in Haiti). Spatial analytical approaches are used for drought assessment in several countries (Han et al., 2016; Zeng et al., 2019). However, this study is more comprehensive as it considers the different risk parameters (vulnerability, hazards, exposure, and adaptive capacity) with their appropriate indicators related to soil properties and climate. Accordingly, this research presents a significant contribution to the broader literature on drought as well as to the major sectors involved in agricultural promotion and development to alleviate the current food crisis resulting from drought in Haiti.

4.6.1. Vulnerability mapping

Drought vulnerability level is depicted in the upper left corner of Figure 28, following the capabilities of the sub-indicators to influence drought conditions, including plant development. Roughly 8.7% and 16.8% of the area respectively fall in the very high and high drought vulnerability categories, collectively representing 6718.35 km^2 of the study area. These vulnerable areas are mainly found in the Artibonite region, particularly in Dessalines, Saint-Marc, Anse-rouge; and the Centre mainly in Hinche, Mirebalais, and finally in the West region. In addition, the map also indicates that the entire study area, with the exception of Grande-Anse, has a very advanced moderate level of drought vulnerability risk which covers approximately 22% (5816.2 km^2) of the study area. On the other hand, areas with low and very low vulnerability to drought risk jointly accounted for 52.59% (13901.99km^2) of the entire study area. These areas are mainly identified in Grande-Anse, South, Nippes and North-West regions. Data from the Ministry of

Agriculture (available at http://statistiques.agriculture.gouv.ht/) highlight that the Artibonite, Centre and West regions are the most prolific areas for crop production in Haiti. As these areas have very-high and highly vulnerability to drought risk, this implies that their potentialities for high agricultural yield are also threatened.

Overall, 47.4% of the study area is under moderate to high and very-high vulnerable drought risk. This means that most of Haiti's croplands show a low percentage of clay and sand, which play a crucial role in retaining nutrients and water in the soil for crop development (Ceballos et al., 2002). It also implies that aeration, free water drainage and gas exchange facilitated by the clay content in the soil (Easton, 2021) are of poor quality, thus retarding plant growth and production yields. These results also suggest that the level of soil moisture is low because a higher level of soil moisture will minimize the level of agricultural drought (Hoque et al., 2020).

4.6.2. Hazard mapping

The hazard map is located in the upper and right corners of Figure 28. Over 44.7% of the study area, covering 12126.9 km^2 is in the very-high and high drought risk category, followed by low risk (26.4% / 7155.8 km^2), moderate risk (19.4% / 5,261 km^2) and very low risk (9.4% / 2,556 km^2). Overall, more than 64.1% of the study area is experiencing moderate/high/very high drought risk level conditions, concentrated in the Grande-Anse, Nippes, South, South-east, North-west and parts of the Artibonite region. These levels of drought hazard risk could be very detrimental to the development of plants. Studies point out that plant growth is heavily influenced by temperature (Hatfield & Prueger, 2015). Thus, plant development and productivity are expected to be negatively affected with extreme temperatures. Consistency was found between the hazard and vulnerability components (correlation 0.7), revealing that the West and other high-yield agricultural regions of the study area fall mainly into the high to very high-risk class. According to our findings, these areas suffer from precipitation deficits and above-normal temperatures, both key factors limiting plant growth (Dahal et al., 2016), and drought conditions are more likely to occur in areas with extreme temperatures (Karamouz et al., 2015), contributing to plant wilting and therefore reducing agricultural productivity.

4.6.3. Exposure mapping

The map in the lower left corner of Figure 28 shows that the area of drought exposure is generally very-high, i.e., 62% (16456.3 km^2) compared to the other categories of drought hazard risk levels. This is followed by high risk (21.3%, 5652 km^2), moderate (11.3%), very low (3%) and low (2.4%) risk levels (Table 12). The very high-risk level extends over the entire territory of the study area. Overall, the results show that more than 94% of the study area classified as moderate-high and very-high risk category is exposed to agricultural drought risk. These results are consistent with field observations because the study site is characterized by steep slopes and more than 72% is not appropriate for agricultural use. Our findings are also consistent with previous studies that found that cropland resources at high elevations and in slope areas are at increased risk of drought due to their low inability to retain water (Zeng et al., 2019). Therefore, the lower the water retention, the slower the plant development process, the lower the crop yield and the higher the level of food insecurity.

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4.7.3. Adaptive capacity mapping

A representation of the spatial distribution of the study area and its adaptive capacity level is shown at the bottom and at the right-hand corner of Figure 29. Areas with very high and high adaptive capacity levels make up 21.1% (5,613 km^2) of the study area, with 5% categorized as very high. In addition, Figure 27 shows that over 15,633 km^2, approximately 59% of the study area, is at low to very low adaptive levels of drought risk. Moderate areas account for 5,316 km^2 or roughly 20 % of the study area. Accordingly, nearly 60% of the study area is insufficiently resilient to withstand drought events and produce adequate yields. This indicates that the adaptive capacity of the study area as well as the soils' ability to store water for plants is very low. Therefore, these types of soils are very prone to droughts and remedial action, such as improving soil quality, is needed maximize available water capacity and minimize the severity of future drought (Stone & Potgieter, 2008).

4.7.4. Risk mapping

Figures 30 and 31 respectively show the spatial distribution of drought and the drought risk severity. Drought risk maps with and without the adaptive capacity were produced to identify and differentiate the drought intensity level in the study area, and to assess the need to incorporate adaptive capacity in the risk equation to assess agricultural drought risk, as suggested by (Hoque et al., 2021; Zeng et al., 2019). First of all, the maps are congruent and consistent with previous maps showing drought zones in the study area. The adaptive capacity figure indicates that approximately 10.3% (2704.84km^2) of the study area is considered to have high to very high drought risk. In contrast, the map without adaptive capacity shows high to very high drought risk areas extend over 5699.54km^2, or 21.7% of the entire study area. This shows that if adaptation means are not included in the risk

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formula to assess the level of drought risk in a given area, the risk degree is expected to be increased compared to an assessment integrating the adaptive capacities.

Figure 30 also shows that the area with moderate drought risk is 20.4% (5335.9km^2) of the study area when integrating adaptive capacity, compared to 24% (6308km^2) without, producing an increase of more than 3.5% from excluding adaptative capacity in the risk formula. We further note that the risk level of the very low risk category and the low-risk category are higher (69.3%) when including adaptive capacity versus 54.25% without. Clearly, the predictive ability of agricultural drought risk models relies on including adaptive capacity for all risk parameters. Overall, using adaptive capacity, 30.7% of the study area is under moderate to very high agricultural risk. The areas of high agricultural potential such as the department of Artibonite, North, Centre, West and Grande-Anse are mostly under of moderate drought risk level, while most of the study area is classified as low or very-low risk. However, this relatively low risk does not imply that the impacts of drought can be considered negligible or insignificant. Agricultural activities and crop yields can be threatened regardless of the level of drought (weak or strong). Drought can have strong repercussions on plants because of their high sensitivity to climatic parameters and soil quality. The consequences can sometimes be disastrous at all levels of the food production chain (Cook et al., 2007; Mishra & Singh, 2010).

An exclusive analysis on these three regions (Artibonite, West and Centre) where the yields of cereals and legumes were more considerable in 2019 was carried out (Figure 31). These regions are the ones reporting the highest economic losses and the largest affected areas due to climate hazards. The results show that the Centre region is the region with the highest level of drought risk (very high), about 126.1km^2 (3.7%) of its area. It is

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followed by the Artibonite, covering approximately 136.8 km^2 (2.9%) of its area, and finally the West region 119.7 km^2 (2.5%). Regarding the high level of risk, both Artibonite and Centre region present a risk level of 12.4% of their area, while only 9.7% of the West region is under high-drought risk level. Likewise, the region with the highest drought moderate risk level is the Centre covering 22.8% of its territory) followed by the Artibonite (24.2% of its area), and the West region (22.1%). Centre region is also the one with the lowest category risk level covering 35% of its territory (see table 13).

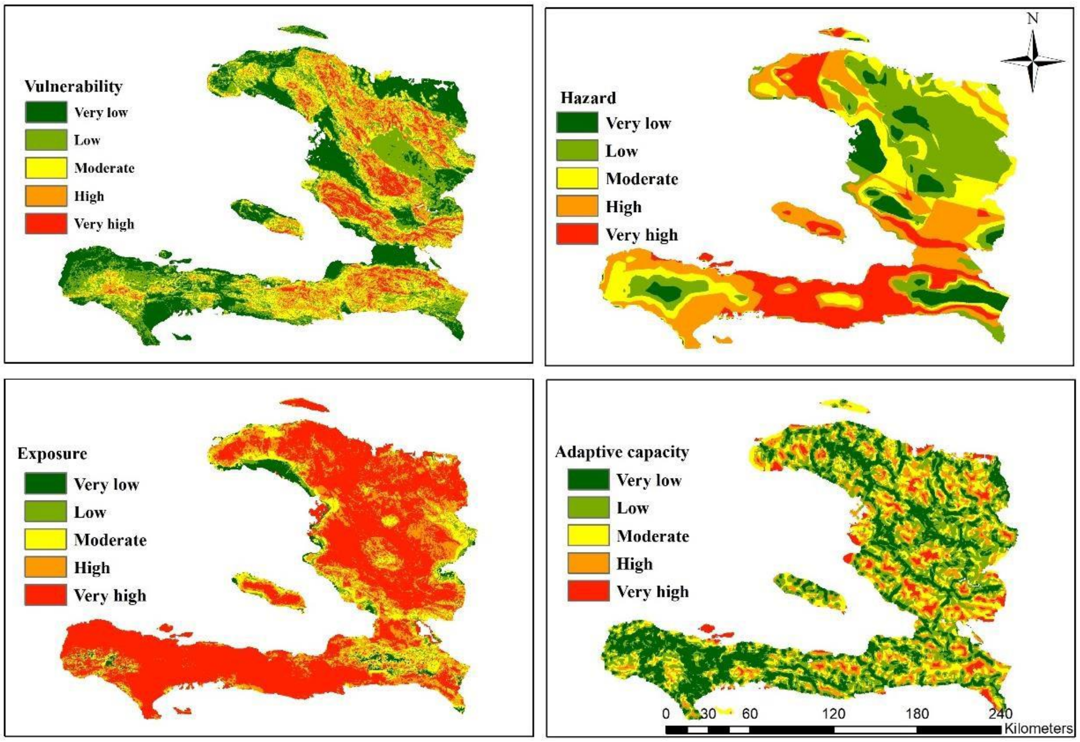

Figure 28 Risk assessment components

Note : The maps presented in this study were created by the Author utilizing a combination of geospatial techniques. The top corner panel of the maps illustrates the vulnerability risk component, whereas the bottom panel represents the exposure risk factor. On the right side of the maps, the top section corresponds to the hazard risk component, while the bottom section depicts the adaptation capacity.

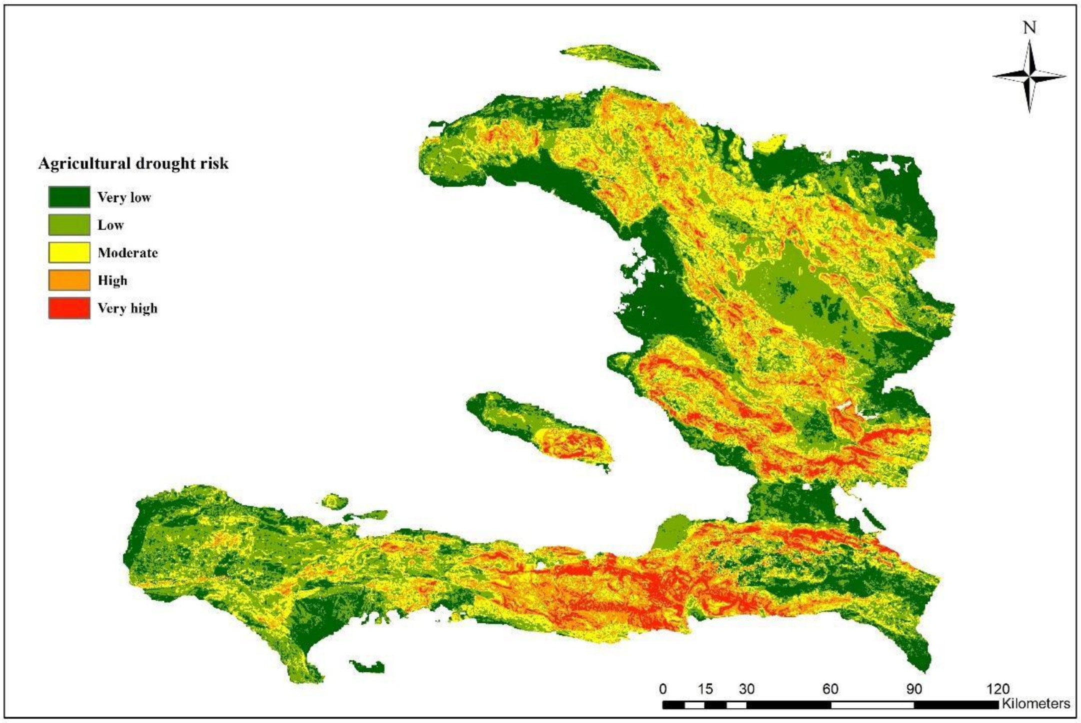

Figure 29 Agricultural drought risk in the study area.
Note : This map is produced by the Author based on the risk equation without the integration of the adaptive capacity. With RISK = V * H*E

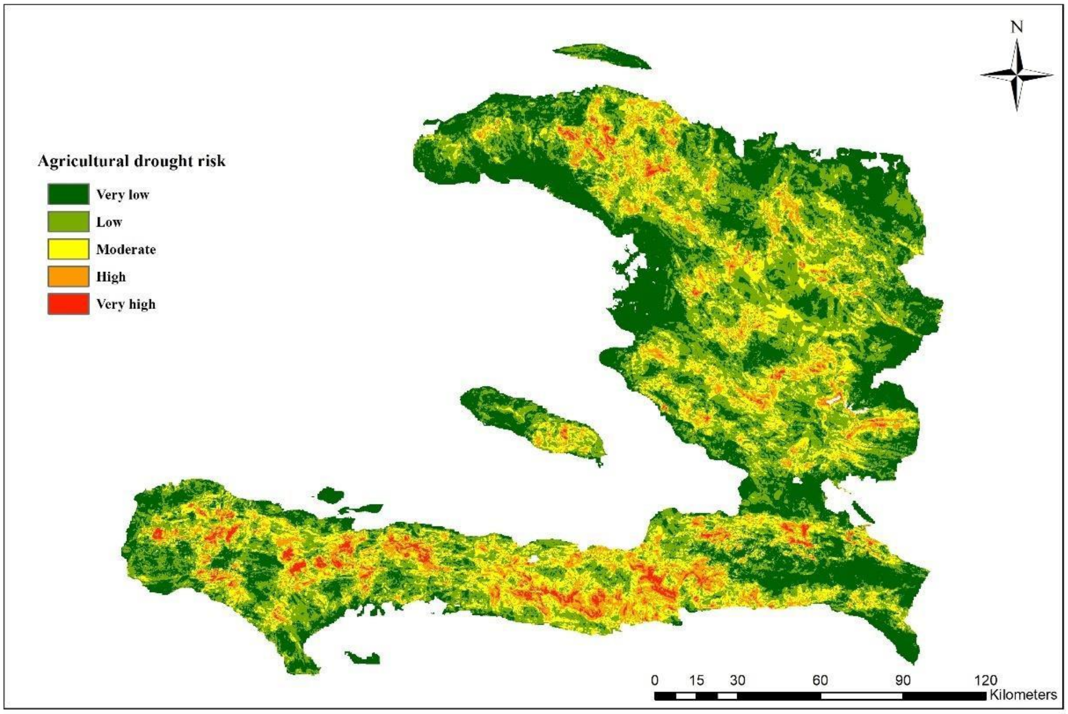

Figure 30 Agricultural drought risk in the study area.

Note : This map is produced by the Author based on the risk equation with the integration of the adaptive capacity with RISK = V *H* E / AC

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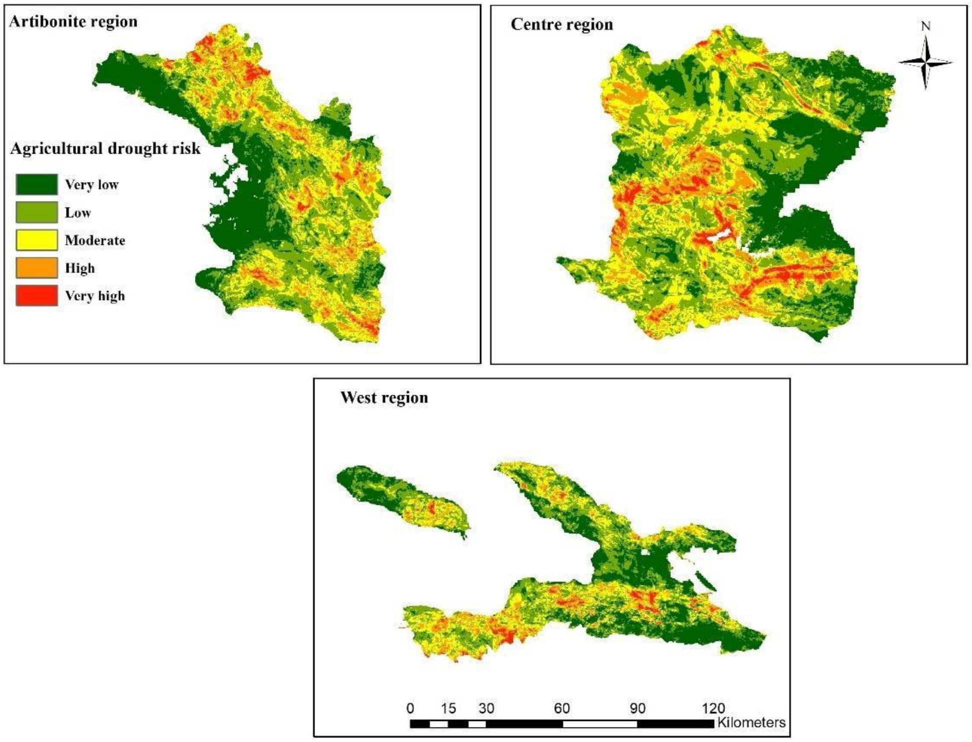

Figure 31 Agricultural drought risk in regions with high agricultural potentialities

Table 12 Distribution of drought risk and risk component levels

	RISK SIGNIFICANCE LEVEL				
RISK COMPONENTS	**Very low**	**Low**	**Moderate**	**High**	**Very high**
Vulnerability	7053.2	6848.8	5816.2	4428.4	2290
%	26.7	25.9	22	16.8	8.7
Hazard	2555.7	7155.8	5260.9	7165.9	4961
%	9.4	26.4	19.4	26.4	18.3
Exposure	806.6	642.6	2995.7	5652	16456.3
%	3	2.4	11.3	21.3	62
Adaptive Capacity	7540.6	8092.8	5316.3	4307.5	1305.9
%	28.4	30.5	20	16.2	4.9
Drought risk without AC (eq(1))	6133.6	8103.6	6308	4133.7	1565.8
%	23.4	30.9	24	15.8	6
Drought risk with AC (eq(2))	8494.7	9664.2	5335.9	2214.8	493.1
%	32.4	36.9	20.4	8.5	1.9

Table 13 Distribution of risk level in the three main farming regions.

	RISK SIGNIFICANCE LEVEL				
Region	Very low	Low	Moderate	High	Very high
Artibonite	1314.5	1564.6	1152.8	587.4	136.8
%	27.6	32.9	24.2	12.4	2.9
Centre	793.7	1199.8	883.2	425.6	126.1
%	23.2	35	25.8	12.4	3.7
West	1488.6	1637	1048.9	459.3	119.7
%	31.3	34.4	22.1	9.7	2.5

4.8. Discussion and Conclusion

In the context of climate change, the literature indicates that drought events will become more frequent (Burke et al., 2006; Rezaei et al., 2015; Wanders & Wada, 2015). In this case, drought disasters will be a continual challenge for food systems in the future, especially food production. Therefore, knowing how to effectively minimize the yield losses caused by drought is particularly important. The agricultural drought risk studied here was the combined result of the drought vulnerability, hazard, exposure, and adaptive capacity. Mitigating the agricultural drought risk should also be based on ways to mitigate the drought vulnerability, hazard, exposure, or increase the adaptive capacity. The study assesses the variation and spatial distribution of agricultural drought in the Caribbean region, specifically focusing on Haiti, applying fuzzy logic approaches and geospatial techniques. Assessment was conducted using the risk equation, including vulnerability, hazard and exposure, and integrating adaptive capacity (AC). Drought risk was examined both with and without integrating adaptive capacity into the risk equation. Integrating adaptive capacity produces a lower moderate to very-high risk (30.7%) compared to without adaptive capacity (45.8%). Most of the indicators used in the study are already selected in other similar research (Dayal et al., 2018a; Gopinath et al., 2015; Palchaudhuri & Biswas, 2016; Zeng et al., 2019); however, these studies do not include the AC in the risk equation for assessing agricultural risk. With the integration of the AC in this study, we obtained a lower moderate to very-high risk value, which is the exact state of the drought condition, compared to an evaluation without the AC. This indicates the importance of including the study site's available adaptive capacity in the risk assessment procedure and analysis for up-to-date risk level. Our results are consistent with a similar research (Hoque et al., 2018) advocating for the inclusion of AC into drought risk assessment procedures.

Regarding the different risk components, our findings indicate that more than 47% of the study area presents drought vulnerability risk conditions from a moderate to very-high risk level, while moderate to very-high drought hazard risk levels are found in more than 64% of the study area, compared to 94.5% for drought exposure risk. On the contrary only 41.1% is found to be resilient to cope with the extreme drought conditions. These findings are consistent with previous study arguing that vulnerability is a function of exposure, sensitivity, and adaptive capacity (Sharma & Ravindranath, 2019). A lowest adaptive capacity, relative to exposure and sensitivity, leads to high vulnerability. By contrast, higher adaptive capacity helps reduce the effects of exposure and sensitivity, and in turn reduces drought vulnerability in the study area.

Areas of high agricultural productivity, such as the Artibonite, Centre and West regions were also examined separately using the risk equation with AC. These areas are characterized of moderate to very high-level drought vulnerability, hazard and exposure. In other words, the high probability of occurrence of severe drought, the high variability of

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hazard indicators, the exposure and the low-level coping capacity when drought occurs made these areas susceptible to drought. The results reveal that respectively 39.5%, 4.9%, and 34.2% of these regions suitable to farming activities experience moderate to very high agricultural drought risk respectively. These results may indicate why the crop production growth rate in Haiti has dramatically declined over the past ten years (Assouline & Dicko, 2019).

Haiti has been recognized as one of the most disaster-prone countries in the Caribbean and Central America (Barton-Dock & Singh, 2015). Given that Haiti is highly expose, and therefore vulnerable to climate hazards; and considering the importance of agriculture as the main source of income, especially for smallholder producers, our study provides a comprehensive assessment of country-wide agricultural drought vulnerability, hazard, exposure, adaptive capacity, and the risk arising due to various criteria. From the perspective of vulnerability to agricultural drought, the wide spatial distribution of areas with extremely high vulnerability to agricultural drought is mainly due to the low proportion of the AC indicators such as the PWAC, or the long distance of rivers relative to croplands. As a result, policies and measures must be implemented to enhance water conservation and improve water-saving techniques. Furthermore, since drought in agricultural areas is unpredictable or difficult to predict, preparedness measures are therefore imperative (Pereira et al., 2002). To prevent administrative delays and provide quick responses to farmers' requests during drought events, the local government should establish a standard operating procedure.

Our cartographic products such as drought vulnerability, hazard, exposure, adaptive capacity and risk maps can therefore assist in visualizing critically drought-stressed areas.

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These will help farmers as well as block-level administrators to make better decisions for agricultural policy and practices, as well as drought mitigation. In addition, these maps also fully describe the climatic, agricultural and socio-economic conditions of the study area. Accordingly, stakeholders and decision makers involved in the formulation of drought mitigation strategies may consider strengthening remediation of drought-prone regions by improving either local socio-economic condition as well as encouraging adaptation to shifting conditions due to climate change. This could be accomplished through improved land management based on local agricultural potential and characteristics, the creation and expansion of irrigation canals, soil and water conservation, the introduction and expansion of drought-resistant crop varieties, and changes to the farming calendar including the training of growers for capacity building. Finally, the presented findings can be used in updating information related to drought vulnerability, hazard, exposure, adaptive capacity as well as drought risk with real-time data for changes in drought mitigation strategies.

In addition, this research has some limitations. While many key criteria were required (higher resolution datasets can provide more accurate results), it was not easy to collect high-quality datasets. It would be good to incorporate a few more criteria, for instance, irrigation, crop yield, sown area, and agricultural output value, GDP etc. However, it was not possible to include those due to data constraints, time frame, and funding. It might be worthwhile to address the above issues in future research. Nonetheless, the prepared approach can still produce useful results when it comes to formulating drought mitigation measures in agricultural areas.

Implementing these policy recommendations can contribute to building farm resilience in Haiti, reducing agricultural drought risk, and ultimately achieving food security in the

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country. It is important to consider the specific local context, involve stakeholders, farmers' perception of climate change and traditional adaptation practices, and regularly evaluate the effectiveness of these policies to make necessary adjustments over time. Farmers' perception of climate change and their traditional adaptation practices can significantly impact food security. First, farmers who understand and adapt to climate change can modify their agricultural practices accordingly, minimizing crop losses and maintaining stable yields. This ensures a consistent food supply and reduces the risk of food shortages. Second, farmers who employ traditional adaptation practices are better equipped to handle climate-related risks and shocks. Their diversified crops and sustainable farming methods provide income stability and protect against food insecurity during adverse climatic events. Third and lastly, farmers' perceptions and traditional adaptation practices can contribute to a broader understanding of climate change impacts and adaptation strategies. Sharing this knowledge among farming communities and policymakers can improve overall food security by fostering resilience and informed decision-making. This issue is addressed in the following chapter.

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Chapter 5

Understanding farmers' perception of climate change and adaptation practices in Haiti

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5. Chapter 5. Understanding farmers’ perception of climate change and adaptation practices in Haiti.

5.1. Introduction

Given that climate change has been acknowledged as one of the most significant challenges faced by humanity (Sachs, 2015), researchers with diverse educational backgrounds have been actively examining the dynamics of farmers' awareness of climate change and the strategies they employ to mitigate its impacts. Concurrently, a growing body of interdisciplinary literature has emerged, exploring the perceptions of the general public, including farmers, regarding climate change. This issue is of utmost scientific importance, as it is riddled with political conflicts and moral concerns. However, these studies have failed to investigate the influence of socio-economic backgrounds on climate change perception and adaptation, particularly with regards to vulnerability, inequality, and decision-making processes in developing nations where agriculture plays a pivotal role in economic growth.

Furthermore, it has been argued that the Caribbean region is currently the second most unequal region in the world. Countries in Latin America and the Caribbean (LAC), such as Haiti, exhibit higher levels of income inequality compared to nations in other regions at similar levels of development[8]. Surprisingly, no comprehensive analysis on the perceptions of climate change among farmers has been conducted, examining the relationship between gender and beliefs about climate change, as well as the mechanisms of adaptation. The existing research, often lacking theoretical discussions, has primarily relied on qualitative analyses of case studies conducted in a few countries (Fierros-

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[8] Sharm el-Sheikh, Egypt, 9 November 2022 (Inter-American Institute for Cooperation on Agriculture) – Members of the Commonwealth. https://shorturl.at/dsAEQ

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González & Lopez-Feldman, 2021; Staub et al., 2020), with minimal attention given to the gender dimension. For instance, Haque et al. (2023) conducted a comprehensive systematic review that explored the gendered perceptions of climate change and agricultural adaptation practices. The study included a selection of 41 papers, with the majority (63.42%) originating from Africa, followed by 37.1% from Asia. Notably, none of the papers included in the review were sourced from the Caribbean region. Therefore, this present study aims to address this research gap and provide a more thorough theoretical analysis of climate change perception among farmers, with a particular focus on socio-economic dimension and gender-related aspects of belief and adaptive strategies.

Climate change presents a significant global environmental issue that holds profound implications for humanity, particularly in the context of the Caribbean's pursuit of modernization, encompassing aspects such as economic growth, human development, technological advancements, and material well-being. Given the region susceptibility to climate-related disasters, including hurricanes, floods, and droughts, the Caribbean stands as one of the most vulnerable regions worldwide (Lewis, 2022). Consequently, climate change offers a compelling opportunity to explore the dynamics of socioeconomic status and gender within the region. In this regard, integrating perspectives from previous studies in climate change research and environmental sociology becomes crucial, considering the scientific foundation and alarming nature of the climate change issue.

In order to achieve this objective, we draw upon theoretical insights derived from relevant literature concerning the influence of socio-economic status and gender on individuals' experiences with local weather variations, as well as socio-economic disparities in climate change concerns. This approach allows us to investigate the socio-economic and gender dynamics in climate change perception, as well as the mechanisms employed for adaptation. By conducting this analysis, we aim to not only evaluate the various hypotheses concerning climate change concerns, but also enhance our understanding of the beliefs and attitudes of individuals in the Caribbean region, particularly the Haitian population, regarding this imminent global environmental challenge.

This study is guided by four key questions. Firstly, we aim to determine whether farmers with lower socio-economic status demonstrate a higher level of risk perception towards climate change compared to their wealthier counterparts in Haiti. Secondly, we seek to explore whether impoverished farmers who possess a heightened perception of climate change are more inclined to adopt off-farm strategies as adaptive measures against the impacts of climate change, in contrast to wealthy farmers. Thirdly, we aim to investigate whether female Haitian farmers exhibit a stronger perception of climate change compared to male farmers. Finally, we aim to ascertain whether female farmers are more actively involved in implementing on-farm strategies to enhance their agricultural productivity, as compared to male farmers. In accordance with the recommendations put forth by Freudenburg (1993) as well as Greenbaum (1995), this study undertakes an analysis of the impacts of various theoretically significant variables on the perception and adaptation to climate change. Traditionally, these variables have been investigated separately in prior studies with similar objectives.

5.1.1. Climate Change Perception and Coping Mechanisms of the Low-Income Group

Various studies have focused on farmers’ perception of and adaptation to climate change in developing countries (Alston, 2014; Amadou et al., 2015; Bastakoti et al., 2017; Bastakoti et al., 2014; Deressa et al., 2008; Gandure et al., 2013). For instance, Amadou et al. (2015) conducted a study in Ghana revealing that 71% of participants observed a rise in temperature, consistent with established climatological data. Additionally, a majority of 95% of respondents reported a decline in rainfall accompanied by a reduced duration. But some studies have argued that some social factors, such as gendered role and political and economic status, are that socially differentiate and generally shape individuals’ vulnerability and local adaptation (Huynh & Resurreccion, 2014; Marino & Ribot, 2012). Mustafa et al. (2019) also argued that farmers' level of awareness is also influenced by socio-economic, institutional, and geographical factors within environmental communication network. This argument implies that these social factors contribute to the differentiation of vulnerability among individuals, meaning that individuals with different gendered roles and varying political and economic statuses may experience different levels of vulnerability to climate change impacts.

Furthermore, it suggests that these social factors also shape individuals' capacity for local adaptation, meaning that individuals' ability to adapt to climate change is influenced by their gendered roles and socio-political and economic contexts. Similarly, Mustafa and his colleague’s arguments imply that farmers' awareness of environmental issues, including climate change, is shaped by various contextual factors. These factors may include the socio-economic conditions they are situated in, the institutional frameworks that govern their agricultural practices, and the geographical context in which

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they operate. By acknowledging the interplay of these factors, their study highlights the complex dynamics that contribute to farmers' awareness levels and underscores the importance of considering multiple factors within the environmental communication network when addressing awareness and understanding of environmental issues among farmers.

However, Sultana (2014) indicated that individuals of low socio-economic status are disproportionately affected by climate change especially in developing countries (Islam & Winkel, 2017). Developing countries with limited resources, poor infrastructure, and unstable institutions have little capacity to adapt and therefore are highly vulnerable to climate change impacts (Smit & Pilifosova, 2003). Thus farmers with low socio-economic background are more vulnerable and have less adaptive capacity to confront climate change, unless they perceive the risk (Hertel & Rosch, 2010). This statement highlights the importance of perception and awareness in addressing this vulnerability. If farmers with low socio-economic backgrounds recognize and understand the risks posed by climate change, they may be more motivated to take action and implement adaptive measures. This implies that increasing awareness and providing information about climate change and its impacts to farmers in vulnerable communities can help empower them to make informed decisions and adopt appropriate adaptation strategies.

According to Myers et al. (2013), climate change perception in the context of agriculture is used to measure farmers’ beliefs that human activities have caused climate change, which poses a threat to their future. And studies found that risk perception plays a fundamental role and therefore serves as a prerequisite for selecting an effective adaptation strategy (O'Connor et al., 1999; Weber, 2010; Zampaligré et al., 2014a). Farmers from low

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socio-economic backgrounds, due to their limited income, are highly susceptible to vulnerability. While they may possess an awareness of the shifting climate conditions, their capacity to establish and maintain sustainable adaptive measures is hindered. This implies that even if farmers from low socio-economic backgrounds are aware of the changing climate conditions and the risks they pose to their livelihoods, they may still face significant barriers in developing sustainable adaptive measures.

The key factor contributing to their inability to develop sustainable adaptive measures is their low level of income. Limited financial resources can prevent these farmers from investing in technologies, infrastructure, and practices that would enable them to effectively adapt to the changing climate conditions. They may lack the funds necessary to purchase drought-resistant seeds, install irrigation systems, or implement other climate-smart agricultural practices. Furthermore, low-income farmers may have difficulty accessing credit or loans to finance adaptation efforts. Financial institutions may perceive them as high-risk borrowers due to their economic circumstances, making it challenging for them to secure the necessary funding.

Moreover, early studies revealed that the education level and farming experience are positively correlated with climate change perception and willingness to adopt mitigation strategies (Lin, 1991). While the level of education is known to have a considerable influence on climate change perception and the formulation of adaptation strategies, it is postulated that farmers belonging to low-income groups may have limited access to formal education. Nevertheless, their accumulated farming experience equips them with the ability to discern and comprehend the evolving climate conditions. A recent study in Selangor, Coast Malaysia, highlighted that low-income group household showed

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higher awareness of climate change than high income group does (Ehsan et al., 2022). This means that low-income households may perceive themselves as more vulnerable to the impacts of climate change. They may be living in areas that are more prone to extreme weather events or have fewer resources to adapt to climate-related challenges. This heightened awareness could stem from a direct experience or observation of climate change impacts in their immediate surroundings. So, in the context of Haitian farmers, we assume that farmers from low-income groups are more sensitive than those from high-income groups in perceiving local climate change. If the low – income groups have stronger climate change perception than do the high – income groups, nonetheless, they would be more willing to adopt off-farm strategies to earn cash income and minimize their losses. Thus, the following hypotheses are proposed: farmers from low socio-economic background farmers exhibit stronger risk perception regarding climate change than would farmers from high socio-economic background (**H1**), and low-income group of farmers who have a strong perception of climate change are more likely to adopt off-farm strategies than would high-income group of farmers (**H2**).

5.1.2. Climate change through a gender lens

Existing research has demonstrated that incorporating an analysis of gender dimensions in climate change studies can provide valuable insights into the disparities in climate change knowledge and experiences between men and women. This includes their respective coping strategies (Denton, 2002; Ludgate, 2016). Therefore, assessing the gender dimensions of climate change perception can offer a comprehensive understanding of the specific challenges encountered by male and female farmers in developing nations like Haiti. This knowledge can further contribute to identifying effective strategies for these

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farmers to enhance their resilience, mitigate the impacts of climate-related disasters, and foster sustainable agricultural practices.

A study revealed that gender rules shape climate change adaptation (Codjoe et al., 2012). This is particularly relevant because women in most developing economies, such as Haiti, are increasingly becoming heads of farm households (Nelson, 2010). In terms of climate change perception and adaptation, this implies that women who become heads of households in developing countries face specific challenges and opportunities. As they take on leadership roles within their households and communities, they may possess a unique perspective on climate change and its impacts. Their experiences as primary caregivers, resource managers, and agricultural producers can shape their understanding of climate-related risks and vulnerabilities. Furthermore, being responsible for the overall well-being of their households, including food security and livelihood sustainability, women in these roles may exhibit resilience and employ adaptive strategies to cope with climate change. They may prioritize the implementation of climate-resilient agricultural practices, diversification of income sources, and engagement in collective action for climate change adaptation.

However, it is important to recognize that gender inequalities and constraints still exist, which can limit women's ability to fully engage in climate change adaptation. Factors such as limited access to resources, financial constraints, and societal norms may hinder their capacity to implement adaptation measures effectively (WomenWatch, 2009). A study reported that women exhibit less confidence in their scientific knowledge and abilities than men do (Jacobs & Simpkins, 2005). Another study revealed that women underestimate their climate change knowledge more than men do (McCright, 2010). In the context of Haiti, this disparity could affect the manner in which female farmers perceive and adjust to climatic variability. In terms of climate change perception and adaptation, these findings have implications for the involvement and engagement of women in addressing climate change challenges. The lower confidence and underestimation of their own knowledge among women may lead to their voices and perspectives being marginalized or overlooked in climate change discussions and decision-making processes. This has important consequences for climate change adaptation efforts, as women's unique knowledge, experiences, and perspectives are valuable in understanding the specific impacts of climate change on different communities, particularly marginalized groups. Women often have firsthand experiences with the social, economic, and environmental consequences of climate change and play crucial roles in household management, natural resource management, and agricultural production (Raney et al., 2011).

The synthesis of findings from a comprehensive review of 41 studies conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, predominantly focused on Africa and Asia, indicates that climate change perceptions and adaptation are profoundly influenced by contextual factors and exhibit notable variations across gender and intersecting identities (Haque et al., 2023). However, studies have indicated that women have a higher tendency than men to address environmental issues, and women’s attitudes toward environmental quality are stronger than those of men in the developed world (Diamantopoulos et al., 2003; Smith Jr et al., 2014). This implies that women may be more inclined to recognize and acknowledge the challenges posed by climate change. They may also be more willing to take action and make necessary adjustments in response to climate change (WomenWatch, 2009). The higher tendency of women to address environmental issues could mean that they are more likely to be aware of the potential consequences of climate change and the need for proactive measures. This awareness can contribute to a greater likelihood of perceiving climate change as a significant threat.

Furthermore, women's stronger attitudes toward environmental quality suggest that they may be more motivated to support and engage in sustainable practices and behaviors. This can include adopting environmentally friendly habits, advocating for policy changes, and participating in initiatives aimed at mitigating or adapting to climate change (Alfthan et al., 2011; WomenWatch, 2009). This is supportive by a study conducted in Bangladesh which revealed that women have a higher level of environmental awareness than their male counterparts (Atiqul Haq, 2013), and another one in Ethiopia reported that female Ethiopians are more likely than men to be aware of climate change (Abegaz & Wims, 2015). But it is important to note that these statements are based on general trends and do not imply that all women or all men behave in the same way regarding climate change in developing nations. Individual attitudes and actions toward the environment can vary widely, influenced by numerous factors such as education, socio-economic status, gender, cultural norms, and personal values (Alfthan et al., 2011). In the Haitian socio-economic context, we assume that female farmers exhibit stronger climate change perception than their male counterparts (**H3**).

Adapting to climate change has long been a challenge for farmers in developing nations, especially for the women (Nightingale, 2009). Some evidence has suggested that female-headed households are typically under-resourced and have lower literacy rates than male-headed households, which limits their capability to grow crops and adapt to climate

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change (Nabikolo et al., 2012; Raney et al., 2011; WomenWatch, 2009). Moreover, male-headed households have a higher likelihood of implementing high-capital strategies in response to climate change than female-headed households (Deressa et al., 2008; WomenWatch, 2009). Female farmers in Haiti, mostly marginalized and lack education and income, might face significant challenges in adapting to climate change. Their lack of access to resources, lower literacy rates might make them highly vulnerable and therefore have less capacity to implement adaptive measures compared to male-headed households.

By contrast, studies have revealed that women are key actors in adjustment to climate variability. For example, female farmers in Rwanda produce over 600 varieties of beans, and in Peru, they plant more than 60 varieties of cassava; both of these represent cropping system adaptation strategies for countering climate change (Women—Users, 1999). These strategies have improved the resilience of cropping systems to various climatic parameters, including soil physical conditions. A study conducted in Zimbabwe also revealed that, to cope with the effects of a drought, women have adopted diverse adaptation practices such as reducing the number of daily meals, buying and storing food items for consumption during dry periods, and cultivating drought-resistant crop varieties (Ncube et al., 2018). A similar study performed in Central Ghana found that gender plays a key role in adaptation practices adopted by the study communities; these practices included changing planting dates, using drought-tolerant hybrids, and obtaining income from property sales (Jamal et al., 2021).

When considering female farmers in Haiti, who face similar socio-economic characteristics to Zimbabwe and Central Ghana, it is possible that they would also engage in a range of coping measures. However, the specific adaptation practices adopted by

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women in Haiti would depend on various factors such as geographical location, access to resources, cultural norms, and institutional support. For example, Haitian women might engage in activities such as water conservation, alternative livelihood strategies, community-based natural resource management, or seeking income-generating opportunities outside the agricultural sector. It is important to recognize that gender roles and dynamics can significantly influence the coping measures adopted by women and men in response to climate change (Cvetković et al., 2018). Women in many societies often bear the burden of household responsibilities, food provision, and caregiving, which can shape their adaptation strategies (Raney et al., 2011). However, it is crucial to avoid generalizations and recognize the diversity of experiences and contexts within any given country, including Haiti. Conducting localized research and engaging with communities directly would provide a clearer understanding of the coping measures adopted by women in Haiti compared to men in the face of climate change. We therefore assume that female farmers in Haiti engage more than male farmers in on-farm strategies to improve their productivity (**H4**).

5.2. Data, Methods, and Research SiteResearch site

This research was conducted in two municipalities in Haiti, Dessalines (also known as Marchand-Dessalines) and Anse-rouge, whose inhabitants mostly depend on food crops

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for a living. Dessalines is an urbanized community with 412,906 inhabitants and a 474.4 km^2 area, whereas Anse-rouge had 43,395 inhabitants overall in 2015 and a 434.4 km^2 area. Anse-rouge and Dessalines were selected for a comparison of climate change risks. According to precipitation records from the WorldClim Database (Fick & Hijmans, 2017), Anse-rouge and Dessalines receive approximately 125 mm and 128 mm of annual precipitation, respectively; the climate conditions of the two municipalities seem similar. Topographically, both municipalities are mainly characterized by flat land and hills, but Anse-rouge specifically features coastal plains and is inhabited by smallholder farmers. Because the municipality of Dessalines is crossed by the Artibonite river, the largest river in Haiti, the farmers there seemed to get a higher standard of living compared to those in Anse-rouge. In both environmental and social aspects, Anse-rouge is much more vulnerable than Dessalines.

5.2.2. Data collection and Method

We used KoBoToolbox's data collection app to collect data in Anse-rouge and Dessalines in October 2020 and April 2021 respectively. Scholars have argued that coping with a drought involves a two-step process (Habiba et al., 2012). The first step is perceiving that a drought is occurring, and the second step is responding to its various effects through adaptation and mitigation. The household surveys took place in Haitian Creole (local

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language) on a pre-tested schedule. We used multistage sampling to select the sample households from the two municipalities. The selected sites are drawn from a range of agro-ecological zones, including arid, semi-arid, and humid areas. The first study site (Dessalines) is representative of semi-arid, arid areas and humid areas with a predominance of intensive pastoralists and agro-pastoralist systems. The second study site (Anse-rouge) is representative of arid crops and livestock production areas. The household survey consisted of three broad parts: (i) basic information about the households, (ii) their perceptions of climate disasters and climate variability, and (iii) information on their coping strategies to build resilience.

Our key dependent variables were off-farm strategies and on-farm strategies. Off-farm strategies were measured using three major questions: whether interviewees took off-farm jobs (Danso-Abbeam et al., 2021; Oppong-Kyeremeh & Bannor, 2018), leased their land (Zhang et al., 2018), or migrated to a different area (Jha et al., 2017; Vinke et al., 2022a). On-farm strategies were measured using three questions: whether interviewees changed their farming calendar (Truong An, 2020; Yegbemey et al., 2014), changing crop variety (Bryan et al., 2013), or changed their irrigation system (Chinasho et al., 2022). For each strategy type, we calculated the number of strategies adopted (range: 0–3). For both types of strategies, the female farmers had mean scores of approximately 1.7, whereas the scores of the male farmers were 1.67 for off-farm strategies and 1.42 for on-farm strategies (Table 1). Thus, the female farmers adopted more farming strategies than did their male counterparts.

For this study, we typically define low-income farmers as those who are characterized by limited financial resources and struggle to meet their basic needs. We assume they often face challenges in accessing essential resources for farming, such as fertile land, water for irrigation purpose, high quality seeds, fertilizers, machinery, and market opportunities. They might have limited access to formal financial services, technical assistance, and agricultural inputs, which can further hinder their productivity and income generation. This definition can also take into account broader socio-economic indicators such as education levels, health status, housing conditions, and access to social services. These additional factors help provide a more holistic understanding of the socio-economic challenges faced by low-income farmers. In the context of gender classification, female farmers are also individuals who identify themselves as female and engage in farming or agricultural activities. Similarly, male farmers are individuals who identify themselves as male and are involved in farming or agricultural practices. This classification takes into account individuals' self-identified gender identities in relation to their agricultural roles and activities.

With regards to climate change, we define climate change perceptions in this study as observed differences in temperature (more hot days) and perceived variations in rainfall (decrease in rainfall; delay in rainfall); or the variability in duration of the rainy season (rainy season finishes early). To distinguish between responses to long-term climate change and responses to recent climate shocks, the survey also asked participants about their experiences with recent climate shocks and coping techniques. We apply an aggregate index of five variables; respondents indicated whether they perceived any of the following: decline in rainfall, delay in rainfall, early end to the rainy season, increase in number of hot days, and late arrival of rainy season (Yes = 1 and No = 0). Thus, the aggregative range of climate change perception was 0–5. With an average score of 3.21, the female farmers had

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greater awareness of climate change than their male counterparts (score = 2.79). Several control variables in this study, namely years of residence, crop land size, household size, years of education, and town of residence (Dessalines = 1 and Anse-rouge = 0) were adopted. According to the results of t-test for the confident interval, none of the control variables are statistically significantly different between the female farmers and male farmers.

5.2.3. Analytical strategy

To elucidate the relationship among gender, class, climate change perception, and coping strategies and to efficiently test the hypotheses, we conducted structural equation modeling (Mimura et al.) using Mplus 7 after completing data management in Stata 15. SEM is particularly appropriate for this study because it enables the testing of models with multiple dependent variables and the identification of the direct and indirect effects among key independent variables simultaneously. After controlling for years of residence, crop land size, household size, years of education, and town of residence, we examined the effects of gender and class on off-farm and on-farm strategies and their indirect effects through the mediator of climate change perception.

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5.3. RESULTS

5.3.1. Descriptive statistics

Table 20 presents a statistical description of our sample (N = 670). The sample comprised 503 (75%) male farmers and 167 female farmers. As one of our key explanatory variables, gender was a dummy variable coded as female = 1 and male = 0. To measure farmers' social class (another independent variable), the different following social classes (upper class, upper-middle class, middle class, or working class) were classified one to assign a class of each respondent in line with their socioeconomic characteristics. However, none of the respondents responded as upper and only a few as upper – middle classes in the survey. To simplify the class analysis, we divided the respondents as ″high – income group‶ for a few higher classes and the other majority as ‶low – income group″ in the sample. In total, 72.46% of the female respondents were in the low – income group, which is significantly higher than the percentage of male farmers in this group (63.42%), see Table 15

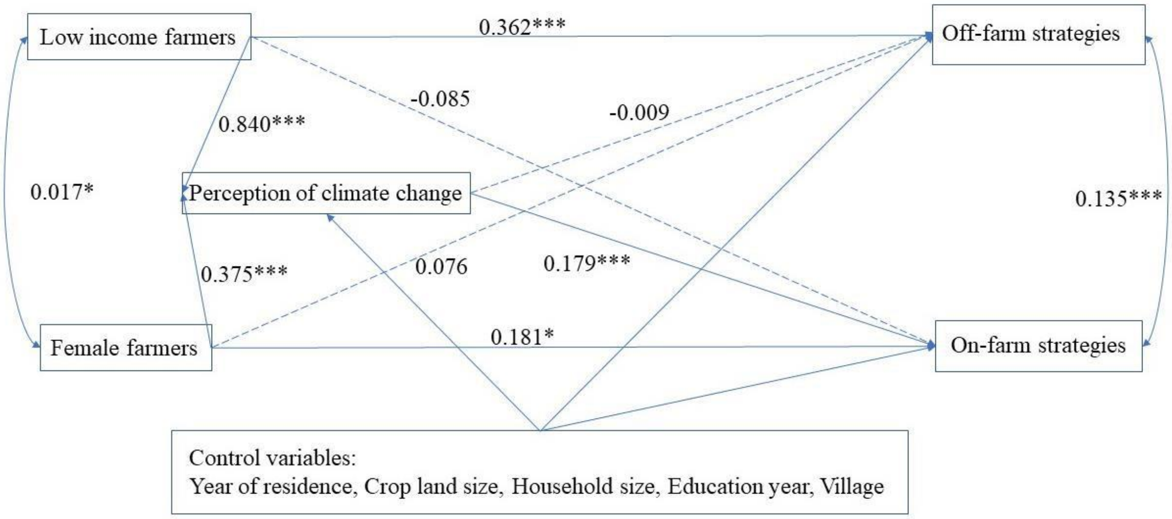
Table 14 Household composition statistics

Variables	Male mean/percentage	Female mean/percentage	t-test/chi square test
Dependent variables			
Off-farm strategies	1.67	1.77	-1.29
On-farm strategies	1.42	1.72	-2.93**
Independent variable			
Low – income farmers	63.42	72.46	4.54*
Mediators			
Perception of climate change	2.79	3.21	-4.11***
Control variables			
Year of residence	24.27	23.28	1.00
Crop land size	2.33	2.08	0.25
Household size	4.74	4.64	1.00
Education year	5.25	4.79	0.46
Village: Dessalines	57.46	61.68	0.92
Total samples	503	167	

*p < .01 **p < .05 ***p < .001

Note: 0/1: Chi-square test but shows the proportion of 1.

More specifically, our model results are illustrated in Figure 31 below. For clarity, we have provided the coefficient values on the lines connecting female gender, low – income group, climate change perception, and dependent variables; we have also used a dashed line to represent nonsignificant effects. According to the results, both low – income farmers and female farmers had positive effects on climate change perception which supported H1 and H3 respectively. When the mediating effect of perception was not considered, the results revealed that the low – income group of farmers adopted more off-farm strategies than did the high – income group of farmers which is described by the solid line in Figure 32 (H2 is supported); by contrast, no difference was observed between the low – income group and the high – income group in on-farm strategies. Moreover, to cope with climate change impacts, the female farmers adopted more on-farm strategies than did their male counterparts; no gender difference was observed in off-farm strategies. Thus, our results supported H4.



N = 670, AIC = 7051.710, BIC = 7209.465, RMSEA = 0.096 (0.076 - 0.118), SRMR = 0.041, CFI = 0.903, TLI = 0.767
*p < 0.05 **p < 0.01 ***p < 0.001

Figure 32 Model Result

Moreover, for simplicity, Figure 31 does not present the effects of control variables; these are addressed in Table 16. The root mean square error of approximation and the standardized root mean square residual values for the model were 0.041 and 0.096, respectively, with a value of <0.08 being acceptable (Hu & Bentler, 1999). Moreover, the comparative fit index of our model was 0.903, and the Tucker–Lewis index was 0.767, with a value of >0.9 or 0.95 being acceptable (Hu & Bentler, 1999). Most of the aforementioned model fit indices suggested that our model fit was acceptable. We also reviewed the modification indices in Mplus 7 to determine whether we missed any key relationships in the model; the result suggested that the correlation among years of education, years of residence in the community, and low – income class may improve the model fit. However, we did not include them in our model structure because our main results remained the same.

Table 15 Relationship between variables

	Perception of climate change		Off-farm strategies		On-farm strategies	
Control variables	**Coef**	**SE**	**Coef**	**SE**	**Coef**	**SE**
Year of residence	0.012***	0.003	-0.003	0.002	0.015***	0.002
Crop land size	-0.028	0.016	-0.018	0.013	-0.026	0.012
Household size	0.015	0.021	0.019	0.017	-0.021	0.016
Education year	0.017	0.009	0.021**	0.007	0.003	0.007
Village: Dessalines	-0.014	0.121	0.499***	0.097	1.289***	0.092
constant	1.875***	0.192	1.070***	0.164	0.016	0.155

*p < .01 **p < .05 ***p < .001

We also conducted path analysis to determine the direct and indirect effects of the variables under study (Table 17). Our results indicated that the low – income class only had a direct effect on off-farm strategies, whereas it affected on-farm strategies by increasing climate change perception. That is, climate change perception is a full mediator of the relation between social class and on-farm strategies. By contrast, gender had no direct or indirect effect on off-farm strategies; however, female gender had a positive effect on on-farm strategies in direct and indirect pathways, thus supporting H4. Research has revealed that gender and social class intersect to shape the ability of Indian women to access agricultural resources (e.g., irrigation water and credit) to cope with the impact of climate change (Ahmed & Fajber, 2009). Although we included interaction terms in the models, we did not obtain significant results. Therefore, we posit that gender and class were two independent determinants of climate change perception and adaptive strategies of the Haitian farmers in our study sites.

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Table 16 Total, direct, and indirect effect of low – income class and female gender on strategies

	Off-farm strategies			**On-farm strategies**		
	Total	Direct	Indirect	Total	Direct	Indirect
Poor	0.355***	0.362***	-0.008	0.066	-0.085	0.150***
Female	0.072	0.076	-0.003	0.248**	0.181*	0.067**

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5.4. Discussion

This study conducted a comprehensive analysis of the influence of socio-economic background and gender dimension on perceptions of climate change and adaptation practices within two agricultural communities in Haiti. The subsequent sections of this paper delve into the primary findings derived from this research, as well as propose potential future policy recommendations.

5.4.1. Low – income farmers and climate change perception

Considering the involvement of low-income individuals in the agricultural sector within developing nations, the perspectives of farmers from economically disadvantaged backgrounds on climate change hold significant importance in selecting appropriate adaptation strategies. It should be noted that perceptions of climate change are inherently contextual and display substantial variation across diverse social groups and intersecting factors (Howe et al., 2013). This assertion recognizes that there is no single universal perspective on climate change. Different social groups may have different levels of awareness, concerns, or priorities regarding climate change based on their distinct contexts. For example, individuals from marginalized communities may have different perspectives on climate change compared to those from privileged backgrounds due to their differing experiences and vulnerabilities. Our findings indicate that farmers with lower incomes exhibit heightened levels of concern towards climate change compared to their higher-income counterparts, which supported H1. This result suggests that there is a correlation between income level, risk perception of climate change, particularly in low-income countries like Haiti. The finding that low-income farmers have a higher risk perception of climate change compared to high-income farmers could be attributed to several factors.

Firstly, low-income farmers in Haiti often heavily rely on agriculture for their livelihoods, making them more vulnerable to climate-related risks such as droughts, floods, or extreme weather events. These farmers may have experienced firsthand the impacts of climate change on their agricultural activities, leading to a heightened awareness of the risks involved. This aligns with previous investigation conducted by Mehmood et al. (2021) and Uddin et al. (2017), which revealed a positive correlation between farmers' perception of climate change and their level of agriculture experience as well as their age. Additionally, low-income farmers may have limited resources and financial capabilities to adapt to or mitigate the effects of climate change. This lack of resources can further exacerbate their perception of risk, as they may feel less equipped to cope with the potential consequences as indicated Mustafa et al. (2019). In contrast, high-income farmers may have more financial means and access to technology, enabling them to invest in adaptive measures and buffer themselves against climate-related risks.

The literature indicates that education plays a pivotal role in climate change perception (Lin, 1991; Roco et al., 2015). In contrast, in this study, the results indicate that the number of years spent in school is not necessarily correlated with the perception of climate change. It does not mean that the level of education or formal schooling a person has completed does not necessarily influence how they perceive or understand climate change. One potential rationale for this phenomenon could be attributed to the educational curriculum in Haiti, which may not prioritize or sufficiently address environmental issues. Additionally, a significant portion of individuals residing in rural areas tend to discontinue their education at an early stage, often at the primary school level. Throughout the country, most of the farmers, in particular low-income groups, are often lack of formal education

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that might shape their perception to climate change. The mention of low-income farmers in developing nations like Haiti lacking formal education highlights another important aspect. Formal education plays a crucial role in providing individuals with knowledge, information, and critical thinking skills. Farmers with formal education are likely to have a better understanding of climate change, its causes, and potential impacts (Roco et al., 2015). This education can influence their perception of climate change risks and their ability to comprehend the scientific evidence supporting climate change. Therefore, the combination of low income and limited formal education in low-income countries like Haiti may contribute to a higher risk perception of climate change among farmers. However, it is essential to note that risk perception is a complex construct influenced by various socio-economic, cultural, and contextual factors (Birkholz et al., 2014; Boholm, 1998; Weinstein, 1989). Further research is necessary to understand the specific mechanisms driving the observed correlation in this study and to explore additional factors that may shape farmers' risk perception of climate change.

5.4.2. Low – income farmers and climate change adaptation

Numerous studies emphasized the significance of farmers' views of climate change in making adaptation decisions (O'Brien et al., 2006). Risk perception for example, according to Zampaligré et al. (2014b), plays a crucial role and is hence a prerequisite for choosing an efficient adaptation option. Within the confines of this investigation, we have determined that not only did farmers with lower incomes demonstrate a greater perception of risk than their higher-income counterparts, but they also relied more heavily on non-agricultural undertakings as adaptive strategies (H2). These endeavors encompassed off-

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farm employment (Danso-Abbeam et al., 2021; Oppong-Kyeremeh & Bannor, 2018); land leasing (Zhang et al., 2018), or relocation to alternative regions (Jha et al., 2017; Vinke et al., 2022a). Conversely, it should be noted that high-income farmers, in comparison to their low-income counterparts, directed their attention primarily towards on-farm activities, which entailed altering their farming calendar (Truong An, 2020; Yegbemey et al., 2014); modifying crop variety (Bryan et al., 2013); or adjusting their irrigation system (Chinasho et al., 2022).

This implies that for farmers with limited financial resources, diversifying their income sources through off-farm jobs, land leasing, or migration to different areas can serve as important strategies to cope with the challenges posed by climate change in Haiti. A similar pattern was found by Kelman et al. (2019). These non-agricultural activities provide alternative means of livelihood and reduce their dependency on agriculture alone, which can help mitigate the risks associated with climate-related uncertainties. On the other hand, high-income farmers appear to focus more on on-farm activities as adaptive measures. By adjusting their farming calendar, changing crop variety, or improving their irrigation systems, these farmers demonstrate a proactive approach to climate change adaptation. This suggests that they may have greater financial resources and technological capabilities to invest in on-farm measures that enhance their resilience to climate variability. Overall, these findings highlight the importance of considering the socioeconomic context and income disparities when designing and implementing climate change adaptation strategies. This provides evidence in favor of previous research suggesting that the ability of individuals to adapt, cope with vulnerabilities, and demonstrate resilience in the face of climate change is contingent upon a variety of factors. These factors encompass the extent

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of their exposure and reliance on weather patterns for sustaining their livelihoods and ensuring food security, as well as their differential capacities for adaptation, which are influenced by variables such as gender, social standing, economic impoverishment, power dynamics, access to resources, and control and ownership over resources within their households, communities, and society (Alfthan et al., 2011).Tailored approaches should be developed to address the specific needs and capacities of different farmer groups. Efforts should be made to support low-income farmers in diversifying their income sources and accessing alternative livelihood opportunities, while providing high-income farmers with resources and knowledge to further enhance their on-farm adaptation practices.

5.4.3. Gender and climate change perception

In line with previous studies by Atiqul Haq (2013) and Abegaz and Wims (2015), which indicated that women tend to exhibit a greater degree of environmental consciousness compared to men, our research also reveals that female farmers in Haiti demonstrated a heightened level of perception regarding climate change when compared to their male counterparts. This discrepancy in perception can potentially be attributed to their socio-economic background and their role in ensuring food security (Raney et al., 2011; WomenWatch, 2009). Notably, a significant proportion of the female farmers (61.68%) belonging to a higher socio-economic status were located in the village of Dessalines, which is recognized for its comparatively improved socio-economic conditions in contrast to the Anse-rouge villages, known to be susceptible to drought. The association between residing in Dessalines and possessing a higher level of perception may be linked to factors such as increased educational attainment among female farmers or an extended duration of

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schooling, thereby fostering a more comprehensive understanding of environmental issues. Moreover, it is worth noting that the mean score of on-farm adaptive activities employed by female farmers to mitigate the impacts of climate change was found to be 1.72, while the corresponding figure for male farmers stood at 1.42. One possible explanation is that female farmers may be more directly affected by the impacts of climate change in their agricultural practices (WomenWatch, 2009). They may have observed or experienced firsthand the adverse effects of changing weather patterns, such as increased droughts, floods, or unpredictable rainfall. These experiences could contribute to a heightened perception of risk and a greater sense of urgency to adapt to the changing climate.

Additionally, societal and gender dynamics may play a role in shaping these findings. Women in many societies, including Haiti, often have different roles and responsibilities than men (Raney et al., 2011). They may have a closer connection to the land and be more involved in agricultural activities, which can increase their awareness and understanding of climate-related challenges. Furthermore, women may have limited access to alternative livelihood options, making them more dependent on successful farming practices and thus more motivated to adapt to climate change. It is also important to consider the socio-cultural context and the existing gender inequalities in Haiti. Women in agricultural communities may face specific barriers to agricultural capital including decision-making power. These challenges can foster resilience and the development of adaptive strategies among female farmers, leading to a higher mean score in on-farm adaptive activities.

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5.4.4. Gender and climate change adaptation practices

In their recent study on the correlation between gender, climate perception, and adaptation strategies, Haque et al. (2023) discovered that individuals of both genders employed a range of adaptation strategies. However, women exhibited a comparatively lower level of climate change adaptation compared to men. The researchers observed that adaptation strategies were strongly influenced by specific contexts and locations, and even within the same gender group, the choice of strategies varied. Furthermore, the prevailing gender roles played a significant role in shaping the selection of adaptation strategies. Notably, certain adaptations placed an additional burden on women, leading to increased labor and time commitments associated with their gender roles and responsibilities (Djoudi & Brockhaus, 2011).

The findings of our investigation indicate that female farmers not only exhibit a higher perception of climate change risk compared to their male counterparts but also tend to engage in on-farm activities as part of their adaptation strategies. These activities include modifying their farming schedules (Truong An, 2020; Yegbemey et al., 2014); selecting different crop varieties (Bryan et al., 2013); and altering their irrigation systems (Chinasho et al., 2022). In contrast, female farmers coping with the impacts of climate change tend to focus more on off-farm employment opportunities (Danso-Abbeam et al., 2021; Oppong-Kyeremeh & Bannor, 2018); leasing their land (Zhang et al., 2018); or migrating to different regions (Jha et al., 2018; Vinke et al., 2022b). This means that the fact that female farmers engage in on-farm activities as part of their adaptation strategies indicates their resilience and resourcefulness in responding to climate change. By modifying farming schedules, selecting different crop varieties, and altering irrigation systems, women are

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actively taking steps to mitigate the effects of climate change on their farming practices. These adaptive measures demonstrate their ability to adapt to changing environmental conditions and ensure the continuity of their agricultural activities.

In contrast, the tendency of male farmers to focus more on off-farm employment opportunities, leasing their land, or migrating to different regions suggests that they may be seeking alternative livelihood options in response to the challenges posed by climate change. This could be due to various factors, such as limited access to resources, lack of support, or the perception that off-farm activities offer greater economic stability or opportunities. This result supported the idea that migration represented one of the most important adaptation strategies for men, and traditionally male activities have been added to the workload of women (Djoudi & Brockhaus, 2011). However, in the Haitian context, where women already face significant inequality and marginalization, these findings raise concerns. It is crucial to recognize and address the existing gender disparities in access to resources, land ownership, and decision-making power within the agricultural sector. Efforts should be made to empower and support women in adapting to climate change, as they are at the forefront of agricultural production and often bear the brunt of its impacts. To ensure a more equitable and sustainable response to climate change in Haiti, it is important to promote gender-responsive policies and interventions that address the specific needs and challenges faced by women farmers. This can include improving access to credit and financial resources, providing training and capacity-building programs, strengthening women's land rights, and promoting women's participation and representation in decision-making processes related to agriculture and climate change. By acknowledging and addressing the gender inequalities and marginalization present in Haitian society, it is possible to leverage the knowledge, skills, and agency of female farmers to build resilience, enhance agricultural productivity, and foster sustainable development in the face of climate change. Additionally, the mean cropland size and household size data (Table 1) indicate that both male and female farmers in Haiti have relatively small-scale agricultural operations and similar household sizes. This insinuates that adaptation strategies and interventions need to consider the specific circumstances of small-scale farmers, both men and women, who are often the most vulnerable to climate change impacts. Supporting these farmers with appropriate technologies, access to information, and capacity-building can contribute to their ability to adapt and improve their livelihoods.

5.5. Conclusion

The primary aim of this study was to utilize theoretical insights from pertinent literature in the fields of climate change research and environmental sociology to investigate the influence of socio-economic background and gender on farmers' perceptions and adaptation strategies concerning climate change—a global environmental issue of paramount importance. Specifically, the phenomenon of climate change provides an intriguing context for analyzing the interplay of socio-economic status and gender dynamics, and this research serves as a theoretical complement to existing studies on climate change perception and adaptation, which often overlook socio-economic and gender dimensions especially in the Caribbean region. In this study, we examined both the socio-economic dynamics and gender dynamics in relation to climate change perception and adaptation strategies. Our findings indicated that farmers belonging to the low-income group and female farmers demonstrated higher levels of climate change perception compared to their high-income counterparts and male counterparts, respectively, even after

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accounting for various relevant variables that are expected to influence climate change perception. The result is consistent with early studies undertaken by Vicente-Molina et al. (2018) or Ramstetter and Habersack (2020). Additionally, our investigation into adaptation strategies revealed that the low-income group of farmers predominantly engaged in off-farm activities as a means to cope with the impacts of climate change, whereas female farmers primarily considered on-farm activities as their strategies for adapting to climate change. In the realm of agricultural practices, the on-farm strategies encompass several measures such as altering the farming calendar, modifying the crop variety, and adjusting the irrigation system. Conversely, the off-farm strategies encompass activities like off – farm jobs, leasing lands and household migration. This is the first study to successfully employ a new survey method in two agricultural sites in Haiti, and this evaluation method can serve as a pretest in future studies at the national level.

The study highlighted that, despite the paucity of evidence and studies on climate change on Haiti, farmers, do notice a shift in the local climate and have come up with a variety of coping mechanisms. More importantly, the study highlights the need for designing gender-sensitive agricultural policies and programs as well as equity-based policies involving adaptation and mitigation measures tailored to local contexts. Adaptive strategies for climate change can succeed only if they empower women given their close ties to the environment and their roles in natural resource management. Female farmers can serve as agents of change, whose knowledge and skills can strengthen resilience to climate disasters. Policy makers should develop strategies to promote sustainable and climate-resilient agriculture. This approach may include gender-sensitive information delivery and capacity-building approaches as well as training in basic entrepreneurship and drought risk management skills in the local context. Finally, Haitian women should participate in the governance of public goods, such as water reservoirs; their input in diverse areas may help improve agricultural production. A gender-sensitive approach involving community knowledge and practices can increase the adaptive capacity of women, especially those who are poor, and help men and children in families to counter the local impact of global climate change.

Nonetheless, our study has some limitations. First, we attempted to employ random sampling based on a geographic grid, but we faced difficulties accessing some areas because of safety concerns. In these areas, the security issues substantially undermined the response rate of female farmers as well as poor farmers. Second, the design of the questionnaire was revised during the survey because the rates of land fallowing and off-farm migration in response to the drought were higher than expected. We defined these responses to climate change as “coping strategies,” rather than as strategies for “adaptation” or “resilience.” We are designing the next wave of surveys to consider the adaptive outcomes of farmers who used these different strategies; this is also a worthwhile direction for future research.

Although we applied the gender ratio of the official census to weight the statistics, a more effective strategy would be to intentionally increase the number of female interviewees, which we intend to do in the next wave of surveys. Instead of focusing on female farmers, future research can examine the social disparities present in the climate change beliefs and attitudes of women in the nonagricultural sector; a target group can be

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the small traders commonly called *Madan Sara*[9], who are regarded as a key player in the marketing of agricultural products in Haiti (Assouline & Dicko, 2019). The aforementioned difficulties, however, also reflect the rarity and value of the present novel survey method, which is yet neglected in Haitian climate change literature.

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[9] The Madan Sara are the principal actors in marketing the agricultural products of small producers Assouline, N., & Dicko, T. F. (2019). Agricultural Financing in Haiti: Diagnosis and Recommendations. They buy from others, distribute and sell foodstuffs, or have their own business. Only women are part of this Madan Sara category, making it possible to define it as a female-dominated sector. They sell either by walking in the streets, or by settling in public markets. They are generally concentrated mostly in large cities. Those in rural areas can sometimes walk more than 25 km to buy agricultural products in one local market and resell them in their own local market.

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Chapter 6

General conclusion and policy recommendations.

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6. Chapter 6 General conclusion and policy recommendations.

The primary objective of the food system is to ensure food security, yet Haiti struggles with one of the most severe levels of food insecurity globally. Approximately 4.9 million Haitians, which accounts for almost half of the population, face insufficient access to food, and 1.8 million individuals are confronted with a state of food insecurity classified as an emergency. The inability of the food system to guarantee food security in Haiti might be attributed to various factors, including the country's heightened susceptibility to natural hazards and socio-economic challenges. This vulnerability places Haiti among the countries most exposed to climate-related disasters and contributes to its status as one of the nations experiencing severe food crisis on a global scale. The vulnerability primarily stems from environmental degradation, a significant issue plaguing Haiti with far-reaching consequences. Deforestation and inappropriate agricultural practices have contributed to soil erosion, degradation, and the expansion of arid areas. As a result, these scenarios increase the likelihood of droughts, floods, and landslides, amplifying the magnitude of losses and damage in the agricultural sector.

In this research, we firstly evaluate and forecast the potential yields of the primary food crops and cash crops cultivated in Haiti, focusing on the years 2030 and 2050. The principal objective is to examine the impact of climate change on these crop yields and determine if the combined production of these crops can adequately sustain the growing food demands of the Haitian population in 2030 – 2040 and 2050. To do so, we based on two distinct scenarios that account for various factors, including climate change, which may impact crop yields and therefore reduce the production levels.

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The first scenario employed is known as "Business As Usual (BAU)". This scenario, as described by the FAO (2018), encompasses the current socio-economic, technological, and environmental patterns that inadequately address the diverse challenges related to food access, utilization, availability, and stability. To define this scenario, the FAO used a range of indicators such as economic growth and policy, international governance and conflicts, human development, conservation practices, energy use and GHG emissions, welfare and lifestyle, land and water use, agricultural policy, innovation, and yields.

According to our examination of the outcomes derived from the "BAU" scenario, the anticipated yield ranges for the specified crops during the timeframe spanning from 2030 to 2050 are as follows: dry pulses (0.9 to 1.08 ton/ha), maize (1.04 to 1.038 ton/ha), sorghum (1.07 to 1.24 ton/ha), and paddy rice (2.7 to 3.02 ton/ha). These figures represent the expected production levels within the given period if current trends and practices continue without significant interventions or improvements. It is important to note that these yield projections are subject to the influence of climate change and other socio-economic factors considered within the scenario. These factors collectively contribute to the potential variation in crop productivity, indicating the need for proactive measures and sustainable agricultural practices to ensure future food security in Haiti.

The second scenario used is referred to as the "Stratified Society" (SSS) scenario, as defined by the FAO. In this scenario, society is characterized by distinct strata, where an elite class holds decision-making power primarily to protect their own interests, neglecting the urgent need for natural resource conservation and climate change mitigation. The SSS scenario incorporates the same indicators as the "BAU" scenario, with only an additional indicator called population growth and inequality.

Under the SSS scenario, the results indicate that projected crop yields are expected to be lower than the BAU scenario, rendering them insufficient to meet local food demand. For instance, the projected yield range for dry pulses is estimated to be between 0.88 and 0.92 tons/ha from 2030 to 2050, 0.96 to 1.15 tons/ha for maize, 0.97 to 0.99 tons/ha for sorghum, and 2.59 to 2.72 tons/ha for paddy rice. These yields are not significantly different from the current national average yield per hectare for these crops, which stands at approximately 1400 kg/ha for dry pulses, 1 ton/ha for grain maize and sorghum respectively, and 3 tons/ha for paddy rice (FEWSNET, 2018).

With the current production level, around 5 million people in Haiti still face severe acute food insecurity. Additionally, data from the United Nations indicates that the Haitian population is expected to increase by another 1 million people in 2030 and an additional 2 million by 2050. So, there will be more people to feed. Consequently, considering the current and projected patterns of these crop productions, the level of food insecurity is likely to be increased. So, it is evident that addressing food insecurity in Haiti necessitates proactive measures to enhance agricultural productivity and ensure sustainable food production. Additionally, interventions must tackle the underlying environmental, social and economic factors, such as climate change, population growth and inequality, as well as promote equitable access to resources and improved conservation practices. These efforts are crucial to mitigate the projected increase in food insecurity, and sustainably meet the growing demand for food in Haiti.

As climate change poses a paramount threat to food production, as highlighted by numerous studies such as Owino et al. (2022), Lachaud et al. (2022) including the IPCC's 2023 report IPCC (2023), which projects an exacerbation of climate change impacts in the

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future. Thus, adaptation emerges as a crucial solution to build resilience in the agricultural sector (Toreti et al., 2022). Acknowledging this premise, we proceed to examine and assess farmers' willingness to adapt, as climate change adaptation policies cannot be neutral to farmers. Out of the 488 participants surveyed, the results show that only approximately 30.5% expressed their willingness to transition to crop rotation, while a substantial 69.52% revealed their resistance to adopting such practices. This finding indicates that although a significant proportion of farmers (73.3%) engage in crop cultivation (Table 10), there exists considerable reluctance among them when it comes to implementing changes in crop rotation between seasons. Multiple factors or barriers may contribute to this hesitancy, including entrenched traditional farming practices, limited awareness regarding the benefits of crop rotation, and apprehensions about potential risks and uncertainties associated with such a change. Indeed, the implementation of crop rotation has proven to be beneficial for plant development and production, as highlighted in previous studies (N’Dayegamiye et al., 2017; Wang et al., 2021). Consequently, it becomes imperative to prioritize farmer training initiatives to emphasize the importance of crop rotation. Such training programs aim to optimize the projected yields of the four mentioned crops in the future, thereby playing a crucial role in ensuring food security in Haiti.

Nevertheless, drought stands out as a notable consequence of climate change. It poses a recurring and substantial environmental hazard in Haiti, as evidenced by studies indicating an increase in both the frequency and intensity of drought events (Li et al., 2019; Mohsenipour et al., 2018). The trend is expected to persist in the future due to climate change and increased water demand. To enhance crop production and establish resilience against this natural hazard, it is imperative to identify regions with varying degrees of

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drought risk, ranging from low to very high. To achieve this, the present study also employed fuzzy logic approaches and geospatial techniques, utilizing a specific set of indicators related to plant development. These approaches aimed to assess the spatial distribution and variation of agricultural drought risk in Haiti. The assessment incorporated a risk equation that encompassed vulnerability, hazard, and exposure components, while also integrating adaptive capacity. The examination of drought risk was conducted both with and without the integration of adaptive capacity in the risk equation. The inclusion of adaptive capacity yielded a lower moderate to very high-risk level (30.7%) compared to the scenario without adaptive capacity (45.8%). This finding demonstrates that over 30% of the examined region faces a significant agricultural drought risk, ranging from moderate to very high. This poses a pressing obstacle for local crop cultivation to adequately satisfy the existing food demand. Furthermore, it represents one of the primary factors that could potentially contribute to the decline in yields for the aforementioned four crops within the timeframe of 2030 to 2050.

In fact, the analysis shows the current and exact level of agricultural drought risk in the study area. Therefore, comprehending the perspectives held by farmers regarding climate change and strategies for adaptation holds utmost significance in facilitating their endeavors and formulating interventions that align better with the specificities of the local milieu. Thus, the final objective of this thesis was to examine the variation in farmers' perception of climate change within the study area, considering their socio-economic status and gender. Additionally, the study aimed to explore the different local coping mechanisms developed by farmers to mitigate the impacts of climate change, particularly drought. Using structural modeling equations, the findings revealed that farmers with lower incomes exhibited a higher level of climate change perception compared to their higher-income counterparts. Similarly, female farmers demonstrated a greater awareness of climate change compared to their male counterparts.

Moreover, the surveyed population employed a range of strategies to adapt to the changing climate. The analysis of adaptation strategies revealed that low-income farmers predominantly relied on off-farm activities, such as securing off-farm jobs, leasing lands, and household migration, as means to cope with climate change impacts. In contrast, female farmers primarily focused on on-farm activities to adapt, including adjusting the farming calendar, altering crop varieties, and modifying the irrigation system. These findings highlight the differential approaches taken by farmers based on their socio-economic status and gender in response to climate change challenges. Overall, the results in this section are vital for developing appropriate and effective interventions to ensure crop productivity, enhance resilience, and secure global food supplies in the face of climate change specially in this timeframe 2030 - 2050.

Based on the findings presented in this research, it is evident that addressing food security, especially the projected growing food demand in Haiti will require to give close attention to: (i) increasing crop productivity, (ii) farmers' willingness to practice adaptation measures such as crop rotations, (iii) building drought resilience on the farms, and lastly (iv) strengthening the resilience of smallholder farmers:

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6.1. Increasing crop productivity

To increase crop productivity and meeting future food demand, the following policy recommendations are proposed:

i. ***Technology transfer and innovation***: Enhancing the transfer of technology and innovation to farming communities in Haiti is crucial. This can be achieved through the introduction of new crop varieties, mechanization, and digital agriculture tools. Such advancements have the potential to improve productivity, reduce post-harvest losses, and enhance market access.

ii. ***Rural infrastructure development***: The lack of adequate infrastructure in rural areas hinders agricultural productivity in Haiti. Investing in rural infrastructure, including roads, storage facilities, and market infrastructure, can improve access to markets and reduce post-harvest losses, thereby contributing to increased crop yield and food security.

iii. ***Policy support***: Policy support plays a vital role in enhancing agricultural productivity and reducing food insecurity. Policies should focus on promoting smallholder agriculture, improving access to credit and inputs, and enhancing market access. However, considering the political and institutional challenges in the region, it is important to address capacity limitations and ensure efficient execution of measures to support agriculture.

iv. ***Sustainable food systems***: Building sustainable food systems that prioritize equity, resilience, and environmental sustainability is essential. This involves promoting local food systems, reducing food waste, and improving the management of natural resources.

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Such measures contribute to long-term food security by ensuring the availability of nutritious food while minimizing negative environmental impacts.

v. ***Cross-sectoral collaboration***: Addressing the complex challenges of food insecurity in Haiti requires collaboration across various sectors, including agriculture, health, education, environment and social protection. Cross-sectoral collaboration can enhance the effectiveness and sustainability of food security interventions by pooling resources, expertise, and knowledge.

vi. ***Climate-smart agriculture*** (Ariani et al., 2018): Given Haiti's vulnerability to climate-related disasters, advocating for the implementation of a climate change adaptation policy is crucial. This policy should be coupled with the promotion of climate-smart agriculture practices, such as using drought-tolerant crops, improved water management, agroforestry, and conservation agriculture. However, the success of these initiatives relies on farmers' willingness to adapt to climate change such as the use of crop rotations, and the need for policies to address the challenges they face in adopting new practices.

6.2. Encouraging farmers to practice crop rotation.

To encourage farmers to practice crop rotations and ensuring crop yield improvement and meeting future food demand:

i. It is crucial to provide farmer education and training programs that focus on climate change resilience and raise awareness about the benefits of crop rotations. Collaborative efforts with agricultural extension services, NGOs, and research institutions can help disseminate information and conduct training sessions on the advantages of crop rotations.

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ii. Establishing demonstration farms and farmer field schools can serve as practical learning spaces where farmers can witness the positive outcomes of crop rotations. These platforms might also enable knowledge and experience exchange among farmers. Financial incentives, such as subsidies or grants, should be offered to encourage farmers to adopt crop rotation practices, offset initial costs, and promote alternative cropping systems that enhance overall farm resilience.

iii. Access to improved seeds and inputs is essential, including locally adapted crop varieties suitable for rotation systems. Collaboration with seed companies, research institutions, and agricultural organizations can help develop and distribute resilient seed varieties. Additionally, access to other inputs like organic fertilizers and biopesticides supports sustainable and productive crop rotation practices.

iv. Facilitating knowledge exchange platforms and farmer networks can allow farmers to share experiences and success stories related to crop rotation. Farmer associations, study tours, mentoring programs, and interactive digital platforms can help connect farmers and experts in crop rotation practices.

v. Strengthening agricultural extension services and providing technical assistance to farmers is necessary for successful implementation and management of crop rotations. Extension agents could offer guidance specific to the local context, including crop selection, timing, and agronomic practices.

vi. Investing in research and development initiatives tailored to local agroecological conditions and farmer needs is crucial. This research should focus on developing context-specific recommendations for crop combinations, rotation intervals, and integration with other sustainable agricultural practices. Collaborations between

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research institutions, universities, and farmers should prioritize participatory research approaches.

vii. Crop rotation practices should be integrated into agricultural policies and regulations to promote their adoption and recognition. This integration can occur through requirements in land use planning, agricultural zoning, and farm management plans. Additionally, the development of market incentives, such as certification schemes or preferential procurement policies, can reward farmers practicing crop rotation for their contribution to sustainable agriculture and food security.

6.3. Building drought resilience to improve crop productivity.

To build drought resilience and improve crop yield to meeting the growing food demand, several recommendations can be implemented:

i. Firstly, enhancing irrigation infrastructure is crucial, including expanding water storage facilities, promoting efficient irrigation techniques, and providing farmers with access to irrigation infrastructure and technologies.

ii. Promoting climate-smart agriculture is essential, encouraging practices such as agroforestry, conservation agriculture, crop diversification, and the use of drought-tolerant crop varieties. Training, resources, and incentives should be provided to support farmers in adopting these practices.

iii. Improving water management involves implementing measures such as watershed management programs, rainwater harvesting techniques, and water-efficient farming practices. Efficient water storage and distribution systems should be encouraged to optimize water resources.

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iv. Establishing and strengthening early warning systems for drought and other climate-related risks is vital. This includes investing in meteorological monitoring, remote sensing technologies, and data collection systems to provide timely and accurate information to farmers. Protocols for disseminating early warnings should be developed, ensuring farmers have access to this information.

v. Developing and implementing disaster risk reduction strategies and insurance mechanisms tailored to the agricultural sector is crucial. Crop insurance, weather-indexed insurance, and other risk-sharing mechanisms can provide financial support to farmers in the event of crop losses due to droughts or other climate related-disasters.

vi. Improving access to financial services and risk management tools, such as agricultural insurance programs and microfinance initiatives, is important. Training and support on financial literacy and risk management strategies should be provided to farmers.

vii. Investing in research and development focused on drought-resistant crop varieties, soil conservation techniques, and sustainable agricultural practices is necessary. Collaboration between research institutions, farmers, and extension services should be promoted to ensure the adoption of innovative and locally relevant solutions.

viii. Supporting the formation and strengthening of farmer organizations and cooperatives provides a platform for knowledge sharing, resource access, and collective problem-solving. Capacity-building initiatives and technical assistance should be facilitated to empower farmers to make informed decisions.

ix. Enhancing market access for farmers through improved transportation infrastructure, storage facilities, and market linkages is crucial. Value chain integration should be

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promoted to ensure fair prices and reduce post-harvest losses. Local processing and storage facilities should be developed to add value to agricultural products.

x. Investing in agricultural education and extension services, including training on climate-resilient practices, water management techniques, and modern farming technologies, is important. Knowledge exchange platforms and farmer-to-farmer learning opportunities should be fostered.

xi. Ensuring policy coherence and governance across sectors related to agriculture, water resources, and climate change is necessary. Improved coordination and collaboration among relevant ministries, departments, and agencies should be promoted. Integrated policies addressing food security, climate change, and sustainable agriculture challenges should be developed and implemented.

6.4. Strengthening the resilience of smallholder farmers

To promote farmers' education of climate change and enhance their mechanisms of adaptation to improving crop yield and achieving food security in Haiti, several recommendations can be implemented.

i. Firstly, educational programs and awareness campaigns should be introduced to enhance farmers' understanding of climate change and its potential impacts on agriculture. These initiatives should provide information on climate-smart farming practices, adaptation strategies, and the benefits of building resilience.

ii. Supporting the diversification of income sources is another crucial step. Low-income farmers should be provided with resources and support to engage in off-farm activities, reducing their vulnerability to climate change by diversifying their income sources. Promoting sustainable farming practices, such as agroecology, organic farming, and

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conservation agriculture, can improve soil health, water management, and overall farm resilience.

iii. Facilitating access to financial services, including microcredit and insurance tailored to farmers' needs, can provide them with the necessary resources to invest in climate-resilient infrastructure, technologies, and inputs, thus mitigating risks associated with climate variability. Strengthening farmer cooperatives and networks can facilitate knowledge sharing, exchange of best practices, and collective action in adapting to climate change.

iv. Investing in water resource management infrastructure and technologies, such as irrigation systems, rainwater harvesting, and water storage facilities, can mitigate the impacts of drought and water scarcity, ensuring sustainable water availability for agricultural activities. Introducing gender-sensitive approaches that acknowledge and address the specific needs, challenges, and opportunities of female farmers is important. Providing training, resources, and decision-making opportunities to women in agriculture can enhance their adaptive capacity.

v. Developing and strengthening early warning systems for climate-related hazards, particularly drought, is essential. Timely and accurate information can enable farmers to take proactive measures, such as adjusting planting and harvesting schedules, implementing water-saving techniques, and adopting appropriate agronomic practices. Investing in research and development initiatives focused on climate-resilient crop varieties, improved farming techniques, and innovative technologies can contribute to the identification and dissemination of context-specific solutions that enhance farm resilience and sustainable food production in Haiti.

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vi. Lastly, establishing supportive policy and institutional frameworks is crucial. Policies promoting climate-resilient agriculture, sustainable land management, and natural resource conservation should be developed and enforced. Institutional mechanisms should be established to coordinate and integrate climate change adaptation efforts across different sectors and stakeholders.

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8. Appendix

Appendix 1

A Survey on Household Perception and Adaptation to Climate Change in the Artibonite Department, Haiti

1. Introduction

The present study was carried out in February 2021 in the Artibonite department of Haiti. The primary objective of the survey was to gather relevant information aligned with the specific research objectives outlined in the thesis. Ethical considerations were taken into account during the survey process, ensuring that participants were informed about the survey's purpose and provided with the right to participate voluntarily. To facilitate better communication and participation, the questionnaire was designed in the local language, Haitian Creole.

2. Methodology

2.1. Survey Design

The survey encompassed inquiries on various domains, including household demographic characteristics, farm attributes, perception of local climate, and strategies for climate change adaptation. The questionnaire consisted of several sections covering the following components:

2.2. Household Demographic Characteristics

The survey gathered data on gender, activities, and educational background of the participating households.

2.3. Farm Characteristics

Farm-related information was collected, focusing on two key components: farming system type and land tenure type.

2.4. Perception of Local Climate

Participants were asked about their perception of the local climate, particularly regarding the rainy season and climate observations over the past decade. They were inquired about whether the rainy season started on time, late, or early compared to previous years.

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Additionally, respondents were asked if they observed changes such as (i) reduced rainfall, (ii) delayed onset of rainfall, (iii) earlier end of the rainy season, (iv) increased number of hot days, and (v) decreased number of hot days during the past decade.

2.5. Adaptation to Climate Change

In the context of climate change adaptation, respondents were asked about their willingness to practice crop rotations if they encountered a 30% crop yield loss compared to the previous season.

3. Data Analysis

Stata was employed as the data management tool for processing the collected data. Descriptive analysis served as the chosen method for data examination, providing an overview of the survey results.

4. Conclusion

In conclusion, the survey conducted in February 2021 in the Artibonite department provided valuable insights into household perception and adaptation to climate change in the region. The survey results contribute to the understanding of local perspectives on climate change and can inform future policies and interventions aimed at enhancing climate resilience in the area. Further research and analysis are recommended to delve deeper into specific aspects of climate change adaptation strategies in the region.

Appendix 2

Weighting the various indicators

Table 17 Subclasses of drought vulnerability, exposure, hazard and adaptive capacity factors and their respective numerical weights.

No.	Indicators (Owning component)	Unit	Break value	Rating	Weight assigned	Fuzzy membership function	Assumption
1	Soil depth (V)	m	75-153	5	Very high	Fuzzy – Small	Inversely related
			154 – 169	10	High		
			170 – 183	15	Moderate		
			184 – 194	20	Low		
			195 – 200	25	Very low		
2	Soil moisture (V)	%	0 – 90	5	Very low	Fuzzy – Small	Inversely related
			91 – 104	10	Low		
			105 – 118	15	Moderate		
			119 – 133	20	High		
			134 – 173	25	Very high		
3	Clay (V)	%	14 – 24	5	Very low	Fuzzy – Large	Directly related
			27 – 30	10	Low		
			31 – 34	15	Moderate		
			35 – 38	20	High		
			39 – 51	25	Very high		
4	Sand (V)	%	18 – 33	5	Very low	Fuzzy – Large	Directly related
			34 – 38	10	Low		
			39 – 42	15	Moderate		
			43 – 46	20	High		
			47 – 61	25	Very high		
5	Elevation (V)	m	2 – 217	5	Very low	Fuzzy – Large	Directedly related
			218 – 432	10	Low		
			433 – 691	15	Moderate		
			692 – 1045	20	High		
			1046 - 1993	25	Very high		
6	Slope (V)		0 – 7	5	Very low	Fuzzy – Large	Directedly related
			8 – 17	10	Low		
			18 – 28	15	Moderate		
			29 – 43	20	High		
			44 – 126	25	Very high		
7	Rainfall (H)	mm	550.6 – 1089.8	5	Very high	Fuzzy – Small	Inversely related
			1089.9 -1352.1	10	High		
			1352.2 -1563.5	15	Moderate		
			1563.6 -1869.5	20	Low		
			1869.6 -2408.8	25	Very low		
8	Temperature (H)	^{0}C	21 – 27	5	Very low	Fuzzy – Large	Directly related

			20 – 30	10	Low		
			31 – 32	15	Moderate		
			33 – 33	20	High		
			34 – 36	25	Very high		
9	Evaporation (H)	mm	0 – 50426	5	Very low	Fuzzy – Large	Directly related
			50427- 60124	10	Low		
			60125 - 66912	15	Moderate		
			66913 - 73377	20	High		
			733778 -82428	25	Very high		
10	Relative humidity (H)	%	72 – 73	5	Very high	Fuzzy – Small	Inversely related
			74 – 75	10	High		
			76 – 77	15	Moderate		
			78 – 79	20	Low		
			79 – 80	25	Very low		
11	LULC (E)		Water body	-100	No member	Fuzzy – Large	Directly related
			Trees	10	Low		
			Snow	-100	No member		
			Scrub/shrub	5	Very low		
			Grassland	20	Moderate		
			Flood veg.	-100	No member		
			Croplands	25	Very high		
			Cloud	-100	No member		
			Built area	15	High		
			Bareground	-100	No member		
12	Population density (E)	Km^2	0 – 2750	5	Very low	Fuzzy – Linear	Directly related
			2751 – 10724	10	Low		
			10725 - 24198	15	Moderate		
			24199 - 44821	20	High		
			44822 - 70118	25	Very high		
13	NDVI (E)		0 - 0.1	5	Very low	Fuzzy – Large	Directly related
			0.1 - 0.2	10	Low		
			0.2 - 0.3	15	Moderate		
			0.3 - 0.4	20	High		
			0.4 - 0.5	25	Very high		
14	Crop production harvest area (E)	(1000ha)		5	Very low	Fuzzy – Large	Directly related
				10	Low		
				15	Moderate		
				20	High		
				25	Very high		
15	Distance to river (AC)	m	0 – 1073	5	Very low	Fuzzy – Large	Directly related
			1074 – 2413	10	Low		
			2414 – 5363	15	Moderate		
			5364 – 12335	20	High		
			12336 - 68382	25	Very high		

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16	River density (AC)	Km^2	0 – 0.2	5	Very low	Fuzzy – Small	Inversely related
			0.21 – 0.36	10	Low		
			0.37 – 0.53	15	Moderate		
			0.54 – 0.74	20	High		
			0.75 – 1.24	25	Very high		
17	Distance to road (AC)	m	0 – 1604	25	Very high	Fuzzy – Large	Directly related
			1605 – 3572	20	High		
			3573 – 6051	15	Moderate		
			6052 – 9623	10	Low		
			12336 - 68382	5	Very low		
18	Available Water Capacity (AC)	%	17 – 23	5	Very low	Fuzzy – Small	Inversely related
			24 – 26	10	Low		
			27 – 30	15	Moderate		
			31 – 38	20	High		
			39 – 54	25	Very high		