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Spécialité : Changement Climatique et Gestion des Risques de Catastrophes

Par

OUATTARA Salimata

L'APICULTURE DURABLE DANS LES CONDITIONS DU CHANGEMENT CLIMATIQUE : FACTEURS DE RISQUE ET STRATEGIES D'ADAPTATION DANS LA REGION DE PORO, NORD DE LA CÔTE D'IVOIRE

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By

OUATTARA Salimata

SUSTAINABLE BEEKEEPING UNDER CLIMATE CHANGE CONDITIONS: RISK DRIVERS AND ADAPTATION STRATEGIES IN THE PORO REGION, NORTHERN CÔTE D'IVOIRE

Publicly defended on Friday, April 25th 2025 before a jury composed of:

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Sustainable beekeeping under climate change conditions: Risk drivers and adaptation strategies in the Poro region, Northern Côte d’Ivoire

Dedication

I dedicate this thesis:

To my beloved Parents,

who have been a constant source of love, encouragement, and support. Your words of wisdom and prayer have been instrumental in my academic journey. I am forever grateful for your sacrifices, guidance, and endless love.

To my brothers and Sisters,

You have given me a lot of encouragement in the realization of this work, and I am grateful for your encouragement and the joy and laughter we have shared.

Epigraph

No living being, not even man, has achieved in the center of its sphere what the bee has achieved in its own; and if an intelligence foreign to ours were to ask the earth for the most perfect object in the logic of life, it would have to present it with the humble honeycomb'.

Maeterlink, « The life of bees »

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Publications

❖ **Articles already published**

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- Ouattara S., Assi-Kaudjhis C., Adjonou K., Kouamé K.F., Koudegnan C.M. & Kokou K. (2023). State of Knowledge on Beekeeping Practices in Côte d'Ivoire in the Face of Challenges and Opportunities in the Context of Climate Change. *European Scientific Journal*, ESJ, 19 (30), 1. https://doi.org/10.19044/esj.2023.v19n30p46

Participation in scientific events

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Title: Sustainable beekeeping under climate change conditions: risk drivers and adaptation strategies in the Poro region, northern Côte d’Ivoire

Abstract

A great deal of research has shown that climate change is one of the current threats to pollinators. It has a significant influence on other strictly related factors, such as diseases and predators, causing the weakening and desertion of honey bees. The loss of colonies, damage bees could pose a threat to global food security and leave the beekeeping sector vulnerable. However, the literature lacks information on the effects of anthropogenic change and activities on beekeeping in the Poro region, Côte d'Ivoire. This study aims to contribute to greater resilience and sustainability of the beekeeping sector in the face of the interactions of climate change and anthropogenic factors in the north of Côte d'Ivoire. The hypothesis is that the sustainability and resilience of beekeeping are influenced by climatic, environmental and socio-economic conditions, and can be ensured by adopting strategies. The study used a mixed methodological approach, integrating a literature review of 43 relevant articles to assess the current state of beekeeping and identify challenges, surveys of 162 beekeepers, an interview with the federation of beekeepers, focus group discussions (5), field observations and an inventory of melliferous plants. The evaluation of the impacts of climate parameters on beekeeping productivity, a combination of multicriteria analysis AHP and GIS for the analysis of favourable areas, the analysis of beekeepers' vulnerability using the IPCC 2014 conceptual framework of vulnerability and Principal Component Analysis (PCA), the evaluation of the effectiveness of adaptation strategies using AHP and the development of new strategies. The results showed that there are more than 100 melliferous species identified in the country, resulting in good quality honeys. Despite this, there are socio-economic and environmental challenges to be overcome, such as pesticides and habitat destruction, which affect bees, leading to a disruption of their ecosystem services. The beekeepers' perceptions of the climatic parameters are confirmed by an analysis of their trend, which shows a decrease in precipitation and an increase in temperature, whereas the trend in production differs from their perception of their production. Precipitation influenced production ($r= 0.78$, $p= 0.04$ ($p < 0.05$)), while the impact of temperature ($r = 0.02$, $p = 0.96$ ($p < 0.05$)) was masked by other factors such as humidity and beekeeping practices. 20 species of melliferous plants were identified, showing preferences for certain species such as *Detarium microcarpum, Hyptis suaveolens*. Unsuitable areas (59%) are more extensive than suitable areas (41%), highlighting the importance of the proximity of bees to floral diversity, water availability and roads. Beekeepers are vulnerable due to susceptibility factors such as household size, production, desertion, pesticides, age and income from beekeeping. Beekeepers' ability to adapt is limited by the index of practices, experience, cooperatives, funding and education. The use of a water reservoir, harvest periods, training in beekeeping, reforestation, location of apiaries are the most effective strategies. The new strategies developed will help beekeepers to mitigate losses and damage and anticipate future dangers by offering solutions to improve their productivity.

Keywords: Climate change adaptation, Honey bees, Beekeepers’ vulnerability, Ecosystemic services, Poro region

Titre : L'apiculture durable dans les conditions du changement climatique : Facteurs de risque et stratégies d'adaptation dans la région du Poro, Nord de la Côte d'Ivoire

Résumé

De nombreuses recherches ont montré que le changement climatique est l'une des menaces actuelles pour les pollinisateurs. Il a une influence significative sur d'autres facteurs strictement liés, tels que les maladies et les prédateurs, provoquant l'affaiblissement et la désertion des abeilles mellifères. La perte de colonies, les dommages causés aux abeilles pourraient constituer une menace pour la sécurité alimentaire mondiale et rendre le secteur apicole vulnérable. Cependant, la littérature manque d'informations sur les effets des changements et activités anthropiques sur l'apiculture dans la région du Poro, en Côte d'Ivoire. Cette étude vise à contribuer à une plus grande résilience et durabilité du secteur apicole face aux interactions du changement climatique et des facteurs anthropiques dans le nord de la Côte d'Ivoire. L'hypothèse est que la durabilité et la résilience de l'apiculture sont influencées par les conditions climatiques, environnementales et socio-économiques, et peuvent être assurées par l'adoption de stratégies. L'étude a utilisé une approche méthodologique mixte, intégrant une revue de la littérature de 43 articles pertinents pour évaluer l'état actuel de l'apiculture et identifier les défis, des enquêtes auprès de 162 apiculteurs, un entretien avec la fédération des apiculteurs, des discussions de groupe (5), des observations sur le terrain et un inventaire des plantes mellifères. L'évaluation des impacts des paramètres climatiques sur la productivité apicole, une combinaison de l'analyse multicritère AHP et GIS pour l'analyse des zones favorables, l'analyse de la vulnérabilité des apiculteurs en utilisant le cadre conceptuel de vulnérabilité IPCC 2014 et l'Analyse en Composantes Principales (ACP), l'évaluation de l'efficacité des stratégies d'adaptation en utilisant l'AHP et le développement de nouvelles stratégies. Les résultats ont montré qu'il existe plus de 100 espèces mellifères identifiées dans le pays, ce qui permet d'obtenir des miels de bonne qualité. Malgré cela, des défis socio-économiques et environnementaux doivent être relevés, tels que les pesticides et la destruction de l'habitat, qui affectent les abeilles, entraînant une perturbation de leurs services écosystémiques. La perception des paramètres climatiques par les apiculteurs est confirmée par l'analyse de leur évolution qui montre une diminution des précipitations et une augmentation de la température, alors que l'évolution de la production diffère de leur perception de leur production. Les précipitations influencent la production ($r = 0,78$, $p = 0,04$ ($p < 0,05$)), tandis que l'impact de la température ($r = 0,02$, $p = 0,96$ ($p < 0,05$)) est masqué par d'autres facteurs tels que l'humidité et les pratiques apicoles. 20 espèces de plantes mellifères ont été identifiées, montrant des préférences pour certaines espèces telles que Detarium microcarpum, Hyptis suaveolens. Les zones inappropriées (59 %) sont plus étendues que les zones appropriées (41 %), ce qui souligne l'importance de la proximité des abeilles par rapport à la diversité florale, à la disponibilité de l'eau et aux routes. Les apiculteurs sont vulnérables en raison de facteurs tels que la taille du ménage, la production, la désertion, les pesticides, l'âge et le revenu de l'apiculture. La capacité d'adaptation des apiculteurs est limitée par l'index des pratiques, l'expérience, les coopératives, le financement et l'éducation. L'utilisation d'un réservoir d'eau, les périodes de récolte, la formation en apiculture, le reboisement, la localisation des ruchers sont les stratégies les plus efficaces. Les nouvelles stratégies développées aideront les apiculteurs à atténuer les pertes et les dommages et à anticiper les dangers futurs en proposant des solutions pour améliorer leur productivité.

Mots clés : Adaptation au changement climatique, abeilles mellifères, vulnérabilité des apiculteurs, Services écosystémiques, région du Poro.

List of abbreviations

Abbreviation	Full meaning
A.C.	Adaptive Capacity
AHP	Analytical Hierarchy Process
Bkp	Beekeeper
EL	Elevation
FAO	Food and Agriculture Organization
FENAPCI	National Federation of Beekeepers of Côte d'Ivoire
GIS	Geographical Information System
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
INS	National Institute of Statistic
LU/LC	Land use/Land cover
MCDA	Multi-Criteria Decision Analysis
MEF	Ministry of Economy and Finance
OECD	Organization for Economic Cooperation and Development
PCA	Principal Component Analysis
PR	Precipitation
SL	Slope
SODEXAM	Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique en Côte d'Ivoire
SUS	Susceptibility
TP	Temperature
UNASCACI	National Union of Beekeepers' Cooperative Societies of Côte d'Ivoire
WASCAL	West African Science Service Center on Climate Change and Adapted Land Use
WB	Water Bodies
RS	Remote Sensing

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GENERAL INTRODUCTION

1. Background and context

Beekeeping is a vital branch of agriculture that involves the management of bees for honey production and other hive products (Mohammed and Hassen, 2021). Beyond its economic benefits, beekeeping is crucial in environmental conservation and socio-economic development (Gemeda, 2014; Sokemawu, 2016; Ubeh *et al.,* 2011). It provides a source of income for stakeholders, contributes to forest preservation, and supports biodiversity by maintaining a high population of pollinating agents essential for plant ecosystems (Ahouandjinou *et al.*, 2017). Globally, the beekeeping sector generates approximately $1.7 million annually (Mwakatobe & Mlingwa, 2005) and employs around two million people in rural areas by marketing honey and beeswax (Mwakatobe & Mlingwa, 2005).

As the primary pollinators of many plant species worldwide, bees are essential to agricultural development and ecological balance. Their pollination services contribute an estimated $156 billion per year to global agricultural production (Gallai *et al.,* 2009), representing 9.5% of the total production value for human food. While wild insect pollinators also play a significant role (Garibaldi *et al.,* 2013), honey bees remain the dominant species, ensuring the pollination of key crops such as *Allium sativum, Solanum aethiopicum, Allium cepa, Ipomoea batatas, Gossypium hirsutum* and medicinal plants such as rosemary (*Rosmarinus officinalis*) and mint (*Mentha* spp.) (Klein *et al.,* 2007). Given their ecological importance, bees serve as a cornerstone of food security and bio-indicators of environmental change (Bogdanov, 2006; Chauzat *et al.*, 2006; Le Conte & Navajas, 2008).

Among beekeeping products, honey is the most valued by populations due to its rich nutritional and therapeutic properties. It is widely used both as a food product and in traditional medicine for treating various diseases (Bradbear, 2005; Lobreau-Callen & Jérémie, 1999). The international honey market has been steadily growing, reaching approximately 1.6 million tons in 2011, driven by significant increases in production in China (+60% in a decade) and the European Union (+30% in a decade) (Coulibaly *et al.*, 2019).

2. Problem statement

Over the past decade, several scientific studies have reported unusual weakening and mortality of bee colonies in several countries around the world (Adjlane *et al.*, 2012). For example, in the 2009 to 2010 season, the mortality of American colonies was 33.8% (van Engelsdorp *et al.*, 2010). Loss rates reported by the Colony Loss Monitoring Group (COLOSS) have fluctuated between very high winter losses with moderate or low mortality rates of 32,048 % and 60,227 % (Brodschneider *et al.,* 2016; Brodschneider *et al.,* 2018; van der Zee *et al.,* 2012; van der Zee *et al.,* 2014) worldwide. A similar trend has been reported by American beekeepers (Kulhanek *et al.*, 2017; van Engelsdorp *et al.,* 2010). Losses of 29.6% in 2009-2010 and 46.2% in 2010-2011 were reported for bees in South Africa (Pirk *et al.*, 2014). Phenomena of weakened apiaries with a decrease in bee activity without the presence of pathogens have also been observed by some authors, such as Faucon and Colin (1983) and Rafalimanana (2003). This observation was also made by Ivorian beekeepers, who are mostly farmers, complaining of frequent desertions and collapses of bee colonies (Assi-Kaudjhis *et al.,* 2020; Ohoueu *et al.,* 2017a).

Beyond these alarming statistics, the disappearance of bee colonies also raises broader concerns for ecosystems and human livelihoods. This loss of colonies and damage to bees could threaten global food security (Klein *et al.,* 2007). Indeed, the survival of plant, animal, and human species is dependent on insect pollination (IPBES, 2016). Food prices may rise, preventing the poor from accessing food. Moreover, this disappearance could be one of the causes of increased poverty among farmers and beekeepers (Gallai *et al.,* 2009).

The causes of this loss are numerous, although the desertion of bee colonies is a natural phenomenon due to the depletion of reserves in the hive (Winston, 1987). Other factors are induced by human activities, including biological factors caused by parasites and diseases, physical factors due to climate change, habitat change, and urbanization, chemical factors through intensive agriculture in all its forms (monoculture, agrosystem, etc.), and industrial activities (Goulson *et al.,* 2015).

Many research studies have shown that climate change is one of the current threats to pollinators (Hegland *et al.,* 2009; IPBES, 2016; Flores *et al.*, 2019; Schweiger *et al.,* 2010). Some authors believe that there is a strong correlation between climate change and bee colony extinction syndrome (Switanek *et al.,* 2017). It significantly influences other strictly related factors such as diseases, parasites, predators, parasitoids, viruses, and pesticide use (Le Conte & Navajas, 2008; Varikou *et al.*, 2020). These impacts can make the beekeeping sector vulnerable by negatively and positively affecting honey production in many parts of the world.

Despite its strong potential, the beekeeping sector faces significant challenges, particularly in the context of climate change. Rising global temperatures and extreme weather events such as droughts, floods, and forest fires are increasingly affecting agricultural yields, land quality, and biodiversity, leading to severe socio-economic consequences (Iglehart, 2008). Given that beekeeping depends heavily on climatic conditions, vegetation, and water availability, these environmental changes directly impact bee populations and honey production. Climate variations influence plant phenology, water resources, and pest infestations, which in turn affect pollination and hive productivity (Le Conte & Navajas, 2008). Additionally, increasing pesticide use and habitat degradation further threaten bee health and the sustainability of apiculture. In this context, understanding the interactions between beekeeping, climate change, and environmental factors is essential for ensuring the resilience and sustainability of the sector. The development of beekeeping depends not only on favorable climatic conditions and floral resources but also on the adaptation strategies and practices of stakeholders.

This gap highlights the need to better understand the vulnerability of local beekeeping systems to climate stressors and to identify the strategies used by beekeepers to cope with these changes. In Côte d'Ivoire, beekeeping is a recent and little practiced activity across the country, although the first practice was initiated in the early 1980s in the department of Katiola (Centre-North) (Kouassi *et al.*, 2018). Traditional beekeeping is the most widely practiced, and among this is 'honey hunting' (Assi-Kaudjhis *et al.*, 2020b; Kouassi *et al.*, 2018). This practice of 'honey hunting' consists of locating bee nests in trees and harvesting honey. This harvesting is done by cutting down the trees sheltering the nest (Soro *et al.*, 2020) and harvesting the honey at night after the colony has been destroyed by fire (Yédomonhan & Akoègninou, 2009). This sometimes leads to the desertion of bee colonies. According to (Kouassi *et al.*, 2018) "honey hunting" has led to the felling of more than 100 trees/year, as well as the destruction by fire of hundreds of bee colonies in savannah areas. Ohoueu *et al.* (2017a) argue that the desertions, collapses, and weakening of hives observed by beekeepers in the north of Côte d'Ivoire can be explained by the use of phytosanitary products in agriculture during the flowering time of the different crops. Indeed, pesticides are used to protect crops from pests and diseases. Farmers often use chemical pesticides because of their effectiveness and immediate action on pests (Ntow *et al.*, 2006; Weinberger & Srinivasan, 2009). Some farmers, however, overdose it to effectively eradicate these problems.

In Côte d'Ivoire, there is limited research in the scientific literature database that addresses the issue of desertion of bee colonies linked to anthropogenic actions and climatic factors. Most of the research conducted on beekeeping has focused on topics such as the diversity of melliferous plants and their potential (Coulibaly *et al.*, 2013; Coulibaly *et al.*, 2019), the morphometric characteristics of bees (Assielou & Marcel, 2019; Kouonon *et al.*, 2020), pollen and physico-chemical analyses of honeys (Diomandé *et al.*, 2018; Kouamé *et al.*, 2021) foraging activities (Coulibaly *et al.*, 2021), the impact of pesticides on beekeeping activities and their contamination by pesticides (Ohoueu, *et al.*, 2017b) The role of the agrosystem in bee activity (Tuo *et al.*, 2019); the place of beekeeping in society and their perceptions of honey bees (Savadogo *et al.*, 2018; Assi-Kaudjhis *et al.*, 2020; Soro *et al.*, 2020); the harvesting, production and marketing of honey (Kouassi *et al.*, 2018). This is because research on the beekeeping sector is recent in Côte d'Ivoire and has focused on bee feeding and honey production. In terms of the review article by Reddy *et al.*, *(2012*) shows that few studies have been carried out on the impacts of climate change on honey bees, particularly on beekeeping activity. These observations highlighted that in Côte d'Ivoire, particularly in the Poro region, the impact of climate change combined with anthropogenic activities on bee survival and the ecosystem services they provide remains poorly understood and under-researched. Few studies have examined the interactions between climate-related stressors, the vulnerability of beekeeping systems, and the adaptive strategies employed by beekeepers. This lack of comprehensive knowledge poses a significant challenge to the development of effective resilience strategies and the promotion of sustainable apiculture. This gap highlights the need to better understand the vulnerability of local beekeeping systems to climate stressors and to identify the strategies used by beekeepers to cope with these changes.

3. Research questions, objectives and assumptions

Aiming to enhance knowledge on the influence of climatic factors and human activities on beekeeping, the present study was initiated focusing on the theme "*Sustainable beekeeping under climate change conditions with specific focus on the risk drivers and adaptation strategies in the Poro region, Northern Côte d'Ivoire*". The study delved into understanding the key research question: How can beekeeping be made more resilient and sustainable under the conditions of climate change in the Poro region? The specific research questions addressed in this study include:

Question 1: What scientific knowledge and gaps have been identified in current research into beekeeping practices in Côte d'Ivoire?

Question 2: How do climatic variables impact beekeeping productivity in the northern Côte d'Ivoire, especially temperature and precipitation?

Question 3: Which areas in northern Côte d'Ivoire offer the most suitable conditions for keeping honeybees?

Question 4: Who are the most vulnerable beekeepers, and what factors explain their vulnerability?

Question 5: Are there any current or potential adaptation strategies for sustainable beekeeping under climate change conditions?

The **general objective** of this study is to contribute to better resilience and sustainability in the beekeeping sector regarding the interactions of climate change and anthropogenic factors in the northern part of Côte d'Ivoire.

Specifically, it will aim to:

Specific objective 1: Analyze the current scientific research and identify the main challenges in beekeeping in Côte d'Ivoire;

Specific objective 2: Analyze the impact of climatic parameters on beekeeping in the northern Côte d'Ivoire;

Specific objective 3: Identify and map suitable areas for keeping honeybees by combining the melliferous plants, the biophysical, and socio-economic criteria through the integration of GIS and the AHP;

Specific objective 4: Assess the vulnerability of beekeepers to climate change, by using the IPCC (2014) vulnerability framework and principal component analysis (PCA);

Specific objective 5: Identify and evaluate the effectiveness of existing strategies to support the development of new sustainable strategies to complement existing ones

These research questions are based on the following hypotheses: The sustainability and resilience of beekeeping are influenced by climatic, environmental, and socio-economic conditions and can be ensured by adopting strategies (**main assumption**).

Assumption 1: Côte d'Ivoire has great potential in beekeeping, but also faces some challenges;

Assumption 2: Climatic parameters have a significant impact on beekeeping activities;

Assumption 3: Some areas are suitable for keeping honeybees, others are unsuitable for honeybees;

Assumption 4: The vulnerability of beekeepers depends on the department, which is a function of their exposure and their ability to adapt;

Assumption 5: There are effective adaptation strategies for sustainable beekeeping

4. Thesis organization and overview of the parts

This thesis is organized into two Parts (Figure 1). Including a general introduction, Part One includes the literature review on the conceptual framework, geographical framework and beekeeping in Côte d'Ivoire. Part Two is devoted to risk drivers for beekeeping, vulnerability and adaptation strategies. Bees are facing many threats, so it is better to identify all the hazards, exposure elements and vulnerabilities of bees and beekeeping activities. We identify what types of strategies and their effectiveness are used by Beekeepers to cope with the risk factors. Then comes the overall discussion and conclusion of the thesis, including the main findings, perspectives and recommendations for further research.

GENERAL INTRODUCTION

- Conceptual and geographical framework
- **Chapter 1**: State of the art of beekeeping practices in Côte d'Ivoire
- **Chapter 2**: Impacts of climatic parameters on beekeeping productivity in the northern of Côte d’Ivoire
- **Chapter 3**: Suitability for beekeeping
- **Chapter 4**: Beekeepers' vulnerability
- **Chapter 5**: Adaptation strategies for sustainable beekeeping

GENERAL DISCUSSION

GENERAL CONCLUSION
PERSPECTIVES
RECOMMANDATIONS

Figure 1: Organization of the thesis

Source: Ouattara, 2024

CONCEPTUAL AND GEOGRAPHICAL FRAMEWORK

1. Conceptual framework

1.1. Definitions of concepts

1.1.1. Sustainable beekeeping

According to the literature, beekeeping has several definitions (Etxegarai-Legarreta & Sanchez-Famoso, 2022). The best known of which is beekeeping is the act or science of keeping honey bees to produce hive products for personal and industrial consumption (Masuku, 2013). Beekeeping plays several roles for both species and humans. The practice enables stakeholders to increase their sources of income (Ahouandjinou *et al.*, 2017) and reduce unemployment. Indeed, households practicing beekeeping increased their income more than those not practicing the activity (Schouten, 2020; Abro *et al.*, 2022) through the marketing of diversified products. This is a gender-neutral activity because it allows women to take part in certain cleaning, water supply, and commercial tasks (Jemase & Chesikaw, 2021) even if the activity is mainly practiced by men (Jemase & Chesikaw, 2021) due to the aggressiveness of bees (Akongte *et al.*, 2023).

Honeybees provide the ecosystem services of provision, regulation, and culture between humans and the ecosystem (Aryal *et al.*, 2020; Papa *et al.*, 2022) (Figure 2). As an example, bee products are used in Apitherapy, the use of bee products in health (Topal *et al.*, 2021), such as bee venom for the treatment of inflammatory diseases and pain (Zhang *et al.*, 2018). In the Environment, Honey bees help to preserve and conserve biodiversity and promote food security by pollinating species in quantity and quality (Topal *et al.*, 2021).

Environmental degradation caused by human activities and climatic conditions is having disastrous consequences for beekeeping. With this in mind, it is becoming necessary to adopt alternatives to preserve this activity. Sustainable beekeeping is emerging as a relevant alternative that combines environmental preservation and socio-economic balance. According to the FAO (2020) and Prodanović *et al.* (2024), sustainable beekeeping ensures the health of bees, preserves biodiversity, respects the environment and the ecology of bees, while providing beekeepers with a stable income. In the case of bee health, this involves the use of natural products and the genetic selection of resistant bees, such as Varroa destructor (Locke, 2016) and the maintenance of apiaries. As for sustainable beekeeping practices, this involves, for example, moving hives in line with the flowering without overexploiting local resources (Simenel *et al.*, 2015), using natural materials

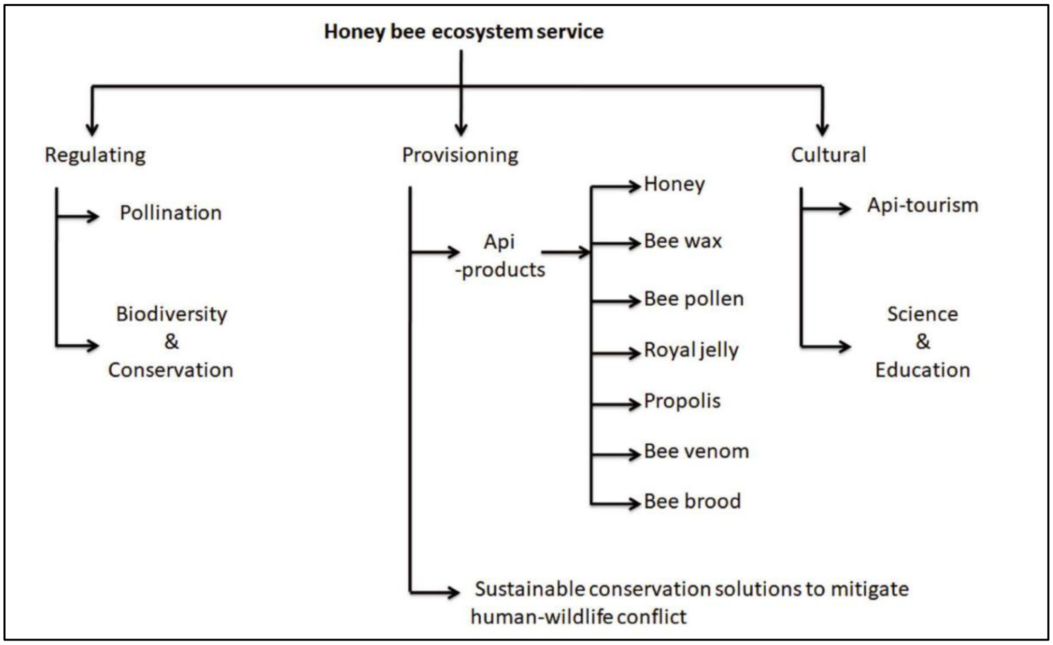


Figure 2: Schematic representation of ecosystem services provided by honeybees

Source: Aryal *et al.*, 2020

that are recyclable and have a low carbon footprint.

1.1.2. Climate Change

The Framework Convention on Climate Change (FCCC) defines Climate Change as "a change of climate which is attributed directly or indirectly to human activity, which alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable periods" (Pielke, 2004). IPCC, (2013) defines Climate change simply as "a lasting change in the climate, due to variations in its averages or variability, often over several decades".

Climate change has affected all the domains and dimensions in the world at varying levels and scales. Beekeeping is affected by Climate Change because honey bees' productivity relies on precipitation and temperature (Akala, 2019). Rising temperatures and variations in rainfall could reduce the availability of resources for bees, as well as colony mortality (Delgado *et al.*, 2012). It could also pose a threat to the health of bees through the proliferation and increase in diseases and alter the behaviour and physiology of bees (Le Conte & Navajas, 2008). Precipitation directly affects floral diversity (Gajardo-Rojas *et al.*, 2022), which can increase or decrease honey production.

1.1.3. Adaptations

Adaptation is not simply the ability to cope with the impact of a risk, but rather a planned strategy that mobilizes available resources and knowledge. It aims to anticipate, plan for and respond effectively to present and future risks, with a view to sustainable resilience. In the case of beekeeping, understanding how beekeepers perceive health risks and colony mortality helps them to adapt their beekeeping management practices (El Agrebi *et al.*, 2022).

Adaptation practices can vary according to the degree of risk factors to which systems are exposed (Moser & Ekstrom, 2010). According to Burton (1996), Smit & Wandel (2006), Moser and Ekstrom (2010) and Zaatra (2022), adaptation strategies are effective when they are anticipated, preventive and less costly than reactive responses imposed by the urgency of change. Simonet (2010) and Biesbroek *et al* (2013) state that implementing adaptation strategies can be difficult. These include limited financial and human resources due to the uncertainty associated with the future evolution of change, and inequalities between policy priorities for action (Eyzaguirre & Warren, 2014; Owen, 2020).

1.1.4. Honeybee-related risks noticed in the literature

Climate change has exposed bees to multiple risks that cause their desertion and mortality. These changes have a direct impact on the needs of bees and the availability of resources (Le Conte & Navajas, 2008). The nutritional quality of diversified resources being essential for the proper development of colonies (Di Pasquale *et al.*, 2013). Then, severe weather events reported by beekeepers lead to weakened or lost colonies, reduced nectar and pollen, lower honey production, increased Varroa infestations, intensified transhumance, and decreased pollination (Vercelli *et al.*, 2021). Prolonged exposure of bees to high temperatures could be one of the causes of their increased sensitivity to pesticides (Albacete *et al.*, 2023). Indeed, these chemical compounds attack the nervous system, reproductive system and reactions of bees (Goulson *et al.*, 2015). One of the causes of the risks to bees is the practices of beekeepers themselves. The poor beekeeping practices can increase the stress on bees in the hives (El Agrebi *et al.*, 2022). In addition, stress and exposure resulting from displaced colonies every time (OIE, 2014) and the inappropriate use of veterinary drugs can lead to parasite resistance (Bietrix & Chauzat, 2022). The interaction of multiple factors could increase the damage done to bees (Hristov *et al.*, 2020) in the future. Understanding beekeepers' risk perceptions regarding bee health and mortality is crucial for analyzing management practice adoption (El Agrebi *et al.*, 2022).

1.2. Summary of the General Methodological Steps

Beekeeping through bees brings together various sectors and disciplines through an inter-transdisciplinary manner. This activity is highly dependent on environmental and climatic factors. Using mixed methods, it is essential to understand the services they play in the various disciplines and to see how these services are affected by climatic and environmental risks. Identifying risk factors for beekeeping in the Poro region was developed using several study approaches. These were case studies associated with the analysis of ethnoapicultural surveys and spatial analysis of the study area. Both qualitative and quantitative data were used to address the issues and objectives. The methods consisted of identifying the problem known from research on this subject, identifying the variables according to the study area and evaluating them, determining the characteristics of the activity, and promoting the protection of the species so as not to lose its services. The data were obtained through a systematic documentary analysis, group discussions with experts in the beekeeping sector, and ethno-apicultural surveys, followed by field observations to better acquire information on all the areas concerned. Participants in the study included community members, experts in Bees, and academics at the regional level. Further details on the methods are included in the following parts. Figure 3 presents a summary of the research design.

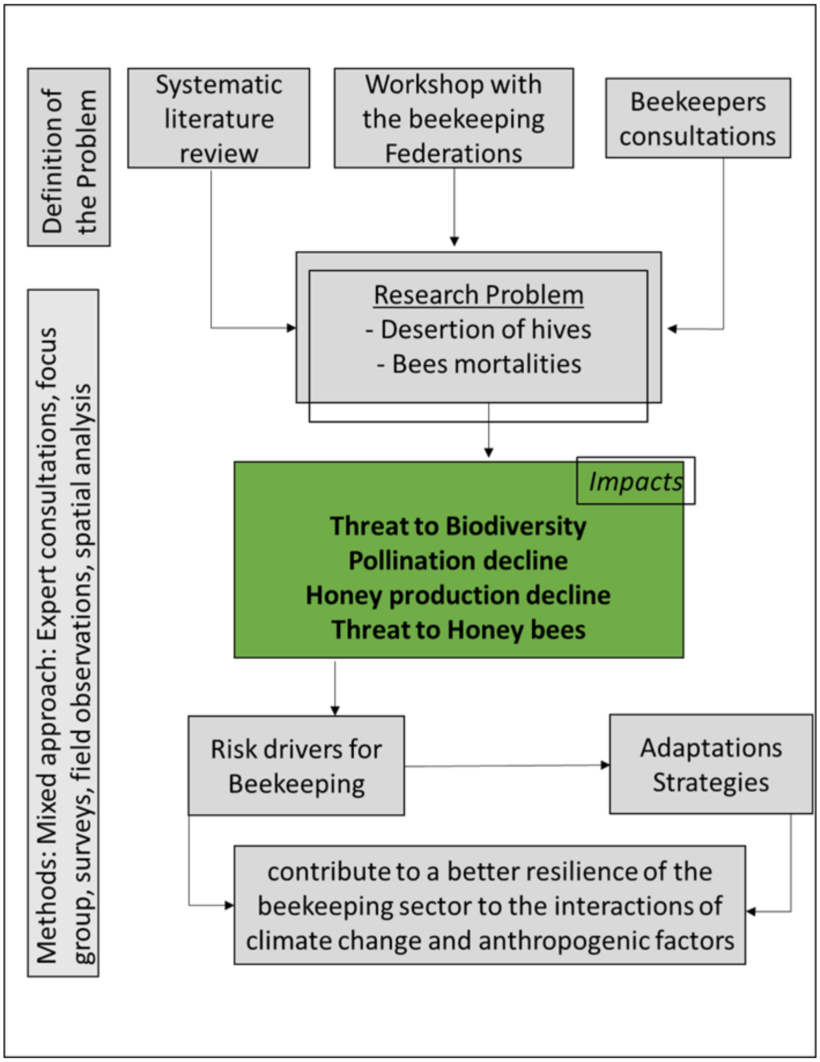


Figure 3: Summary of the research design

Source: Ouattara, 2024

2. Geographical framework

2.1. Description of the study area

The study sites of this thesis focused on the Poro region, located in the department of Korhogo in the northern part of Côte d'Ivoire, extending between 5°3 'W and 6°46' W and 8°32' N and 10°42' N. It covers an area of 12.550 km^2 including departments such as Dikodougou, M'Bengué, Sinematiali, and Korhogo. Korhogo is the departmental capital of the Poro region (Figure 4). The choice of this region is justified by the long history of beekeeping and the presence of beekeepers organized into cooperatives recognized by the authorities (Kouassi *et al.*, 2018).

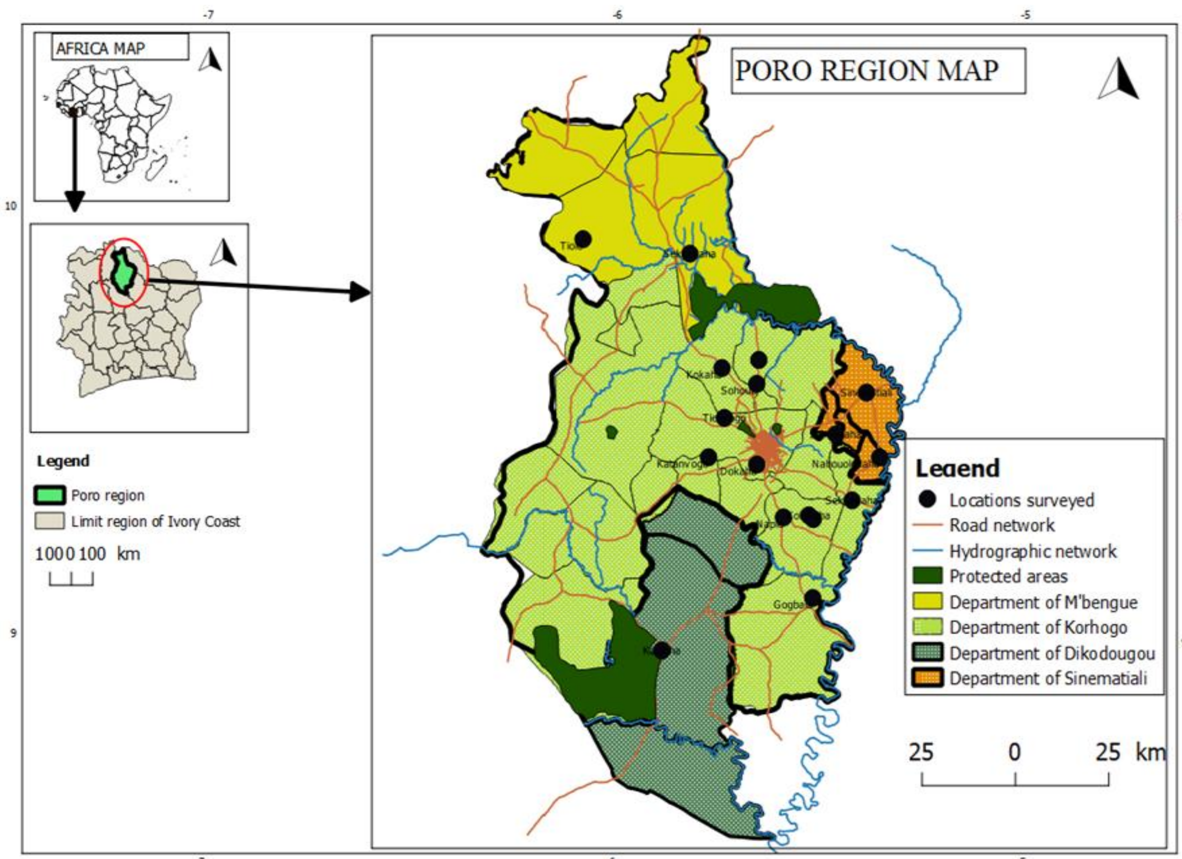


Figure 4: Location of the Poro region

2.2. The biophysical environment

2.2.1. Climate

Côte d'Ivoire is divided into four main climatic zones. These are the Guinean zone in the south, the Sudano-Guinean zone in the Centre, the Sudanian zone in the north and the mountainous zone in the west. Korhogo climate is dry Tropical-Sudanese (Jourda, 2015) and has two seasons including a rainy season from May to September with maximum rainfall in September and a dry season from October to April (Siéné *et al.*, 2020). This is due to the monomodal patterns (Barthelemy *et al.*, 2014). The season is characterised by the harmatan that blows from December to February (Sodexam, 2017) (Figure 5). The average annual temperature in the Korhogo department is 27°C with a maximum temperature of 33.8% (Sodexam, 2018). The annual rainfall varies between 1000 mm and 1600 mm, with an annual average of 1200 mm (Sodexam, 2014). According to Coulibaly *et al.*, (2021), the region has had an average annual rainfall fluctuating around 1200 mm for the last 3 decades. The average relative humidity of the Poro region varies between 35% and 79% (Soro *et al.*, 2013); it has the lowest humidity in the country. The average monthly temperature over the period 1980-2022 is 26°C.

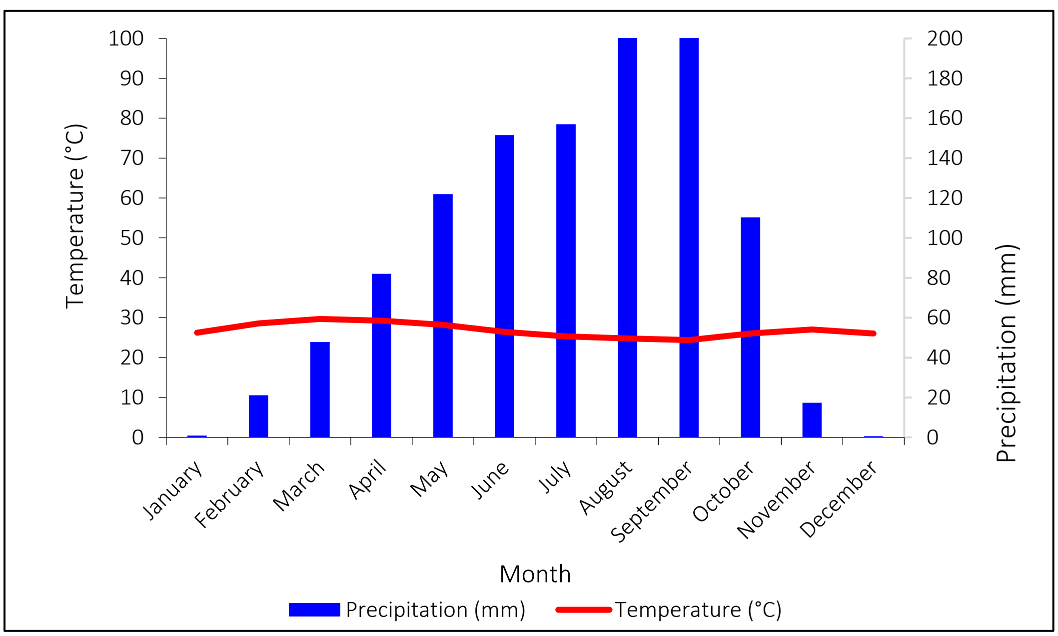


Figure 5: Umbrothermal diagram of Korhogo (2012 - 2022)

2.2.2. Topography and soil

The upland landscape dominates the land with an altitude of 300 – 400 m (Barthelemy *et al.*, 2014; Gnamba *et al.*, 2020) and a little accidental (Gnamba *et al.*, 2020). The region is essentially constituted of a bedrock of granite and schist on which humus soils are found (Zagbaï *et al.*, 2006) with medium fertility (Diomandé *et al.*, 2021). Savannah soils are acidic with a low pH, which may cause a low concentration of nutrients such as iron.

2.2.3. Hydrography

This region is fed by one of the tributaries of the Bandama River (Gnamba *et al.*, 2020). The town of Korhogo, which is the departmental capital, had a water shortage in 2016 because it contains the majority of the Poro population, whose needs are great (Gnamba *et al.*, 2020).The area has experienced two extreme climatic events: a period of drought (2000-2005) followed by flooding (2006-2007) (Boko-Koiadia *et al.*, 2016; M'Bra *et al.*, 2018).

2.2.4. Vegetation

The vegetation in the north consists mainly of tree and shrub savannahs, wooded savannahs, open forests and forest galleries along watercourses (Guillaumet & Adjanohoun, 1971). Côte d'Ivoire's diversity of flora and climate offers bees a high potential for honey production. The region is a reservoir of floral diversity as the most abundant families are Combretaceae, Fabaceae, Euphorbiaceae, Rubiaceae, and Chrysobalanaceae (Soro *et al.*, 2021). The flora is dominated by leguminous and grassy species such as *Imperata cylindrica* (Poaceae) and *Panicum maximum* (Poaceae), woody species including *Isoberlinia doka* (Fabaceae) and *Anogeissus leiocarpus* (Combretaceae) (Adjanohoun, 1964). Indeed, it is an area of high agricultural pressure where one also finds orchards, fields, and forests of sacred nature (Assi-Kaudjhis *et al.*, 2020).

2.3. The human environment

2.3.1. Socio-cultural characteristics

The Niarafolos (Senoufos) and Dioulas are the dominant ethnic groups in the territory, which is also home to several non-native Ivorian populations, as well as foreigners of African origin, in particular, Malians and Burkinabés (Dagnogo *et al.*, 2021). The region covers a population of 1,040,461 inhabitants, according to the INS, (2022), with almost as many men as women.

2.3.2. Economic activities

The region is the fourth largest in Côte d'Ivoire in terms of population and economy. The economy of the Poro region is based on agriculture, livestock farming, and trade. It is one of the greatest agricultural areas in the country (Ohoueu, *et al.,* 2017b). Cash crops include mango, cashew nuts and cotton, and food crops such as rice, maize, and groundnuts. They also produce shea butter (Dagnogo *et al.*, 2021). The women practice agriculture in low-land areas due to the lack of education and are sometimes not involved in decision-making due to patriarchal systems (Kouadio *et al.*, 2023). These assets are essential for good honey productivity. Beekeeping helps to increase the income of the local population and reduce poverty. In addition, Côte d'Ivoire's population is young and dynamic, which promises to boost the beekeeping sector and reduce unemployment.

CHAPTER 1: STATE OF THE ART OF BEEKEEPING PRACTICES IN CÔTE D'IVOIRE

1.1. Introduction

Beekeeping is an agricultural sector that raises bees to produce honey and other hive products. It is a very old activity, with honey gathering being recognized in Africa. It plays an important role in socio-economic development and environmental conservation. It appears to be one of the activities that increase the monetary income of stakeholders, limit the destruction of forests, and generate a large population of pollinating agents for the plant environment (Ahouandjinou *et al.*, 2017). Bees are of interest to beekeeping and are also an essential part of the world's environmental balance as pollinators of many plant species (Adjlane *et al.*, 2012). As such, it contributes to food security, and pollinators act as bio-indicators of environmental change (Bogdanov, 2006; Chauzat *et al.*, 2006; Le Conte & Navajas, 2008). Honey is the most highly prized beekeeping product, thanks to its nutritional and therapeutic properties. It is used in food and the treatment of several illnesses and diseases (Assi-Kaudjhis *et al.*, 2020a).

In Côte d'Ivoire, modern beekeeping is practiced alongside traditional honey harvesting, offering rural communities an opportunity to improve their income and access natural remedies for common illnesses. The country's diverse climate and vegetation provide favorable conditions for apiculture. Despite this potential, traditional honey-gathering remains the dominant practice (Assi-Kaudjhis *et al.*, 2020d; Kouassi *et al.*, 2018; Savadogo *et al.*, 2018).

However, research on beekeeping in Côte d'Ivoire has primarily focused on specific aspects, such as the economic importance of the sector, the identification of melliferous plants, and the typology of honey bees. Studies on honey quality have largely been limited to physico-chemical and melissopalynological analyses. A critical gap remains in the comprehensive assessment of local beekeeping knowledge, bee biodiversity, and the nutritional properties of honey. Additionally, scientific publications in this domain are scarce (Coulibaly *et al.*, 2019) and geographically concentrated in the central and northern regions of the country.

This chapter seeks to address these gaps by exploring the following research question: To what extent do existing studies on beekeeping in Côte d'Ivoire provide a holistic understanding of the sector, and what are the missing dimensions that need further investigation? The main objective is to move beyond a mere inventory of past research and critically assess the knowledge gaps that hinder the development of a sustainable and scientifically informed beekeeping industry in Côte d'Ivoire. The specific objectives are to analyse the State of Knowledge on Beekeeping Practices in

Côte d'Ivoire and identify the main challenges faced by the sector to guide future research towards sustainable development, particularly in the current context of climate change.

1.2. Materials and methods

1.2.1. Climate and vegetation

The vegetation in the north consists mainly of tree and shrub savannahs, wooded savannahs, open forests and forest galleries along watercourses, while the Guinean domain is dominated by dense evergreen, deciduous and semi-deciduous moist forests (Guillaumet & Adjanohoun, 1971). The Sudanese domain includes orchards. The Guinean domain alone accounts for 90% of the plant species recorded in Côte d'Ivoire (Aké-Assi, 2002; Kouamé *et al.*, 2010).

Côte d'Ivoire's diversity of flora and climate offer bees a high potential for honey production. These assets are essential for good honey productivity. Beekeeping helps to increase the income of the local population and reduce poverty. In addition, Côte d'Ivoire's population is young and dynamic, which promises to boost the beekeeping sector and reduce unemployment.

Côte d'Ivoire is divided into four main climatic zones (Figure 6). These are the Guinean zone in the south, the Sudano-Guinean zone in the Centre, the Sudanian zone in the north and the mountainous zone in the west. The Guinean zone has a sub-equatorial climate with two rainy and two dry seasons. An equatorial climate in transition between the Guinean and Sudanian climates characterizes the Sudano-Guinean zone. It also has two rainy seasons and two dry seasons. The Sudanian zone has one rainy season, one dry season, and a subhumid tropical climate (Siéné *et al.*, 2020). The mountainous zone has a tropical humid climate with four seasons (Bigot *et al.*, 2005). Côte d'Ivoire's climate offers better conditions for bee activity.

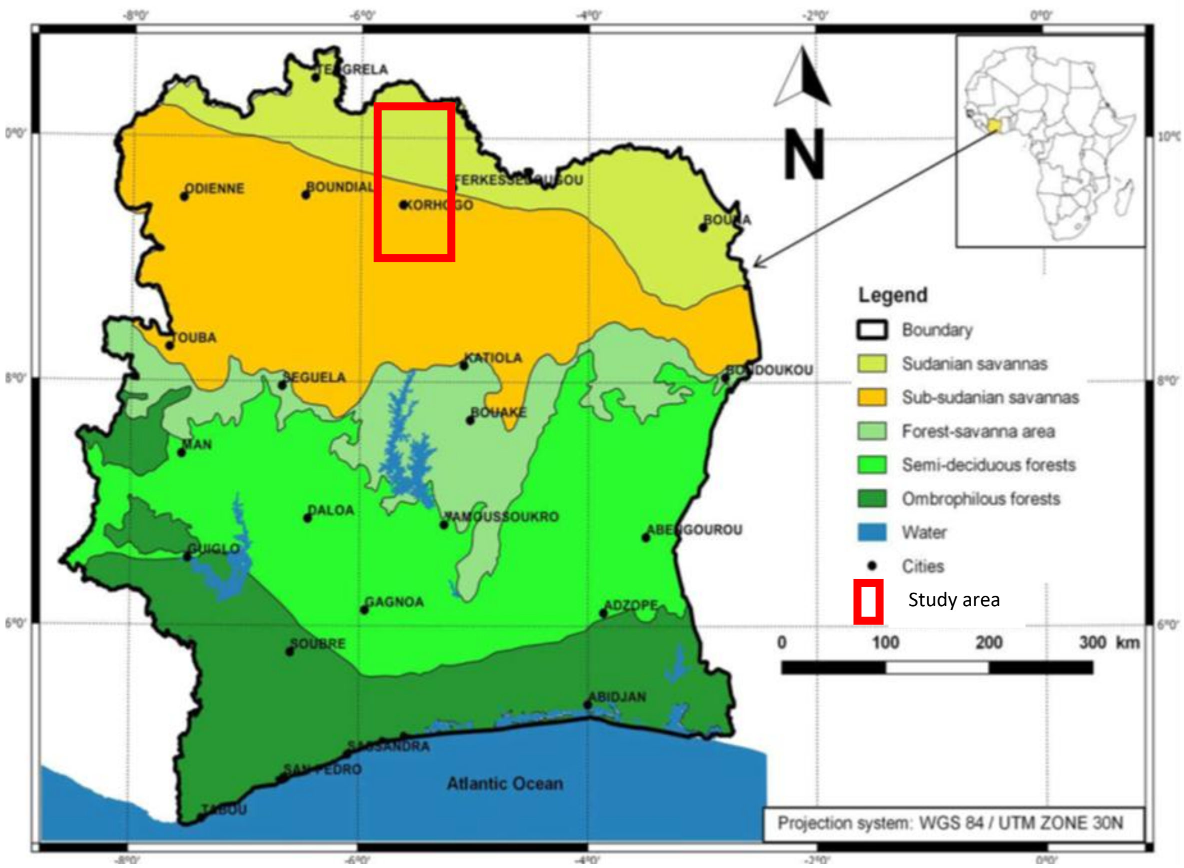


Figure 6:Map of the Côte d’Ivoire with its different types of vegetation

Sources: (Soro *et al*., 2021)

1.2.2. Methodology

The work is based on a search for recently published scientific articles on beekeeping practices in Côte d'Ivoire and the rest of the world. Searches were carried out using the keywords "Beekeeping", "melliferous plants", "Honey bees" and "Honey analysis", each time adding the name of the country preceded by the command "AND". Google Scholar was used as the search engine, and the majority of these articles were also found on Science Direct. The searches were carried out from March to May 2022 and the beginning of 2023. The publication sources of the articles were diverse and included research articles, methods articles, review articles, and books. A total of 103 articles were obtained and analyzed, of which 43 relevant pieces of information from Ivorian articles and the rest from the rest of the world were used to support this research work.

The interests are divided as follows: the first studies focused on characterizing the plants visited by bees, finding their preferences, and identifying areas suitable for beekeeping practices. As the vegetation is varied, the analysis of bee typologies must be studied to master these species for better protection. Then focused on the actors of beekeeping on their characteristics, the quality of honey and the challenges faced by the sector in actual climate conditions. These results encouraged the authors to take an interest in the quality of the honey sold by analyzing it to promote it on the local and international markets. The types of beekeeping practices and the players in the sector are taken into account for an overview of the sector's activities. All these articles aim to develop and promote sustainable beekeeping in Côte d'Ivoire.

1.3. Results

1.3.1. Melliferous plant in Côte d'Ivoire

Studies on melliferous plants in Côte d'Ivoire are relatively recent (Table 1). Various studies have shown that the number of inventoried melliferous species varies by region, with research efforts mainly focused on the central, southern, and northern parts of the country. The number of recorded species ranges from forty-eight (48) to one hundred and sixty (160).

Botanical inventories conducted by different authors indicate that the family Fabaceae is the most frequently visited by honeybees, with representation ranging from 5.46% to 26.38%, followed by Asteraceae (5%–6.94%), Rubiaceae (5%–5.46%), and Euphorbiaceae (7%–7.81%). Most of the identified melliferous species are cultivated plants, highlighting the essential role of bees in providing ecosystem services.

The most frequently visited genera include *Cassia* (Fabaceae), *Albizia* (Fabaceae), *Acacia* (Fabaceae), *Centrosema* (Fabaceae), *Lonchocarpus* (Fabaceae), *Parkia* (Fabaceae), *Jatropha* (Euphorbiaceae), *Croton* (Euphorbiaceae), *Aspilia* (Asteraceae), *Keetia* (Rubiaceae), *Spermacoce* (Rubiaceae), *Euphorbia* (Euphorbiaceae), *Manihot* (Euphorbiaceae), *Ficus* (Moraceae), *Ceiba* (Malvaceae), *Terminalia* (Combretaceae), and *Mangifera* (Anacardiaceae). Frequently cited melliferous species include *Albizia lebbeck*, *Albizia zygia*, *Senna siamea* (syn. *Cassia siamea*), *Delonix regia*, *Aspilia africana*, *Spermacoce verticillata*, *Croton hirtus*, *Euphorbia heterophylla*, *Manihot esculenta*, *Ceiba pentandra*, *Carica papaya*, and *Mangifera indica*.

Flowering periods vary across species, influencing nectar availability for honeybees. Some species, such as *Ficus sur* (Moraceae family), flower throughout the year, while others, like *Chromolaena odorata* (Asteraceae family), bloom mainly during the rainy season. Certain species from the Fabaceae family, such as *Albizia zygia*, and others like *Bombax buonopozense* (Malvaceae family), flower predominantly in the dry season.

Table 1:List of melliferous plants identified in the different studied zones in Côte d'Ivoire

Authors	**Number of melliferous plants identified**	**Number of families**	**The most popular families foraging**	**Flowering period of plants**	**Geographical location**
Iritié *et al.* (2014)	160	47	Fabaceae (15%), Euphorbiaceae (7%), Meliaceae (5%), Sterculiaceae (5%)	Rainy season (89%), Dry season (5%), Flowering all the year (4%)	Centre (Forest-Savannah transition)
Kouassi *et al.* (2019)	126	40	Fabaceae (18%), Malvaceae (7%), Lamiaceae (5%), Asteraceae (5%), Rubiaceae (5%)	Annual flowering (74.6%), Sub-annual (25.5%), 3 months (73.01%), 2 months (26.19%), 1 month (0,80%)	Centre-North
Coulibaly *et al.* (2019)	128	51	Euphorbiaceae (7.81%), Asteraceae (6.25%), Rubiaceae (6.25%), Fabaceae (12,49%)	Annual cycle (84.37%), Cycle sub-annual (15.63%), 3 months (57.03%), 2 months (28.13%), 1 month (14.84%)	Centre-East
Kouamé *et al.* (2020)	48	19	Malvaceae (18.75%), Fabaceae (12.5%), Combretaceae (8.33%), Moraceae (8.33%)	Rainy season (60.41%), Dry season (21%), Dry and Rainy season (18.59%)	South
Assi-Kaudjhis *et al*. (2020)	157	42	Fabaceae (24.74%)	Rainy season (55.41%), Dry season (32.48%), Dry and wet months (12.10%)	Centre (Forest-Savannah transition)
Assi-Kaudjhis *et al*. (2023)	72	29	Fabaceae (26.38%), Verbenaceae (9.72%), Asteraceae (6.94%)	Rainy season (62.5%), Dry month (22.22%), Dry and wet months (15.28%)	Centre-North

1.3.2. Bees studied

The first study on bees was carried out in 1976. The other studies were done after over 30 years, the Ivorian bees vary morphologically. Morphometry analysis made by the authors is important to know the type of species of bees present in the country. The analysis was made on the size, the leg's length, the proboscis, and the pilosity. According to the authors, the bees are characterized by a small size in the north while the size is large. The authors' characteristics are according to the study area because they were measured. Figure 7 is an example of the measurement. Concerning the role of the different variables (Table 2), the leg length, the proboscis, and pilosity are reputed to collect the nutrients while the wing size allows them to fly long distances.

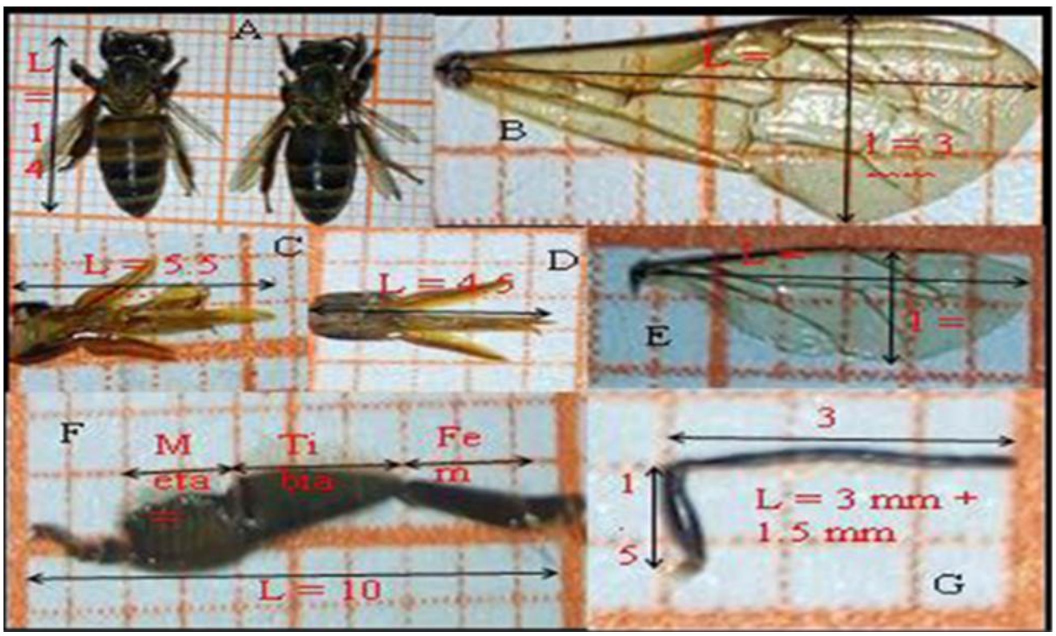


Figure 7: Black and yellow-black bees

Sources: (Kouamé *et al.,* 2020)

Table 2:Types of *Apis mellifera* in Côte d'Ivoire

Type of bee	Distribution geographical	Main anatomical characteristics for the extraction of nutrients from flora
Black (Borneck, 1976 ; Brou *et al.,* 2019 ; Kouonon *et al.,* 2020 ; Kouamé *et al.,* 2021)	All of Côte d'Ivoire (recent studies have been carried out in the south-west, south-east and centre)	Size (Depends on the environment and availability of nutrients (Large in the south and small in the north) - Leg length (Pollen collection); -Wing size (Ability to fly long distances); -Proboscis (Ability to collect nutrients at the bottom of the corolla and on the stamens); -Pilosity (Pollen collection).
Yellow (Borneck, 1976 ; Brou *et al.,* 2019 ; Kouonon *et al.,* 2020 ; Kouamé *et al.,* 2021)	All of Côte d'Ivoire (recent studies have been carried out in the south-west, south-east and centre)	
Yellow-black (Kouamé *et al.,* 2021)	South-east	

2.3.3. Profile of beekeepers and beekeeping practices

1.3.3.1. Types of beekeeping

A beehive is a compartment in which bees collect and produce honey for their nutrition and which protects them from bad weather. Three types of beekeeping exist and are practiced in Côte d'Ivoire: honey gathering, traditional beekeeping and modern beekeeping.

a) Honey gathering

This activity is practiced by rural populations and is known as "honey hunting" or honey gathering. Apart from the disadvantages, one advantage is that beekeepers harvest the honey from the trees, so no equipment or land is needed for the practices. Honey is already available in nature.

b) Traditional beekeeping

Traditional beekeeping is done by beekeepers after honey hunting using accessible materials such as wood, bamboo or straw. This is why beekeepers use it more than any other. Harvesting generally takes place at night because of the aggressiveness of the bees.

c) Modern beekeeping

Modern beekeeping is another type of beekeeping done by beekeepers. Modern hives made of wood are the most frequent. These hives are found in fields, forests and mango and cashew orchards. The use of modern beehives has many advantages. According to beekeepers installed in orchards, they allow bees to increase crop productivity through pollination, thereby perpetuating biodiversity. The honey obtained is of good quality. The Kenyan hive is the most used followed by Langstroth and Iritié. The central zone concentrates the maximum number of modern hives, while in the northern zone, traditional gathering and beekeeping persists, even though we note the presence of modern beekeepers.

1.3.3.2. Place of beekeeping for the people and the social situation of beekeepers

Beekeepers range in age from under 30 to over 50, with an average age of 35 and a predominance of men. It is either a source of income, inherited from parents or an activity carried out of passion. Beekeeping experience varies from one region to another, with some beekeepers having more than 10 or 20 years of experience, while others have less than 10 years. Some beekeepers are organized into cooperatives recognized by the authorities. while others are not members of any beekeeping association. To date, FENAPCI (National Federation of Beekeepers of Côte d'Ivoire) and UNASCACI (National Union of Beekeeping Cooperatives of Côte d'Ivoire) are recognized by the ministries as the major associations that bring together all the beekeeping cooperatives. There are not many women beekeepers, as the honey is harvested at night and they fear insect bites. Most of them are honey traders.

1.3.4. Production and honey quality

1.3.4.1. Production

Beekeeping in Côte d'Ivoire produces honey, beeswax, bee bread, and royal jelly. According to Figures provided by the MEF (2008), beekeepers produced 645 tonnes of natural honey. Current official Figures are not available, and data from the Food and Agriculture Organization (FAO) contain unofficial Figures (Figure 8).

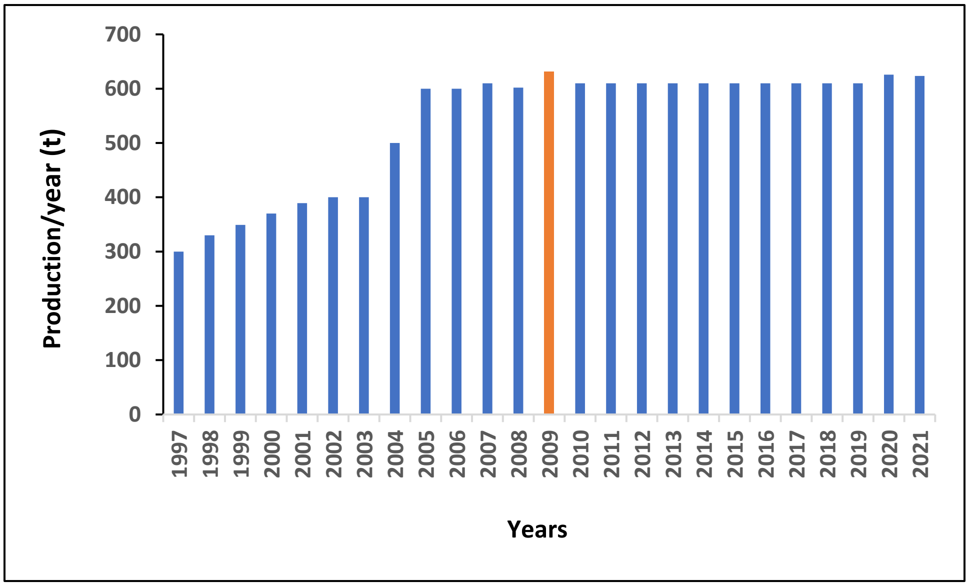


Figure 8: Honey production in Côte d'Ivoire

Sources: FAO, 2022

Due to the differences in beekeeping practices used (harvesting, traditional, modern), which can impact the nutrients contained in honey, it is necessary to analyze them to check their quality. According to the Codex Alimentarius, for honey to be consumed and exported, it must be. Despite the country's great honey-growing potential and favorable climatic conditions, production is too low to cover the needs of the local population or to be exported. Product prices vary from one beekeeper to another, although honey is sold on average at 2,000 francs per kilogram. However, this price is not respected by all beekeepers as we observe a variation from one region to another of good quality, which requires it to be analyzed. In Côte d'Ivoire, the honey analyses carried out by researchers in the laboratories used the same methodology for studying the parameters. The common objective of all the analyses is to assess the quality of the honey to promote it on national and international markets.

1.3.4.2. Physico-chemical analyses

pH, water content, sugar content, electrical conductivity, and acidity are the parameters that will be considered for the study of the physico-chemical quality of honey. A specific methodology was used for each parameter. However, the results obtained by the authors were reported differently with significant differences ($p < 0.05$) between the parameters for the majority. The results were presented as the mean with standard deviations (Table 3). For statistical analysis, ANOVA-ONE WAY and Bartlett tests were used with SPSS software. The results were compared with the international standards of the Codex Alimentarius.

a) pH and acidity

PH values are determined using a pH meter. The study of this parameter is important because it determines the shelf life of the honey and is an important element in determining the origin of the honey. An acidic honey confirms that the bees have gathered plant pollen and nectar. The average pH values reported by the authors are 4.02±0.2 and 4.12±0.1 (Table 3), comparing fresh and aged honey. Other authors found Ph values of between 3.7 ± 0.1 and 4.77 ± 0.06 for honey from the centre-west. In the forest-savannah transition, another author found a Ph value of 3.77 ± 0.10; in the south, Ph is 3.55 ± 0.46, while others have found between 2.92 and 3.19 for honey from the north-west and west. And from 3.93 ± 0.37 for honey from the north between 3.11 and 4.20 for honey from all regions of Côte d'Ivoire.

The studies carried out by the researchers showed that the acidity (free and total) of honey complied with the Codex Alimentarius standard, which is a maximum of ≤ 50 meq/kg, except for one honey with 61.15 meq/kg; 16.67±2.89- 33.33±2.89; 16.67 ± 2.89 - 33.33 ± 2.89; 49.00± 0.00); 19.50±4.47;7.50 - 24.20; 49.9 and 61.15; 20.41 ± 5.20 (Table 4) Acidity is a good criterion for evaluating honey. Indeed, it provides information on the level of fermentation of honey.

b) Water content

The results of the analyses showed (Table 3) that Ivorian honey complies with Codex standards as the amount of water contained in honey should not exceed 21% (17.24 ±0.6 and 17.12 ±0.6; 17.02± 0.02; 20.2±3.11; 20.81 ±0.75 and 21.79 ± 0.98; 16.72 ± 1.49). According to the authors, the higher the water content, the greater the chance of fermentation. Temperature and storage have a significant effect on honey. The water content is the quantity of water contained in the honey used by bees for their various transformations. It is one of the most important properties for determining honey quality.

c) Sugar content

Analyses showed that the majority of Ivorian honey is sweet and exceeds the Codex Alimentarius standard, which must be less than or equal to 65% (≤ 65%): 75.4±1.1 - 80.0±1.6; 41.71±6.54-45.5%±00; 41.71 ± 6.54 to 45.50 ± 0.0; 75.23± 0.38; 78.31±0.19; 78.60 - 83.80 % 77.28 ± 0.71%; 81.75 ± 1.56% (Table 3).

d) Electrical conductivity

The electrical conductivity values vary between 98.01±31 and 705.72 ±0.9 - 597.80± 1.5, which comply with Codex Alimentarius standards (Table 3).

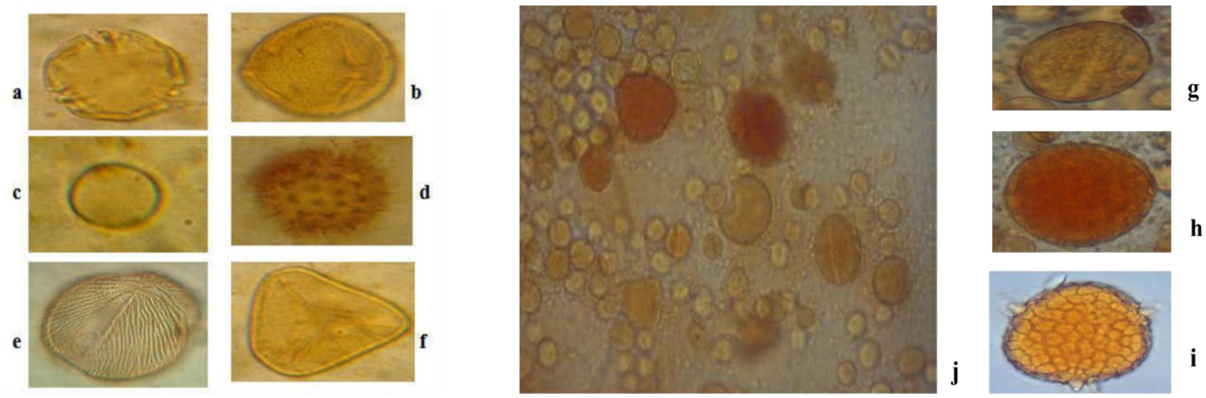
1.3.4.3. Pollen analysis

The contents of honey are analyzed under an optical microscope to check for the presence of pollen, which is the floral element consumed by bees. The results of the studies show that honey is rich in pollen (Figure 9). These are multifloral honeys resulting from the foraging of several plant species. They reflect the diversity and specific richness of Ivorian vegetation.

Table 3: Average values of physico-chemical parameters (mean ± SD) including pH, water content, sugar content, electrical conductivity, and acidity of honey from Ivory Coast, compared with the international standards of the Codex Alimentarius.

Authors	**pH**	**Water content (%)**	**Sugar content (%)**	**Electrical conductivity (µS/cm)**	**Acidity (meq /kg)**	**Location and the number of samples**
	Mean	**Mean± Std**	**Mean± Std**	**Mean± Std**	**Mean± Std**	
Iritié *et al.*,2014	4.02±0.2 -4.12±0.1	17.24 ±0.6 and 17.12 ±0.6	75.4±1.1- 80.0±1.6	705.72 ±0.9 - 597.80± 1.5	43.54±0.7 - 42.60 ±0.4 (Free)	Centre (Samples not specified)
Diomandé *et al.*, 2018	3,7 ± 0,1 - 4,77 ± 0,06		41,71±6,54- 45,5%±00		16,67±2,89- 33,33±2,89 (Total acidity)	Centre-West (4 samples)
Coulibaly *et al.*, 2019	3,7 - 4,77		41,71 ± 6,54 - 45,50 ± 0.0		Entre 16,67 ± 2,89 - 33,33 ± 2,89 (Total acidity)	Centre-West (50 samples)
Assi-Kaudjhis *et al.*, 2021	3,77± 0,10	17,02± 0,02	75,23± 0,38	268,00 ± 0,00	49,00± 0,00 (Total acidity)	Centre (Samples not specified)

Kouamé *et al.*, 2021	3.55±0.46	20,2±3,11	78,31±0,19	98,01±31	19,50±4,47 (Free)	South-east (5 samples)
Yeboué *et al.*, 2021	3.11 - 4.20		78,60 - 83.80 %		7,50 - 24,20 (Total)	South, Centre, West, North, Centre-East, Centre-West, North-West, North-East
Ahui *et al.*, 2022	2.92 - 3.19	20.81 ±0.75 et 21.79 ± 0.98	77.28 ± 0.71%		49.9 et 61.15	North-West, West (18 samples)
Guédé et al., 2022	3.93 ± 0.37	16.72 ± 1.49	81.75 ± 1.56%	471.20 ± 203.74	20.41 ± 5.20 (Free acidity)	North (From markets) 60 samples
Norme Codex Alimentarius, 2000, 2001	[3.5– 4.5] Nectar honey [5 – 5.5] Honeydew honey	≤ 21 % With some exceptions	≤ 65 % Nectar honey ; ≤ 45% Honeydew honey; ≤ 53% blended honey	≤0.8Ms/cm Nectar honey ≥ 1.2Ms/cm Honeydew honey	≤50 meq /kg All types of honey	



a: Alchonea cordifolia (EupHorbiaceae);
b: Anacardium occidentale (Anacardiaceae);
c: Ficus sycomorus (Moraceae);
d: Aspilia africana(Asteracee);
e: Isoberlinia doka (Caesalpiniaceae)
From Diomandé *et al.,* 2018

g: PHoenix reclinata (Arecaceae);
h: Ceiba pentandra (Malvaceae);
i: Bombax buonopozense (Malvaceae)
J: pollen content of a sample
From Assi-Kaudjhis *et al.,* 2021

Figure 9: Samples of honey from the forest-savannah transition overview of pollen content

1.3.4.4. Other analyses

The majority of analyses of honey quality were carried out by combining two analyses such as physico-chemical and biological analyses, physico-chemical and sensory analyses, and physico-chemical and pollen analyses. Other authors, who checked only physico-chemical constituents, were interested in pesticides, polycyclic aromatic hydrocarbons and aflatoxins, which can contaminate honey. The studies confirm that Ivorian honey meets international standards because they are of good quality and presents no danger for consumption.

1.3.5. Issues and challenges for improving the productivity of the beekeeping sector in Côte d'Ivoire

1.3.5.1. Insufficient funding and difficulties in developing and promoting beekeeping products

Modern beekeeping is developing in Côte d'Ivoire. The State's lack of involvement in decision-making to improve the functioning of this sector and the shortage of beekeeping production equipment are hindering its development. Initiatives have been taken by NGOs, the UNDP and FIRCA, but these are insufficient to ensure the sustainability of beekeeping. The first cause is the level of education among beekeepers, especially older beekeepers, some of whom have no formal education, while others have a low level of education. The second cause is the lack of training for beekeepers in the use of equipment and the protection of endangered bees.

Beekeepers lack support; the marketing circuit is unregulated, making it difficult for them to promote their products. In addition, product prices are not fixed and vary from one beekeeper to another, and from one region to another.

1.3.5.2. Environmental challenges

For decades now, bees worldwide have had to contend with numerous environmental stressors. According to the authors, Beekeepers have mentioned some challenges that their activities face. The first challenge is the deforestation. Its origins are diverse, namely the transformation of forests into agriculture, transport and urbanization. The second challenge is the use of pesticides by farmers to protect their crops against pests and diseases. The center and north of the country are facing bushfires each year during the dry season, causing the burning of hives.

1.4. Discussion

The diversity of melliferous (nectar-producing) plants, the species of bees, and the quality of honey are intricately connected. Bees forage on various flowering plants to collect nectar and pollen, which directly influences the characteristics of the honey they produce. The specific plants available in a region, combined with the foraging behaviours of local bee species, determine the honey's flavour, colour, and nutritional profile.

The predominance of specific plant families in the study areas suggests their high nutritional and pollen content, essential for honey production (Keller *et al.,* 2005). Despite the relatively recent focus on melliferous plants in Côte d'Ivoire, research has identified several species across different regions: the central zone records 160 species (Iritié *et al.,* 2014a), 128 species (Coulibaly *et al.*, 2019), and 157 species (Assi-Kaudjhis *et al*., 2020c); the Center-North has 126 species (Kouassi *et al.,* 2019) and 72 species (Assi-Kaudjhis *et al.,* 2023); while the South-East Forest zone records 48 species (Kouamé *et al.,* 2020). These numbers differ from those reported in Burkina Faso (97 species, Nombré *et al.,* 2009) and Benin (87 species, Yedomonhan *et al.,* 2009), highlighting regional variations. For the sustainability of the beekeeping sector, studies on species protection and conservation have been undertaken in various regions (Brou *et al.,* 2019; Kouonon *et al.,* 2020; Kouamé *et al.,* 2021).

The Ivorian bees exhibit morphological diversity based on ecotypes and ecological zones, which influence their foraging behavior and honey production (Brou *et al.,* 2019; Kouamé *et al.,* 2021). Globally, China leads honey production and export, followed by Turkey, Argentina, Iran, Ukraine, the USA, and India (FAO, 2020). In Africa, Ethiopia is the largest producer, followed by Zambia and several North African countries. In West Africa, beekeeping research is more advanced in Benin, Burkina Faso, Togo, and Nigeria (Dietemann *et al.,* 2009). Honey quality in Côte d'Ivoire meets international standards, with acidity and pH levels aligning with Codex Alimentarius norms (Bogdanov, 1995; FAO, 2001). Variations in honey characteristics result from factors such as floral origin, extraction methods, and storage conditions (Gebeyehu & Jalata, 2023; Nanda *et al*., 2003; Terrab *et al.,* 2002). Honey from Côte d'Ivoire exhibits high sweetness, attributed to nectar-based foraging (Louveaux, 1968). Conductivity variations also indicate the botanical origin of honey (Fechner *et al.,* 2016). However, honey adulteration due to scarcity remains a challenge

(Zábrodská & Vorlová, 2015).

The experience of beekeepers plays a pivotal role in influencing the diversity of melliferous plants utilized by bees. Experienced beekeepers are more likely to recognize the importance of providing access to a wide variety of flowering plants, ensuring that bees have a continuous and diverse nectar flow throughout the foraging season. They may implement practices such as planting or encouraging the growth of diverse melliferous species near apiaries, selecting bee species or strains that are efficient foragers across various plants, and managing hive placements to optimize access to diverse floral resources. These practices not only enhance honey production but also improve its quality by incorporating a broader spectrum of nectar sources, leading to richer and more complex flavors. Beekeepers employ various strategies to mitigate risks, such as using natural barriers against wild animals and natural disasters (Cheng *et al.*, 2020). Traditional honey hunting, which requires minimal investment, involves harvesting honey from trees and dead trunks using smoke to drive away colonies (Kouassi *et al.*, 2018). However, this method significantly disrupts colonies and degrades the environment (Crane, 1999). Traditional beekeeping, relying on hives made from natural materials such as wood, straw, and clay, contrasts with modern beekeeping, which utilizes mobile-frame hives such as the Kenyan, Langstroth, and Iritié hives (Gratzer *et al.*, 2021).

The Kenyan hive, being cost-effective and easy to handle, is the most widely used in Côte d'Ivoire (Ohoueu *et al.*, 2017a; Coulibaly *et al.*, 2019). Beekeepers, mostly farmers, operate within cooperatives recognized by authorities, though a significant number remain independent (Kouassi *et al.*, 2018). In 2008, Côte d'Ivoire had approximately 12,000 hives, with modern hives concentrated in the central region, while traditional practices persist in the northern areas (MEF, 2008; Ohoueu *et al.*, 2017a). Beekeeping is predominantly male-dominated, with an average beekeeper age of 35 years (Assi-Kaudjhis *et al.*, 2020a; Kouassi *et al.*, 2018; Ohoueu *et al.*, 2017a; Savadogo *et al.*, 2018; Soro *et al.*, 2020).

Urbanization, pollution, and pesticide use threaten honey quality and bee populations (Goretti *et al.*, 2020; Forfert *et al.*, 2017). The northern and central regions, major agricultural zones, frequently use pesticides, posing risks to bees and honey production (Douhet, 1980). While studies indicate low contamination levels in Ivorian honey (Gnonsoro *et al.*, 2018; Ohoueu *et al.*, 2017b), continued monitoring is essential. Despite challenges, Ivorian honey contains significant antioxidants, flavonoids, and polyphenols, enhancing its nutritional profile (Mida *et al.*, 2021).

Economic challenges include price fluctuations, limited marketing infrastructure, and inadequate funding (Assi-Kaudjhis *et al.,* 2020b). In 2016-2017, honey prices ranged from 1610 to 1955 F CFA in Katiola, while the average price was 2000 F CFA/kg in central and northern regions (Kouassi *et al.*, 2018; Ohoueu *et al.,* 2017a). These prices exceed those in Benin (1600 F CFA/kg) due to lower production and scarcity (Ahouandjinou *et al*., 2016; Khenfer & Zitouni, 2014). Higher prices in urban areas reflect consumers' purchasing power (Kouassi *et al.,* 2018).

Environmental threats such as deforestation, pesticide use, and climate change significantly impact beekeeping in Côte d'Ivoire (Ohoueu *et al.*, 2017a; Savadogo *et al.*, 2018; Assi-Kaudjhis *et al.*, 2020a, d). Deforestation, driven by agricultural expansion and urbanization, reduces bee forage areas (Kouassi *et al.*, 2021; Ifo *et al.*, 2019). Although honey hunting minimally contributes to deforestation, it remains a concern (Kouassi *et al.,* 2018). Bee colony losses due to pesticide exposure and habitat destruction highlight the need for sustainable practices (Xiao *et al.,* 2022; Rortais *et al.,* 2017). Additionally, bushfires in central and northern regions further threaten beekeeping activities (Dahan *et al.*, 2021; Assi-Kaudjhis *et al.,* 2020c). Despite its potential, beekeeping in Côte d'Ivoire faces multiple challenges, including environmental threats, economic constraints, and limited research on melliferous plants. Addressing these issues requires continued scientific investigations, policy interventions, and sustainable beekeeping practices to enhance productivity and preserve bee populations.

1.5. Conclusion

The analysis of beekeeping practices in Côte d'Ivoire reveals a significant melliferous potential, with over a hundred identified species contributing to high-quality honey that meets international standards. The morphological diversity of local bee populations enhances their foraging efficiency, further supporting the production of premium honey. Variations in beekeeping outcomes are influenced by climatic conditions, geographical factors, and specific practices employed by beekeepers. Despite these advantages, the sector faces challenges such as environmental threats, including habitat destruction, pesticide use, and bushfires, as well as limitations in beekeeping knowledge due to inadequate training and education. Also, the lack of robust governmental support hampers the country's development and sustainability of beekeeping.

These challenges present gaps that have not been addressed by previous research into how they affect bees, their ecology and the socio-economic situation of beekeepers. Filling these gaps is essential to ensure the sustainable growth of the sector and unlock its full potential. To address these issues, the following chapters will provide a detailed analysis of their impact on beekeeping practices, focusing on bees, their ecology and the socio-economic conditions of beekeepers. This will help us to better understand the challenges and develop targeted strategies to strengthen the sector.

CHAPTER 2: IMPACTS OF CLIMATIC PARAMETERS ON BEEKEEPING PRODUCTIVITY IN THE NORTHERN OF CÔTE D'IVOIRE

2.1. Introduction

Climate change and variability are a global issue and their impacts vary across space, geography and time (Akala, 2019). Climate change has affected people's livelihoods, impacting development, economic stability, biodiversity and ecosystems (Thornton *et al.*, 2011). Africa, like all other continents, is sensitive to the impacts of climate variability and change. The continent could face increased poverty, higher food prices, high inequality, food insecurity, higher energy prices, a barrier to development and a high incidence of disasters (Parry *et al.*, 2007). According to Sylla *et al.* (2016), analysis of the climate in West Africa has shown that climate parameters have changed over the last few decades. As a result, agriculture, mainly rain-fed, has emerged as the major economic sector most vulnerable to climate change (Roudier *et al.*, 2011).

In this context, beekeeping is one of the branches of agriculture that raises bees to produce honey Other hive products (Masuku, 2013). It is also impacted by the effects of climate change and variability. Beekeeping plays an important role in socio-economic development and environmental conservation (Etxegarai-Legarreta & Sanchez-Famoso, 2022 ; Papa *et al.*, 2022; Aryal *et al.*, 2020). It increases the monetary income of stakeholders limits the destruction of forests and generates a large population of pollinating agents for the plant environment (Ahouandjinou *et al.*, 2017). Bees are essential to the global environmental balance as pollinators of many plants' species (Adjlane *et al.*, 2012). Bees contribute to food security by increasing yields and the availability of food diversity and their behavior reflects the impacts of disturbances (Bogdanov, 2006; Chauzat *et al.*, 2006; Le Conte & Navajas, 2008).

Despite the many benefits of beekeeping, particularly in improving people's livelihoods in rural areas (Masuku, 2013). Beekeepers have reported a fall in production in recent years (Van Espen *et al.*, 2023; Nyunza, 2018), leading to consumer complaints about the scarcity of products and rising prices. There are several reasons why beekeepers have reported a fall in productivity, and climate variability and change are some of the most frequently mentioned factors (Gajardo-Rojas *et al.*, 2022; Ijigbade, 2017), given the current context of climate change in the countries of West Africa. Over the last decade, several scientific publications have reported an unusual weakening and mortality of bee colonies especially *Apis mellifera* in several countries around the world (Faucon & Colin, 1983; Rafalimanana, 2003; van Engelsdorp *et al.*, 2010; Adjlane *et al.*, 2012); Van Der Zee *et al.*, 2012; Pirk, 2014; Van Der Zee *et al.*, 2014; Brodschneider *et al.*, 2016;

Kulhanek *et al.*, 2017; Brodschneider *et al.*, 2018). Indeed, numerous research studies have shown that climate change is one of the current threats to pollinators (Hegland *et al.*, 2009; Schweiger *et al.*, 2010; IPBES, 2016; Flores *et al.*, 2019). This loss of colonies, in addition to causing damage to bees, could be a threat to food security.

However, there is a lack of information in the literature on the effects of climate change on the ecosystem services provided by bees and on beekeeping productivity in Côte d'Ivoire. This article aims to assess the impact of climate variability on honey production in the Poro region, a beekeeping basin in Côte d'Ivoire. Specifically, the aim is to: Assess beekeepers' perceptions of climatic parameters and their impacts on productivity; (2) assess trends in climatic variability from 1982 to 2022 and the temporal evolution of honey production in the Poro region, and (3) to assess the relationship between trends in climatic variability and honey production.

2.2. Materials and Methods

2.2.1. Surveys of beekeepers using questionnaires

Collection sheets and Kobo collect tools helped record beekeepers' answers concerning the questionnaire. A pre-survey was carried out in December 2022 to test the questionnaire and gauge beekeepers' understanding. Snowball sampling (Naderifar *et al.*, 2017) was used in the semi-structured interviews, added to the questionnaire and focus group discussion, which included 162 beekeepers (Appendix 1). The questionnaire was possible with the agreement of the co-supervisor, who recommended us (Appendix 2) to reassure the beekeepers about the importance of the work. First, after a meeting with the National Federation of Beekeepers of Côte d'Ivoire (FENAPCI), we were given a list of beekeepers. Then, after meeting these beekeepers, we obtained a complementary list of other beekeepers in the region. The questionnaire aimed to assess the impact of climatic variability on beekeeping activity and honey production. It was carried out to obtain statistics on honey production and the number of hives used, using KoboToolbox software. The questionnaire covered the following main areas: (1) the social situation and economic activity of beekeepers, (2) bee management, (3) beekeepers' perception of climate variability and honey production, (4) climate variability and honey production. These interviews were conducted in the presence of the beekeepers and only two of them completed the questionnaire by e-mail.

2.2.2. Honey production

The data has been collected from 3 to 7 years and is different from one beekeeper to another in 2023. Unfortunately, due to a lack of records, only eleven (11) beekeepers (Bkp) were able to report on their production. Some beeekeepers have a similar period of record and were analyzed together. Three beekeepers have a production from 2016 to 2022, three others have a production from 2019 to 2022 and two have a production from 2020 to 2022. The beekeepers had several years of experience but were unable to record all their production. The fact is that they encountered some challenges and did not know that it was important to record production.

2.2.3. Climatic data

Temperature and rainfall data for the period 1982 to 2022 were collected from the national meteorological services (SODEXAM) with interpolation of missing data (ERA5 climate models). The climatic data have been adjusted to correspond to the specific periods of honey production data available.

2.2.4. Climatic parameters and honey production

The values of the temperature and precipitation parameters were used over 10 years to calculate the correlation with honey production (3 to 7 years). This analysis precedes the qualitative analysis of beekeepers' perceptions of the impact of climatic parameters on their production. By assessing the correlation between temperature and honey production, we calculated the deviation from the mean resulting from the difference between total and annual production over the given study period, adapted from (Shanku & Ijara, 2024). Deviation from the average = Annual production - Average production.

2.2.5. Data analysis and processing

XLStat (2019 edition) software was used to carry out the following tests. The Pettitt, Buishand and Homogeneity tests were used to assess climate variability through the annual climatic parameters. These tests examine time series and identify breakpoints, which correspond to a change in the distribution of the parameters within the series (Bougara *et al.*, 2020). Validation of the results is based on the p-values and the consistency of the results between the three tests. Descriptive statistics were used to analyze the information gathered from the questionnaire and interviews. Trends in honey production were assessed using the Mann-Kendall test and Sen’s slope with thresholds of $p < 0.05$ and $p < 0.1$. The Mann-Kendall test is a non-parametric test developed by Mann (1945) and Kendall (1948) to detect trends in time series. Sen's slope method (Sen, 1968) is a non-parametric approach frequently used to accurately determine the slope corresponding to the trend present in the data of a time series. To assess the relationship between climate and honey production, Pearson's correlation was used. According to Sedgwick, (2012), Pearson's correlation measures the strength of the linear relationship between two variables. To calculate the correlation, the values of the Bkp2, Bkp5, and Bkp9 productions that have the highest values in honey production (2016-2022) were combined and used to evaluate the relationship of climate parameters on honey production. The analysis highlighted the climatic factors that could directly impact optimum production. So, the beekeepers representing those with the most significant production performance were considered. The mean values of the temperature and precipitation parameters were used for ten years to calculate the correlation.

2.3. Results

2.3.1. Beekeeping characteristics

2.3.1.1. Socio-demographic characteristics

The results showed that the majority of beekeepers in the Poro region are males (87.65 %) and that only 12.35% are females (Table 4). The age of these beekeepers varies from 31 to 40, the most common (with 38.27%), followed by the ranges 41 to 50 (33.33%) and over 50 (25.93 %). The younger beekeepers from 20 to 30 are not numerous (2.47%). Concerning the educational level, Beekeepers with no education (37.65 %) followed by those with primary education (33.95 %) are the most represented. Those with a secondary level represented 22.84%, while beekeepers with a higher degree are not numerous (5.56%).

Table 4: Socio-demographic characteristics of beekeeping in the Poro region

Variables types	Variables	Frequency (number)	Percentage (%)
Gender	Female	20	12.35
	Male	142	87.65
Age (Years)	20 - 30	4	2.47
	31 - 40	62	38.27
	41 - 50	54	33.33
	Over 50	42	25.93
Education	Higher degree	9	5.56
	No formal education	61	37.65
	Primary	55	33.95
	Secondary	37	22.84

2.3.1.2. Structural, professional and socio-economic

The type of hives used by beekeepers are majority represented by modern hives with 85.19% while traditional hives represent 14.81% (Table 5; Appendix 3). Beekeepers have started practicing the activity by the influence of neighbourhoods (63.6%) while some claim to raise awareness through agricultural extension services (26.5%). It is only a personal interest for 8.6 % of beekeepers and 1.2% inherit from parents. Their experience ranged from under 5 to over 16 years old. The range between 0 to 5 experiences is the most represented (55.56%). The hives are located in several places (Appendix 3). The majority of them are on the farm (83.95%) and the others went back to the bush (8.64%), farm and bush (3.09%), protected area (2.47%), protected and farm (1.23%), protected area and bush (0.62%). The number of hives varies from 2 to 90 per beekeeper with a mean of 18.95% (Table 6).

Table 5: Structural, professional and socio-economic characteristics of beekeepers

Variables types	Variables	Frequency (number)	Percentage (%)
Hive type	Modern beehive	138	85.19
	Traditional beehive	24	14.81
Interests for beekeeping	Raising awareness through agricultural extension services	43	26.5
	Influenced by neighbours	103	63.6
	Personal interest	14	8.6
	Inherited from the parents	2	1.2
Experience (Years)	[0 - 5]	90	55.56
	[6 - 10]	27	16.67
	[11 - 16]	21	12.96
	Over 16	24	14.82
Hive location	Bush	14	8.64
	Farm	136	83.95
	Farm and Bush	5	3.09
	Protected area	4	2.47
	Protected area and Farm	2	1.23
	Protected area and bush	1	0.62

Table 6:Hives number by beekeeper

	Hive number
Minimum	2
Maximum	90
Mean	18.95

2.3.1.3. Cross-analysis of beekeepers' characteristics

The cross-analysis of beekeepers' characteristics showed that the males are the most educated than women. Also, older beekeepers have more experience than younger ones All the modern hives are located in several places while traditional hives are only in the bush and farm. Beekeepers belonging to cooperatives are less experienced than beekeepers without cooperatives (Appendix 4).

2.3.2. Perception of trend production

Based on the quantities harvested, beekeepers have made some estimations. The beekeepers' perceptions showed that 67.90% of them think that their production has decreased over 10 years. For 22.22% of them, they have a good perception that their production has increased, while 9.88% think that their production varies. Variation here means that production decreases from one year to the next, increases the following year and vice-versa Figure 10.

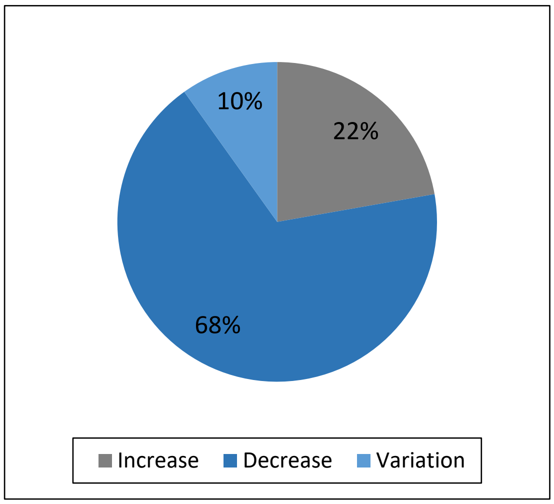


Figure 10: Beekeepers' perception of honey production trends

2.3.3. Perception of climatic parameters

Beekeepers (129) say the temperature has increased, and they suggest (106) that the precipitation varies. They debate the dry season because some think it has been prolonged (78), while others think it varies according to rainfall (82) Figure 11.

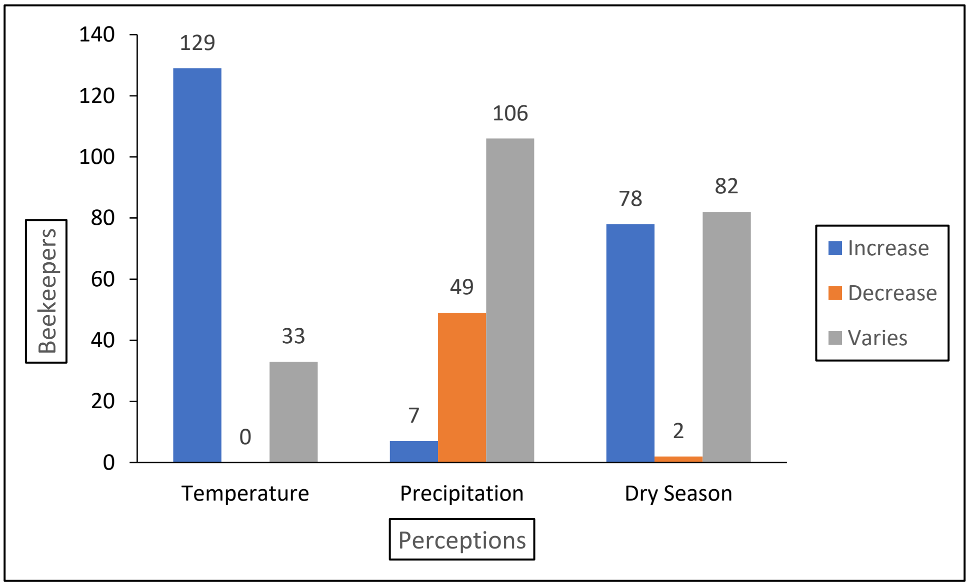


Figure 11: Perception of climatic parameters

2.3.4. Trend in honey production

Results showed that production averages ranged from 68.16 kg to 1579.293 kg, with standard deviations ranged from 48.830 to 505.234 (Table 7). Mann-Kendall showed no significant difference between the p-values of observed production and the threshold p-values ($p < 0.05$ and $p < 0.1$) (Figure 12). There is no trend in the production. However, Sen's slope showed some variable trends (Figure 12). An increasing slope for the beekeepers Bkp4, Bkp5, Bkp6, which shows a slight increase in honey production. A decreasing slope for the beekeepers Bkp3 which shows a decrease in honey production. A third zero slope for the beekeeper Bkp1 indicates stable production.

Table 7: Annual honey production of 11 beekeepers in the Poro region

Beekeepers (Bkp)	Production year (kg)	Means of production	Standard deviation
Bkp1	2015 – 2019	68.16	48.830
Bkp2	2016 – 2022	1587.86	505.234
Bkp3	2017 – 2022	262.92	86.163
Bkp4	2018 – 2022	641.84	197.375
Bkp5	2019 – 2022	1325.30	272.250
Bkp6	2020 – 2022	345.53	57.389

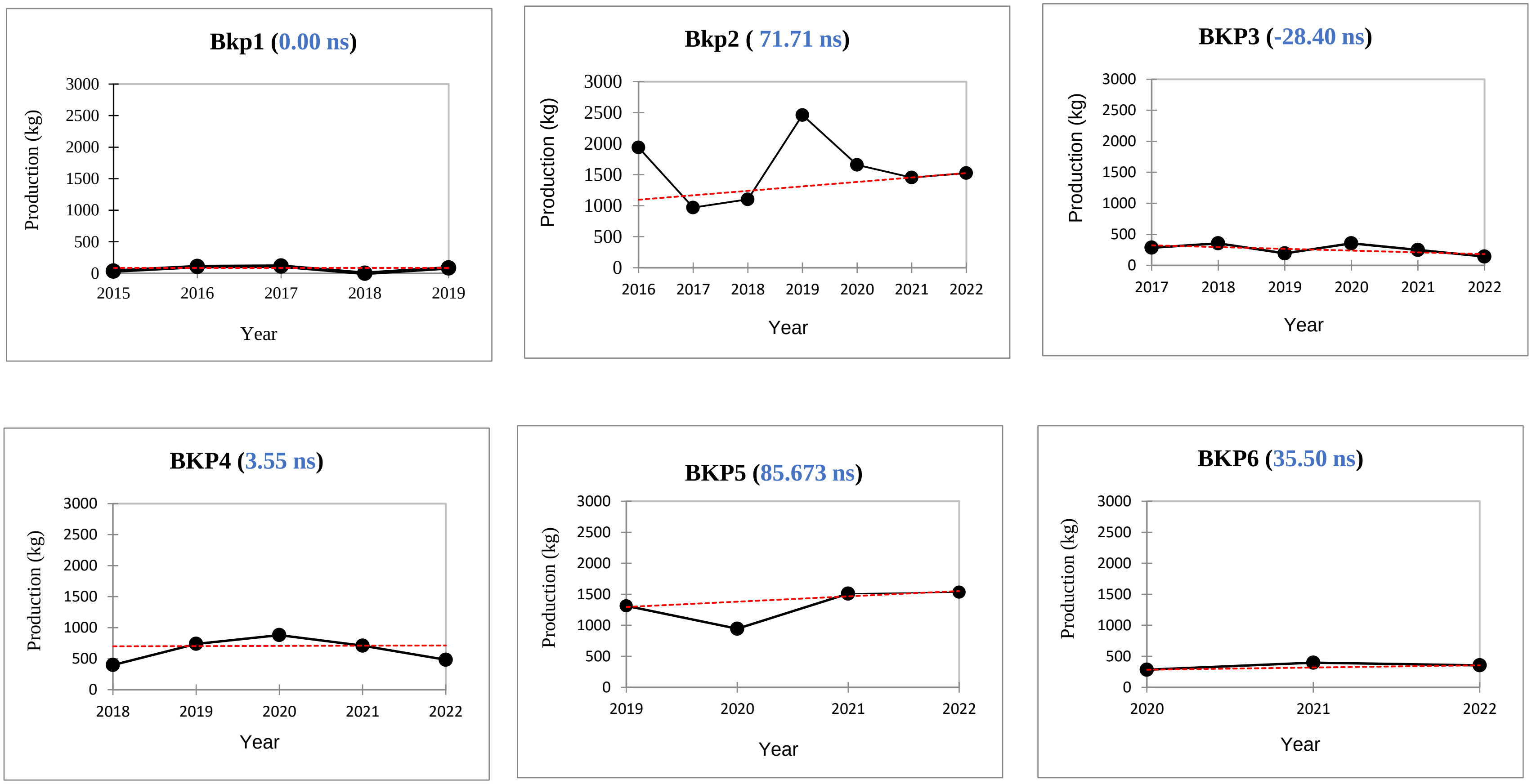


Figure 12: Temporal variation and trends in annual honey production between 2016 and 2022 in the Poro region. The parentheses values indicate the trend's Mann-Kendall slope and its statistical significance (*p < 0.05, **p < 0.1). The dotted lines (in red) represent the linear trends for the analyzed period.

2.3.5. Temporal variability of the main climatic parameters

2.3.5.1. Temperature

The average temperatures observed increased over the years since 2002 (Figure 13). Temperature values ranged from 26.03°C to 27.30°C. In the time series, the Pettitt, homogeneity, and Buishand (p< 0,0001) tests showed a discontinuity in the data series, with a break in 2001 (Pettitt test) and 2002 (homogeneity and Buishand). The warmest year was 2010 with an average of 27.29 °C.

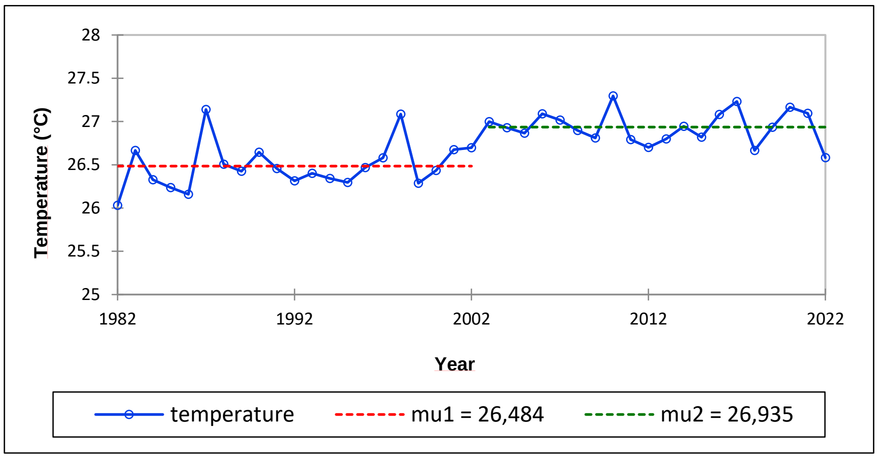


Figure 13: Annual mean temperature in Poro Region

2.3.5.2. Precipitation

The results show that there has been a deficit in rainfall since 1998. Only the Pettitt and Buishand test showed a break in rainfall in 1998 while homogeneity showed a break in 2014 (Figure 14). Rainfall fell continuously in 2017, reaching a value of 184.04 mm, before increasing to reach a peak in 2019 with a value of 1,621.3 mm.

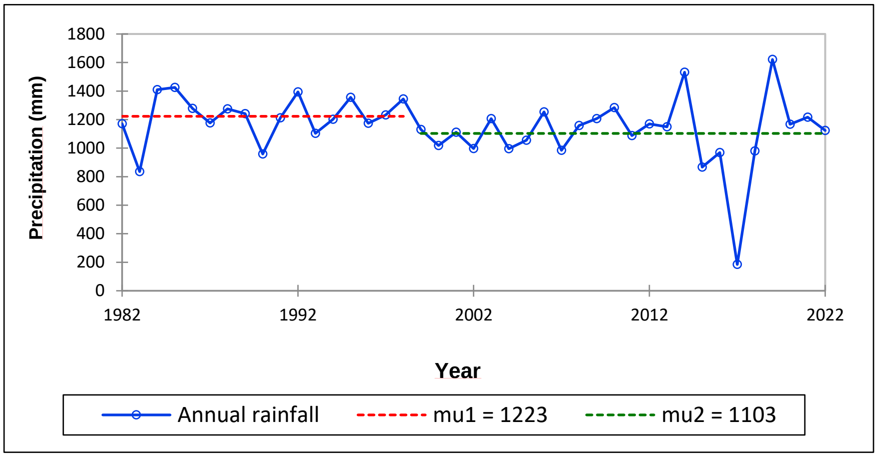


Figure 14: Annual mean precipitation in the Poro region

2.3.6. Correlation between temperature and honey production

The results show that there is no correlation between temperature variability (10 years) and honey production of BKP ($r = 0.02$, $p = 0.96$ ($p < 0.05$)), whereas the graph showed a correlation between the two factors. Temperature is not the only factor directly influencing honey production (Figure 15)

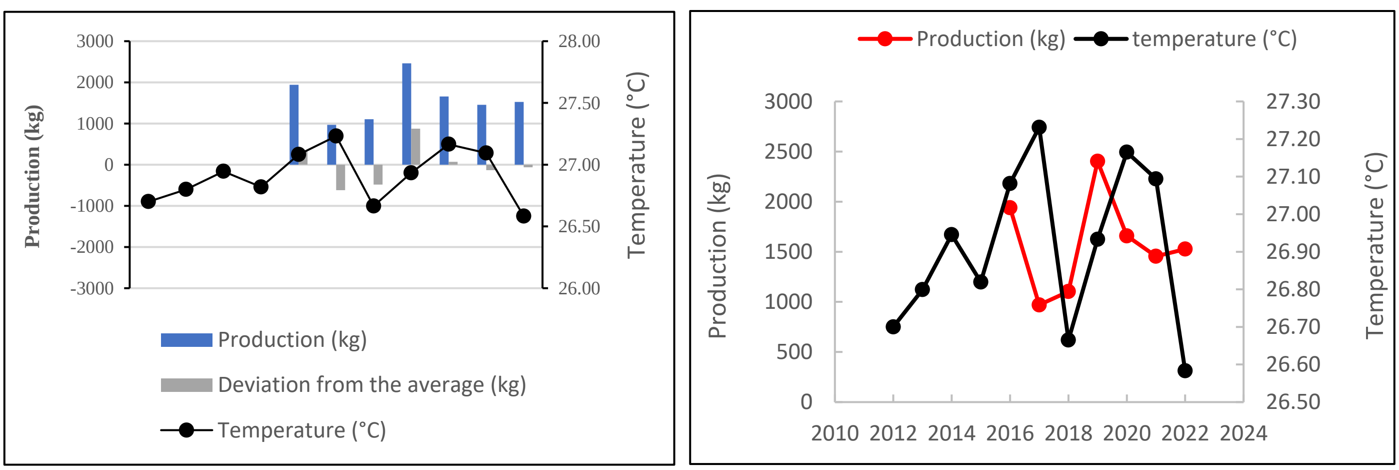


Figure 15: Correlation between temperature and honey production (Bkp2)

2.3.7. Correlation between precipitation and honey production

There is a strong positive correlation between precipitation (10 years) and honey production (BKP) ($r= 0.78$, $p= 0.04$ ($p < 0.05$)) (Figure 16). When there is a drop in rainfall, a drop in honey production follows. An increase in rainfall is followed by an increase in honey production. The year 2019 recorded a record production (2462.28 kg) correlated with high rainfall (1621.3 mm), whereas 2017 recorded low production (969.86 kg) with low rainfall (184.4 mm).

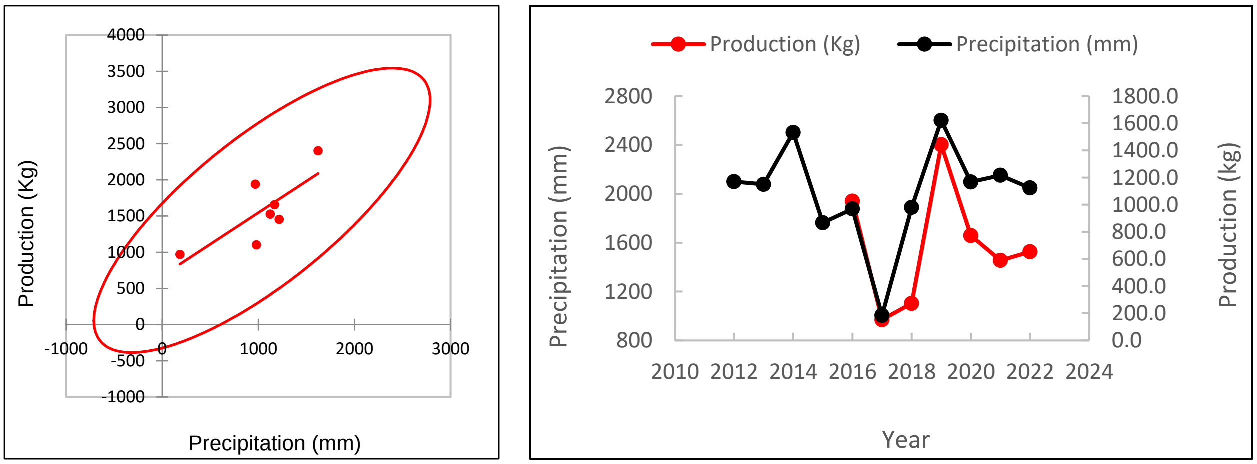


Figure 16: Correlation between precipitation and honey production (Bkp2)

2.4. Discussion

The vulnerability of African populations to climate change (Roudier *et al.*, 2011) is a worrying phenomenon. Increased temperatures and variations in precipitation (Roudier *et al.*, 2011) can alter the availability of crop yields. Studies on the impact of climatic parameters on bee productivity are limited in the Poro region. This study raised the question of the impact of climatic parameters on beekeeping productivity. It aimed to fill a gap in assessing the impact of climatic parameters on honey productivity. The results indicated that beekeepers observed an increase in temperature, variations in rainfall patterns, and a prolongation of the dry season. They reported that these climatic impacts adversely affected their beekeeping activities, particularly leading to a decrease in honey production. The analysis of honey production did not show a significant trend. To understand the relationship between climatic factors and honey production, the study analyzed the combination of these parameters to predict beekeeping productivity in the region. This shows that precipitation is significantly correlated with productivity, with a correlation coefficient of $r = 0.78$ and a p-value of 0.04 ($p < 0.05$). On the other hand, temperature did not show any significant correlation with productivity. However, this relationship was not statistically significant, with a Pearson correlation coefficient of $r = 0.02$ and a p-value of 0.96 ($p < 0.05$).

The perception concerning the decrease in honey production is similar to the research carried out by Degu (2022), who found that some Ethiopian beekeepers have reported a reduction in honey production. Additionally, 80.9% of Tanzanian beekeepers surveyed indicated a decrease in honey production (Nyunza, 2018). Likewise, in Nigeria, despite an increase in the number of hives, honey production has diminished due to several climatic factors (Ukamaka & Eberechukwu, 2018). This similarity could be related to management practices, which can increase or decrease production. Especially, the socio-economic, technical and physical factors (Brodschneider *et al.,* 2016; Jacques *et al.,* 2017; Sperandio *et al.*, 2019). Moreover, beekeepers' perceptions via questionnaires and interviews are the most commonly used by the authors for perception analysis. On the other hand, the remaining production outcomes align with the research conducted by Shopova *et al.* (2022), which showed no significant trends in honey production from 2008 to 2020 in Bulgaria, suggesting a level of stability in the region. However, other researchers such as Kohsaka *et al.* (2017); Gajardo-Rojas *et al.* (2022); and Romero-Leiton *et al.* (2022) have noted decreasing trends in beekeeping production by beekeepers respectively in Chile, United States, Japan and South Korea. These differences can be explained by the type of methodology used, the climatic and environmental conditions. Additionally, the type and the number of hives used, the beekeepers' experience, and the level of education in recording information affect the production. According to Nyunza, (2018) and Tarekegn & Ayele (2020), the level of education affects beekeepers' ability to record honey production statistics and manage beekeeping activity. Indeed, in Côte d'Ivoire, Ouattara *et al.* (2023) suggested that the use of honey production statistics is difficult to obtain due to the lack of archives in the country concerning the education level.

The trend analysis of temperature and precipitation over 40 years has confirmed beekeepers' perception of climatic parameters concerning the changes. The result is confirmed by the IPCC AR5 report (IPCC, 2021) and Switanek *et al.* (2017). This perception, particularly the decrease in precipitation, the increase in temperature leading to long dry seasons, and the decrease in watercourses, is also reflected in their activities. They have a direct impact on the bees' food sources, such as the availability of water and floral resources (Landaverde *et al.,* 2023), and the reduction in the production of nectar, pollen, and honey (Vercelli *et al.,* 2021).

The strongest correlation between precipitation and honey production (Bkp) in our study area showed that it is an important factor for the productivity of beekeeping. It is in agreement with the study of Gajardo-Rojas *et al.* (2022), who showed that rainfall influenced production during the 12 months preceding the beekeeping season. According to Schweitzer *et al.* (2013) and Akala *et al.* (2018), the decrease in honey production is due to the significant effect of rainfall on plant phenology, which modifies the flowering and foraging period of bees (Schweitzer *et al.,* 2013). The effects of climate change and variability are harmful to beekeeping. Their impact on bees has a negative effect on honey production. Some of these impacts are desertion in the hives (Ohoueu *et al.,* 2017); mortality (Brodschneider *et al.*, 2018); and a decline in honey production (Gajardo-Rojas *et al.,* 2022). Although the graph showed that there is a correlation between temperature and honey production, the Pearson correlation showed a lack of correlation. This could be explained by the interaction of temperature with other factors such as humidity, diseases and parasites, the types of flowers foraged by the bees and their sensitivity to pesticides. This may mask the impact on honey production (Gajardo-Rojas *et al.*, 2022). This is why Pătruică *et al.* (2021) state that the feeding of honey bees is strongly influenced by temperature and humidity. We can also state that the temperature between 26°C and 27°C obtained in the Poro region could be ideal for good honey production. According to Schweitzer *et al.* (2013), an optimal foraging temperature for bees is between 25°C and 35°C. This will allow the bees to take full advantage of the harvest of plant products. In addition to climatic factors, which play an important role in the survival of bees and their goods, other factors need to be taken into account such as anthropogenic factors. In other words, hives management and beekeeping management practices(Schouten, 2020) can cause damage to bees. Both can contribute to the reduction in the quantity of honey (Nyunza, 2018), since effective management has the potential to reduce stress, whereas inadequate management may exacerbate it (El Agrebi *et al.*, 2022).

The use of Pearson's correlation could not show the correlation between temperature and honey production. This implies the integration of other statistical analysis methods such as linear regression used by Schweitzer *et al.* (2013) and Mann-Kendall and Sen’s slope. The next analysis should take into consideration other climatic factors such as humidity, which could clarify the impact of temperature, and the number of hives associated with honey production.

2.5. Conclusion

The beekeepers' perception of climatic parameters and their beekeeping production, as well as the correlation between these factors, enabled us to understand the effect of climatic variables on beekeeping production in the region. From a statistical point of view, there is no trend in honey production except Bkp8 and Bkp9. There is no correlation between temperature and honey production even though we observe an effect on the graphic, while precipitation strongly correlated with honey production. Beekeepers have a good knowledge of the impacts of climate variability and recognize that it affects their activities; some adaptation strategies will be proposed to beekeepers to cope with climate impacts like the use of water tanks, transhumance, reforestation and changes in management practices.

We must urge the authorities, scientists and producers to be ever-vigilant and to take steps to anticipate the situation. It is necessary to take into account all the environmental parameters, the number of hives used, and the location of the apiary, beekeeping management practices, other climatic factors to improve productivity. This study will enable the implementation of adaptation strategies to be put in place to improve productivity.

CHAPTER 3: SUITABILITY FOR BEEKEEPING

3.1. Introduction

Bees play a major role in pollination, contributing between 73% and 80% of pollination (Sahu *et al.*, 2024). Wild plants need between 60% and 80%, while agricultural plants benefit from 30% of their activity (Greenleaf & Kremen, 2006; Sahu *et al.*, 2024). Their activity guarantees food and health security for mankind (Kaya *et al.*, 2023). Their visits to plants are favoured by climatic and geographical conditions (Hung *et al.*, 2018). This enables honey bees to produce consumer products such as honey, royal jelly, bee bread, etc., which are then harvested by beekeepers for human consumption.

Beekeeping is an activity that keeps honey bees for the production of honey and other products. The activity participates in economic diversification by increasing the Income of rural communities (Etxegarai-Legarreta & Sanchez-Famoso, 2022; Prodanović *et al.*, 2024).

However, the intensification of activities such as agriculture and urbanization could reduce bee activity, just as the reduction in semi-natural habitats could lead to a reduction in bee species (Hristov *et al.*, 2020; Schlager *et al.*, 2024; Stein *et al.*, 2018). For example, the loss of colonies (Gray *et al.*, 2023) in the beehive due to mortalities and desertion (Ohoueu *et al.*, 2017).

It is becoming crucial to find alternatives to protect bees and, by extension, the beekeeping industry. Because bees live in a complex environment, many criteria need to be taken into account. Which areas offer the most suitable conditions for keeping honeybees? This is how Multi-Criteria Decision Analysis (MCDA) is involved. The development of Multicriteria Analysis has recently been used in Beekeeping activities. The purpose is to increase activity productivity (Elmastaş *et al.*, 2022) and help reduce bee colony losses (Abou-Shaara *et al.*, 2013). This method is the most commonly used by many researchers to find the best places in beekeeping (Roque *et al.*, 2024). To determine suitable areas for keeping bees, Multi-Criteria Decision Analysis (MCDA) is widely used by researchers in combination with Geographical Information System (GIS) (Awad *et al.*, 2019; Fazel Amiri, 2012; Kotovs & Zacepins, 2023) contributes to visualize the information by mapping information according to the selected criteria. GIS aids in describing, planning, and managing the hives spatiotemporally (Awad *et al.*, 2019). Concerning MCDA, there are several methods to assess suitability. AHP is the most used (Abou-Shaara *et al.*, 2013; Maris *et al.*, 2008; Zoccali *et al.*, 2017). Some studies have used AHP and PROMETHEE (Sari *et al.*, 2020) or the AHP-GIS model, followed by fuzzy normalization (Roque *et al.*, 2024). Before such analyses, the knowledge of the plants foraged by bees is important to determine the floral diversity available for our study area.

The objective is to identify the melliferous plants and map suitable areas for keeping honeybees by combining the biophysical and socio-economic criteria through the integration of AHP and GIS. It is to improve beekeeping productivity and sustainability in the Poro region bastion of beekeeping in Côte d'Ivoire, according to the ecological, climatic and socio-economic data for the region.

3.2. Materials and methods

Methodology

We adopted the Multi-Criteria Decision Analysis (MCDA), especially the Analytical Hierarchy Process (AHP) with the integration of a Geographical Information System (GIS) and Remote Sensing (RS), preceded by the melliferous plant inventories to find the best suitable area to practice beekeeping and improve his productivity following the methodology in Figure 17.

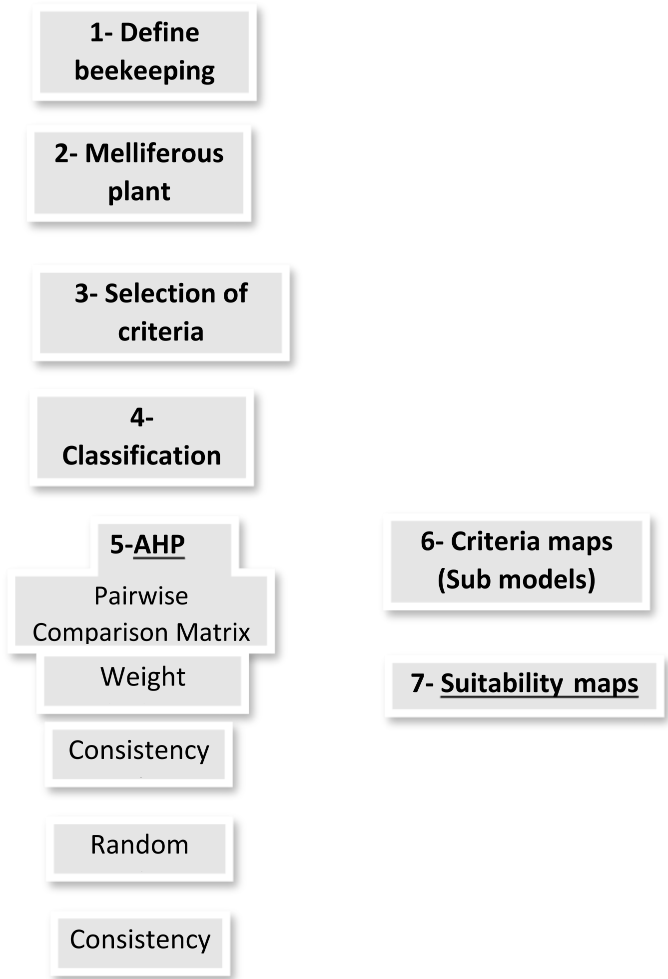


Figure 17: Methodological steps for the suitability map

3.2.1. Beekeeping requirements

Apiaries should be located in rural areas with a high diversity of bee flora (Roque *et al*., 2024) to ensure population security and honeybees' well-being and health.

3.2.2. Melliferous plant inventories

Adapting from Cheng *et al* (2020), our method consisted of a participatory survey using a questionnaire and interviews with beekeepers on the species foraged by bees around their apiary. These operations were followed by field observations with the beekeepers. Photographs were taken to identify the scientific names of unidentified species by comparing them with determination keys. The surveys took place between December 2022 and October 2023, which corresponds to the flowering of the species in the region. The beekeepers were selected based on several criteria: in addition to their experience (more than 5 years), the type of hive (which influences access to resources), the location of the apiaries, and their knowledge of plants (the majority being farmers). A total of 72 beekeepers were interviewed in the 4 departments of the Poro region.

These species were then used as criteria in the analysis, considering factors such as the nature of the plants, the botanical families most visited and the most attractive species.

3.2.3. Selection of criteria and sub-criteria

Two criteria have been chosen according to beekeeping requirements (Appendix 1) (Figure 18). Biophysical criteria include uncontrolled factors due to nature. Socio-economic criteria encompass all the human management activities that can be controlled. Different variables were selected according to their importance for the objective. Elevation, slope, and precipitation, factors influence the distribution of forest areas, crop production, floral resources, and, consequently, honey production (Cotrina-Sanchez *et al.*,2023). Temperature is a key determinant of plant phenology and bee biology. For the water bodies, areas close to the river increase production, as water is an essential resource for bees. When the locations are close to roads, the transportation and the installation of hives are facilitated (Cotrina-Sanchez *et al.*, 2023). Concerning the Land Use/ Land Cover**,** areas with a diversity of plants are more suitable for Bees. The final map was obtained by aggregating the weight of the criteria on the normalized map (Roque *et al.*, 2024) (Figure 19).

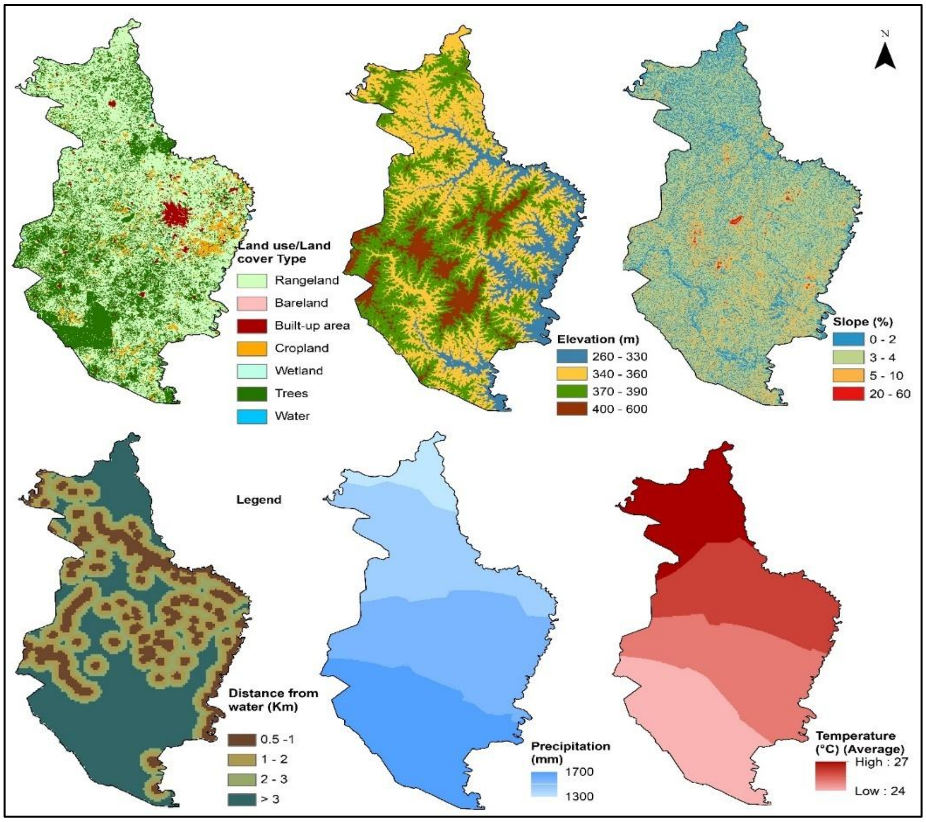


Figure 18: Biophysical sub-criteria

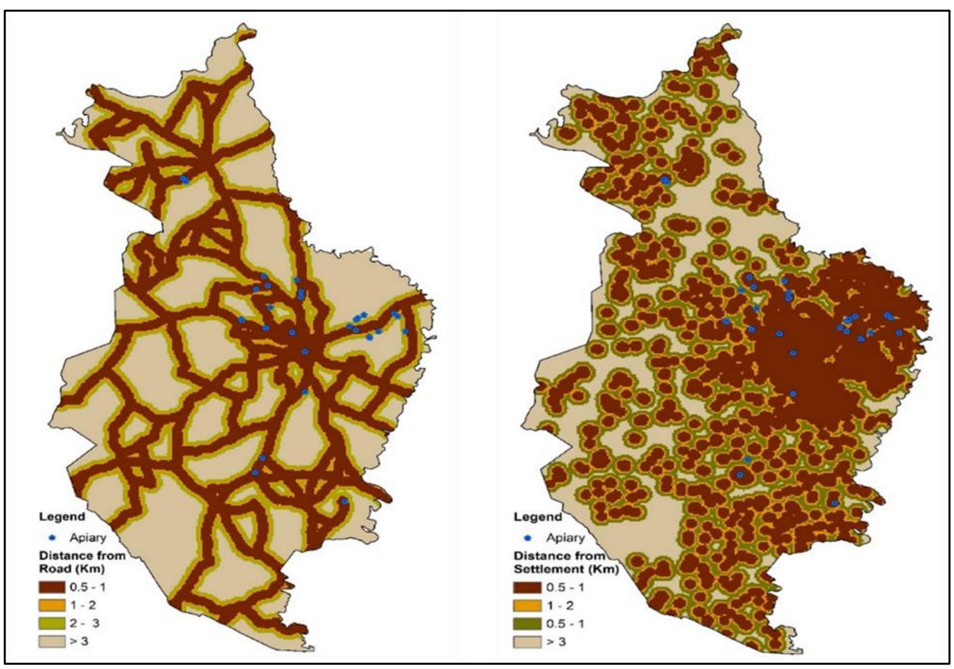


Figure 19: Socio-economic sub-criteria

3.2.4. Reclassification of the criteria

The criteria were based on literature and beekeepers' consultation, describing suitability reclassification into four groups: Highly suitable, suitable, slightly suitable, and unsuitable (Table 8). According to beekeeping requirements, the sub-criteria were reclassified based on literature review and beekeepers' needs. Highly suitable defines the optimal conditions for the criteria followed by suitable, slightly suitable defines the conditions where honey bees can manage it, but unsuitable presents some constraints for honey bees.

Table 8: Reclassification of sub-criteria

Sub-criteria	Highly suitable	Suitable	Slightly suitable	Unsuitable	Sources
Biophysical criteria					
Land use/Land cover	Field, grass, shrub, forest gallery, savannah	mixed agricultural	Single crops	Water surfaces, Mining area, Rice field	Ambarwulan, *et al.*, 2016
Slope (%)	<5 / >45	5–20	20–45	>45	Cotrina-Sanchez *et al.*, (2023
Distance to water bodies (km)	0 – 0.5	0.5 – 1.5	1.5 – 3.0	>3.0	Sarı *et al.*, (2020), Cotrina-Sanchez *et al.*, (2023) ; Ambarwulan, *et al.*, (2016)
Elevation (m)	Below 500 meters	500- 1000	1000 - 1500	0–200/>2000	Sarı *et al.*, (2020), Cotrina-Sanchez *et al.*, (2023)
Temperature (°C)	24 - 27	20 – 24 / 27 - 30	15 – 20 / 30 - 35	<15 / >35	Ambarwulan, *et al.*, (2016)
Precipitation (mm)	2 000 - 2 500	2000 - 3000 1500 - 2000	3000 – 3500 1200 - 1500	>3 500 <1 200	Ambarwulan, *et al.*, (2016)
Socio-economic criteria					

Distance to roads (km)	0.5 – 1.5	1.5 – 2	2 – 3	<0.5 and >3.5	Ambarwulan, *et al.*, (2016), Sarı *et al.*, (2020)
Distance to settlements (km)	1000 - 2000	500 - 1000 2000 - 3000	200 - 500 3000 - 4000	<200 / >4 000	Ambarwulan, *et al.*, (2016)

3.2.5. Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a method developed by Saaty (1980) to help decision-making by weighting the criterion and sub-criterion in the reclassification of the suitability maps. We followed the importance scale proposed by Saaty (1977, 1980) to do the pairwise comparison ranging from 1 to 9 (Table 9). The *(dnn)* importance scales of each criterion are involved in the pairwise comparison matrix (Table 10).

Table 9: Scale value

Scale	Importance
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
1/3, 1/5, 1/7, 1/9	Values for inverse comparison

Table 10: Pairwise matrix

A	*Criteria 1*	*Criteria 2*	*Criteria 3*	…	*Criteria n*
Criteria 1	d_{11}	d_{12}	d_{13}	…	d_{1n}
Criteria 2	d_{21}	d_{22}	d_{32}		d_{2n}
…	…	…	…	…	…
Criteria n	d_{n1}	d_{n2}	d_{n3}	…	d_{nn}

The normalized matrix was determined by the division of each (ann) to the sum of its columns (Equation 1).

$$a_{ij}^{1} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad (1)$$

The average sum refers to the weights of each criterion (Equation 2).

$$w_i = \left(\frac{1}{n}\right)\sum_{i=1}^{n} a'_{ij} \ , (i, j = 1,2,3, \dots, n) \qquad (2)$$

A consistency calculation is proposed by Saaty (1994) to decide whether weight calculation is consistent or not. For this purpose, the Index Consistency *(IC)* is used to determine the coefficient of the pairwise comparison matrix (Equation 3).

$$IC = \frac{\lambda_{max} - n}{n - 1} \qquad (3)$$

The consistency ratio *(CR)* is an indicator of the consistency of the calculation (Equation 4). If *CR* exceeds 0.1, based on expert knowledge and experience (Saaty and Vargas 1991), a revision of the pairwise comparison matrix with different values is required (Saaty 1980).

$$CR = \frac{IC}{RI} \qquad (4)$$

3.2.5. Final suitability map

The finalization of the overall map was done by overlapping the AHP information with reclassification information. The number of species inventories and the data on melliferous plants are essential for the analysis. The following formula helped in the analysis (Equation 5):

Final map = Biophysical criteria + Socio-economic criteria (5)

3.3. Results

3.3.1. Melliferous plants visited by honey bees

Given the plants foraged by honeybees, 65% are derived from natural plants, and the other 35% have been collected from cultivated plants (Figure 20). A total of 20 species of melliferous plants have been identified in the area surveyed (Table 11). Species such as *Mangifera indica* L., *Anacardium occidentale* L., *Detarium microcarpum, Gossypium hirsutum, Vitellaria paradoxa*, *Adansonia digitata* L., *Hyptis suaveolens, Tectona grandis and Zea mays* are most visited by honeybees for their nectar and pollen according to beekeepers. Melliferous species like *Flacourtia flavescens*, *Azadirachta indica* are moderately foraged by honeybees. *Alternanthera sessilis*, *Mitracarpus hirtus*, *Arachis hypogaea*, *Tridax procumbens*, *Abelmoschus esculentus, Ageratum conyzoïdes, Sida acuta, Spermacoce stachydea*, and *Oryza sativa* have weakly foraged by honeybees according to observations by beekeepers. The most representative and diversified families are Malvaceae with 20% of species followed by Anacardiaceae, Fabaceae, Poaceae, Rubiaceae, and Asteraceae. The less diversified families concern Facourtiaceae, Amaranthaceae, Sapotaceae, Lamiaceae, Meliaceae and Verbenaceae (Figure 21). Some images of some plants foraged by honeybees are presented in Figure 22.

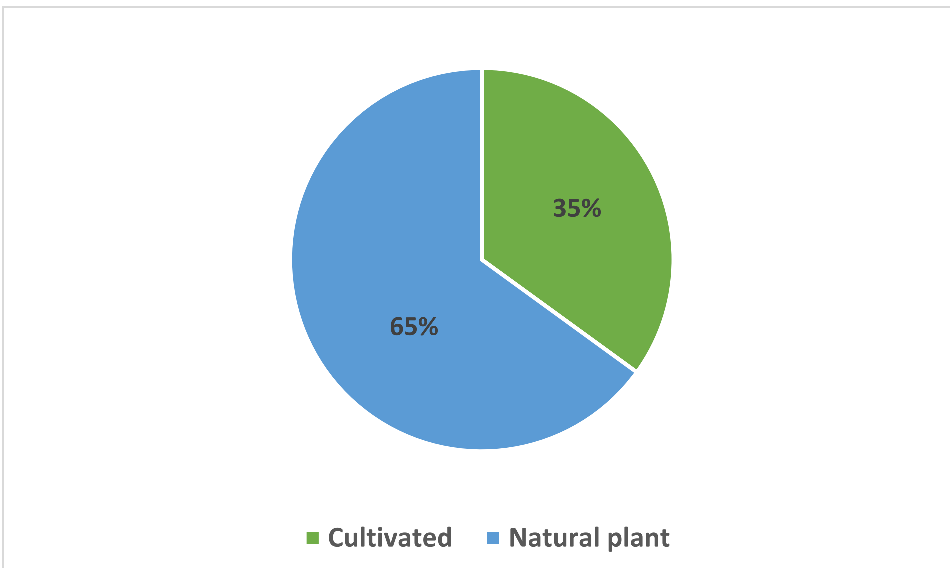


Figure 20: Nature of plants foraged by honeybees

Table 11: Melliferous plants inventoried in the study area Melliferous plants inventoried in the study area

N°	Plant species	Type	Vernacular name	Preference
1	*Mangifera indica*	Tree	Mango tree	***
2	*Anacardium occidentale*	Tree	Cashew nut	***
3	*Detarium Microcarpum*	Tree	Sweet detar	***
4	*Flacourtia flavescens*	Tree	wild prune	**
5	*Alternanthera sessilis*	Weed	-	*
6	*Zea mays*	Grass	Maize	***
7	*Arachis hypogaea*	Grass	Groundnut	*
8	*Mitracarpus hirtus*	Shrub	-	*
9	*Gossypium hirsutum*	Grass	Cotton	***
10	*Tridax procumbens*	Weed	-	*
11	*Vitellaria paradoxa*	Tree	Shea	***
12	*Adansonia digitata*	Tree	baobab tree	***
13	*Abelmoschus esculentus*	Grass	Okra	*
14	*Ageratum conyzoïdes*	Grass	The herbed king	*
15	*Hyptis suaveolens*	Weed	Insect repellent	***
16	*Sida acuta*	Grass	Broom grass	*
17	*Spermacoce stachydea*	Grass	-	*
18	*Azadirachta indica*	Tree	Neem	**
19	*Tectona grandis*	Tree	-	***
20	*Oryza sativa*	Grass	Rice	*

*: weakly foraged**;** **: Moderately foraged**;** ***: Most foraged

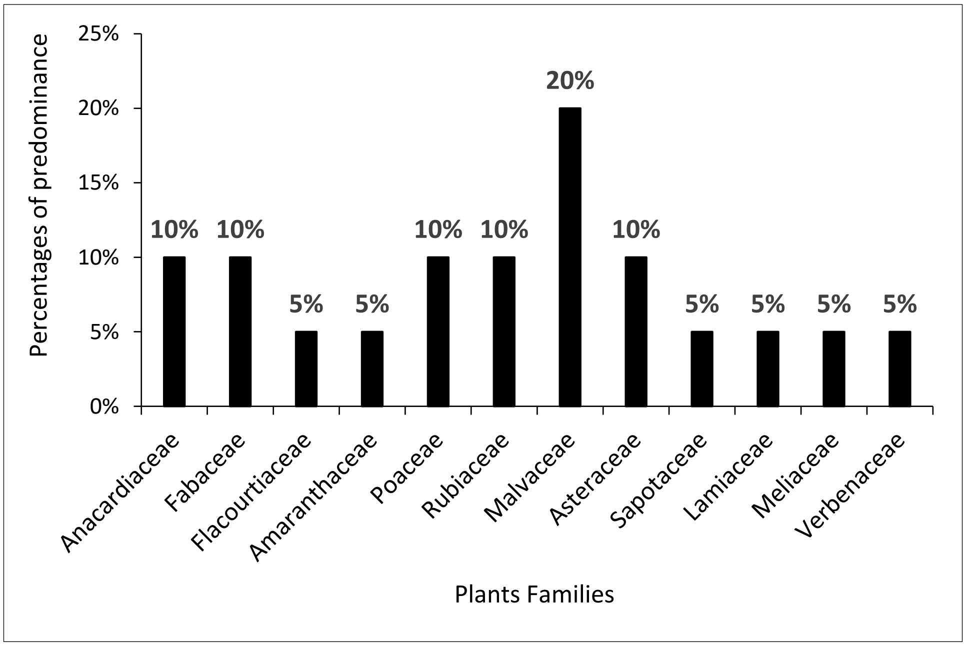


Figure 21: Most visited plants families by honeybees

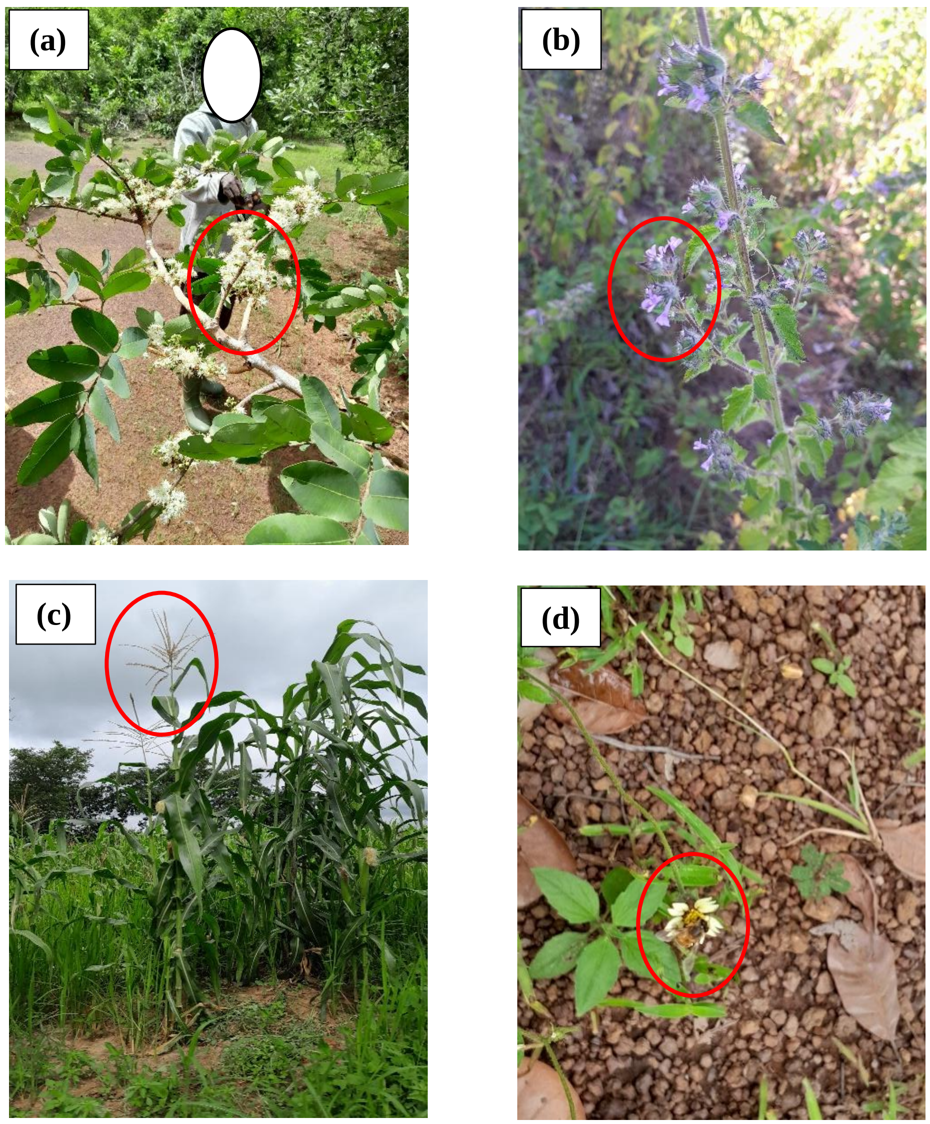


Figure 22: Species flowers visited by honeybees: *Detarium microcarpum (a); Hyptis suaveolens (b); Zea mays (c); Tridax procumbens (d).* ***Source:*** Ouattara, 2023

3.3.2. Analytical Hierarchy Process (AHP)

The AHP made it possible by weighing the importance of each criterion through the sub-criteria for suitability in the Poro region. AHP weightings obtained in Tables 12 and 13 show that the suitability of land for beekeeping is determined by biophysical criteria: 29% for Land use/Land cover (LU/LC), 28 % for distance from waterbodies (WB), 11% for temperature (TP), 13 % for precipitation (PR), 9% for slope (SL), 10 % for elevation (EL). The socio-economic criteria place more importance on distance from roads (RD) (67%) than distance from settlements (SL) (33%) to facilitate the movement of equipment and beekeepers themselves.

Table 12: Biophysical criteria

Sub-criteria	Criteria Weights	Criteria weight (%)
LU/LC	0.2875	29
PR	0.1321	13
SL	0.0883	9
TP	0.1069	11
EL	0.1017	10
WB	0.2835	28

Table 13:Socio-economic criteria

Sub-criteria	Criteria Weights	Criteria weight (%)
RD	0.6667	67
SL	0.3333	33

3.3.3. Maps of biophysical and socio-economic criteria

3.3.3.1. Biophysical criteria

The Poro region covers a total area of 12568 Km^2. The results obtained show that according to biophysical criteria, the highly suitable (13%) area represents 1581 Km^2 (Table 14; Figure 23). This area presents a rich composition of plant species, where the optimum temperature varies between 24 to 27 °C with precipitation between 2 000 and 2 500. The slope and elevation are low and the area is close to water bodies. The suitable area is the best for high bee health and therefore great honey productivity. Then, followed by a suitable area (27%) representing 3379 Km^2. The party represents the agricultural area with average climatic conditions and a medium slope and elevation. A suitable area is good for beekeeping productivity. Whereas a slightly suitable area (24 %) covers 3077 Km^2. We can find the presence of single crops with some climatic and topographic constraints. The unsuitable (36 %) area is the largest with 4531 Km^2. Presents a high risk for honey bees' productivity due to the absence of plant species and extreme climatic conditions.

Table 14: Distribution of areas reclassified for biophysical criteria

	Level of Suitability	**Area (Km^2)**	**Percentage (%)**
Biophysical Criteria	Highly suitable	1581	13
	Suitable	3379	27
	Slightly Suitable	3077	24
	Unsuitable	4531	36
	Totals	**12568**	**100**

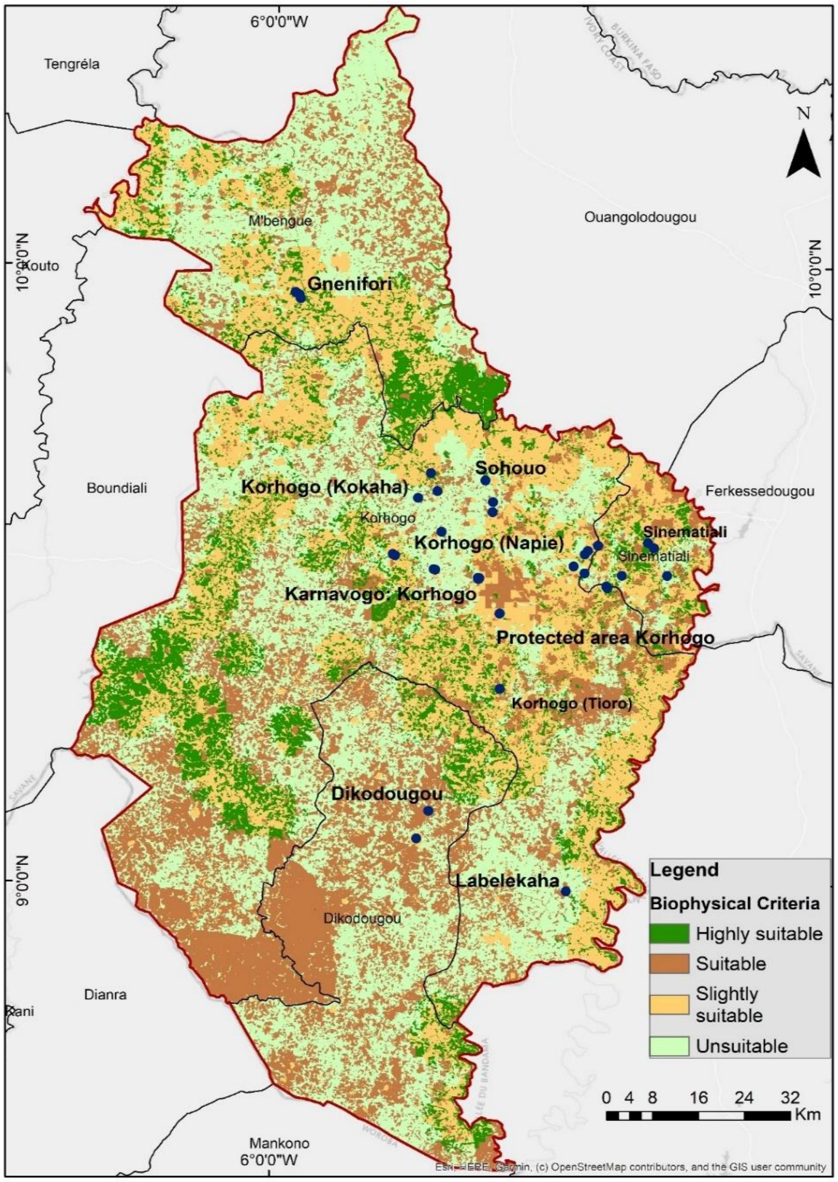


Figure 23: Biophysical suitability map

3.3.3.2. Socio-economic criteria

The results show that the area where roads are close to the apiaries and far from settlement areas is the most suitable (28%), with 3544 Km^2 (Table 15 and Figure 24). Transporting the materials is easy and visiting the apiaries can be done in a minimum of time. But when the apiaries start to move away from roads and closer to residential areas, the zones are either suitable (19%) or slightly suitable (26%), with 2351 Km^2 and 3246 Km^2 respectively. Relocation is always possible but may present certain constraints. On the other hand, locating the apiary too close to roads and/or settlements is a high risk for the bees and the local population. This area is classified as unsuitable (27%) and covers 3427 $Km.^2$

Table 15: Distribution of areas reclassified for socio-economic criteria

	Level of Suitability	**Area (Km^2)**	**Percentage (%)**
	Highly suitable	3544	28
	Suitable	2351	19
Socio-economic criteria	Slightly Suitable	3246	26
	Unsuitable	3427	27
	Totals	**12568**	**100**

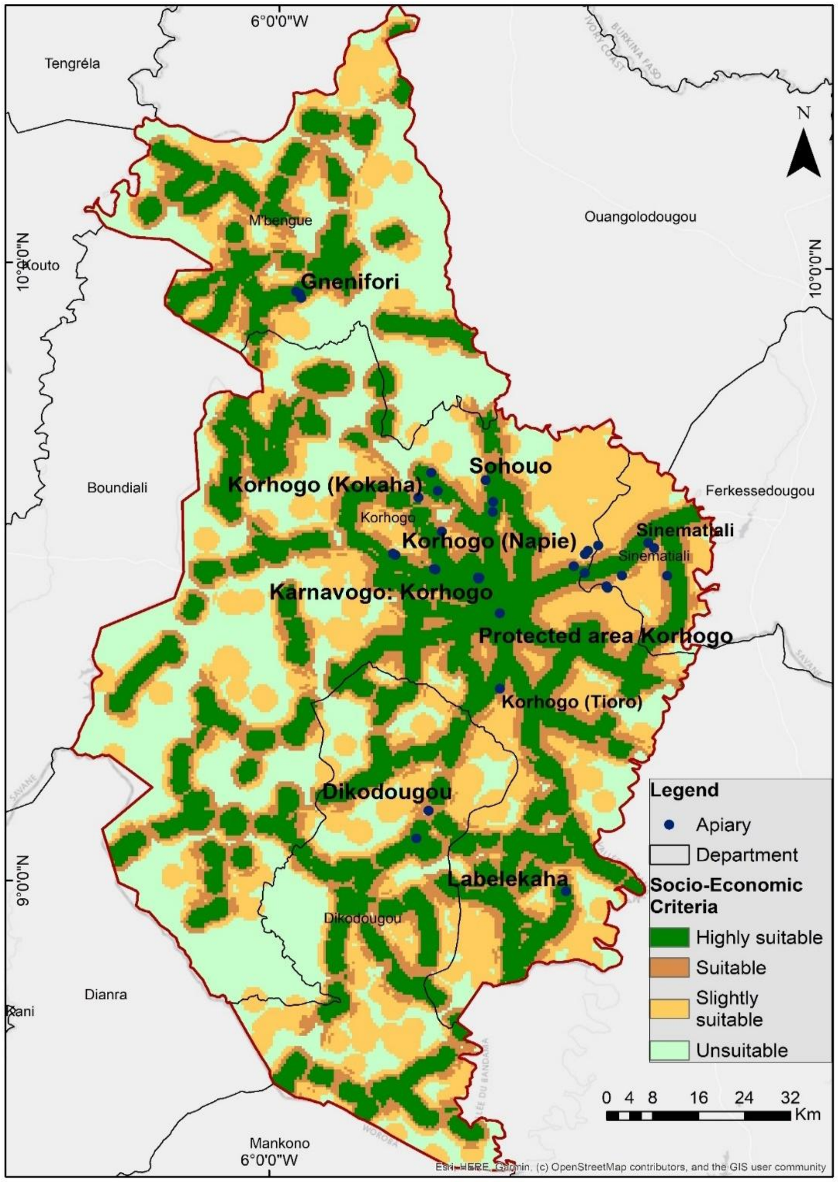


Figure 25: Socio-economic suitability map

3.3.3.3. Final suitability map

The results show that the area is dominated by the slightly suitable area (32%) with 3975 km^2 focused in the South part (Figure 25; Table 16). Followed by the unsuitable area (27 %) covering 3409 km^2. Both highly suitable and suitable areas (sum up to 41% of the total area) are considered to be ideal for keeping bees, while the majority of 59 % of the area is slightly suitable and unsuitable for bees. The majority of apiaries are located in highly suitable areas and areas close to agricultural and semi-habitat (Figure 26; Figure 27). The west, south, and north parts of the study area do not have an apiary. The suitability and unsuitability are unevenly distributed in the study area.

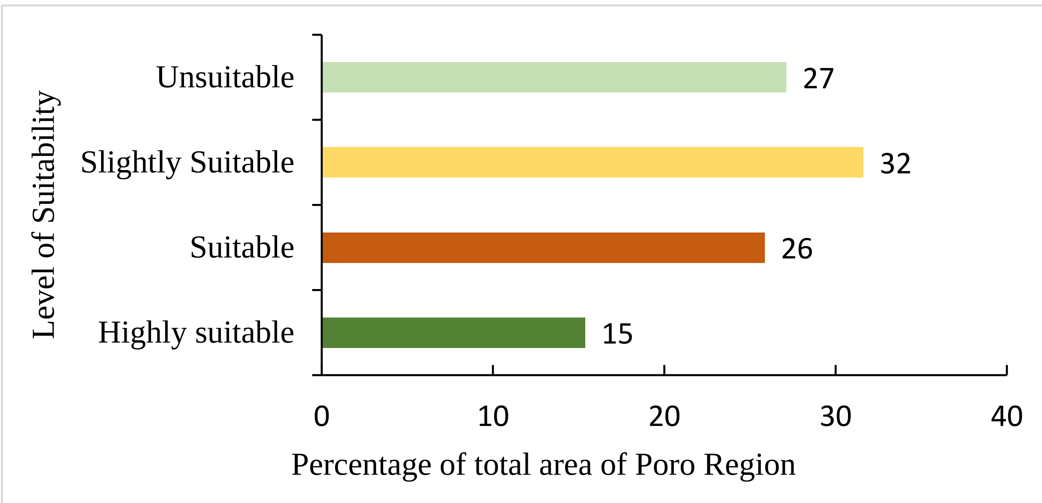


Figure 26: Percentage of area suitable for keeping honeybees in the Poro region

Table 16: Distribution of reclassified areas in the Poro region

	Level of suitability	Area (Km^2)	Percentage (%)
Final Suitability	Highly suitable	1934	15
	Suitable	3250	26
	Slightly Suitable	3975	32
	Unsuitable	3409	27
	Totals	**12568**	**100**

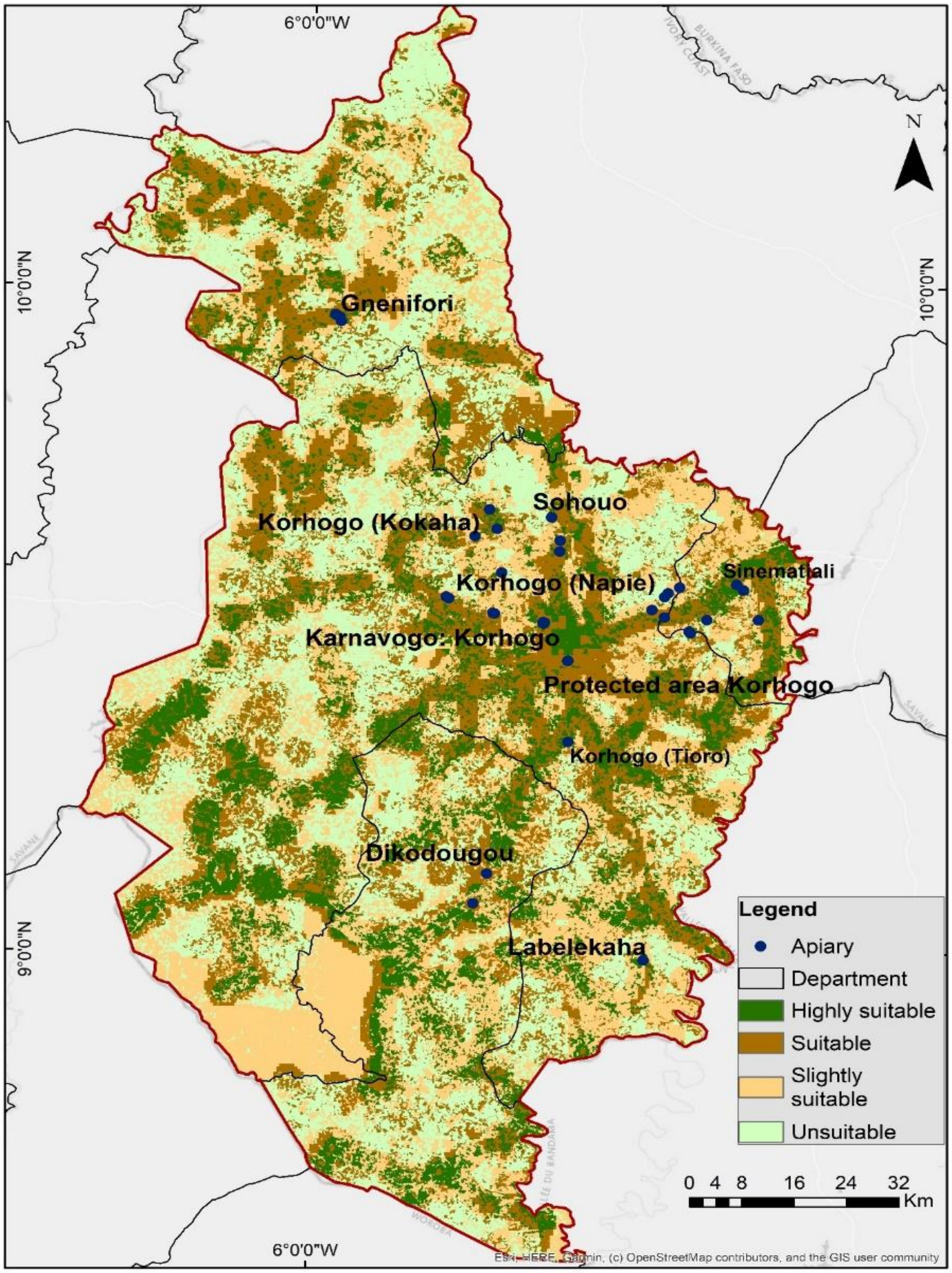


Figure 27: Final suitability map

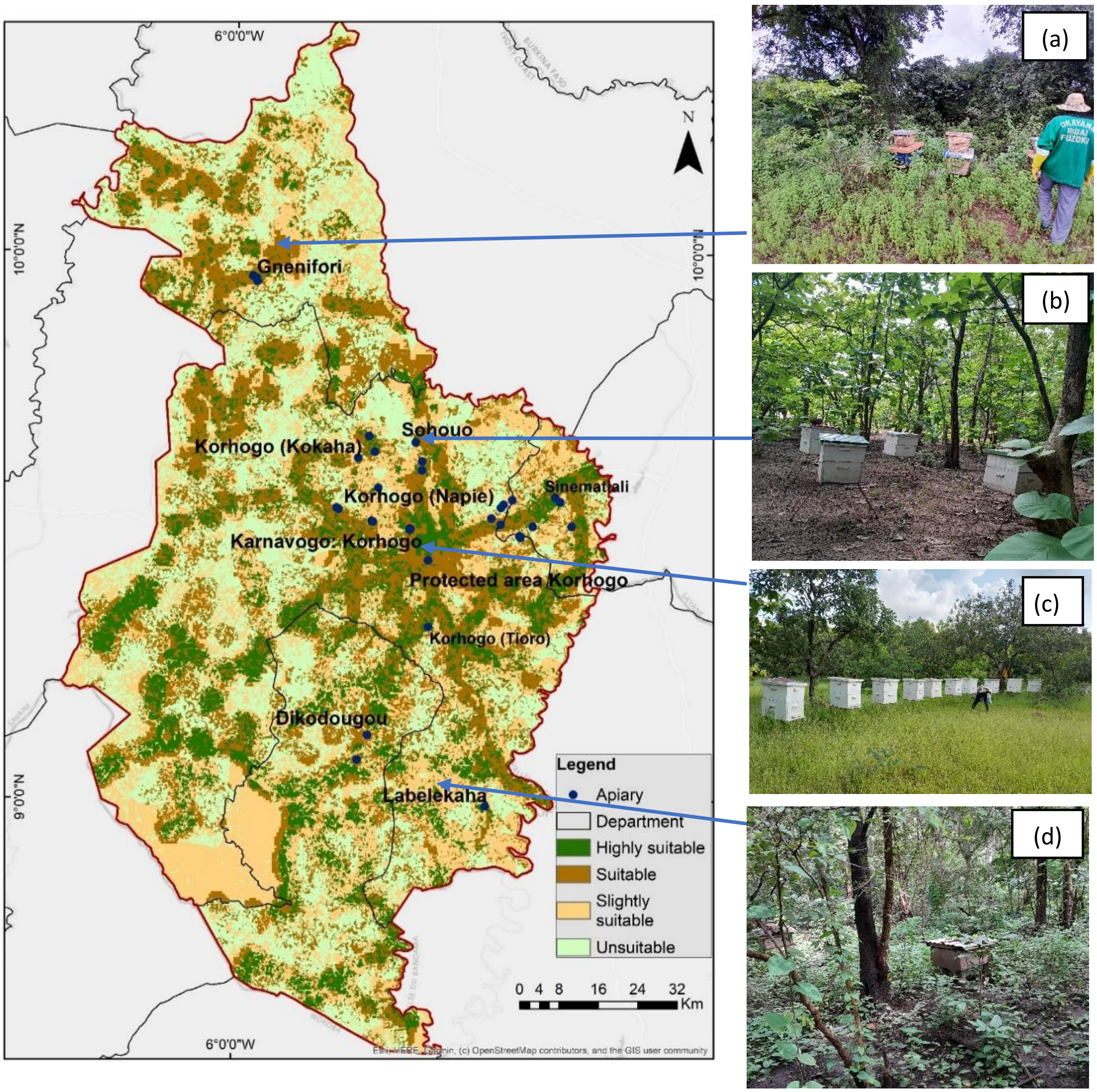


Figure 28: Examples of apiaries in the different levels of suitability

Suitable area (**a**), Unsuitable area (**b**), Highly suitable (c), Slightly suitable (**d**)

3.4. Discussion

We used AHP in combination with GIS and melliferous inventories to determine the most suitable areas to improve beekeeping productivity and ensure honeybees' health. The effects of climate change are having an impact on ecological mechanisms, particularly plant distribution. This confirms that of the twenty (20) melliferous species inventoried, 65% are natural plants and 35% come from cultivated plants, of which Malvaceae is the most diverse family. Bees have a preference for certain species such as *Mangifera indica L., Anacardium occidentale L., Detarium microcarpum, Gossypium hirsutum, Vitellaria paradoxa, Adansonia digitata, Hyptis suaveolens, Tectona grandis and Zea mays.* For this reason, the results of the Hierarchical Analysis Process (AHP) show that land use and land cover (29%) are the most important sub-criteria, followed by distance to water bodies (28%) for the biophysical criteria. For the socio-economic sub-criteria, access to roads (67%) is more important than distance from built-up areas (33%). The biophysical criteria are dominated by the area unsuitable for beekeeping (36%), while the socio-economic criteria are very suitable (28%). The AHP/GIS crossing suggests that in the Poro region, only 41% of areas are very suitable and suitable for beekeeping, and 59% of areas are slightly suitable and unsuitable for beekeeping. Suitable areas include gallery forests, savannahs and a multitude of agricultural zones. Areas unsuitable for beekeeping, might be due to the prolonged dry season, the expansion of agriculture, especially monoculture, and deforestation, which could reduce honey bees' natural habitats. Also, the lack of access to water in certain areas is a constraint to the development of beekeeping. This constraint is particularly marked in the Poro region. Another constraint is the Poro region is a highly agricultural area where the use of pesticides by farmers can pose a threat to honey bees (Ohoueu *et al.*, 2017a).

The suitability allows the installation of the new apiary and or the moving of the existing ones (Roque *et al.,* 2024). According to Abou-Shaara *et al.* (2013), Fernández-Manso *et al.* (2016); Zoccali *et al.* (2017), Sarı *et al.* (2020), and Sarı (2022), the best way to increase the productivity of bees in the apiary is in highly suitable and suitable areas. The proximity of roads means that equipment can be transported, apiaries can be visited, and emergencies can be dealt with in a short space of time. On the other hand, we are in West Africa, and bees are very aggressive, so it is advisable to keep apiaries away from dwellings. These results were confirmed in the Poro region, where most of the apiaries visited were far from houses and had access to roads. While in our study area, proximity to roads is more important, in north-western Peru, beekeepers prefer their apiaries to be close to their homes (Cotrina-Sanchez *et al.*, 2023).

The AHP results are similar to the studies of Cotrina-Sanchez *et al.* (2023) and Roque *et al.* (2024) where land use/ land cover and water availability are the most relevant criteria for suitability. The climatic factors are also important, but in this case, they constitute uncontrolled factors. The low proportion of highly suitable areas identified in the mapping indicates a major constraint to beekeeping resilience. Even if certain floral species are present, biophysical and socio-economic conditions may not allow them to be exploited to their full potential. The suitability area for beekeeping in the Poro region is discordant with the studies of Roque *et al.* (2024), who found that 60% of the apiaries are in the high or very high suitability area. The same goes for Bareke *et al.* (2024) in Southern Ethiopia, where 65.86 % of the land is highly suitable and suitable. Sari *et al.* (2020) found that in Turkey, 67.4% of the study area was suitable, and 32.6% of the study area was not suitable. The reason is that some studies have applied the AHP and PROMETHEE approach to analysis (Sari *et al.*, 2020), while others have combined the AHP and normalized the fuzzy approach. Additionally, the choice of criteria depends on the beekeepers' needs and the apiaries' locations. Concerning the criteria, land use/land cover, climatic factors, topography, and hydrography are the most used with some differences, such as flora, bee forage, solar radiation, distance to ionizing radiation sources, proximity to landfills, and natural hazards (Sari, 2022), honey type, air pollution (Signorelli *et al.*, 2023).

The analysis reflects the perceptions of beekeepers interviewed in the study area, showing that ecological, climatic, topographic, and socio-economic factors are very useful for beekeeping, therefore the productivity of the activity. The use of GIS and AHP in determining appropriate places for beekeeping activities is one of the steps in the decision-making for the sectors and governments. Identifying highly favourable areas could guide beekeeping zoning, melliferous reforestation or targeted transhumance policies.

One of the limitations is that our study does not consider other criteria such as humidity, wind, and pesticides for analysis. Furthermore, the areas identified as suitable do not always take into account the land use conflicts (agriculture, livestock and others) that could expose them to vulnerability. These results provide a valuable basis for supporting income diversification initiatives in rural areas and promoting sustainable activity with high socio-economic potential. This integrated discussion shows that the sustainability of beekeeping in the context of climate change depends on a detailed, cross-cutting understanding of climatic pressures, available melliferous resources and local capacities for exploiting these resources. It highlights the value of multi-criteria spatial approaches in guiding more targeted and effective adaptation responses.

3.5. Conclusion

The results have shown that both highly suitable and suitable areas for practicing beekeeping in Poro regions are 41 % dominated by both slightly suitable and unsuitable 59%. This was achieved by combining environmental and socio-economic data. Using a geographic information system (GIS) with multi-criteria decision-making has improved knowledge of bee ecology in the Poro region. The agricultural expansion and urbanization are the main challenges to the suitability maps in the future.

Future studies need to focus on the integration of future climate change scenarios and climate data with higher spatial and temporal resolution to assess the sustainability of suitable areas. Also, promoting reforestation with melliferous species to restore bee habitats is a kind of association between beekeepers and farmers. It is important to raise awareness among local communities of the need for sustainable management of areas identified as suitable. In addition to this work, it is essential to understand its socio-economic impact on practitioners, such as vulnerability.

CHAPTER 4: BEEKEEPERS' VULNERABILITY

4.1. Introduction

Poverty is one of the greatest challenges facing populations, especially in developing countries (Chamma, 2024). Indeed, it is one of the factors that increase people's sensitivity and exposure to climate change (Leichenko & Silva, 2014). Poverty therefore, drives people to diversify their sources of income (Adom, 2024).

It is in this sense that beekeeping appears to be an activity that can reduce poverty (Thomas & Tounkara, 2020; Tadilo & Ambaw, 2024) through the trading of bees and their goods (Tadilo & Ambaw, 2024). One of the main advantages of this activity is that it requires fewer resources (Schouten, 2020). In addition, this activity provides pollination services (IPBES 2016), contributing to food security (Gallai *et al.*, 2009) and biodiversity conservation (Potts *et al.*, 2016).

The existence of a clear link between climatic parameters (temperature, rainfall) and beekeeping productivity, as perceived by producers, is confirmed by empirical data (Ouattara *et al.*, 2025). Beekeepers face many challenges. The best known is the collapse, desertion and mortality of bee colonies in apiaries (Brodschneider *et al.*, 2016, Kulhanek *et al.*, 2017; Ohoueu *et al.*, 2017). The causes are converging towards climate change (Flores *et al.*, 2019; Durant *et al.*, 2023) and environmental change (Garantonakis *et al.*, 2016), which are increasing the presence of parasites and diseases (Varikou *et al.*, 2020), leading to losses of bee ecosystem services such as honey production (Ouattara *et al.*, 2025). For example, rising temperatures can delay plant fall, which harms pollinator ecology and reduces their productivity (Louveaux *et al.*, 1966).

These environmental and climatic constraints raise the central question of how these pressures affect beekeepers' living and production conditions. The vulnerability of populations, especially in Africa, to climate change is a worrying phenomenon (Roudier *et al.*, 2011). In this context, it is essential to address the issue of the vulnerability of beekeepers in our study area.

Scientific research on the vulnerability of beekeepers is limited in the Poro region, particularly in terms of approaches integrating local perceptions and environmental and socio-economic characteristics. It is this gap that the present research seeks to fill. It aims to analyze the vulnerability of producers, particularly beekeepers, to climate change.

Who are the most vulnerable beekeepers, where are they located in the Poro region, and what factors explain their vulnerability?

The aim is to assess the vulnerability of beekeepers to climate change by using the IPCC (2014) vulnerability framework and principal component analysis (PCA);

4.2. Methodology

4.2.1. Conceptual Framework

Our study used the vulnerability framework developed by (IPCC, 2014). This framework was developed in the context of research on vulnerability and adaptation measures to limit climate change impacts. According to the IPCC (2022), Vulnerability is the predisposition or propensity of the human or natural system to suffer adverse effects. The IPCC framework characterizes vulnerability in two factors: susceptibility to damage and inability to cope and adapt (Figure 28). It is the degree to which a system or species is affected by change, directly or indirectly. In beekeeping, sensitivity is the level of impact of hazards on beekeeping and beekeepers, all the issues they encounter concerning their needs. While adaptive capacity represents the coping ability of a system or community to mitigate or avoid the adverse impacts of climate variability, Beekeepers can withstand the damage caused by hazards. We exclude exposure because bees have already been affected by multiple hazards. We acknowledge that exposure is a part of risk elements, where risk is defined by the location of bees and all the characteristics they are exposed. Here, the concept of vulnerability derives from the notion of environmental and socio-economic vulnerability in which climatic and environmental factors and human activities interact and simultaneously define the bees' living environment. The ecological aspects were the most studied

in the last decade, some authors have started to be interested in economic issues (Biswas and Nautiyal, 2023). Finally, we analyze beekeepers' vulnerability to climate change. This involves identifying the most vulnerable beekeepers and mapping their locations. We employ Principal Component Analysis (PCA) alongside the IPCC AR5 vulnerability framework to assess their sensitivity and adaptive capacity.

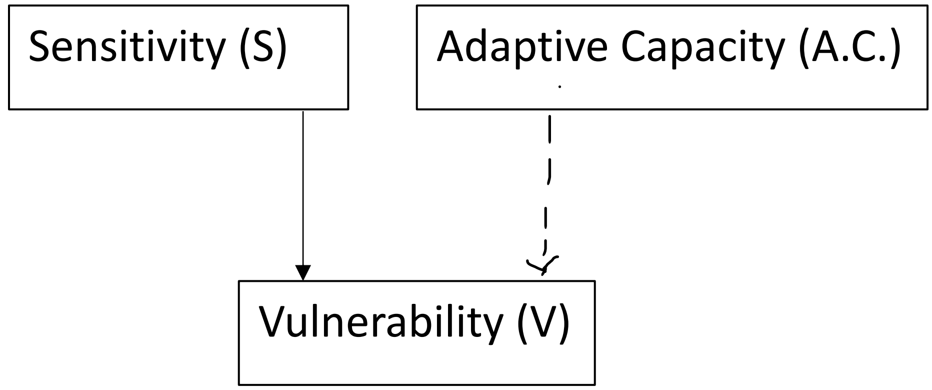


Figure 29: Adapted from IPCC AR5 2014 vulnerability framework

This structured approach allows us to first understand climate-related risks, then optimize beekeeping site selection, and finally, evaluate beekeepers' vulnerability for improved resilience strategies.

We developed a workflow on a set of environmental and socio-economic indicators. This workflow (Figure 29) is adopted following the OECD guidelines, (2008). The stages include (1) definition of the conceptual framework, (2) identification of a representative set of indicators based on existing literature and data transformation, (3) multivariate analysis (Pearson correlation), (4) normalization, (5) weighting (By using PCA), (6) aggregation and (7) visualization of Beekeepers vulnerability index.

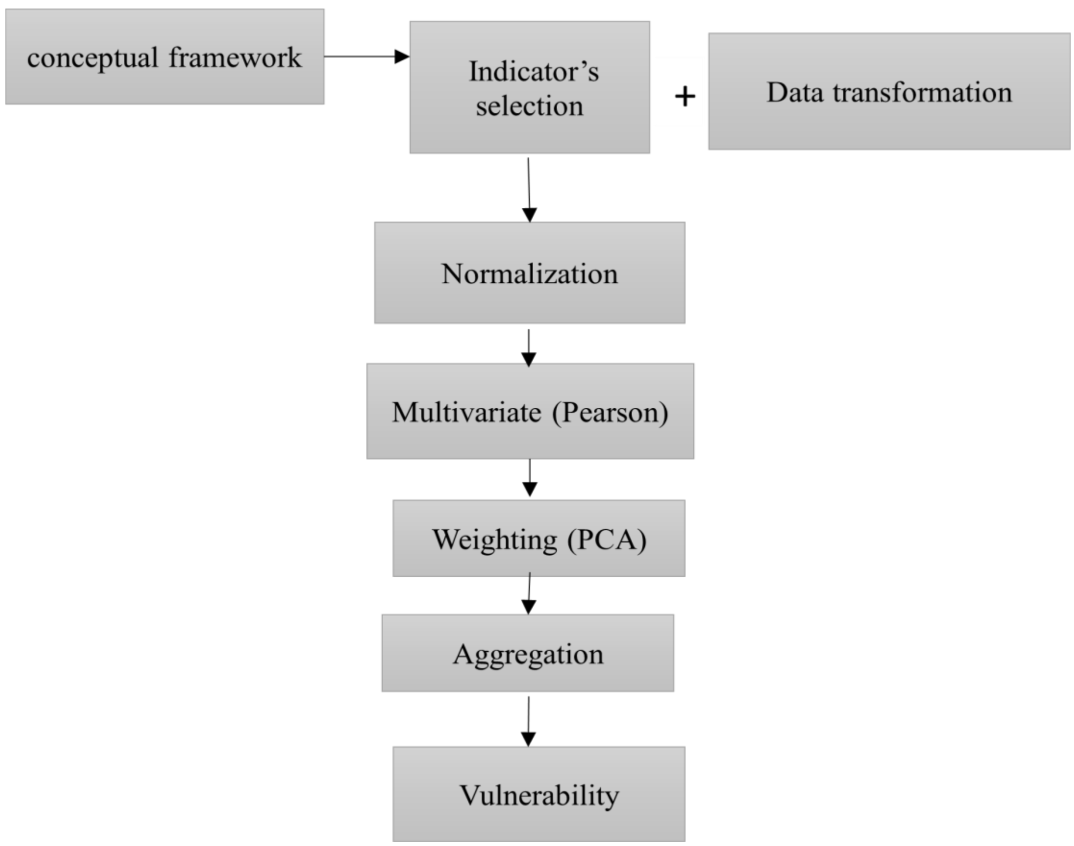


Figure 30: Beekeeping vulnerability workflow

4.2.2. Selection of indicators

A literature review is one of the most important activities that helps to choose the best indicators. and after that, a discussion with the Federation of Ivorian Beekeepers and some Beekeepers on the field allowed us to group all the indicators. Interviews were conducted with 162 beekeepers (Appendix 1), followed by participant observation in-depth. The information developed from this enables the experts to confirm and retain the important indicators for the analysis. We used the index-based method to analyze Beekeepers' vulnerability. This method is the most widely used in vulnerability research because it is easy to use, summarizes data and is easy to interpret (Biswas and Nautiyal, 2023). Susceptibility refers to beekeepers' capacity to the level of impact of hazards on beekeeping and beekeepers. These impacts concern the socio-economic aspects, technologic, and bees' biology with thirteen indicators (13) (Appendix 5; Table 17). The ability of beekeepers to withstand the damage caused by hazards, exposure, and susceptibility is called Adaptation Capacity (Table 17). 11 indicators of Adaptive Capacity were selected to analyze the Beekeepers' vulnerability to Climate Change.

Table 17: Identification of the beekeeping vulnerability indicators

Vulnerability components	Indicators (Units)	Abbr.	Description	Influence of the Indicators on Vulnerability	F.R.	Sources
Susceptibility	Household size	HS	The number of beekeepers by department	If H.S. ↑, Vuln ↑	+	(Kiptoo & Machio, 2023)
	Gender Female (%)	FEM	The number of women who practice beekeeping	If FEM ↓, Vuln ↓	-	(Caroline Jemase & Chesikaw, 2021)
	Age Younger (%)	AGE Y	Beekeepers Younger between 20-30 and 31-40	If AGE Y ↑, Vuln ↑	+	(Tijani *et al*., 2011)
	Age Elder (%)	AGE E	Elderly between 41-50 and Over 50	If AGE E↑, Vuln ↓	-	(Tijani *et al*., 2011)
	Average Beekeeping Income (FCA/year)	INC-BEEK	Beekeepers' average income (in FCFA)	If INC-BEEK ↓, Vuln ↑	+	(Schouten, 2020)
	Honey Production trend (%)	PROD	Beekeepers who have mentioned "Decrease" in the trend production	If PROD↓, Vuln ↑	+	Nyunza, 2018 ; Vercelli *et al*., 2021 ; Van Espen *et al*., 2023
	Hives (avg.)	HIVE	The number of hives owned by beekeepers	If HIVE ↑, Vuln ↑	+	(Aksoy *et al*., 2018)

	Traditional hives (%)	TRAD	The number of modern hives owned by Beekeepers	If TRAD ↓, Vuln ↓	-	(Kiptoo & Machio, 2023)
	Hives deserted	HD	Beekeepers who have mentioned "Desertion" in the trend production	If HD ↑, Vuln ↑	+	Ohoueu *et al.*, 2017, Nyunza, 2018
	Beekeeping Management Practices	BMP	The number of beekeepers who think Management practices also influence the production	If BMP ↑, Vuln ↑	+	(El Agrebi *et al.*, 2022)
	Pest/Diseases	P/D	Beekeepers who have mentioned the "presence of disease"	If P/D ↑, Vuln ↑	+	(Vercelli *et al.*, 2021); (El Agrebi *et al.*, 2022)
	Sensitivity to Pesticides	PEST	Beekeepers who have mentioned the "Presence of pesticides" in the trend production	If PES ↑, Vuln ↑	+	(Rortais *et al.*, 2017)
	No access to water	NO WATER	Several beekeepers have mentioned no access to water		-	
Adaptive Capacity	Education (%)	EDU	The beekeeper with a level of education	If ↑ EDUC, then VULN ↓	-	(Nyunza, 2018); Duah *et al.*

					(2017); Tijani *et al.* (2011)
Off-beekeeping activities (avg.)	OFF-BEEK	Beekeepers’ average other than Beekeeping	If ↓ INCOME_BEEK, VULN ↑	-	
Experience (avg.)	EXP	Number of years of Experience	If ↑ EXP, VULN ↓	-	
Training (%)	TRAIN	The number of beekeepers who undergo training can manage their hives properly	If ↑ TRAIN, VULN ↓	-	
Change site (%)	SITE	The number of beekeepers who have changed their apiary site	If ↑ SITE, VULN ↑	-	(Vercelli *et al.*, 2021), (Gajardo-Rojas *et al.*, 2022)
Water tank (%)	WATER	The number of beekeepers who have used a water tank to feed Honeybees	If ↑ WATER, VULN ↓	-	
Increase hives (%)	INC-HIVE	The number of beekeepers who have increased the number of their hives	If HIVE ↑, VULN ↑	+	
Changes in Beekeeping practices	CHAN	The number of beekeepers who change their practice	If CHAN ↑, VULN ↓	-	

Member of cooperative (%)	COOP	The number of beekeepers in a cooperative or association can manage the issues well	If COOP ↑, VULN ↓	-
Public financial support (%)	FINAN	Public financial support to the beekeeping sector (%)	If FINAN ↓, VULN ↑	+
Access to Climate information (%)	INFO	The number of beekeepers who have access to Climate information	If ↑ INFO, VULN ↓	+

Abbr.: Abbreviation; **F.R.**: Functional relationship; **Vuln**: Vulnerability; ↑: Vulnerability increases; ↓: Vulnerability decreases

4.2.3. Data Transformation and Multicollinearity

The data were recoded using the software Xlstat to facilitate the next analysis (normalization, weighting, and aggregation). descriptive and explorative analyses were carried out to assess the suitability of the dataset and to provide an understanding of the implications of the methodological choices (Damm, 2010). For the indicators with Percentage (%), it is calculated using the following formula:

$$\% \text{ A}= \frac{n}{N} \times 100 \text{ (1)} \qquad (6)$$

A: Selected Indicator, n: Number of the indicator and N: Total number of Beekeepers

4.2.4. Normalization

The normalization of indicators is calculated according to their functional relationship with vulnerability. Deux formulas will be used:

1. For the positive relationship (+):

$$\text{Normalization} = \frac{(Actual\ value(or\ mean) - minimum\ value)}{(maximum\ value - minimum\ value)} \quad (7)$$

2. For the negative relationship (-)

$$\text{Normalization} = \frac{(maximum\ value - Actual\ value(or\ mean))}{(maximum\ value - minimum\ value)} \quad (8)$$

4.2.5. Multivariate analysis

The analysis of multicollinearity by using Pearson correlation (r>0.92) is an excellent tool to reduce the impact of the high values of indicators before performing Principal Component Analysis (PCA) during their weighting. Appendix 6 shows the calculated Pearson correlation r>0.92. The values in red dark and bleu dark are higher than the threshold (r>0.92). It means that there is a high correlation between some indicators. In the susceptibility part (appendix 6) there is a high correlation between Household size and pests/diseases (-0.97), household size and females (-0.97), desertion and hive number (1), pesticides and no access to water (-1), increased hive and age elder (-0.94), increased hive and age younger (-0.94), pests/diseases and females (0.98), age elder and age younger (1). The high multicollinearities mean that the indicators share the same information in the contribution of susceptibility. To reduce these multicollinearities, the combination of some indicators was necessary. As age younger and age older share the same information they are combined to form Age. The other indicators were eliminated. The final set of susceptibility indicators is 8 in number (Figure 30). In the Adaptive capacity part, there is a strong correlation between education and the water reservoir (0.93), the cooperative and the change in beekeeping practices (0.98), and experience and the increase in the number of hives (0.94) (Appendix 6).

	H.S.	*PROD*	*DESER*	*BMP*	*PEST*	*INC-BEEK*	*AGE*	*TRAD*
H.S.	1.00							
PROD	-0.83	1.00						
DESER	-0.81	0.70	1.00					
BMP	0.49	-0.87	-0.27	1.00				
PEST	-0.50	0.59	0.89	-0.27	1.00			
INC-BEEK	0.27	-0.25	0.34	0.44	0.63	1.00		
AGE	-0.50	0.24	-0.09	-0.23	-0.50	-0.91	1.00	
TRAD	-0.22	-0.24	0.51	0.68	0.40	0.59	-0.20	1.00

	EDUC	*TRAIN*	*COOP*	*EXP*	*OFF-BEEK*	*Practices Index*	*FINAN*	*INFO*
EDUC	1.00							
TRAIN	0.24	1.00						
COOP	-0.12	-0.24	1.00					
EXP	0.57	0.78	-0.68	1.00				
OFF-BEEK	-0.47	0.21	-0.81	0.36	1.00			
Practices index	-0.69	0.28	0.53	-0.36	0.01	1.00		
FINAN	0.03	-0.37	-0.81	0.21	0.61	-0.72	1.00	
INFO	0.15	-0.64	-0.54	-0.04	0.27	-0.82	0.92	1.00

Figure 31: Visualization of correlation matrices with values of Pearson's (Up: Susceptibility components (8) (SUS); Down: Adaptive capacity components (8).

We decided to combine the water reservoir, the change in beekeeping practices, and the increase in the number of hives because they play the same role in beekeeping: to increase productivity: Practices Index. Pearson correlation analysis again showed that practices index and site change are collinear (0.99). So, we decided to add a change site in the practices index, which has the same roles as the previous indicators. Figure 32 shows the final set of indicators for adaptive capacity (from 11 to 8 indicators).

4.2.6. Weighting the indicators

There are three (3) ways to assign weight. Mostly assigning equal weights, inverse of variance, expert opinion, and principal component analysis (PCA) are commonly used methods (Adhav *et al., 2021)*. PCA has been used in this study. The most common standard practice is to choose factors that (OECD, 2008, p.89):

- Have associated eigenvalues larger than one (Kaiser criterion);
- Contribute individually to the explanation of overall variance by more than 10%;
- Contribute cumulatively to the explanation of the overall variance by more than 60%.

After addressing the multicollinearity, the PCA test analysis was elaborated. The weight is derived from the factors loading squared divided by the total variance and scaled.

$$\text{Eq: } W_i = \frac{f2}{v} \qquad (9)$$

W_i : Weight of indicator *i*, f^2: factor loading squared, *V:* total variance

In this study, the three components have an eigenvalue higher than 1, and only the first two components have an explained variance greater than 60% of the variation in the data (Tables 18 and 19). In the susceptibility results, the first two components have an explained variance of 83.3 %. The first component accounted for 44.4 % of the variance and the second component for 38.8 % of the variance. In the adaptive Capacity results, the first two components have an explained variance of 76.4%. The first component accounted for 46.6% of the variance and the second component for 29.8%. However, after varimax rotation, the values of variance have changed except for the eigenvalues. Susceptibility variances passed from 83.3% to 73.7% and from 76.4% to 76.3%. Considering the variance, the first two components were extracted.

Table 18: Factor loadings and weights for susceptibility indicators

Rotated component matrix				
Indicators	**Factors**		**Weight**	**Scaled weight**
	F1	**F2**		
H.S.	**0.85**	0.15	0.45	0.17
PROD	**0.69**	0.01	0.37	0.14
DESER	**0.94**	0.04	0.50	0.19
BMP	**0.21**	0.02	0.11	0.04
PEST	**0.63**	0.37	0.34	0.13
INC-BEEK	0.01	**0.82**	0.39	0.14
AGE	0.01	**0.98**	0.46	0.17
TRAD	**0.12**	0.04	0.06	0.02
Explained variance	3.55	3.11	2.67	1.00
	6.66			
Explained total	0.53	0.47		

Table 19: Factor loadings and weights for Adaptive Capacity indicators

Rotated component matrix				
Adaptive capacity	**Component**		**Weight**	**Scaled weight**
	PC1	**PC2**		
EDUC	0.019	**0.113**	0.04	0.02
TRAIN	0.175	**0.825**	0.32	0.12
COOP	**0.584**	0.374	0.36	0.13
EXP	0.038	**0.907**	0.35	0.13
OFF-BEEK	**0.248**	0.206	0.15	0.05
Practices Index	**0.640**	0.004	0.39	0.14
FINAN	**0.980**	0.002	0.60	0.22
INFO	**0.916**	0.072	0.56	0.20

Explained variance	**3.73**	2.38	2.77	1.00
6.11				
Explained total	0.61	0.39		

The majority of susceptibility indicators were in the first component which involves: Household size (HS), production (PROD), Desertion (DESER), Beekeeping Management Practices (BMP), pesticides (PEST), traditional hive (TRAD) whereas, the second component there are income beekeeping (INC-BEEK) and Age (AGE). The majority of adaptive capacity is in the first component with cooperative (coop), off-beekeeping (OFF-BEEK), practices index, finance (FINAN), and Information (INFO). Education (EDU), training (TRAIN) and experience (EXP) are in the second component. Concerning the factor loading the values equal to or greater than 0.50 were chosen according to OECD, (2008). In our study, some indicators have a factor loading less than 0.30 in the two components but we have taken the component where the values are great. This is the case of BMP and TRAD (see table) for susceptibility indicators, and EDU and OFF-BEEK (see table) for adaptive capacity.

4.2.7. Aggregation

The aggregation was made in two steps. Step 1 concerns aggregating the indicator into susceptibility and adaptive capacity domains.

$SUS/AC = \sum_{i=0}^{n} WiXi$ (10) Where:

SUS/AC: Vulnerability domain, Wi: weight of indicator i, Xi: the normalized value of indicator i

The second step concerns aggregating the two domains into the vulnerability index.

Beekeeping Vulnerability Index (BVI) = $\frac{\text{SUS+AC}}{2}$ (11)

4.2.8. Visualization of vulnerability

The vulnerability will be visualized according to the information in the following table 20.

Table 20: Description of vulnerability values

Index Value	Description	Colour
Very High	V > 0.8	Red
High	$0.5 < V \leq 0.8$	Orange
Moderate	$0.2 < V \leq 0.5$	Yellow
Low	$V \leq 0.2$	Green

Adapted from Balica, 2007 and Oyedele *et al.*, 2022

4.2.9. Data analysis and processing

In this study, statistical analyses were carried out on the data collected to analyse the impact of climatic parameters on beekeeping productivity, on areas suitable for beekeeping and the vulnerability of beekeepers. The software Excel, Xlstat and QGIS were used to analyse the different purposes in these parts. XLSTAT (version 2019.2.2) software was used to carry out the analysis. The analysis of beekeepers' vulnerability was possible using the percentage (%) of different variables, and the Principal Component Analysis (PCA) helped to find the vulnerability component values. QGIS was used to map the vulnerability in the different departments.

4.3. Results

4.3.1. Beekeepers' Vulnerability Index

The results of the vulnerability index for the Poro region showed that there are three levels of vulnerability on the map: low, medium and high vulnerability **(**Figure 31**)**. The department of Korhogo has high vulnerability (0.59), while the department of Dikodougou has medium vulnerability (0.46). M'Bengué and Sinematiali have a low vulnerability (0.44 and 0.45) (Table 21).

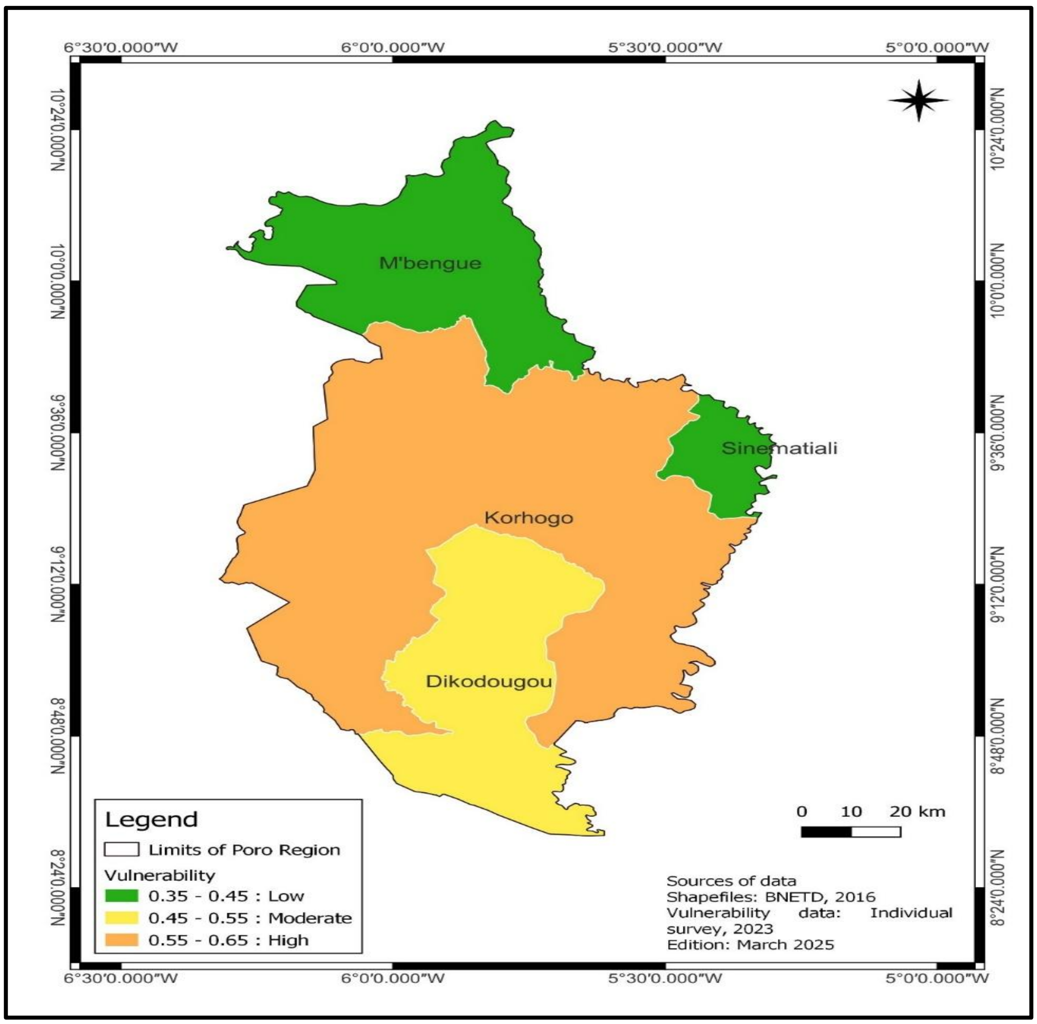


Figure 32: Beekeeping vulnerability to Climate Change in the Poro region

Table 21: Contribution of vulnerability domain

Department	SUS index	A.C. index	Beekeepers Vulnerability
Dikodougou	0.62	0.29	0.46
Korhogo	0.53	0.65	0.59
M’Bengué	0.47	0.41	0.44
Sinematiali	0.32	0.58	0.45

4.3.2. Importance of each domain in the contribution of vulnerability

Vulnerability is the combination of factors of exposure, susceptibility and adaptive capacity of a system or community to a hazard or disaster. Figures 32 show that, despite the high vulnerability of the Korhogo department, beekeepers have a high adaptive capacity (0.65), which is slightly higher than their sensitivity (0.53) to climate change. Dikodougou and Sinematiali, with moderate vulnerability, have different sensitivities and adaptive capacities. Dikodougou has a higher sensitivity (0.62) and an average adaptation capacity (0.29) whereas in Sinematiali, the beekeepers have a high adaptation capacity (0.58) combined with an average sensitivity (0.32). The beekeepers at M'Bengué have average vulnerability characteristics (susceptibility (0.47) and adaptability (0.41).

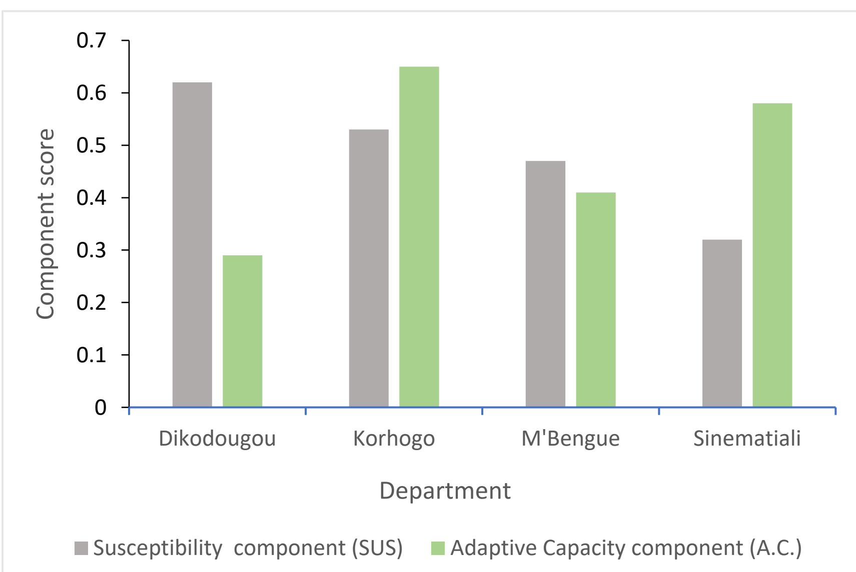


Figure 33: Comparison of vulnerability components in different departments

4.3.3. Specific indicators contributing most to vulnerability (susceptibility)

Results shows that PROD, DESER, PEST, INC-BEEK, AGE and TRAD increase the susceptibility of beekeepers in the Dikodougou department (Figure 33) As for beekeepers in the Korhogo department, they are H.S., DESER, BMP, PEST, INC-BEEK and TRAD. For those of M’Bengué, H.S., PROD, DESER, BMP, PEST, INC-BEEK, AGE, TRAD. Beekeepers in Sinematiali have low sensitivity due to the number of contributing indicators. These are H.S., PROD, BMP and AGE. M’Bengué has eight susceptibility indicators. Whereas the other departments have 6 or 4. H.S., PROD., DESER., PEST, AGE, and INC-BEEK contribute the most to beekeepers’ susceptibility.

4.3.4. External factors that reduce vulnerability (adaptive capacity)

Beekeepers in Dikodougou and M'Bengué have a low capacity to adapt, while those in Korhogo and Sinematiali have a high capacity well (Figure 34). In the Korhogo department, the Financing, experience and practices index contribute to reducing vulnerability, the other indicators do not affect vulnerability. Sinématiali beekeepers can decrease the impacts because of the financing, information, cooperatives and experience. In the M’Bengué practices index, cooperatives, training and experience are more sufficient to cope with the impacts. Beekeepers from Dikodougou have a great capacity thanks to the cooperatives and practices index.

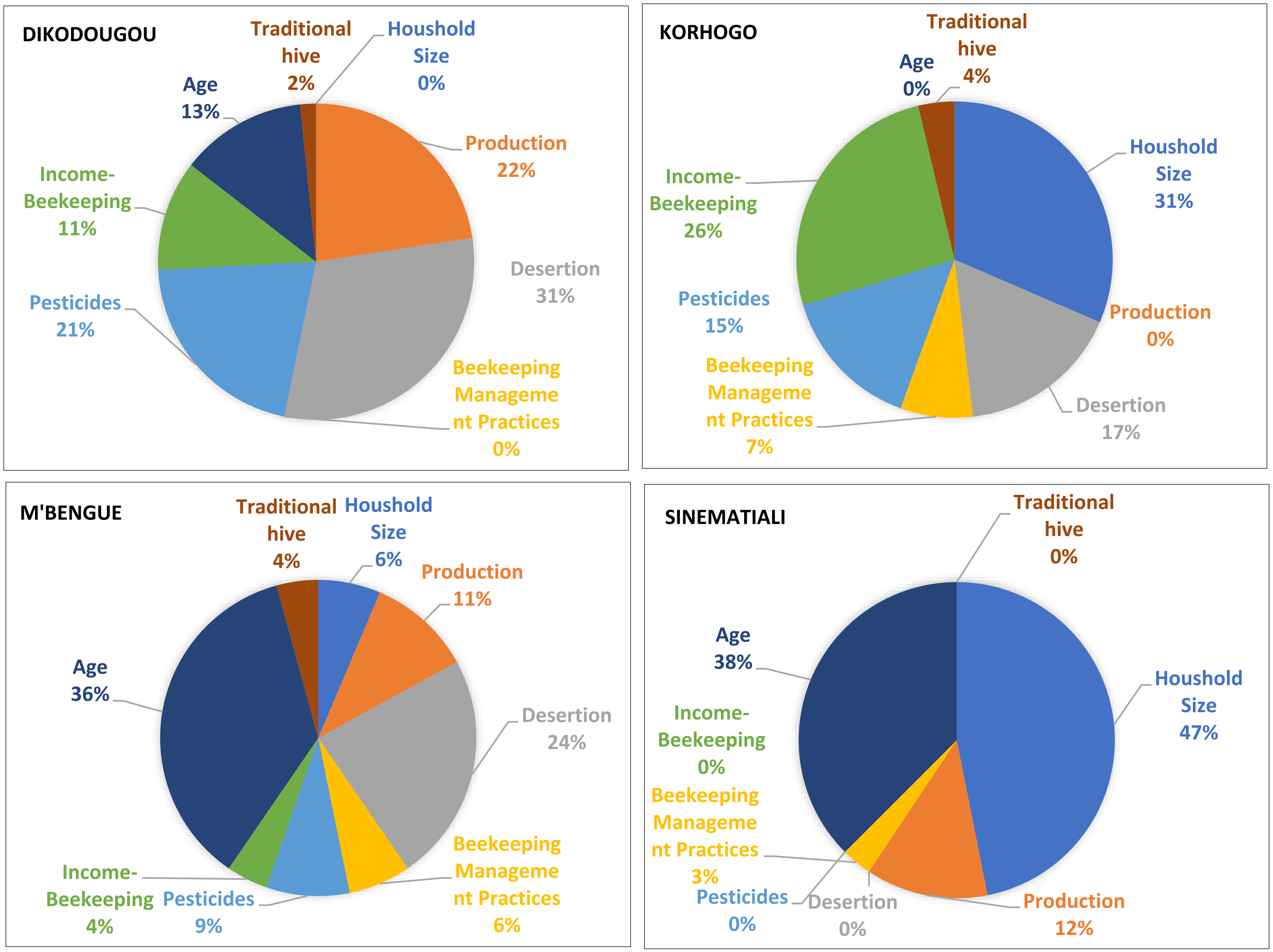


Figure 34: Relative contribution of the indicators to beekeeping vulnerability for susceptibility in each department

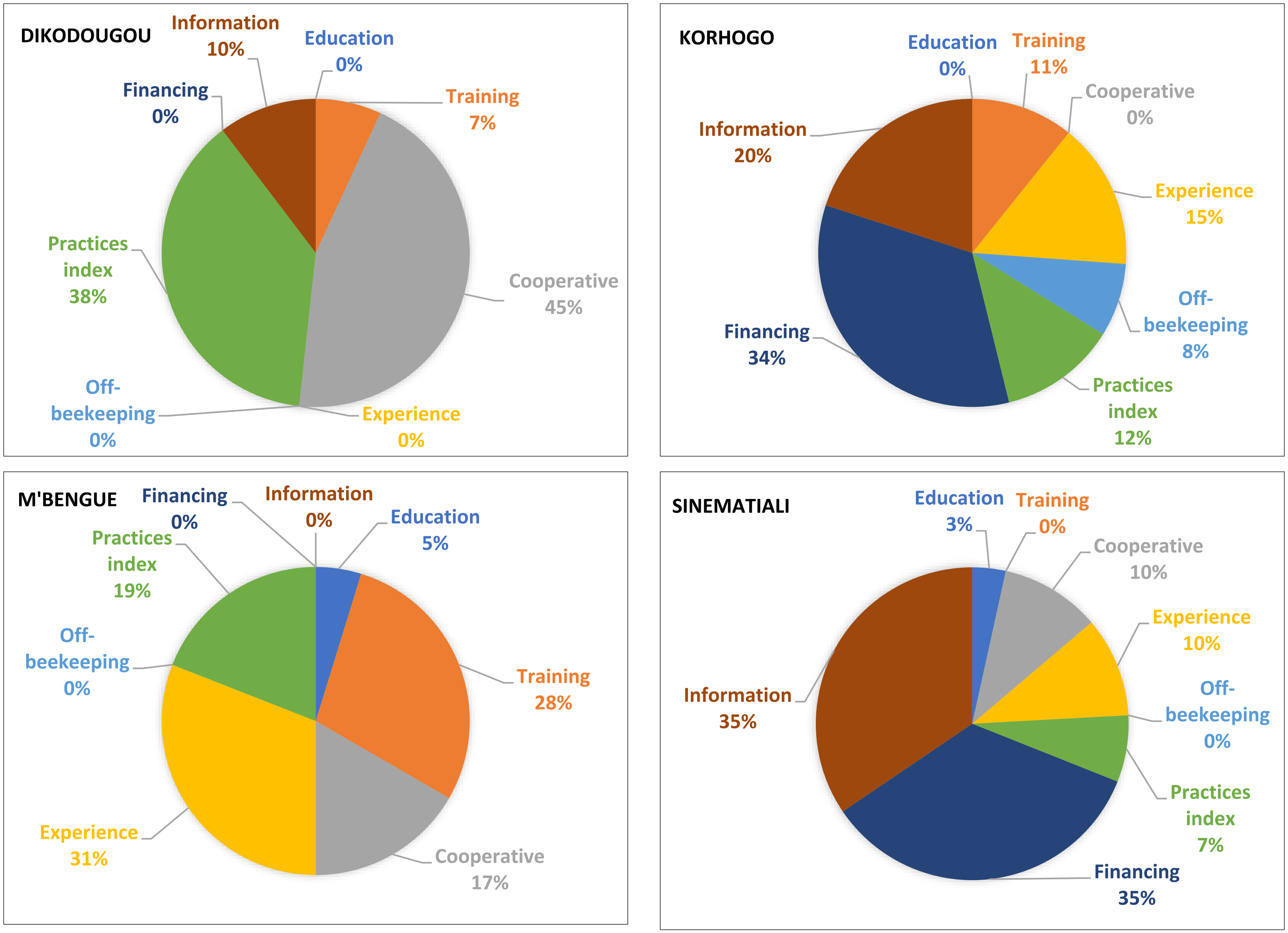


Figure 35: Relative contribution of the indicators to beekeeping vulnerability for adaptive capacity in each department

4.4. Discussion

By analyzing beekeeping perceptions in conjunction with climatic data and the spatial characteristics of the environment, it was possible to identify several critical dimensions of beekeepers' vulnerability in the study area. The study aims to understand the questions concerning who the most vulnerable beekeepers are, where they are located in the Poro region and why they are vulnerable.

The results suggest that Beekeepers in the Korhogo department have a high vulnerability, those in Dikodougou have moderate vulnerability, while those in M'Bengué and Sinématiali have low vulnerability. Beekeepers in Korhogo and Sinematiali have a high capacity to adapt concerning susceptibility, while Dikodougou has a high level of susceptibility. The specific indicators contributing to the susceptibility of beekeepers differ from one department to another, with the same to the adaptive capacity.

The high vulnerability of Korhogo could be due to a large number of beekeepers, which creates a high exposure and competition between bees for food, although it has the greatest capacity for adaptation. This result is in line with studies by López-i-Gelats *et al* (2025), where the size of beekeeping operations has a greater influence on beekeepers' ability to adapt than on their perception of the main changes affecting the sector. Korhogo is also a large agricultural area, and the use of pesticides by farmers could lead to the desertion of hives. The presence of pesticides and desertion in the hives influence the beekeeping income.

The moderate vulnerability of beekeepers in the department of Dikodougou is due to a low adaptive capacity resulting from the lack of education to collect information and the lack of experience of beekeepers. According to Aksoy *et al.* (2018) and Schouten, (2020), education services are one of the drivers that contribute to beekeeping productivity and income. Education is an important factor. Education can help beekeepers acquire basic beekeeping skills, but it can also lead them to seek other off-farm income (Schouten, 2020). Financing, off-beekeeping, experience and training are also weak to participate in adaptive capacity.

The low vulnerability of beekeepers from M'Bengué and Sinematiali can be explained by their low susceptibility to the various indicators and their great capacity to adapt. Except for a small experience for Sinematiali beekeepers, they have the same factor that contributes most to reducing vulnerability.

As honey production by bees is one of the indicators contributing to the vulnerability of beekeepers, bees are faced with several environmental stressors and pesticides (Rortais *et al.*, 2017). These factors trigger the desertion of bees in the hives (Ohoueu *et al.*, 2017a) and the decline in colonies (Vercelli *et al.*, 2021). As a result, honey production is falling, affecting beekeepers' sources of income. In addition to environmental factors, socio-economic factors and the practices of the beekeepers themselves influence their activity (Schouten, 2020), which can either reduce or increase their vulnerability to climatic hazards. The type and number of hives used and the size of the beekeepers can have a positive or a negative impact on productivity (Aksoy *et al*., 2016, Schouten, 2020; Kiptoo & Machio, 2023).

The susceptibility of beekeeping systems is not only the result of environmental pressures but is exacerbated by diverse socio-economic constraints. The majority of beekeepers operate with low levels of investment capital, which limits their ability to adopt technical innovations, renew hives or improve production conditions (Ghilardi-Lopes *et al.*, 2019), as well as often limited access to water, particularly during the dry season (Wodajo *et al.*, 2023). In addition, the lack of diversification of income sources makes beekeepers more dependent on beekeeping, increasing their economic vulnerability in the event of bad seasons or climatic crises (Sabiiti *et al.*, 2020; Tarekegn *et al.*, 2017). These different factors combined contribute to making beekeeping producers particularly vulnerable to climatic disturbances, especially those located in areas classified as high or medium vulnerability, according to the biophysical and socio-economic criteria established in this study and confirmed by the literature on spatial vulnerability (Deressa *et al.*, 2008; Turner *et al.*, 2003).

Although beekeepers' capacity to adapt is limited, some are adopting effective strategies, such as transhumance or diversifying foraging sites (Le Conte & Navajas, 2008; Ghilardi-Lopes *et al.*, 2019; Tarekegn *et al.*, 2017). However, these practices often remain isolated and poorly supported by public policies to adapt or support beekeeping (FAO, 2021; Sabiiti *et al.*, 2020). Furthermore, the lack of specialized technical training, combined with limited access to agricultural extension services and up-to-date climate information, decreases beekeepers' ability to anticipate climate risks and plan effective responses (Adjare, 1990; Kwapong *et al.*, 2010; Wodajo *et al.*, 2023).

One of the limitations was that the weights of the indicators were not weighted taking into account the opinion of those who could have facilitated and taken into account the eliminated indicators (multicollinearities) during the Pearson correlation analysis.

Thus, beekeeping vulnerability in our study area is the result of a complex interaction between several factors: environmental, socio-economic, technical and institutional factors. Hence a need for an integrated approach to build more resilient beekeeping. This study aims to assess the level of vulnerability of beekeepers to improve their working and living conditions through New Strategies.

4.5. Conclusion

Information on the level of vulnerability is known, showing that the large number of beekeepers in the Korhogo department is more vulnerable than the others, where vulnerability is moderate in Dikodougou and low in M'Bengué and Sinematiali. Analysis of the different areas of vulnerability has enabled us to gain a better understanding of the real causes of this vulnerability. The susceptibility of beekeeping systems is not only the result of environmental pressures, but is exacerbated by various socio-economic constraints. Although some strategies exist, they are limited in their ability to reduce vulnerability. The analysis highlighted the impact of environmental factors combined with socio-economic factors on beekeepers' vulnerability. Factors such as household size, production, desertion, pesticides, age and income from beekeeping are the factors that contribute most to beekeepers' vulnerability. Other factors such as the level of practices, experience, cooperatives and financing limit their ability to adapt.

It is now necessary to strengthen beekeepers' ability to adapt by modifying existing strategies and developing new ones, in order to make them resilient to the impacts of climate change on their activity. These strategies must take into account the environmental conditions of the apiaries and the socio-economic situation of those involved.

CHAPTER 5: ADAPTATION STRATEGIES FOR SUSTAINABLE BEEKEEPING

5.1. Introduction

Beekeeping participates in the generation of good (Etxegarai-Legarreta & Sanchez-Famoso, 2022). The purpose of the activity is to increase stakeholder income (Abro *et al.*, 2022). It is the rearing of bees to produce honey. Bees offer a multitude of ecosystemic services (Aryal *et al.*, 2020), by regulating (Klatt *et al.*, 2014), provisioning (Papa *et al.*, 2022) and participating in cultural functions (Topal *et al.*, 2021). Honey bee colony losses are triggered by the interactions of several factors including socio-economic, climatic, and environmental (Hristov *et al.*, 2020; Potts *et al.*, 2010). Climate Change is one of the challenges that face beekeepers, leading them to change their habits (Van Espen *et al.*, 2023). It already affects honey and its keepers (Neumann & Straub, 2023).

The proliferation of diseases (Le Conte & Navajas, 2008), more sensitive to pesticides (Albacete *et al.*, 2023), mortalities (Gray *et al*., 2023), and income (Neumann & Straub, 2023) are just a few examples.

Despite the measures used by beekeepers, the impact persists. Strategies must be adopted to help beekeepers cope with the consequences of the impacts (Vercelli *et al.*, 2021). The question is to understand how these beekeepers cope with the various risks, despite the socio-economic constraints and their endogenous knowledge. The aim is to identify and evaluate the effectiveness of existing strategies and develop new strategies to complement existing ones.

5.2. Materials and methods

Data were collected from a questionnaire and a focus group discussion with beekeepers. The questions were concerned with their perception of hazards that trigger losses and damages in the beekeeping activity, the types of adaptation strategies they are using, and the analysis of these strategies. The different strategies listed allowed the beekeepers to respond with the answer “Yes” or “No” (Appendix 1). Data were presented on the number of beekeepers who have used the strategies and the percentage. The Multi-Criteria Decision Analysis through the use of an Analytical Hierarchy Process (AHP) allowed the assessment of the effectiveness of the strategies used. News adaptation strategies were elaborated by taking into account the beekeepers' perspectives, the results of effectiveness, and the literature. The methodology is summarized in Figure 35 below.

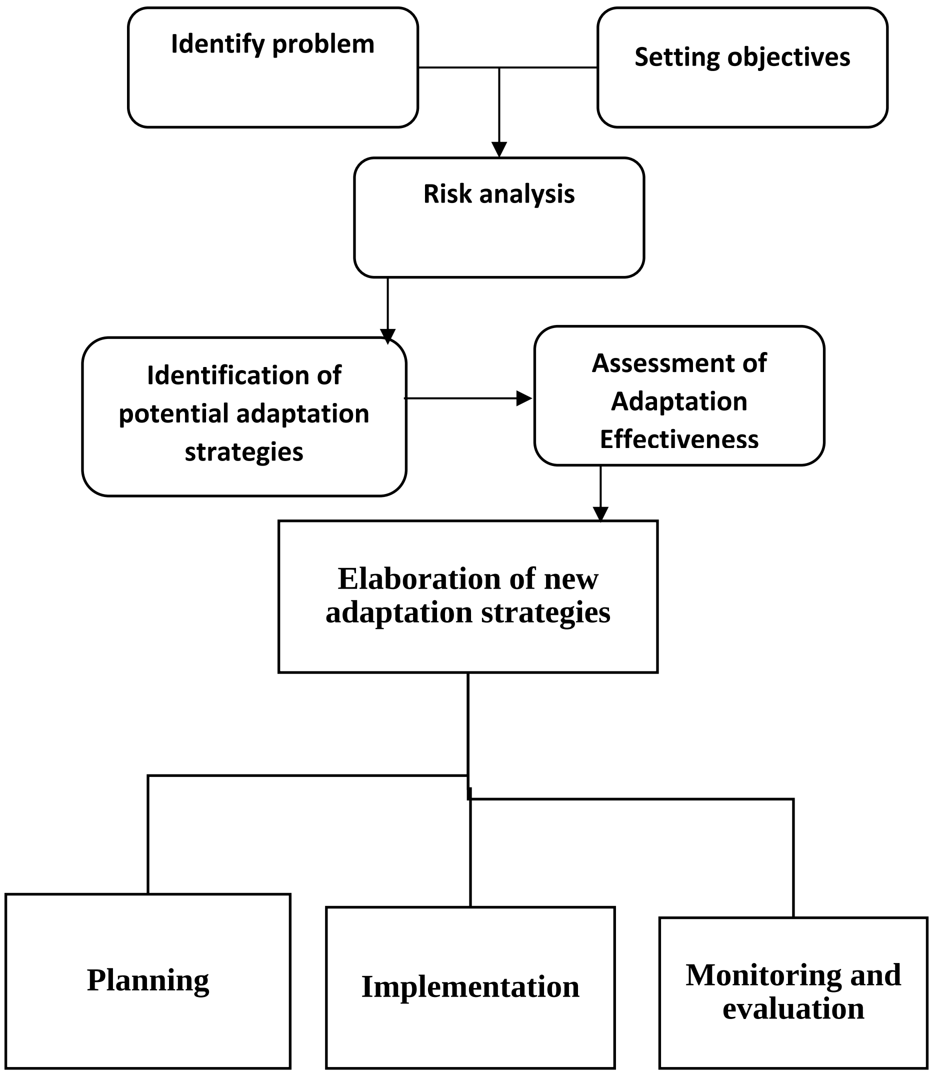


Figure 36: Methodological step of beekeeping adaptation strategies

5.3. Results

Beekeepers have mentioned the presence of several drivers impacting their activities (Table 22). The drivers of risk were analyzed in the previous part (Chapters 2,3, and 4).

Table 22: Results from risk analysis

Drivers of risk	Elements affected	Impacts
- High temperature - Variation of precipitation - Dry season (prolonged) - Sensitivity to pesticides - Variation in floral diversity - Land use changes - Proliferation of Pests and diseases - Interactions between drivers	- Bees - Honey production - Hives - Pollination income - Beekeepers - Customers	- Reduce colonies' strengths - Mortalities of colonies - Desertion of hives - Bees' ecology affected - Reduce food availability - Decreased honey production - Loss of customers - Income reduces - Beekeepers are discouraged

5.3.1. Adaptation strategies used in the Poro region

The results show that the adaptive strategies used by beekeepers are water tanks (72.84 %), increased hive numbers (72.22%), training (95.06%), changing sites (56.17%), reforestation (80.25%), changing beekeeping practices (56.17%), modifying hive location (4.94%), reducing harvest time (42.59%), and using modern hives (85.19%) (Figure 36; Table 23). Each beekeeper has combined several adaptation strategies. The most used are training to improve their knowledge, followed by the use of water tanks near the apiaries, increasing the number of hives, using modern hives, trying to change apiary location (Change site) and other practices (change of beekeeping practices). Modifying the location of apiaries and reducing harvest time were the least used by beekeepers to improve their activities. The beekeepers were asked about the reason for the multiple-choice strategies used. Some of them replied that. One of the beekeepers confided that

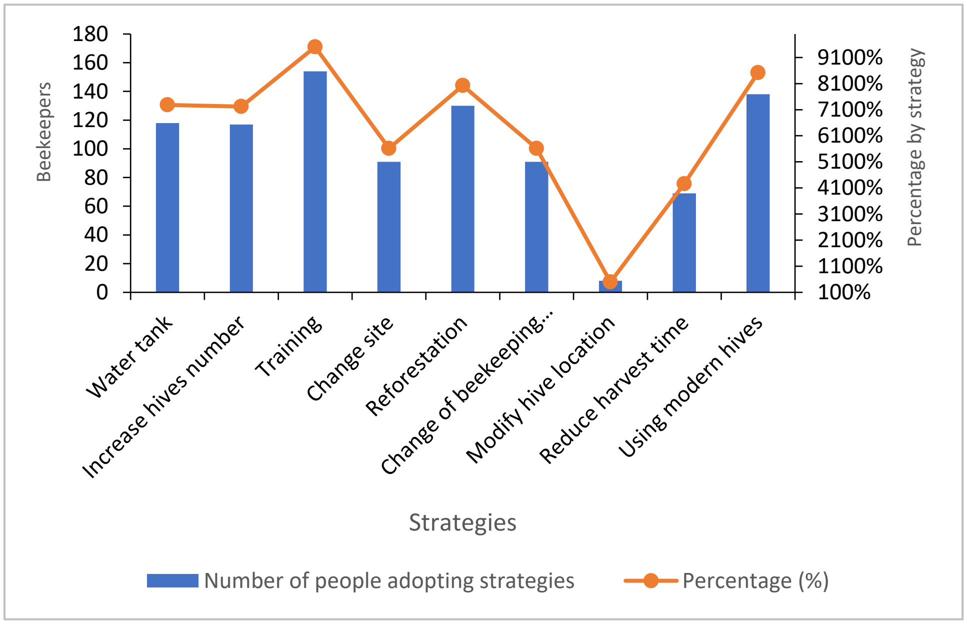


Figure 37: Visualization of strategies adopted by beekeepers

<< the use of water tanks meant that the bees did not have to travel so far to get water, as the streams were far from the apiaries >>. He then increased the number of his hives to increase his honey production. << I then increased the number of hives to increase honey production >>.

Another beekeeper changed his management habits by using three strategies simultaneously: << by reducing the honey harvest from two to one, I was going to obtain a large quantity of honey, so I increased the number of hives and improved the location of the apiaries >>.

Table 23: Number and Percentage of beekeepers adopting adaptation strategies

Strategies	**Number of people adopting strategies (“Yes”)**	**Percentage (%)**
Water tank	118	72.84
Increase hives number	117	72.22
Training	154	95.06
Site changing	91	56.17
Reforestation	130	80.25
Change of beekeeping practices	91	56.17
Modify hive location	8	4.94
Reduce harvest period	69	42.59
Using modern hives	138	85.19

5.3.2. Effectiveness of the strategies used by beekeepers according to their perception

The results of the analysis of the effectiveness of the strategies used by the beekeepers (Table 25) showed that they were all satisfied with the use of a water tank (first) to supply the bees with water. This measure is very effective because it reduces the bees' journeys in search of water so that they can spend less time collecting water and more time foraging. To prevent the bees from getting lost in the hives, harvesting times (second) have been reduced. Beekeeping training (third) enabled them to improve their knowledge of their activity to increase productivity. They thought that reforestation (fourth) of honey plants was beneficial for bees, as was diversifying the location of apiaries (fifth). On the other hand, changing beekeeping practices (sixth), using modern hives (seventh), changing site (eighth), and increasing hives number (ninth) were considered the least effective for their productivity (Table 24).

Table 24: Effectiveness of adaptive strategies used by beekeepers by rank

Strategies	Criteria					
	Costs and advantages	**Impacts**	**Application**	**Beekeepers' Perception**	**Total**	**Rank**
Water tank	4	5	3.5	5	4.25	1st
Reduce harvest time	5	3	3.5	3	3.75	2nd
Training	3	4	3.5	4	3.55	3rd
Reforestation	3	5	3	3.5	3.5	4th
Modify hive location	2.5	3.5	3	4	3.15	5th
Change of beekeeping practices	2.5	2.5	3	3.5	2.85	6th
Using modern hives	2	3	3	3.5	2.8	7th
Change site	3	2.5	2.5	3	2.75	8th
Increase hives number	2	2.5	3	3.5	2.7	9th

5.3.3. Elaboration of new adaptation strategies for sustainable beekeeping

After discussions with the beekeepers and an analysis of the risk drivers, a set of strategies was put in place to reinforce the existing strategies used by the beekeepers. The new strategies take account of bee health, cooperation between stakeholders, enabling beekeepers to be insured and improving climate information systems. Increasing knowledge of beekeeping and environmental management is one of the most effective measures for promoting sustainable beekeeping (Table 25).

Table 25: Elaboration of adaptation strategies for sustainable beekeeping

N°	**Planning**	**Implementation**	**Monitoring**	**Evaluation**
1	Bee health	Reduce pests and diseases	Check the presence of the types of pests and diseases in the hive and on bees regularly (Beekeepers)	Inspection of the hive by the veterinarian in the year
		Raising farmers' awareness of the consequences of using pesticides in the wrong doses	Collaboration between farmers, beekeepers and experts	Find buffer zones close to the agricultural zone for the installation of beehives.
		Toxicological analysis	Monitor the presence of pesticides in honey	Each year after harvest
2	Improve local floral diversity	Reforestation	Inventory plants foraged by bees and promote reforestation	Planting the most foraging species by bees near the apiary
3	Risk insurance	Insuring beekeepers	Made insurance-based production, insurance-based materials	Facilitate process
4	Education, awareness and training	Reinforcing the activities of cooperatives and collaboration with farmers	Improved beekeepers' education on beekeeping, bees, and protection of the environment	Training and update every 6 months

5	Suitable area for honey bees	Planning: spatio-temporal analysis of areas suitable for beekeeping	Biophysical criteria Socio-economic criteria Beekeepers' management practices	Spatial observation Fieldwork observation
6	Improve hive technology	Review the types of hives used to reduce attacks	Analyze the type of wood and beehives used	Choose the appropriate after the results of the analysis
7	Local climate		monitoring meteorological and climatic data on climatic stress, drought and flooding	Provide an early warning system for climate information

5.4. Discussion

The aim was to identify and develop adaptation strategies to improve the sustainability of beekeeping and protect the environment. The results showed that beekeepers used several strategies simultaneously and found that the use of water tanks, reduced harvest time, training, reforestation, and modified hive location were the most effective. Other strategies, such as changing beekeeping practices, using modern hives, changing sites, and increasing the number of hives, were considered less effective by the beekeepers. New strategies have been developed to reinforce existing strategies.

The most effective strategies have a direct impact on bee productivity. The Poro region is an area where rivers sometimes dry up, especially during the dry season. The use of water containers alleviates this shortage for the bees during this season. The participation of beekeepers in strengthening their knowledge of their activity enables reforestation and the management of various areas for the placement of their apiaries. On the other hand, the least effective is due to economic problems with the purchase of equipment, which is often expensive.

Beekeepers are faced with numerous difficulties that jeopardize their business. This is why they must modify their management practices by adopting adaptation strategies to cope with the effects of hazards. This result is consistent with the work of Vercelli *et al.* (2021); Gajardo-Rojas *et al.* (2022); Van Espen *et al.* (2023); Ukamaka and Eberechukwu (2018); Paraïso *et al.* (2011). 72.5% of beekeepers are satisfied, while the remaining 27.5% consider it insufficient (Gajardo-Rojas *et al.*, 2022). Beekeepers are keen to learn methods of protecting bees and preserving the apiary environment by replanting melliferous plants. Transhumance is a safety measure for beekeeping, as it is a compulsory activity for feeding bees (Novelli *et al.*, 2021; Vercelli *et al*., 2021).

However, it would be challenging to apply some strategies in our study area. As most beekeepers are landowners, it would be difficult to change sites (transhumance). Transhumance is out of their reach because it would entail additional expenses due to the difficulty of accessing the land and the cost of transporting the hives. These barriers limit the feasibility of transhumance**,** especially in low-income rural contexts (Sabiiti *et al.,* 2020; Ghilardi-Lopes *et al.,* 2019; Wodajo *et al.,* 2023).

Today, increasing the number of hives is another type of adaptation used by beekeepers. According to Gajardo-Rojas *et al.* (2022), studies carried out in Chile have shown that increasing the number of hives can lead to competition between beekeepers. While beekeepers in other countries agree that the best way to help bees is to provide them with extra food (Vercelli *et al.,* 2021), we do not have this problem because of the diversity of flora present (Ouattara *et al.,* 2023). The high level of availability of hives is not related to their colonization in the hives as well as to the availability of honey (Ukamaka & Eberechukwu, 2018). Hives are deserted even if their number increases (Ukamaka & Eberechukwu, 2018). Strategy analysis revealed that a beekeeper may use more than three strategies. This could be attributed to several factors such as technical, economic, edaphic and most importantly environmental/climatic factors (Ukamaka & Eberechukwu, 2018).

One of the strengths is that beekeepers are motivated to maintain the activity, taking part in training courses and joining cooperatives, but the high cost of the equipment used for maintenance and moving the hives is a major obstacle.

Changing sites is a problem for some beekeepers because of the cost of removal and payment for land. Despite all these strategies, honey production is falling, diseases and pests are proliferating and bees are deserting the apiaries. The new strategies will only make beekeepers richer.

The monitoring and evaluation (M&E) of beekeeping practices is essential for improving the productivity and resilience of beekeepers and also for ensuring healthier and more sustainable bee populations. Regular assessment allows for early detection of colony stress, guides adaptive management strategies, and contributes to the long-term viability of apicultural systems (FAO, 2017; Ghosh & Jung, 2016).

5.5. Conclusion

The study of adaptation strategies revealed that there is a diversity of strategies. Beekeepers used several strategies simultaneously to increase their effectiveness and production. The adaptation strategies used by beekeepers have enabled them to meet certain challenges and have proved effective. This allowed them to find that some strategies, such as the use of water tanks, reduced harvest time, training, reforestation, and modified hive location were the most effective. The less effective ones require time and financial support to improve their activity. Despite this, they are limited in time to ensure maximum protection for the bees and, consequently, high productivity. This has led to the development of new strategies to reinforce existing strategies. These strategies concern both honeybees for their protection against diseases, the collaboration between beekeepers and farmers, and the creation of risk insurance for beekeepers and the creation of policies by the government. Taking into account the new strategies developed will enable beekeepers to increase their crisis management skills to improve the health of honey bees and boost productivity. We urge researchers, beekeepers and farmers to work together, with the support of the government, to promote the sector that provides the majority of ecosystem services.

GENERAL DISCUSSION

GENERAL DISCUSSION

Interpretation of objectives

Côte d'Ivoire has strong beekeeping potential in terms of availability of melliferous resources, bees and honey qualities. Unfortunately, the sector is facing environmental challenges (Ouattara *et al.*, 2023), characterised by intensive agriculture (Tscharntke *et al.*, 2005), the use of pesticides (Ohoueu *et al.*, 2017a) and the loss of floral habitats (IPBES, 2016). As for the socio-economic challenges, the lack of commitment from political players and socio-economic disparities (Ouattara *et al.*, 2023) are capable of weakening the beekeeping sector. Moreover, bees are under threat from climate change (Flores *et al.*, 2019). Temperature increases and decreases in precipitation reduce the availability of their resources (Landaverde *et al.*, 2023), such as water and melliferous plants. This research aimed to help improve the resilience and sustainability of the beekeeping sector in the face of the interactions between climate change and anthropogenic factors in northern Côte d'Ivoire. In addition, it aimed to understand how bees can thrive to continue to provide ecosystem services to communities, especially pollination and the sustainability of beekeeping in Côte d'Ivoire. This research was made possible by using a mixed approach (questionnaire, interviews, focus group discussion, floristic inventory, spatial analysis, etc.)

Beekeepers are the first to be affected. Beekeeping suitability analysis, which is an effective decision-making tool, can help them make a better choice of areas in which to set up their apiaries. The aim is to maximize production and significantly reduce losses of bee colonies (Abou-Shaara *et al.*, 2013), products and environmental damage. These tools will also help to maximize access to honey resources and watercourses and roads (for evacuation). The vulnerability analysis showed that, in addition to environmental constraints, socio-economic conditions also have an impact on their activity (Schouten, 2020). Beekeepers need to diversify their sources of income and focus on effective adaptation strategies, above all, working in collaboration with scientists and farmers.

Farmers are also concerned by this research. Indeed, knowledge of the contribution of bees to pollination is essential in agriculture through the installation of apiaries close to agricultural areas. Leconte & Navajas (2008), suggest that bees increase crop yields, but that their disappearance could have the opposite effect. It is also essential for them to minimize the use of chemical products by using alternatives such as biopesticides (Hossain *et al.,* 2017), which are less aggressive on bees.

In scientific terms, this has shown that it is possible to use mixed approaches that combine several analysis tools (MCDA, geospatial tools, participatory methods and climate data). In addition, the methodologies used in this work can be applied or adapted to other regions facing climate problems. For example, these analyses have been used in the field of agriculture (Talukder *et al.*, 2018), in environmental science (Romero-Perdomo & González-Curbelo, 2023) and especially on interdisciplinary issues related to climate change. This work also shows that sectors vulnerable to climate change can be resilient if disciplines are interconnected. In our case, we linked biodiversity, climate and human practices.

At the level of government, NGO and institutions, this work aims to guide them in their management policies. It provides an overview of the risks and specific strategies in programmes to combat climate change in West Africa. They will be able to focus on the problems that deserve more attention. In particular, they will be able to target the most vulnerable players and areas to draw up effective action plans. For example, decision-makers will be able to better ensure territorial planning (Cotrina-Sanchez *et al.*, 2023; Novelli *et al.*, 2021) to avoid land conflicts between different sectors of activity. The adaptation strategies identified could enrich policies concerning strategies for adapting to climate change. Beekeeping can also be considered as a programme for combating climate change (Yohana & Saria, 2020) through biodiversity conservation.

Contributions for local communities

Beekeeping is a less costly activity in terms of equipment and time, and is environmentally friendly. It will stimulate self-employment. It involves the creation of local industries based around bee products, such as processing, marketing and exporting products. These activities will help to reduce poverty and improve their incomes, combat the rural exodus and promote the integration of vulnerable people.

Contributions to the local economy

The beekeeping sector represents a considerable economic opportunity. The goods production of beehive products is a positive sign for the local economy, generating significant revenues for stakeholders.

Contributions to the environment

In addition to the economic and social issues at stake, this thesis contributes to the preservation of local biodiversity by encouraging the restoration and protection of natural bee habitats. It encourages reforestation and protection policies for certain species. The species identified can be the subject of ecological enhancement programmes, particularly in degraded areas or areas subject to anthropogenic pressure.

Roles and recommendations to the stakeholders

Local authorities and NGOs could promote the development of micro-entrepreneurial beekeeping projects. This would involve training programmes, technical support and project funding. For example, helping unemployed young people, women in rural areas, and farmers wishing to diversify their sources of income. Governments can introduce beekeeping into rural development programmes. As beekeeping is a sustainable and profitable activity, and rural areas have limited resources, planning could reduce investment gaps and target productive areas for beekeeping. This will minimize losses and maximize yields.

Limitations and conclusion

Although the study contributed to the identification of risks and strategies, it has certain limitations. The honey production data are less than 10 years old and only temperature and rainfall parameters were used in our research, but the analyses produced satisfactory results. The analyses also covered past and current projections. The Pearson correlation showed no relationship between temperature and honey production, whereas there was a significant impact between precipitation and honey production. Averages of climatic data were used, and maximum data were not taken into account. In addition, the combination of AHP and GIS only took into account current planning; we were unable to make future projections due to time limits. The inventory of melliferous plants was carried out using a participatory method in which beekeepers may forget or not pay attention to other species. About vulnerability, one of the limitations was that the weights of the indicators were not weighted, taking into account the opinion of the beekeepers who could have facilitated and taken into account the indicators eliminated (multicollinearities) during the Pearson correlation analysis. The evaluation of the effectiveness of the strategies showed that the observation time for some strategies, such as reforestation and change of site, required years to produce visible results. Another problem is that there may be challenges in funding the research by the authors.

The results obtained provide decision-makers, researchers and communities with precise information that can be used to improve people's living conditions if it is translated into concrete action.

GENERAL CONCLUSION, RECOMMENDATIONS AND PERSPECTIVES

GENERAL CONCLUSION

The objective of this thesis was to contribute to a better resilience of the beekeeping sector facing Climate Change conditions. We were able to use a mixed-method approach, including surveys, field observations, and stakeholder participation, using focus group discussions, and expert consultations to analyze the state of Knowledge on Beekeeping Practices in Côte d'Ivoire, determine the risk factors for beekeeping, develop adaptation strategies for sustainable beekeeping. Precipitation strongly affects the production while the temperature effects are masked by other factors. The addition of other factors to climatic factors such as socio-economic factors, topographic and the use of water bodies to find the area most susceptible for bees in terms of risk has shown that 59 % of the study area is at risk for their security. Beekeepers have adviced to practice their activity in the 41 % of the area. Even though the department of Korhogo has a great adaptive capacity, their beekeepers are the most vulnerable followed by Dikodougou with moderate vulnerability. The analysis of the adaptation strategies has allowed us to perceive the most effective strategies and to propose a new one to be evaluated in time.

Also, to achieve this, the study employed a range of approaches including numerical modelling, GIS-based modelling, empirical methods, statistical analyses, and index calculations. The main findings suggest that, understand what are the impacts in the context of beekeeping from the environmental side, from the social and economic side, and how climate change (climate variables) and or human management contribute to losses and damages both for Bees, food and human security. In Climate Change conditions, Honey bees through beekeeping are exposed to Increased temperature and a decrease in precipitation that can lead to the dry season. There are Also, confronted with the appearance of diseases, pests and the prolonged use of pesticides on plants. The ecosystemic services provided by honey bees are affected. The exposed elements play an important role where Honey bees are susceptible to all these interactions making Beekeepers vulnerable. Identifying the drivers of risk allows us to anticipate future hazards by proposing solutions for beekeepers to improve their productivity.

RECOMMENDATIONS

We recommend the following measures to the government, beekeepers and other related sectors: To strengthen the resilience of beekeepers and improve and protect services, it is important to make some important recommendations.

As bees are considered an endangered species, policies must also take into account beekeeping as a vulnerable sector that is important for food security and biodiversity conservation. Strengthen beekeeping governance frameworks through multi-stakeholder dialogue platforms between beekeepers, researchers' governments and NGOs to facilitate adaptive management. The governments could facilitate transport to improve transhumance for beekeepers in unsuitable areas.

Furthermore, we need the roles of researchers to protect the bees' sources of forage, and their preferences for honey plants, to guarantee an adequate supply. This is why the mapping of at-risk areas needs to be extended to other regions so that strategies can be perfectly planned. This involves combining climatic parameters, environmental parameters, floral inventories and beekeepers' practices to minimize losses and damage.

Beekeepers need regular training sessions on sustainable management practices, reading climate data, managing hives under stress, and diversifying hive products are essential. The facilitation of access to climate information by setting up early warning systems and agro-climatic bulletins tailored to beekeepers would enable better anticipation and more effective planning. Also, we could provide cooperative beekeepers with risk insurance to support them in the event of danger, promote awareness campaigns in communities on the importance of bees through beekeeping and encourage the population to reforest plants visited by bees and to use biogenic fertilizers that have less effect on bees. To make their activity more professional the improve their skills, beekeepers could be encouraged by recording their production and all the challenges they are facing.

The resilience of beekeeping under climatic conditions is a synergy between environmental, economic and social issues and the integration of traditional knowledge, and must be tackled in an integrated and inclusive way by beekeepers, researchers and decision-makers.

PERSPECTIVES

As perspectives, for the analysis of the impacts of climatic parameters on beekeeping, we suggest integrating other maximum meteorological data, such as humidity and wind speed, associated with those mentioned in this thesis, to evaluate their impact on honey production. Then, future projections of these parameters need to be made to see their real impact. Use honey production data from at least 10 years for the real effect of climate impacts. In addition, it is important to carry out a linear regression analysis to see the correlation between temperature and honey production.

Make a future projection of suitability for beekeeping by completing the analysis criteria, such as pesticide contamination, air pollution, soil quality, fire risk index and flood risk index. Complete the inventory of melliferous plants with pollen analysis for a full understanding of the foraged plants in the study area. For the vulnerability of beekeepers, we suggest a weighting based on the judgments of the stakeholders concerned. Building a long-term simulation model to understand the effectiveness of reforestation strategies and site changes.

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APPENDICES

Appendix 1: Collected data process, questionnaire and focus group Discussion

Appendix 2: Ethical approval from Laboratory of Botany, University Felix Houphouet Boigny

REPUBLIQUE DE COTE D'IVOIRE
Union-Discipline-Travail

Ministère de l'Enseignement supérieur
et de la Recherche Scientifique

UNIVERSITE Félix HOUPHOUET-BOIGNY

Abidjan le 15/02/2023

UFR BIOSCIENCES

22 BP : 582 Abidjan 22

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A
Monsieur le Directeur de SODIPEX
Korhogo

OBJET : **Demande d'autorisation d'activités de recherche dans le site d'exploitation de SODIPEX**

Monsieur le Directeur Général,

Dans le cadre des activités de recherche de l'UPR de Botanique relatives à la promotion de l'apiculture ivoirienne, il a été proposé à Mlle OUATTARA SALIMATA, le thème : « ***Evaluation des impacts du changement climatique et contribution à la réduction de la vulnérabilité des exploitations apicoles du Nord de la Côte d'Ivoire*** ». Les résultats de cette étude permettront aussi bien à la communauté scientique qu'à la filière apicole d'avoir des informations sur les potentialités mellifères de la région ainsi que la production de miel en contexte de changements climatiques afin de contribuer à l'amélioration de la production apicole.

À cet effet, j'ai l'honneur de solliciter auprès de votre bienveillance, l'autorisation d'accès à la dite exploitation. Cette étude a pour objet d'évaluer les facteurs climatiques impactant la production du miel de la région.

Ces recherches seront sanctionnées par une thèse qui sera aussi mise à la disposition de votre société.

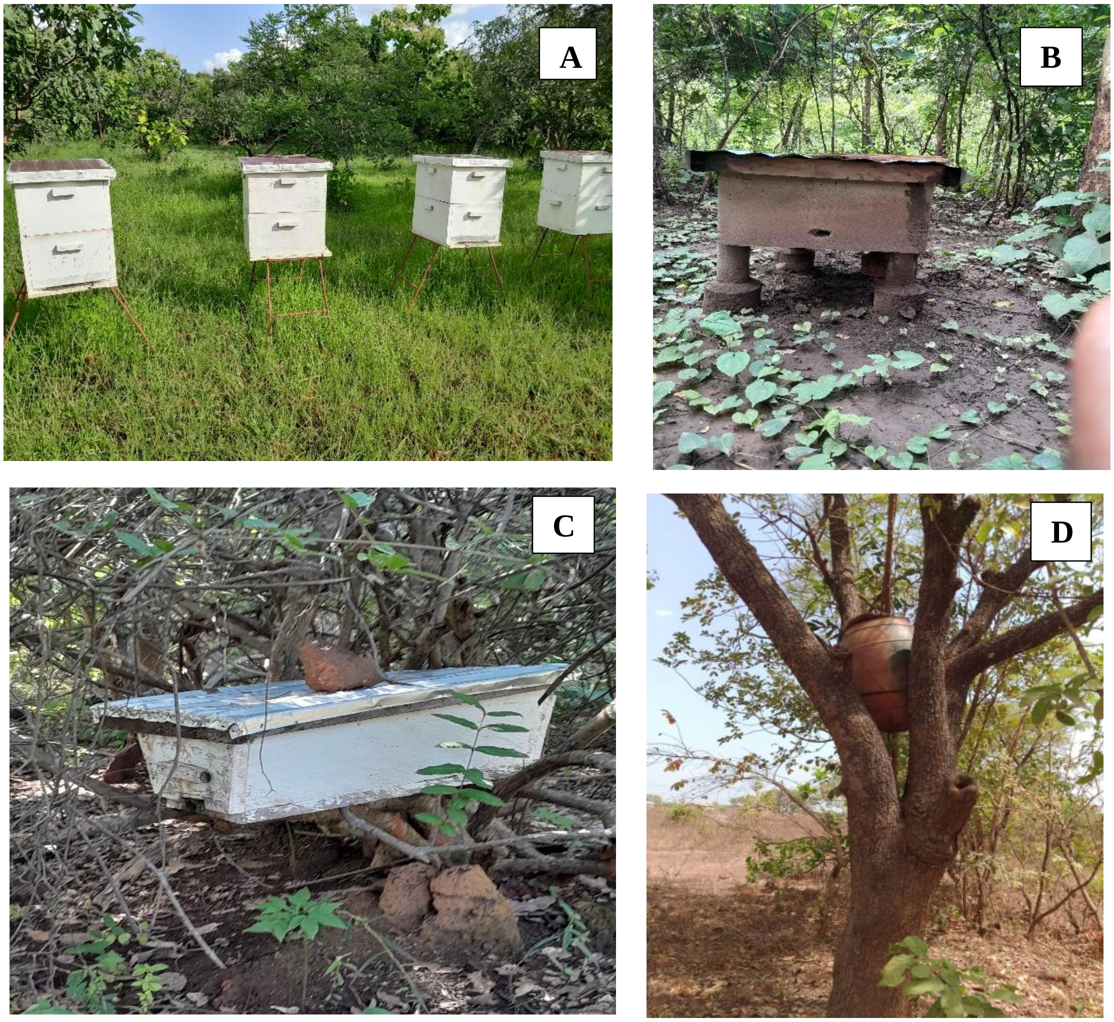
Espérant que vous acceptiez que l'étudiante Mlle OUATTARA SALIMATA puisse mener ses activités de recherche dans votre domaine, je vous prie d'agréer, Monsieur le Directeur Général, ma haute gratitude.

Le Co-Directeur

ASSI KAUDJHIS Chimène C.
Palynologue, Enseignant-Chercheur
Université Félix Houphouët-Boigny

Pr. ASSI KAUDJHIS CHIMENE

Appendix 3: Structural professional and socio-economic characteristics of beekeeping



A: Langstroth (modern hives); **B**: Concrete; **C**: Kenyan (modern hive); **D**: Clay canary (Traditional hive)

Appendix 3 (continued): Structural professional and socio-economic characteristics of beekeeping

1. **Farm**: Mango orchard

2. Bush

3. **Farm**: Cashew nut orchard

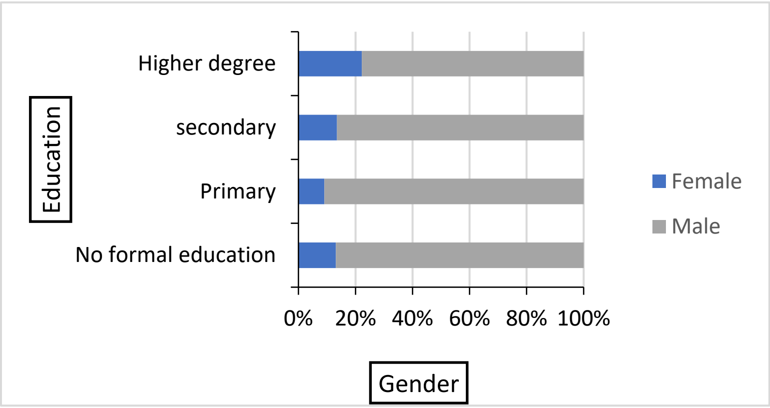
4. Protected area

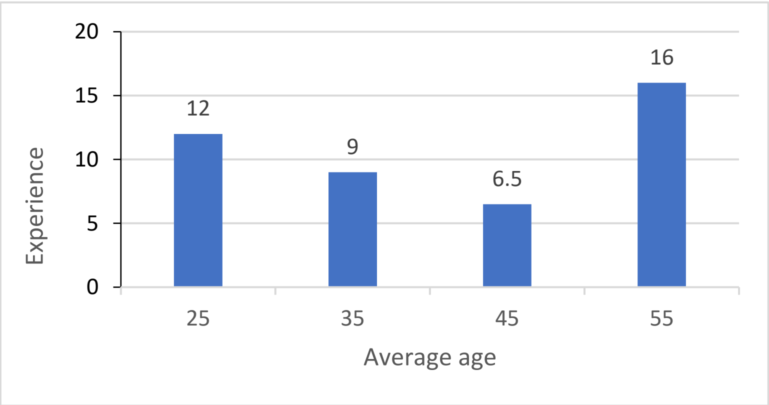
Appendix 3 (continued): Images of susceptibility indicators noticed

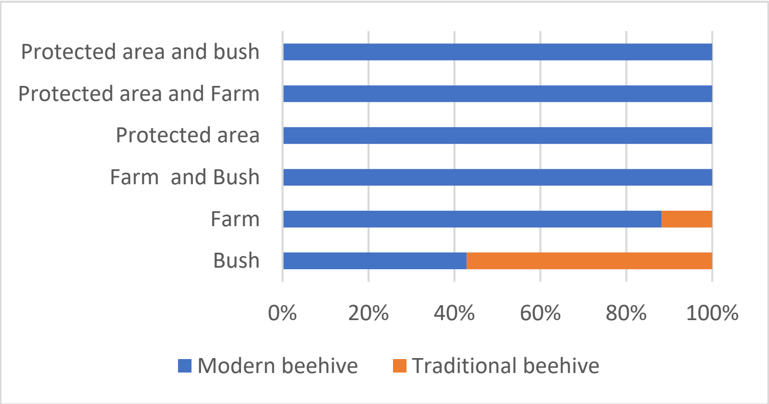
Presence of black (left) and orange (right) ants in the hive

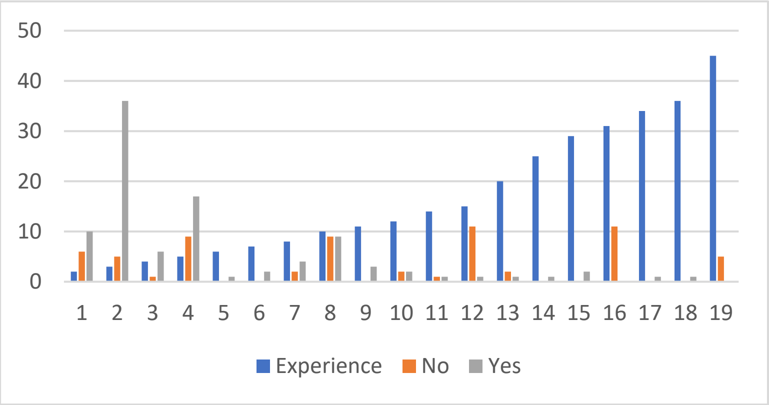
Presence of disease (hives on the right), hives eaten away by pests (middle hives), burnt hives (right)

Appendix 4: Cross-analysis between beekeepers' characteristics









Appendix 5: Images of susceptibility indicators noticed

Hives deserted by honeybees

Presences of pesticides in the field

Appendix 6: Pearson correlation for the two domains of vulnerability: Susceptibility and adaptive capacity (Pearson Correlation (r> 0.92) SUS (13 indicators), A.C. (11 indicators))

	H.S.	*PROD*	*DESER*	*BMP*	*PEST*	*INC-BEEK*	*TRAD*	*PEST/DIS*	*AGE.E*	*AGE.Y*	*FEM*	*HIVE*	*NO. WATER*
H.S.	1												
PROD	-0.83	1.00											
DESER	-0.81	0.70	1.00										
BMP	0.49	-0.87	-0.27	1.00									
PEST	-0.50	0.59	0.89	-0.27	1.00								
INC-BEEK	0.27	-0.25	0.34	0.44	0.63	1.00							
TRAD	-0.22	-0.24	0.51	0.68	0.40	0.59	1.00						
PEST/DIS	-0.97	0.86	0.67	-0.62	0.35	-0.47	0.00	1.00					
AGE.E	-0.02	0.18	-0.53	-0.52	-0.67	-0.94	-0.83	0.25	1.00				
AGE.Y	-0.02	0.18	-0.53	-0.52	-0.67	-0.94	-0.83	0.25	1.00	1.00			
FEM	-0.97	0.76	0.66	-0.47	0.29	-0.47	0.13	0.98	0.20	0.20	1.00		
HIVE	-0.80	0.69	1.00	-0.27	0.90	0.35	0.52	0.66	-0.54	-0.54	0.65	1.00	
NO. WATER	0.50	-0.61	-0.88	0.31	-1.00	-0.61	-0.36	-0.35	0.64	0.64	-0.28	-0.89	1.00

Susceptibility

	EDUC	TRAIN	COOP	EXP	OFF-BEEK	W. TANK	INC-HIVE	CHANGE	SITE	FINAN	INFO
EDUC	**1.00**										
TRAIN	**0.24**	**1.00**									
COOP	**-0.12**	**-0.24**	**1.00**								
EXP	**0.57**	**0.78**	**-0.68**	**1.00**							
OFF-BEEK	**-0.47**	**0.21**	**-0.81**	**0.36**	**1.00**						
W. TANK	**-0.93**	**-0.13**	**0.44**	**-0.64**	**0.17**	**1.00**					
INC-HIVE	**0.63**	**0.52**	**-0.82**	**0.94**	**0.39**	**-0.79**	**1.00**				
CHANGE	**-0.29**	**-0.38**	**0.98**	**-0.82**	**-0.71**	**0.57**	**-0.92**	**1.00**			
SITE	**-0.65**	**0.42**	**0.42**	**-0.21**	**0.10**	**0.83**	**-0.51**	**0.44**	**1.00**		
FINAN	**0.03**	**-0.37**	**-0.81**	**0.21**	**0.61**	**-0.40**	**0.50**	**-0.72**	**-0.69**	**1.00**	
INFO	**0.15**	**-0.64**	**-0.54**	**-0.04**	**0.27**	**-0.46**	**0.30**	**-0.45**	**-0.85**	**0.92**	**1.00**

Adaptive Capacity

Appendix 7: Questionnaire

Section 1: Geographical location

Location	Department
Region	Village

Section 2: Social situation of the beekeeper

1.	Name of interviewee						
	Gender	Male ☐				Female ☐	
	Place						
	État civil	Married			Divorced	widow(er)	Single
	Educational level	No formal education ☐	Primary ☐		Secondary ☐	Higher degree ☐	
	Age :	20-25 ☐	26-31 ☐	32-37 ☐	38-43 ☐	44-49 ☐	50+ ☐
		Farmer ☐	Teacher ☐		Company ☐	Others ☐	

Section 3 : Socio-economic activities

2. What type of hives do you have ? traditional hive ☐ modern hives ☐

3. How did you get into beekeeping ? Personal interests ☐ Influenced by ☐ neighbors

Inherited from parents ☐ Raising awareness through agricultural extension services ☐
Other raisons (precise) ☐

4. How long have you been beekeeping? ....

5. Where do you keep the bee colonies?

Apiary location	Check the appropriate box	Number of apiaries
Farm		
Clinging to the trees on the farm		
In the bush		
Proximity to bush		

Section 4 : Climate variability

6. Have you ever noticed the following weather changes over the last 20 years?

	Tendance sur les 20 dernières années (cocher la tendance appropriée)		
Quantity of precipitations	Increasing	Decreasing	No change
Duration of precipitations	☐	☐	☐
Gravity et frequency of dry season	☐	☐	☐
Temperature	☐	☐	☐

7. If your answer to question (6) above is temperature change, what indicators do you use to assess the temperature of the climate?

Drying up rivers and others ☐

Loss of biodiversity ☐

Decreasing in precipitation quantity ☐

Section 5 : Effects of climate variability on forage availability and distribution

8. Honey species present in the study area

Local name of the flora	More abundant	Abundant	Average	Rare	Very rare
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					

9.Do you think that meteorological variations have led to a change in the flowering and anthesis of the flora?

Yes ☐ No ☐

10. If yes, has the flowering of the flora changed in recent years? Yes ☐ ☐ No

11. How is the change ?

Very good ☐ More ☐ Minimal ☐ Very poor ☐

12. At what time of year is there a shortage of bee forage?

Season	Month	Critical shortage	Less shortage

13. Have you ever noticed the impact of climate variability on flora?

	Trends in recent years		
	Increasing	Decreasing	Stable
Number of flowers			
Duration of flowers on the flora			
Quantity of preferred flora			
Invasion of non-preferred flora			

Section 6 : What were the driving forces behind your decision to start producing honey?

14. Climate change and honey production

Income ☐

Domestic consumption ☐

To obtain skills ☐

Others ☐

15. Combien de fois par an récoltez-vous le miel d'une même ruche ?

Once ☐

Two times ☐

Three times ☐

More than times ☐

Never ☐

16. When is the peak honey harvest in the year?

17. Do you practise migratory beekeeping? Yes ☐ No ☐

18. How long does your colony stay in the hive?

0-1 year ☐ 2-3 years ☐ ☐ 4 years

19. Are there any patterns that bees follow? Yes ☐ No ☐

20. Are there any changes in migration routes? Yes ☐ No ☐

21.

If so, do you think the change in weather conditions has led to a change in migration?	Yes ☐		No ☐	
Have there been any variations in honey production over the last 20 years?	Yes ☐		No ☐	
If so, what is the trend?	Decreased	increased	Stable	Varie each year
Is water available for bees?	Yes ☐		No ☐	

22. If yes, tick in the table below

Water	Tick for yes
Rare	☐
Less available	☐
Available	☐
More available	☐

23. Where do honeybees get their water?

Water tank ☐ Ruisseau ☐ River ☐ ☐ Lakes ☐ Others

24.

Do you associate the lack of water with the migration of colonies?	Yes ☐	No ☐
If not, how do you supply the bees with water?		
Does water availability affect production?	Yes ☐	No ☐

25. If it has decreased, please use the options to answer the following questions as they have led to low honey production, from agree to disagree

1 totally agree 2 Agree 3 Desagree 4 strongly disagree

Factors leading to honey production	1	2	3	4
Variation in temperature				
Variation in rainfall				
Impact of pests and predation				
Variation in flowering				
Distance between the hive and surrounding flora				
Absenteeism				
Lack of forage				
Shading of the hive				
Low availability of quality forage for bees				

26- Consumers of beekeeping products

• What do you use honey for?

Do you use honey for nutrition ?	Yes ☐	No ☐
Do you use honey for medicinal purposes ?		
Other (please specify)	Yes ☐	No ☐

• Have you noticed any differences in the availability of honey? Yes ☐ ☐ No

• Do you know how honey is collected or harvested? Yes ☐ ☐ No

• Do you know any beekeepers? Yes ☐ ☐ No

• Did you know that bees are important? Yes ☐ ☐ No

Agriculture

• What crops do you grow?

	1	2	3	4

- What crops do you sell? Where do you sell?

- Do you have beehives? If so, why?

- What role do bees play in agriculture?

- What melliferous species do you plant?

When do they flower?

Have you seen any changes in flowering (VEGETATION)?

Why do you think this changes?

- Are they used for pollen, nectar or honey?

- How do you divide up your year?

- When does your year start?

- What are the weather patterns associated with your seasons?

- What are the hottest, coolest, driest and wettest seasons?

• How do the seasons change?

• Have you seen any changes to the seasonal timetable? Yes ☐ No ☐

• Have you changed your practices to combat this? ? Yes ☐ No ☐

How ?
……
……………………………………………

• Do bees play a role in agriculture? If so, how important is it? ?

Questionnaire Vulnerabilities

I- **Beekeeper's situation**

1.	Name of interviewee						
	Gender	Male				Female	
	Place						
	État civil	Married			Divorced	widow(er)	Single
	Educational level	No formal education	Primary	Secondary	Higher degree		
	Age :	20-25	26-31	32-37	38-43	44-49	50+
		Farmer	Teacher	Company	Others		

Full-time consecration ___; Part-time consecration ___.

- If you work part-time, what other activity do you combine it with? ____

Number of employees ? _____ ; Family members___, Workers hired____.

Number of beehives? _____. Recent development? ___increase ; ___stable ; ___decrease.

What products do you produce? Honey; ___pollen; ___propolis; ___wax; ___royal jelly; ___other. Which are they?____

Type of marketing (%) : ___ own consumption; ___ direct sale; ___ intermediary : ___ other.

Which ones ? ____

Pourquoi pratiquez-vous l'apiculture ? ____

Do you advise your children/young people to become beekeepers? Yes; No.

Why ?____

II : Changes and transformations

Which of the following climate changes have you observed? What are the effects on your business?

Chanes	Impacts
Seasonal shift	
Rising and falling temperatures	
Lower relative humidity	
Increase in wind speed	
Lower river basin flows	
Extreme events (floods, winds, droughts (less rain))	

- Trends in the political sphere that affect your business?

Changes	Impacts
Labelling of local products	
Marginalisation of beekeeping	
Beekeepers (hives in poor condition to be paid)	
Outdated health programmes	

- What trends are affecting your business?

CHANGES	Impacts
Abuse of pesticides (by farmers)	
Monocultures	
Falsification of honey	

Over-exploitation (more hives, more colonies nearby)	

- Trends in the social sphere that affect your business

Changes	Impacts
Increased ecological awareness among producers (the value of bees)	
Greater appreciation of local products	
Lack of training for beekeepers (health requirements)	

- Environmental trends affecting your business?

Changes	Experimental effects (Impacts)
Expansion of species that are enemies of bees: wasps, Asian wasps and small hive beetles	
Emergence and continuation of pathologies and syndromes.	
Loss of biodiversity and habitats	
Disappearance of wild beehives	
Reduced flowering period	
Concentration of flowering periods	
Fires	

Partie III : Adaptation

Strategies for dealing with the changes and impacts on beekeepers and beekeeping?

Strategies	Observations	Implementation
Economic diversification of the beekeeping family		
Diversification of locations		
Diversifying the production of beehive products		
Mobility		
Changes in transhumance itineraries		
Changes to the way the hives are set up (shelter from wind and sun, etc.)		
Increased mobility distances		
Adoption of sedentary beekeeping		
Transhumance		
Intensification of beekeeping		
Increased use of inputs (systematic or planned sanitary treatments)		
Use of artificial reinforcement feed for the non-blooming period		
Wholesale sales		
Agroecology		
Management adapted to the nature of the bee (e.g. vertical hives)		
Measures to ensure animal welfare		
Location of hives (e.g. Hartmann lines)		
Cooperation		
Family business		
Labour Exchange		
Participatory health (raising beekeepers' awareness to compensate for the lack of technicians)		
The assembly cooperatives in the organisation of beekeepers		

Other management changes		
Adapting management to health treatment (preventive management, application when there are fewer broods)		
Change in genetic lineage (change of queen)		
Abandonment of beekeeping activity		
Alternating treatments for the same pathology avoids generating tolerance).		
Training		
Research		

Partie IV : Needs

What needs do you see in the sector? ____

____

____

Potentialities ? ____

Section 7 : Climate variability and pest infestation

26. Do you visit your hive and colonies? Yes ☐ ☐ No

27. If so, what of inspection do you always carry out? ☐ External inspection ☐ Internal inspection Both of them ☐

28. How often do you inspect the hive? Rarely ☐ Frequently☐ Sometimes ☐

29. Quels types de parasites avez-vous remarqué dans votre ruche ? Mettez-les dans le rang

No	Pests and diseases	Rank	Increase	Decrease	stable

1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

30. If parasitic infestation is increasing, what are the factors leading to this increase?

Increased dry season ☐ ☐ Human activities

Increased rainy season ☐

31. What types of human activity ?

1………………………….........., 2……………………………………,
3……………………………., 4……………………………………….

Human activities

A. Agriculture

Crops grown within a 1 km radius of the apiary

1……………….., 2…………….., 3………………….., 4………………., 5……………………

Flowering dates for crops

1………………., 2…………….., 3…………………., 4………………., 5……………………

Plant protection products used on crops

1………………., 2…………….., 3…………………., 4………………., 5……………………

Dosages and frequency of use of plant protection products

a. Doses

1………………………… , 2…………………………

b. Frequency

1……………………… , 2……………………………

1. Is beekeeping a hobby or a profession ?

2. How many living colonies did you have at the beginning?

3. How many live colonies do you have now?

4. What type of bees did you keep (information on subspecies)?

5. Did you migrate with your bees? If so, to which crops?

6. Did you feed your colonies ?

7. Have you used spoke replacement ? (1km, 2km, 3km)

8. Have you treated against diseases?

9. What pests/diseases have you found in your colonies over the last 12 months?

10. Additional information on other pests/diseases/parasites found in their hives.

11. How many colonies have been lost in the last 12 months?

12. In your opinion, what factor(s) has (have) been the main cause(s) of colony deaths on your farm over the last 2 years?

BEE COLONY MORTALITY SURVEY QUESTIONNAIRE

Surname and First Name : ____

Telephone : ___________________________ /_________________________

Department: ____

1. **Geographical location of your apiaries**

	Yes	No
In the orchard		
Proximity to farm		
Far from a farm		
In the city		
Far from the city		

2. In your opinion, what are the main causes of mortality in your colonies? (Please tick and rank in order of importance all the causes suspected of being associated with mortality)

Causes of death	Ranking (1 = most important cause)
Starving to death	
Poor disease control	
Adverse weather conditions	
Human activities	
Other (please specify):	
Other (please specify):	
Other (please specify):	
I do not know	
No mortalities	

1. **Disease control treatments**

Please indicate the treatment methods used for disease control

Traitment	% of treated hives

Methodological document for conducting focus groups

Ressources : 1 instructor and 1 observer

Nombre de participants : beekeepers

Lieu : neutral, agreable, calm ?

Durée : 1h-2h

Introduction : PhD project carried out in two areas (north)

Principal objective : To contribute to the resilience of the beekeeping sector to the interactions between climate change and man-made factors in Côte d'Ivoire

Thematic: **Sustainable beekeeping under climate change conditions: Sustainable beekeeping under climate change conditions: Risk drivers and adaptation strategies in the Poro region, Northern Côte d'Ivoire** (to be noted on a flip chart displayed throughout the focus group)

Focus group :

Discussion-debate around 3 main questions and exchange of ideas, there are no right or wrong answers, we just want to know your opinion, your experience. It's important to know that this is an anonymous debate. Do you mind if I record ? We'll also take note of the information, but not by name. As moderator, I'm the guarantor of the framework -> respect for speaking time and everyone's ideas, and non-judgement. If we stray from the subject of the meeting, I'll take the liberty of cutting you off and refocusing the debate. For the focus group to be a success, your participation and creativity are important.

Procedure

First part :

a) Presentation

Second part :

b) Questions

Thèmes	**Questions**
1. Perception of climate change	What effects of climate change have you observed on bees and beekeeping over the last 10 years?
1. Adaptation and mitigation strategies	Have the effects of climate change led to the adoption of adaptation or mitigation strategies, or to changes in beekeeping management practices?

3. SWOT and social life	What are the positive aspects and main difficulties of beekeeping? • What impact does beekeeping have on your social life? • Do the working hours make a social life difficult? Does the image of the profession have an impact on your social life?
4.Age	
5. Activities	• Are you a professional beekeeper or an amateur? • Do you do any other activities?

Summary of the debate: The facilitator hands out a sheet to each participant and asks them to write down what struck them most after all the discussion.

TABLE OF CONTENT

Title: Sustainable beekeeping under climate change conditions: Risk drivers and adaptation strategies in the Poro region, Northern Côte d'Ivoire

Abstract

A great deal of research has shown that climate change is one of the current threats to pollinators. It has a significant influence on other strictly related factors, such as diseases and predators, causing the weakening and desertion of honey bees. The loss of colonies, damage bees could pose a threat to global food security and leave the beekeeping sector vulnerable. However, the literature lacks information on the effects of anthropogenic change and activities on beekeeping in the Poro region, Côte d'Ivoire. This study aims to contribute to greater resilience and sustainability of the beekeeping sector in the face of the interactions of climate change and anthropogenic factors in the north of Côte d'Ivoire. The hypothesis is that the sustainability and resilience of beekeeping are influenced by climatic, environmental and socio-economic conditions, and can be ensured by adopting strategies. The study used a mixed methodological approach, integrating a literature review of 43 relevant articles to assess the current state of beekeeping and identify challenges, surveys of 162 beekeepers, an interview with the federation of beekeepers, focus group discussions (5), field observations and an inventory of melliferous plants. The evaluation of the impacts of climate parameters on beekeeping productivity, a combination of multicriteria analysis AHP and GIS for the analysis of favourable areas, the analysis of beekeepers' vulnerability using the IPCC 2014 conceptual framework of vulnerability and Principal Component Analysis (PCA), the evaluation of the effectiveness of adaptation strategies using AHP and the development of new strategies. The results showed that there are more than 100 melliferous species identified in the country, resulting in good quality honeys. Despite this, there are socio-economic and environmental challenges to be overcome, such as pesticides and habitat destruction, which affect bees, leading to a disruption of their ecosystem services. The beekeepers' perceptions of the climatic parameters are confirmed by an analysis of their trend, which shows a decrease in precipitation and an increase in temperature, whereas the trend in production differs from their perception of their production. Precipitation influenced production ($r= 0.78$, $p= 0.04$ ($p < 0.05$)), while the impact of temperature ($r = 0.02$, $p = 0.96$ ($p < 0.05$)) was masked by other factors such as humidity and beekeeping practices. 20 species of melliferous plants were identified, showing preferences for certain species such as *Detarium microcarpum, Hyptis suaveolens*. Unsuitable areas (59%) are more extensive than suitable areas (41%), highlighting the importance of the proximity of bees to floral diversity, water availability and roads. Beekeepers are vulnerable due to susceptibility factors such as household size, production, desertion, pesticides, age and income from beekeeping. Beekeepers' ability to adapt is limited by the index of practices, experience, cooperatives, funding and education. The use of a water reservoir, harvest periods, training in beekeeping, reforestation, location of apiaries are the most effective strategies. The new strategies developed will help beekeepers to mitigate losses and damage and anticipate future dangers by offering solutions to improve their productivity.

Keywords: Climate change adaptation, Honey bees, Beekeepers' vulnerability, Ecosystemic services, Poro region

Titre : L'apiculture durable dans les conditions du changement climatique : Facteurs de risque et stratégies d'adaptation dans la région du Poro, Nord de la Côte d'Ivoire

Résumé

De nombreuses recherches ont montré que le changement climatique est l'une des menaces actuelles pour les pollinisateurs. Il a une influence significative sur d'autres facteurs strictement liés, tels que les maladies et les prédateurs, provoquant l'affaiblissement et la désertion des abeilles mellifères. La perte de colonies, les dommages causés aux abeilles pourraient constituer une menace pour la sécurité alimentaire mondiale et rendre le secteur apicole vulnérable. Cependant, la littérature manque d'informations sur les effets des changements et activités anthropiques sur l'apiculture dans la région du Poro, en Côte d'Ivoire. Cette étude vise à contribuer à une plus grande résilience et durabilité du secteur apicole face aux interactions du changement climatique et des facteurs anthropiques dans le nord de la Côte d'Ivoire. L'hypothèse est que la durabilité et la résilience de l'apiculture sont influencées par les conditions climatiques, environnementales et socio-économiques, et peuvent être assurées par l'adoption de stratégies. L'étude a utilisé une approche méthodologique mixte, intégrant une revue de la littérature de 43 articles pertinents pour évaluer l'état actuel de l'apiculture et identifier les défis, des enquêtes auprès de 162 apiculteurs, un entretien avec la fédération des apiculteurs, des discussions de groupe (5), des observations sur le terrain et un inventaire des plantes mellifères. L'évaluation des impacts des paramètres climatiques sur la productivité apicole, une combinaison de l'analyse multicritère AHP et GIS pour l'analyse des zones favorables, l'analyse de la vulnérabilité des apiculteurs en utilisant le cadre conceptuel de vulnérabilité IPCC 2014 et l'Analyse en Composantes Principales (ACP), l'évaluation de l'efficacité des stratégies d'adaptation en utilisant l'AHP et le développement de nouvelles stratégies. Les résultats ont montré qu'il existe plus de 100 espèces mellifères identifiées dans le pays, ce qui permet d'obtenir des miels de bonne qualité. Malgré cela, des défis socio-économiques et environnementaux doivent être relevés, tels que les pesticides et la destruction de l'habitat, qui affectent les abeilles, entraînant une perturbation de leurs services écosystémiques. La perception des paramètres climatiques par les apiculteurs est confirmée par l'analyse de leur évolution qui montre une diminution des précipitations et une augmentation de la température, alors que l'évolution de la production diffère de leur perception de leur production. Les précipitations influencent la production ($r = 0,78$, $p = 0,04$ ($p < 0,05$)), tandis que l'impact de la température ($r = 0,02$, $p = 0,96$ ($p < 0,05$)) est masqué par d'autres facteurs tels que l'humidité et les pratiques apicoles. 20 espèces de plantes mellifères ont été identifiées, montrant des préférences pour certaines espèces telles que Detarium microcarpum, Hyptis suaveolens. Les zones inappropriées (59 %) sont plus étendues que les zones appropriées (41 %), ce qui souligne l'importance de la proximité des abeilles par rapport à la diversité florale, à la disponibilité de l'eau et aux routes. Les apiculteurs sont vulnérables en raison de facteurs tels que la taille du ménage, la production, la désertion, les pesticides, l'âge et le revenu de l'apiculture. La capacité d'adaptation des apiculteurs est limitée par l'index des pratiques, l'expérience, les coopératives, le financement et l'éducation. L'utilisation d'un réservoir d'eau, les périodes de récolte, la formation en apiculture, le reboisement, la localisation des ruchers sont les stratégies les plus efficaces. Les nouvelles stratégies développées aideront les apiculteurs à atténuer les pertes et les dommages et à anticiper les dangers futurs en proposant des solutions pour améliorer leur productivité.

Mots clés : Adaptation au changement climatique, abeilles mellifères, vulnérabilité des apiculteurs, Services écosystémiques, région du Poro.