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ASSESSMENT OF NATURE-BASED SOLUTIONS TO CLIMATE VARIABILITY AND ADAPTATION STRATEGIES AMONG TOMATO FARMERS IN TECHIMAN NORTH MUNICIPAL GHANA

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NOVEMBER, 2025

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A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL MANAGEMENT AND SCHOOL OF NATURAL RESOURCES, UNIVERSITY OF ENERGY AND NATURAL RESOURCES, SUNYANI IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF MASTER OF PHILOSOPHY IN ENVIRONMENT, WATER, AND SUSTAINABILITY

NOVEMBER, 2025

DECLARATION

I, George Frimpong Enchill (UEMP2100223), hereby declare that except for references and citations which have been duly acknowledged, this submission is my own original work towards a Master's of Philosophy in Environment, Water and Sustainability, and that to the best of my knowledge, it contains no material previously published by another person. I also declare that this has not been presented either in whole or in part for another degree in this University or elsewhere.

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ABSTRACT

The concept of nature-based solutions has emerged as a comprehensive strategy worldwide for addressing complex societal issues, such as climate change. This study explores the naturebased climate adaptation strategies adopted by tomato farmers in Techiman North Municipality of Ghana. Using a mixed-methods approach and a cross-sectional design, data were collected from 255 farmers through structured questionnaires, interviews, and field observations. Quantitative data were analysed using SPSS (version 26.0), applying descriptive statistics, onesample t-tests, and binary logistic regression, while qualitative data were analysed thematically. Findings showed that farmers widely use strategies such as restoring natural vegetation (33.6%), contour farming (32.4%), organic fertilizers (31.6%), agroforestry (30.5%), and intercropping (29.3%). Composting, buffer zones, and rainwater harvesting were rated the most effective nature-based adaptation strategies (mean > 3.08), while crop rotation was rated significantly less effective (M = 2.78, p = .015). Overall, 73.8% of farmers believed that their adaptation efforts were successful. Logistic regression revealed that the strategy for adoption was influenced by access to training (p = .040), perceived profitability (p = .039), traditional beliefs (p = .019), and policy constraints (p = .025). These results highlight the role of cultural norms, shared experiences, and institutional support in shaping farmer responses. The study concludes that smallholder farmers are not just responding to climate challenges but are proactively using nature-based solutions to improve resilience. Recommendations from the study include strengthening farmer training, promoting peer learning, enhancing policy support, improving land access, and expanding financial support for scaling up effective strategies.

DEDICATION

To my family and mentors, who made this journey possible.

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LIST OF ABREVIATIONS

CAADP	Comprehensive Africa Agriculture Development Programme
CBA	Community-Based Adaptation
CSIR	Centre for Scientific and Industrial Research
DFID	Department for International Development
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GSS	Ghana Statistical Service
GMA	Ghana Meteorological Agency
IBM	International Business Machine
IPCC	Intergovernmental Panel on Climate Change
ISFM	Integrated Soil Fertility Management
IUCN	International Union for Conservation of Nature
MADU	Ministry of Agriculture and Development Unions

MOFA	Ministry of Food and Agriculture
NbS	Nature-Base Solution
NGO	Non-Governmental Organizations
NCCP	National Climate Change Policy
SDG	Sustainable Development Goals
SPSS	Statistical Package for Social Science
SLF	Sustainable Livelihood Framework
TAMD	Tracking Adaptation Measuring Development
TNM	Techiman North Municipal
TWN	Third World Network
UNFCCC	United Nations Framework Convention on Climate Change

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Climate variability alters precipitation patterns, leading to transformations in farming systems, food security, and economic development. These changes also result in higher temperatures, an increased occurrence of disease-carrying vector populations, reduced access to clean water, rising ocean levels, and more unpredictable patterns of flooding and drought conditions (Nelson et al., 2008). Throughout the last two and a half centuries, forest clearing, burning of fossil fuels, and agricultural activities, including rice cultivation and animal husbandry, have significantly elevated the atmospheric levels of carbon dioxide (CO_2) and additional greenhouse gases. Agricultural producers experience impacts during cultivation processes and across their overall means of subsistence, leading them to develop coping mechanisms to address current circumstances.

Ghana, similar to other nations in sub-Saharan Africa, confronts growing difficulties as unpredictable precipitation, rising temperatures, and severe weather phenomena interrupt conventional agricultural methods and jeopardize food stability (Antwi-agyei & Dougill, 2013). Climate change constitutes one of the most pressing issues of our current century, carrying substantial consequences for global farming systems (IPCC, 2007). Within Ghana, mirroring the situation across numerous sub-Saharan African territories, agriculture continues to serve as an economic foundation, accounting for roughly 18.5% of the gross domestic product and providing employment for approximately 30% of the labour force (Ghana Statistical Service, 2021).

The IPCC's fifth assessment report indicates that climate change over the past three decades has reduced global agricultural production by 1-5% per decade compared to what would have happened without climate change (Robinson, 2020). Besides, recent studies indicate that even a 2-degree rise in global temperature will affect agricultural productivity, particularly in the tropics, where the effects of climate variability increase with temperature. The magnitude of climate variability significantly affects numerous aspects of human activity, with threats to food security representing the most critical concern (IPCC, 2007; Werners et al., 2021). The agriculture sector faces the greatest risk from climate fluctuations because crop production, both for sustenance and commercial purposes, depends heavily on precipitation patterns (Guodaar et al., 2017). Since agriculture forms the economic foundation of many developing nations, disruptions to this sector will disproportionately harm small-scale farmers, particularly those in rural communities who rely primarily on farming for their survival.

Climate change is expected to directly influence the frequency and intensity of crop diseases, posing serious risks to global food security (Ali et al., 2016). Also, climate projections globally suggest a further temperature increase of 1.5 degrees Celsius above preindustrial levels to 3.0°C by 2050, with greater rainfall variability and increased frequency of extreme weather events (Abadata & Ze, 2025; Brown et al., 2018). Without effective adaptation measures, these changes threaten to undermine agricultural productivity, food security, and the livelihoods of farming communities in regions like Techiman North Municipal.

The concept of nature-based solutions (NbS) has emerged as a comprehensive strategy worldwide for addressing complex societal issues, such as climate change, while simultaneously enhancing human welfare and biodiversity benefits (Mensah, 2023). Naturebased solutions are interventions that work in conjunction with natural systems to address social problems while delivering benefits for both people and wildlife. These approaches involve safeguarding, responsibly managing, or rehabilitating ecosystems, whether they're pristine or human-altered, in ways that effectively address challenges facing society. The key principle is that these solutions provide dual outcomes: enhancing human welfare while also supporting biodiversity conservation (Frantzeskaki et al., 2019; Manes et al., 2022). Naturebased solutions (NbS) have emerged as promising approaches to climate adaptation that work with natural processes to enhance resilience while providing multiple co-benefits for ecosystems and communities (Seddon et al., 2020). Climate-adaptive agricultural approaches like agroforestry, conservation farming methods, integrated water resource management, and drought-tolerant crop cultivars provide viable strategies for tomato growers to manage climate uncertainty while maintaining productive and sustainable farming operations (CohenShacham et al., 2019).

Nature-based solutions (NbS) have become increasingly popular as an integrated strategy for tackling climate change and biodiversity decline while promoting sustainable development. While properly designed NbS can provide numerous advantages for both humans and ecosystems, recent attention has focused heavily on tree planting initiatives aimed at carbon capture (Mensah, 2023). This emphasis raises significant concerns that it may divert attention from the urgent need to eliminate fossil fuel dependency and safeguard existing undisturbed natural habitats. The concept of nature-based solutions first appeared in academic literature through a 2008 World Bank report by Mackinnon and colleagues, which examined how the Bank's biodiversity conservation investments could help mitigate and adapt to climate change (Robinson, 2020). Subsequently, the International Union for Conservation of Nature (IUCN) embraced NbS and advocated for their use in addressing climate adaptation and mitigation, ensuring water, food, and energy security, alleviating poverty, and fostering economic development in its policy document for the United Nations Framework Convention on Climate Change (Seddon et al., 2020).

In Ghana, tomato serves as a significant vegetable crop grown by numerous farmers in both rural and urban areas. The Techiman North Municipal region of Ghana has become a major tomato production area due to its fertile soils that are well-suited for tomato and other vegetable cultivation (Young, 2023). Farmers in this region engage in tomato production at varying scales, with some focusing on small-scale subsistence farming while others operate large-scale commercial farming. The livelihood of the majority of the people in the municipality is highly dependent on the cultivation of tomatoes.

High temperatures during the flowering stage cause tomato plants to drop their flowers, develop abnormally shaped blooms, and produce sterile pollen, which ultimately leads to reduced flowering success and poor fruit production (Johkan et al., 2011). Recent data from the Ministry of Food and Agriculture indicates that tomato production contributes approximately 7.2% to Ghana's horticultural subsector GDP (Poulton et al.2014). However, tomato farming in Ghana is predominantly rainfed, making it especially susceptible to climate-related changes and fluctuations (Nyantakyi-Frimpong, 2020). Tomato production, a vital component of Ghana's agricultural sector and food systems, has become increasingly vulnerable to these climate-related stressors, necessitating effective adaptation strategies to ensure sustainable livelihoods and food security (File et al., 2023).

Adaptation strategies have become critically important in discussions about climate variability, requiring farmers to implement nature-based approaches that combine responsive techniques and practices at individual farm levels. Adaptation is defined as adjusting to current or anticipated climate conditions and their impacts, aiming to minimize negative effects and take advantage of positive opportunities in human systems (Smit & Wandel, 2006). Key adaptation strategies available to farmers include intercropping systems, switching crop varieties, relocating farming operations, using agricultural chemicals, expanding into non-agricultural income sources, relocating to different areas, and growing diverse crop types (Bisbis et al., 2018).

Several nature-based adaptation strategies have been identified in climate variability discussions (Creswell & Creswell, 2017). These approaches can be categorized into two main types: those implemented directly on agricultural land, such as irrigation systems, fertilizer use, crop variety selection, soil conservation measures, and mulching techniques; and those that extend beyond the farm boundaries, including population migration, adjustments to planting schedules, and livestock management practices (Nhemachena & Hassan, 2007). All these strategies are implemented to help farmers cope with the costs and risks associated with the changing climate and to show resilience in improving their livelihoods (RodriguezSolorzano, 2014).

Adaptation strategies for nature-based tomato production directly support SDG 2 targets by enhancing the stability of food. Thorn et al. (2020) analysed the contribution of agroecological approaches in tomato systems across five countries to multiple SDG 2 indicators, finding that diversified systems employing NbS produced more stable yields during climate anomalies while improving nutritional outcomes through increased dietary diversity. A comprehensive assessment of SDG interactions in agricultural adaptation is critical for informed policy development. Rasul and Sharma (2016) mapped synergies and trade-offs between climate-smart agriculture practices in tomato systems and multiple SDGs, finding strong positive correlations between NbS approaches and SDGs 6 (Clean Water) and 13 (Climate Action). However, Van Zanten et al. (2014) identified potential short-term tradeoffs between yield maximization (SDG 2) and biodiversity conservation (SDG 15) during transition periods to NbS approaches, highlighting the need for targeted policy support during adaptation phases.

Ghana's National Climate Change Policy (NCCP) incorporated agricultural adaptation strategies with direct relevance to tomato production. These included the promotion of drought-resistant tomato varieties. Adeline et al. (2016) and Abass et al. (2018) found that while the policy framework was comprehensive, most small-scale tomato farmers had limited awareness of the specific programs and support available through Ghana's National Climate Change Policy. The Comprehensive Africa Agriculture Development Programme (CAADP), a continent-wide framework under the African Union, has influenced national policies for horticultural crops, including tomatoes, across Africa through Commitments to allocate at least 10% of national budgets to agriculture, Support for agricultural research and technology dissemination. Poulton et al. (2014) noted that while the Comprehensive Africa Agriculture Development Programme has been influential in shaping policy discourse, implementation has varied widely across countries, with some tomato-producing nations achieving greater success than others in translating CAADP principles into tangible support for farmers.

This research presents a novelty on nature-based solutions (NbS) for tomato farmers in Techiman North Municipal. This stands out by using the concept of "Adaptive Agroecological Networks." This concept integrates traditional ecological knowledge with modern climate science through community-based monitoring systems. This novel approach would: Establish farmer-scientist collaborative monitoring networks to track microclimate variables specific to tomato cultivation. This will also provide knowledge repositories that will preserve and validate indigenous adaptation techniques, and develop a mutual feedback system where empirical observations inform scientific models and vice versa. This concept is unique because it moves beyond conventional NbS approaches by emphasizing knowledge co-production rather than top-down implementation. It acknowledges farmers not merely as recipients of adaptation strategies but as active knowledge generators.

The framework would enable quantification of adaptation effectiveness through participatory metrics, addressing a critical gap in current NbS evaluation methodologies for smallholder farming systems. The Adaptive Agroecological Networks concept will directly enhance tomato yields for farmers in Techiman North Municipal through several specific mechanisms: the concept will help document effective indigenous conservation techniques combined with appropriate modern methods to reduce water stress during critical flowering and fruiting periods, potentially increasing marketable tomato yield.

The study provides a reliability study that uses a sequential explanatory design that begins with quantitative data collection, followed by qualitative inquiry to explain unexpected results (Creswell & Creswell, 2017). The innovation lies in incorporating indigenous knowledge systems throughout the research process rather than treating them as separate data sources. This approach will help generate effective nature-based solutions to improve tomato production among tomato farmers in Techiman North Municipality. As Nyantakyi-Frimpong (2020) demonstrates, this integration yields more contextually relevant findings in Ghanaian agricultural communities than conventional approaches.

1.2 Problem Statement

Tomato farming in Ghana's Techiman North Municipality is increasingly threatened by climate variability. Rising temperatures accelerate evapotranspiration, intensifying water stress during critical growth stages, while irregular rainfall patterns disrupt planting schedules and crop development cycles (Arfasa et al., 2023; Owusu-Sekyere & Aladago, 2023. High temperatures during flowering further reduce fruit set due to pollen sterility, resulting in yield losses (Johkan et al., 2011). These climatic stresses undermine farmers' livelihoods and food security, particularly because tomato production in Ghana is predominantly rainfed and highly sensitive to precipitation fluctuations (Nyantakyi-Frimpong, 2020).

Although nature-based solutions (NbS) such as agroforestry, mulching, intercropping, and rainwater harvesting have been promoted as sustainable adaptation strategies (CobenShachan et al, 2019; Seddon et al, 2020), their application in the tomato farming system remains fragmented. Farmers often rely on traditional coping techniques, such as shifting planting dates or increasing chemical inputs, which provide short-term relief but contribute to soil depletion, water pollution, and biodiversity loss (Altieri & Nicholls, 2017). The critical gap is the absence of empirically grounded evidence on which Nbs are most effective in the specific agroecological context of Techiman North Municipality. While studies in other regions have demonstrated the potential of NbS to enhance resilience and stabilize yields (Thorn et al, 2020; Rasul & Sharma, 2016), little is known about their effectiveness, adoption drivers, and constraints in Ghana's transition zone. Without such evidence, farmers, policymakers, and development partners lack the knowledge needed to prioritize strategies, allocate resources, and design interventions that strengthen resilience in tomato farming systems. This study, therefore, seeks to address this gap by statistically assessing the adoption, perceived effectiveness, and determinants of NbS among tomato farmers in Techiman North Municipality.

1.3 Research Objectives

1.3.1 General Objective

To assess the nature-based solutions adopted by tomato farmers in Techiman North Municipality as strategies for climate variability adaptation.

1.3.2 Specific Objectives

The specific objectives in the study were to:

i. Identify the range of nature-based climate variability adaptation strategies currently employed by tomato farmers.

ii. Analyse the factors that are influencing the adoption or choices of nature-based climate adaptation strategies by the farmers.

iii. Assess farmers' perceptions of the effectiveness of the identified nature-based climate adaptive strategies they employed in tomato farming.

iv. Provide recommendations for scaling up effective nature-based climate adaptive strategies to enhance resilience in the tomato farming system.

1.4 Research Questions

The study sought to find answers to the following questions:

i. What nature-based climate adaptation strategies are currently used by tomato farmers in Techiman North Municipality?

ii. What factors (environmental, socioeconomics, cultural, and institutional) influence the adaptation of nature-based climate adaptation strategies in tomato farming?

iii. How do farmers perceive the effectiveness of those identified nature-based adaptation strategies employed in tomato farming?

iv. What policy and practical measures can support the scaling up of effective nature-based adaptation strategies?

1.5 Justification and Significance of the Study

The study will contribute theoretically by integrating NbS frameworks with the smallholder adaptation literature and providing empirical evidence on how traditional and innovative nature-based practices function under real-world conditions in sub-Saharan Africa. Furthermore, it advances methodological approaches by developing assessment tools that can evaluate the effectiveness of multiple NbS simultaneously within smallholder farming systems, thereby enriching the discourse on climate-smart agriculture and offering comparative insights for similar Agro-ecological contexts across West Africa.

The findings will provide evidence-based recommendations crucial for developing targeted climate adaptation policies at local, regional, and national levels. Given Ghana's commitments under the Paris Agreement and its National Adaptation Plan (PANAP), this research offers practical insights into which nature-based solutions yield the most significant results for vulnerable farming communities. Policymakers will utilize these findings to design more effective agricultural extension programs, allocate resources efficiently toward proven

NbS interventions, and integrate farmer-tested strategies into district-level climate action plans.

This research will directly address farmers' livelihood concerns by documenting which adaptation strategies effectively reduce crop losses, stabilize yields, and improve income security. By assessing the practical effectiveness and accessibility of various nature-based solutions, the study empowers farmers with knowledge about proven techniques they can implement with available resources. Additionally, understanding successful adaptation pathways can help farmers make informed decisions about resource allocation, crop management practices, and risk mitigation strategies that protect their economic well-being and food security.

This study will examine how practices such as agroforestry, mulching, cover cropping, water harvesting, and biodiversity conservation contribute to soil health restoration, water retention capacity, and ecosystem functioning within tomato production systems. By assessing these environmental co-benefits, the research demonstrates how NbS can reverse land degradation, enhance soil organic matter, improve microbial activity, and create more resilient agroecosystems capable of withstanding climate stresses. The findings will illustrate how farmer-level actions contribute to broader landscape-scale environmental resilience, including watershed protection, carbon sequestration, and biodiversity preservation

This research will directly support multiple Sustainable Development Goals (SDGs), creating a strong justification for its societal importance. It will contribute to SDG 2 (Zero Hunger) by identifying strategies that enhance food production stability and improve nutrition security through increased vegetable availability. The study will advance SDG 13 (Climate Action) by documenting effective adaptation measures that build resilience among vulnerable agricultural communities. The research will also contribute to achieving African Union Agenda 2063 aspirations for sustainable agriculture and environmental management, demonstrating its relevance across multiple scales of development planning and making it a valuable investment in understanding pathways toward sustainable and resilient agricultural futures.

1.6 Scope and Limitations

This study assesses the nature-based solutions (NbS) as strategies to adapt to changing and unpredictable climate conditions among tomato farmers in the Techiman North Municipal area of Ghana. The geographical scope is limited to the Techiman North Municipal area, a significant tomato-producing region in Ghana's Bono East Region, which has experienced notable impacts of climate variability on agricultural productivity.

The research focused on four key tomato-producing communities in the Municipal (Tuobodom, Offuman, Aworowa, and Buoyam), which collectively account for the majority of tomato production in the area (Young 2023). Within this framework, the study examined and characterized the different types of natural climate variations and adaptation strategies among tomato farmers and also evaluated the factors that influence their choices, and then assessed the effectiveness of the identified nature-based adaptation strategies employed by the tomato farmers.

Due to budget limitations and time restrictions, the researcher was unable to include the majority of communities in the study area, despite originally planning for broader coverage across the district. Also, the study's focus on tomato farming in Techiman North Municipal may limit the generalizability of findings to other crops or regions with different agroecological conditions or socioeconomic contexts. Again, the assessment period may not fully capture the long-term effectiveness of certain nature-based solutions that require extended timeframes to demonstrate their full potential benefits, particularly those related to ecosystem restoration or biodiversity enhancement.

The cross-sectional approach provided valuable insights into current climate adaptation practices and nature-based solutions at a specific point in time; it has inherited limitations that should be acknowledged: The primary limitation is the inability to capture temporal dynamics and causality. Since data were collected at a single moment, the design cannot track how adaptation strategies evolve, how their effectiveness changes across seasons, or how communities modify their approaches in response to varying climate conditions.

Additionally, cross-sectional data provide a static view that may not reflect the adaptive learning processes communities undergo as they gain experience with nature-based solutions. To address these limitations, longitudinal or panel studies are strongly recommended for future research. Such designs would allow researchers to track seasonal variations in the effectiveness of nature-based solutions.

1.7 Organization of the Study

The structure of this thesis comprises five chapters, with the initial chapter serving as an introduction to the research, including the background, problem statement, research questions, objectives, significance, justification of the study, and scope of the study. The second chapter presents a comprehensive review of relevant literature, examining the theoretical perspective underpinning the research on nature-based climate adaptation, definitions and explanations of climate concepts and nature-based solutions, evidence of their effectiveness in agricultural systems in tomato production, climate variability and impacts on tomato production, and the factors influencing their adoption among smallholder farmers, etc. The third chapter outlines the research methodology and study area, including location and geography, vegetation and climate, agricultural activities, also research design, sampling procedures, data collection methods, analytical approaches, and ethical considerations.

The fourth chapter presents the results and findings of the study, organized according to the research objectives and questions. It also offers an in-depth analysis and discussions of these results, examining them within the context of current scholarship and conceptual models, while emphasizing their significance for comprehending and nature-based solutions approaches to climate adaptation. The fifth chapter presents the conclusion of the thesis with a summary of key findings, conclusions drawn from the research, recommendations for various stakeholders, acknowledgment of limitations, and suggestions for further research.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter endeavours to establish the study's academic context through an analysis of relevant scholarly works and research contributions from multiple authorities and scholars on nature-based solutions and adaptation strategies by tomato farmers. The researcher reviewed literature from numerous sources, including journal articles, books, newspapers, as well as dissertations and theses. These were obtained from multiple database sources such as Science Direct, Scopus, and Google Scholar, among others. This allowed the researcher to frame the problem correctly, resulting in enhanced understanding and greater insight into the matter under investigation.

2.2 Definitions and Explanations of Climate Concepts

2.2.1 Climate Change

Climate change represents a statistically meaningful and enduring modification in average climate conditions or their variability that continues over extended timeframes, usually spanning decades or more (Kader et al., 2017; Palm et al., 2014). This differs from natural climate variability, which encompasses typical fluctuations around average conditions, as climate change involves actual shifts in these average conditions themselves.

According to the United Nations Framework Convention on Climate Change [UNFCCC], climate transformation occurs through direct or indirect modifications to global atmospheric composition, beyond the natural climate variations observed during similar timeframes (Burton et al., 2002; Dawson & Spannagle, 2008). Arku (2009) provides a broader perspective, characterizing climate change as any temporal shift in climate patterns, whether resulting from natural processes, human influences, or a combination of both. The

Intergovernmental Panel on Climate Change (IPCC) similarly adopts an inclusive approach that considers both natural and human-induced factors.

In the IPCC's Sixth Assessment Report, climate change encompasses "any systematic change in the long-term statistics of climate variables such as temperature, precipitation, pressure, or wind sustained over several decades or longer," irrespective of the underlying cause (Werners et al., 2021). Modifications in extreme weather patterns offer further confirmation of climate change. Knutti and Rugenstein, (2015) reveal that "About 75% of the moderate daily hot extremes over land are attributable to warming," indicating that climate change enhances both the occurrence and severity of global heatwaves. Research also shows the amplification of extreme precipitation events across numerous regions, aligning with expectations for a warming planet (Allan & Soden, 2008).

2.2.2 Climate Variability

Climate Variability refers to natural changes and fluctuations in climate patterns that occur at different periods and geographic scales throughout Earth's climate system (Ghil et al., 2002). According to Trenberth et al. (2015) this concept encompasses the temporal changes that happen in the combined atmosphere-ocean system relative to average conditions. Researchers categorize climate variability into two primary types: internal and external sources. Internal sources originate from inherent mechanisms operating within the climate system, whereas external sources result from influences beyond the climate system, including changes in solar energy or volcanic activity (Bindoff et al., 2013). Deser et al. (2012) clarified that "Internal climate variability refers to variations in the mean state due to processes intrinsic to the coupled atmosphere-ocean-land system," emphasizing how interconnected natural processes create climate fluctuations.

The IPCC (2007) shares similar perspectives on climate variability, both highlighting its dimensional aspects. Climate variability can be understood through two fundamental categories: variations driven by internal climate system processes and those caused by external forcing factors. Climate variability operates across multiple timescales, from seasonal oscillations to millennial-scale changes. Intra-seasonal variability is associated with phenomena such as the Madden-Julian Oscillation (MJO), which affects weather patterns in the tropics over periods of 30-60 days (Z. Zhang et al., 2024).

2.2.3 Drivers of Climate Change

Climate change arises from a combination of natural phenomena and human activities. Natural factors encompass fluctuations in the sun's energy output, volcanic activity, and shifts in Earth's orbital patterns. (Milankovitch cycles). However, contemporary climate change is predominantly attributed to human activities, particularly greenhouse gas emissions (Stocker et al., 2014). Carbon dioxide (CO_2) represents the most significant human-caused greenhouse gas because of its high concentration levels and extended persistence in the atmosphere. As Friedlingstein et al. (2020) noted, "Anthropogenic CO_2 emissions have accumulated in the atmosphere, ocean, and land over the industrial period, with the atmosphere being the largest sink, followed by the ocean and then the land." By 2019, atmospheric CO_2 concentrations had reached 410 parts per million (ppm), approximately 47% higher than pre-industrial levels (Werners et al., 2021). Methane (CH_4) and nitrous oxide (N_2O) are also major contributors to human-caused climate change.

As reported by Saunois et al. (2019) Methane is a powerful greenhouse gas that traps 28 times more heat than carbon dioxide over a century-long period, even though it breaks down more quickly in the atmosphere than CO_2 does. Agricultural activities, fossil fuel production, and waste management represent primary sources of methane emissions (Saunois et al., 2019). Land-use changes, particularly deforestation and agricultural expansion, further contribute to climate change by reducing carbon sinks and altering surface albedo. As Pongratz et al. (2018) explain, "Land-use change affects climate through biogeochemical effects, mainly by altering atmospheric CO_2 concentration, and through biophysical effects, mainly by altering landsurface properties.

2.2.4 Climate Adaptation

Climate adaptation, as defined by the IPCC in 2014, refers to how societies and natural systems adjust to their climate behaviour and structures in response to current or anticipated climate change. For human communities, this adjustment process aims to minimize negative impacts from climate effects while also taking advantage of any positive outcomes that may arise. Climate adaptation refers to the modifications made by natural or human systems to cope with current or anticipated climate changes and their impacts, aiming to minimize negative effects while capitalizing on potential benefits (Smit & Wandel, 2006). This approach differs from mitigation strategies, as it concentrates on addressing the outcomes of climate change rather than tackling its root causes. In certain natural environments, human involvement may be necessary to help systems adjust to projected climatic conditions and their consequences. The UNFCCC provides a similar definition, describing climate adaptation as the process by which natural or human systems modify themselves in response to current or projected climate patterns and their impacts, thereby reducing harm and taking advantage of favourable circumstances (Burton et al., 2002).

The IPCC offers complementary perspectives on this concept. In 2007, the IPCC characterized climate adaptation as actions and strategies designed to decrease the susceptibility of both natural and human systems to the actual or anticipated effects of climate change. More recently, the IPCC refined this definition, describing adaptation as "the adjustment process to current or expected climate conditions and their consequences, aimed at reducing harm or leveraging beneficial opportunities (Werners et al., 2021)." This updated definition highlights the dual nature of adaptation, encompassing both responsive actions to climate impacts already being experienced and proactive measures based on future climate projections.

2.2.5 Nature-Based Solutions (NbS)

Nature-based solutions are strategies that utilize and strengthen natural systems to tackle social and environmental problems, simultaneously providing advantages for both human welfare and ecosystem diversity (Cohen-Shacham et al., 2019). The International Union for Conservation of Nature (IUCN) defined NbS as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (CohenShacham et al., 2016; Hess & McShane, 2013)." Seddon et al., (2020) classified NbS into three broad categories: (1) ecosystem protection approaches that maintain ecosystem services; (2) ecosystem management approaches that improve the sustainability of managed ecosystems; and (3) ecosystem restoration approaches that recover degraded ecosystems. In the agricultural context, Seddon et al., (2020) further categorized NbS into soil-focused, water-focused, and biodiversity-focused interventions, emphasizing their interconnectedness and potential synergies.

Within smallholder agricultural systems, NbS manifests as various practices that enhance resilience to climate change and variability. Antwi-Agyei et al. (2021) identified several NbS relevant to Ghanaian smallholder contexts, including agroforestry, conservation agriculture, integrated soil fertility management, and water harvesting techniques. These approaches leverage ecological processes to build resilience while maintaining or enhancing productivity. For tomato production specifically, Ouédraogo et al. (2017) highlighted the potential of NbS to address multiple climate-related challenges simultaneously. For instance, mulching serves to retain water in the soil, control unwanted plant growth, and maintain stable ground temperatures, while also enhancing soil organic matter over time. Similarly, agroforestry systems can provide shade, reduce evapotranspiration, and increase biodiversity, thereby mitigating the impacts of temperature extremes and pest outbreaks.

2.3 Tomato Cropping in Ghana

Tomato (Lycopersicon esculentum) serves as a significant vegetable crop in Ghana, playing a crucial role in the nation's socio-economic growth. The cultivation of tomatoes is predominantly concentrated in Ghana's Northern and Upper East regions, the Southern Volta Region, and important Middle Belt locations, including the Techiman North Municipal area and Wenchi Municipal in the Bono East and Bono Regions, respectively (Young, 2023). Tomato farming in Ghana plays an essential role in the country's agricultural sector, functioning as both a crucial food security staple and an important income source for smallscale farmers operating across various ecological regions (Adimabuno, 2010). While Ghana faces the combined pressures of nourishing its expanding population and responding to climate change and variability impacts, tomato cultivation has become a central focus for agricultural development programs. However, Ghana's tomato demand exceeds domestic production capacity, requiring imports from surrounding nations to satisfy local market requirements (Asante et al., 2016; Etwire, 2020).

Current research presents a multifaceted picture of Ghana's tomato farming sector, highlighting both encouraging production developments and ongoing obstacles that challenge the industry's long-term viability. Data from the Ministry of Food and Agriculture (MoFA) indicates that Ghana produced approximately 420,000 tons of tomatoes in 2019 across 47,000 hectares of cultivated land, with market values demonstrating recent improvement following a three-year downturn (Adams et al., 2020). By 2024, Ghana's tomato market expanded by 4.9% to reach $145 million, indicating revitalized sector growth despite existing limitations. Market values grew at an average yearly rate of +2.4% between 2012 and 2024, maintaining consistent growth patterns even with notable variations (Adams et al., 2020). Nevertheless, technical efficiency research indicates substantial opportunities for enhancement, particularly in Northern Ghana, where production limitations prevent optimal harvest outcomes (Etwire, 2020). The susceptibility of tomato farming to climate fluctuations encompasses more than basic weather variations, involving comprehensive ecological disturbances. Continuous production methods, single-crop farming approaches, and genetically similar hybrid cultivars planted across extensive areas lead to pest accumulation and recurring pest outbreaks, generating additional climate-associated production hazards.

2.4 Climate Variability and Impacts on Tomato Production

2.4.1 Susceptibility of the Tomato Crop to Climatic Factors

Tomatoes rank among the most extensively grown vegetable crops globally, with production spanning diverse agroecological zones (Arah, et al. (2015) and Kumah al.(2015). However, its physiological characteristics render it particularly sensitive to climate variability. Hatfield & Prueger (2015) documented that tomatoes have specific temperature thresholds for optimal growth, with ideal ranges between 18-29°C for most varieties. Temperatures outside this range can significantly impact fruit set, ripening processes, and overall yields.

Water availability represents another critical factor influencing tomato production vulnerability. Bisbis et al. (2018) analysed water requirements of tomato crops across different growth stages and found that both water deficit and excess can negatively impact yields, though the effects vary depending on the timing and intensity of stress. Their comprehensive review indicated that mild water stress during vegetative growth might enhance fruit quality parameters such as soluble solids content, while high levels of stress or flooding at any stage generally reduce marketable yields.

Temperature effects also significantly impact tomato production systems. Kugblenu et al. (2013) and Osei-Bonsu et al. (2022) demonstrated that tomato varieties commonly grown in Ghana experience optimal growth and fruit development between 18-27°C, with significant physiological stress occurring above 32°C. Their controlled trials showed that exposure to temperatures exceeding 35°C for just 3-4 consecutive days during flowering reduced fruit set by up to 70% in commonly grown varieties. With temperature exceedances becoming more frequent in the region, this represents a substantial vulnerability. The interaction between temperature and water availability further complicates the vulnerability assessment of tomato crops. Lamaoui et al. (2018) demonstrated that high temperatures exacerbate drought effects by increasing evapotranspiration rates and plant water demand. Their field experiments with multiple tomato varieties demonstrated that the simultaneous effects of heat stress and lack of rainfall diminished yields by 40-65%, significantly more than either stressor alone.

2.4.2 Climate Trends and Projections in Ghana

Ghana's climate has undergone significant changes in recent decades, with observable shifts in temperature and precipitation patterns. According to Boamah et al. (2024) The average yearly temperature in Ghana has gone up by approximately 1°C since 1960, with projections suggesting further warming of 1.5-3°C by 2050, depending on emissions scenarios. Rainfall patterns demonstrate increasing variability, with changes in seasonal distribution rather than total annual precipitation being the most problematic for agricultural planning (Yengoh et al., 2010).

For Ghana specifically, Mensah (2023) documented an increasing frequency of midseason dry spells during critical growing periods, with their analysis of 30-year meteorological data revealing a 27% increase in dry spell frequency during the minor rainy season, which coincides with important tomato production windows. These changes manifest in delayed onset of rains, irregular distribution, and more frequent, intense rainfall events separated by longer dry periods, all presenting significant challenges for rainfed agriculture, particularly for moisture-sensitive crops like tomatoes (Amisigo et al., 2015).

Climate projections for Ghana's middle belt, where Techiman North is situated, indicate continued warming trends with annual mean temperature data increases of 2.1°C by the 2050s under moderate emissions scenarios (Boamah et al., 2024). Precipitation projections show greater uncertainty but consistently predict increased variability and more frequent extreme events, with particular concerns for the transitional zone where Techiman North lies (AntwiAgyei et al., 2021). These forecasts underscore the critical need for robust adaptation approaches that can effectively handle both gradual changes in agricultural conditions and more frequent, severe weather events.

2.4.3 Projected Climate Impacts on Global Tomato Production

Regional modelling studies have attempted to project the future effect of change in climate in tomato production across other geographies. Bisbis et al. (2018) synthesized findings from multiple modelling studies and concluded that climate change impacts on tomato yields would likely be geographically heterogeneous, with potential yield increases in currently cool regions and substantial decreases in already warm areas. Their analysis of 25 simulation studies showed projected yield reductions of 10-30% in Mediterranean regions by 2050 under medium emission scenarios.

Challinor et al. (2016) employed ensemble modelling approaches to assess climate change impacts on multiple crops, including tomatoes. Their meta-analysis of 1,700 published simulations suggested that without adaptation measures, global tomato yields could decline by an average of 7.6% for each degree Celsius of warming, with greater impacts in tropical regions. However, they noted substantial uncertainty in these projections, particularly regarding the potential benefits of elevated CO_2 concentrations. More recent studies have incorporated additional climate variables beyond temperature and precipitation into impact models. Pham et al. (2020) included solar radiation changes and humidity effects in their evaluation of climate impacts on tomato production in Southeast Asia. Their analysis indicated that changes in diurnal temperature range and humidity levels might affect disease pressure and fruit quality parameters even more significantly than mean temperature changes in some regions.

2.4.4 Climate Impacts on Tomato Farming Communities

Beyond modelling studies, empirical research has documented how climate variability is already affecting tomato farming communities. Fadina & Barjolle (2018) conducted a comprehensive survey of 200 tomato farmers in West Africa and found that 87% reported experiencing negative impacts from changing climate patterns, including decreased yields (reported by 76%), increased pest pressures (68%), and declining fruit quality (53%). Their mixed-methods approach revealed that farmers primarily attributed these changes to increasingly erratic rainfall patterns and more frequent heat waves. Ethnographic work by Davidson (2016) in Central America documented how climate variability has disrupted traditional tomato farming calendars and knowledge systems. Through extensive interviews with 45 tomato farmers across three countries, Davidson found that unpredictable seasonal transitions had undermined traditional planting indicators and timing strategies passed down through generations, creating new uncertainties for farming communities.

Socioeconomic impacts of climate variability on tomato value chains have been examined by Rao et al. (2020), who analysed price volatility data from major tomatoproducing regions in Asia. Their time-series analysis revealed increasing price volatility correlated with extreme weather events, with economic impacts extending beyond farmers to affect processors, distributors, and consumers. The research highlighted how climate-induced supply disruptions propagate through food systems, creating complex adaptation challenges. Tomato (Solanum lycopersicum) cultivation represents a vital component of both food security and livelihood strategies in Ghana, particularly in the middle belt of Ghana.

Antwi-Agyei & Nyantakyi-Frimpong (2021) identified critical climate-related stressors affecting tomato production in Ghanaian communities, categorizing them as direct biophysical impacts and indirect socioeconomic effects. Direct impacts include heat stress during flowering (reducing fruit set), irregular water availability (causing blossom end rot and fruit cracking), and increased pest and disease pressure under changing climatic conditions. Their mixed-methods research across four regions of Ghana. Huang et al. (2021) further highlighted the paradoxical challenge faced by tomato farmers who must contend with both water scarcity during dry spells and excessive moisture during heavy rainfall events, sometimes within the same growing season.

Temperature effects also significantly impact tomato production systems. Boamah et al. (2024) demonstrated that tomato varieties commonly grown in some parts of Ghana experience optimal growth and fruit development between 18-27°C, with significant physiological stress occurring above 32°C. Their controlled trials showed that exposure to temperatures exceeding 35°C for just 3-4 consecutive days during flowering reduced fruit set by up to 70% in commonly grown varieties. With temperature exceedances becoming more frequent in the region, this represents a substantial vulnerability.

Disease and pest dynamics present additional climate-linked challenges. Mensah, (2023) documented shifting patterns of tomato diseases in Ghana's middle belt, noting the increased incidence of fungal pathogens, including early and late blight, during periods of fluctuating humidity. These multiple stressors interact with socioeconomic vulnerabilities, creating complex challenges for tomato farmers. Antwi-Agyei & Nyantakyi-Frimpong (2021) emphasized that climate impacts on tomato production have disproportionate effects on different farmer demographics, with female-headed households and people who have restricted access to financial resources demonstrating reduced adaptive capacity.

2.5 Adaptation to Climate Change and Variability

2.5.1 Conceptual Framework of Climate Adaptation

The conceptual understanding of climate adaptation has undergone significant changes in recent decades. Early approaches often conceptualized adaptation as an engineering or technological solution designed to address particular climate-related effects (Burton et al., 2002). However, more scholars have emphasized adaptation's social, economic, and political dimensions. Brooks et al. (2005) characterize adaptation as modifications made within ecological, social, or economic systems to respond to actual or anticipated climate-related changes and their consequences to reduce harmful effects or capitalize on beneficial possibilities. This highlights the multidimensional nature of adaptation, which encompasses both reactive responses to experienced climate impacts and anticipatory measures based on projected changes.

Literature distinguishes between autonomous adaptations, which occur spontaneously in response to climate stimuli, and planned adaptations, which result from deliberate policy decisions (Smit & Wandel, 2006). Furthermore, adaptations can be categorized as incremental adjustments to existing practices or transformational changes that fundamentally alter systems and structures (Kates et al., 2012). Noble (2015) and Frantzeskaki et al. (2019) argue that while incremental adaptations may be sufficient in the short term, transformational adaptations will become increasingly necessary as climate impacts intensify.

Adaptive capacity, which refers to how systems, institutions, and individuals can modify their responses to minimize harm, capitalize on new possibilities, or manage the effects of change, is fundamental to comprehending how adaptation occurs (Roco et al., 2017). The ability to adapt is shaped by various elements such as financial resources, technological capabilities, knowledge and expertise, physical infrastructure, institutional frameworks, and social equity (Brooks et al., 2005a; Yohe & Tol, 2002). Research has emphasized the importance of social capital, governance structures, and power relations in shaping adaptive capacity across different contexts (Brooks et al., 2005b; Pelling & High, 2005).

2.5.2 Agricultural Adaptation Strategies

Agriculture faces heightened susceptibility to climate fluctuations because of its dependence on climatic conditions. Numerous studies have documented adaptation strategies employed by farmers worldwide (Rost et al., 2009). Crop diversification has emerged as a common adaptation to spread risk and enhance resilience to climate variability (Howden et al., 2007; Ji et al., 2011). For instance, Altieri & Nicholls (2017) found that diversified farming systems in Latin America demonstrated greater resilience to extreme weather events compared to monoculture systems. Changes in planting dates and crop varieties represent another widespread adaptation strategy. Challinor et al. (2014) documented how farmers across sub-Saharan Africa have adapted their agricultural practices by adjusting when they plant crops to align with altered precipitation patterns. In related research, Challinor and colleagues performed a comprehensive review and statistical analysis of multiple studies examining crop productivity outcomes, which concluded that switching to varieties with greater heat tolerance could significantly reduce climate-related yield losses in many regions (Challinor et al., 2014, 2016).

Water management techniques, including irrigation systems, water harvesting, and soil moisture conservation, constitute important adaptation strategies in both rainfed and irrigated agricultural systems (Rost et al., 2009). Rockström et al. (2012) demonstrated how smallscale water harvesting techniques improved crop yields and reduced vulnerability to drought in East African farming systems. Similarly, Berbel et al. (2018) analysed the adoption of drip irrigation technology in Mediterranean agriculture and found significant improvements in water use efficiency, though they noted that increasing irrigation efficiency sometimes led to expanded cultivation rather than reduced water consumption.

Institutional and policy interventions also function as vital components in farming adaptation. Perrin (2009) identify different types of adaptation practices facilitated by institutions, including transferability, preservation, varieties, group collaboration, and trading. Agricultural insurance schemes have gained attention as a risk management tool, though their effectiveness depends on design and implementation (Greatrex et al., 2015). Vermeulen et al. (2012) argue that while technical adaptations are important, transformative changes in agricultural systems, markets, and policies are necessary for long-term resilience to climate change.

2.5.3 Community-Based Adaptation Approaches

Community-based adaptation (CBA) has gained prominence as an approach that emphasizes local knowledge, participatory processes, and context-specific solutions. CBA is particularly relevant in settings where centralized adaptation planning may be limited by resource constraints or institutional capacity. Reid et al. (2013) characterize CBA as an approach driven by local communities themselves, grounded in their own identified priorities, requirements, existing knowledge systems, and available resources. This framework is designed to strengthen communities' ability to prepare for and manage climate change effects through their own planning and decision-making processes. This approach recognizes that communities have been adjusting to environmental changes for generations and possess valuable knowledge and experience that can inform adaptation efforts.

Empirical studies have documented diverse CBA initiatives across different contexts. Purcell (2020) identified key factors contributing to successful CBA, including strong local institutions, secure resource rights, and links to higher-level support systems. Similarly, McNamara & Buggy (2017) review CBA projects in vulnerable island states and highlight the importance of integrating scientific and local knowledge, addressing underlying vulnerabilities, and ensuring long-term institutional support.

However, CBA approaches also face challenges and limitations. Kirkby et al. (2018) caution against romanticizing "community" and emphasize the need to recognize power dynamics and differences within communities. They argue that effective CBA requires attention to intra-community inequalities and linkages to broader structural changes. Furthermore, Forsyth (2013) Raises questions whether CBA can deal with the fundamental reasons for susceptibility, which often lie in broader political and economic structures. The incorporation of CBA with national and international adaptation efforts represents an ongoing challenge. Nalau et al. (2018) analyses the tensions between locally-driven adaptation processes and requirements for standardized strategic planning and progress reporting across domestic and global scales. They argue for approaches that can bridge these scales while maintaining the core principles of community participation and ownership.

2.5.4 Assessing and Evaluating Adaptations

Measuring the effectiveness of adaptation remains challenging due to conceptual and methodological difficulties. As Ford et al. (2013) noted, the absence of a shared understanding regarding what qualifies as 'successful' adaptation “complicates efforts to develop standardized metrics," highlighting the subjective nature of adaptation assessments. The tracking adaptation and measuring development (TAMD) framework, for example, assesses both the processes of adaptation and their outcomes in terms of development benefits (Brooks et al., 2005b).

According to Brooks et al. (2005b, 2005a), TAMD "enables the assessment of adaptation success as a function of how successfully climate risks are handled, and well development proceeds in a living example of climate consequences. Recent advances in adaptation metrics focus on measuring adaptive capacity, reducing vulnerability, and cobenefits for sustainable development. As Berrang-Ford et al. (2021) and Ford et al. (2013) argue, "Tracking adaptation progress requires metrics that capture multiple dimensions, including adaptation readiness, adaptation needs, and adaptation actions," emphasizing the need for comprehensive evaluation frameworks.

2.5.5 Limitations and Constraints to Adaptation

Despite its importance, adaptation faces numerous barriers and limits. Barriers refer to factors that hinder adaptation efforts but can still be addressed with additional effort, resources, or changes in thinking. According to Moser & Ekstrom (2010), adaptation challenges can be categorized as "institutional, attitudinal, financial, political, adaptation knowledge/information related," highlighting the diverse challenges to implementing adaptation measures. Limits to adaptation represent thresholds beyond which adaptation cannot prevent intolerable risks. Adaptation limits are explained as "thresholds beyond which existing adaptation strategies cannot protect things that societal stakeholders value from intolerable risk" (Pelling et al., 2015), indicating points at which transformational changes become necessary.

Financial constraints represent a significant barrier, particularly in developing countries. As noted by Moser & Ekstrom (2010). Governance challenges also impede adaptation efforts. Biesbroek et al. (2013) identified institutional crowdedness and institutional void, conflicting timescales, and lack of multi-level governance coordination" as key governance barriers, emphasizing the need for institutional reforms to facilitate effective adaptation.

2.5.6 Socio-Technical Transitions and Adaptation Pathways

Climate change adaptation strategies in agricultural systems can be conceptualized as a socio-technical transition requiring changes in technologies, practices, knowledge systems, and organizational structures. Patterson et al. (2017) applied the Multi-Level Perspective framework to analyse agricultural transitions toward climate resilience, identifying how niche innovations, regime dynamics, and landscape pressures interact to facilitate or constrain adaptation processes. This framework helps explain why certain nature-based solutions gain traction in some contexts but face barriers in others.

The concept of adaptation pathways has gained prominence for understanding how adaptation options evolve under different climate and socioeconomic scenarios. Werners et al. (2021) developed an adaptation pathways approach specifically for agricultural systems that incorporates climate uncertainties, adaptation thresholds, and decision points. Their framework emphasizes how early adaptation decisions can either enable or constrain future options, highlighting the importance of flexible, adaptive management approaches. Applied to tomato farming, this suggests the value of integrating immediate solutions like mulching with longer-term approaches like developing climate-resilient varieties.

Adaptation to climate variability in agricultural systems inevitably involves knowledge generation, integration, and application processes. Sumane et al. (2018) examined how different knowledge systems, including scientific, farmer, indigenous, and hybrid knowledge, contribute to agricultural innovation and adaptation. Their research across European farming systems demonstrated that successful adaptation often involves the co-production of knowledge that bridges traditional and scientific understanding. For tomato farming, this implies the value of combining farmers' experiential knowledge about local microclimates with scientific insights on crop physiology under stress conditions.

2.6 Nature-Based Solution Strategies for Tomato Production

2.6.1 Soil Management Practices

Sustainable farming methods, including limited ploughing and leaving plant debris on the soil surface, have been examined for their benefits in maintaining soil structure, enhancing water infiltration, and reducing erosion during extreme rainfall events (Palm et al., 2014).

Martin-Gorriz et al. (2020) conducted a ten-year study in Mediterranean tomato systems and found that conservation tillage practices resulted in a 23% increase in soil organic carbon relative to conventional tillage approaches. while improving water holding capacity by 1520% and reducing erosion rates by more than 50% during extreme rainfall events. Soil organic matter enhancement strategies have demonstrated particular promise for building resilience in tomato production. Scotti et al. (2015) conducted field trials comparing various organic amendments in tomato systems and found that compost applications at 20 tons/ha increased water holding capacity by 25% and reduced irrigation requirements by approximately 15% during drought periods.

Their controlled experiments also demonstrated that enhanced organic matter improved soil structure resilience to both drought and heavy rainfall events, minimizing the harmful effects of climate change extremes on root development and nutrient availability. Biochar applications have emerged as another promising soil-based adaptation strategy. Vaccari et al. (2015) conducted field trials with biochar amendments in tomato cultivation and documented yield increases of 15-25% compared to control plots, with particularly pronounced benefits during water-limited conditions. Their analysis indicated that biochar's water retention properties and ability to reduce nutrient leaching provided resilience benefits during both drought and heavy rainfall events. However, Abdul-Aziz et al. (2025) cautioned that biochar performance is highly dependent on production methods, application rates, and soil types, underscoring the need for context-specific implementation guidelines.

2.6.1.2. Mulching and Cover Cropping

Mulching is the practice of applying a layer of material over the soil surface to protect and improve the growing environment for plants, which can be organic (plant residues, compost, straw) or inorganic (plastic films, gravel) to modify soil conditions and protect crops (Kader et al., 2017). Each type of mulch offers distinct benefits for climate adaptation in tomato production. Organic mulches enhance soil composition, boost moisture retention, and improve soil quality and biological activity, while plastic mulches primarily control soil temperature and suppress weeds (Steinmetz et al., 2016).

A comprehensive review by Kasirajan & Ngouajio (2012) highlighted that biodegradable mulches offer similar agronomic benefits to conventional plastic mulches while reducing environmental pollution. Recent advances in biodegradable mulch technology have addressed earlier limitations related to premature degradation and insufficient durability (Ding et al., 2022). One of the primary mechanisms through which mulching aids climate adaptation is soil temperature regulation. Tomatoes are sensitive to both excessive heat and cold, with optimal growing temperatures between 21-24°C (Hatfield and Prueger, 2015). Mulumba & Lal (2008) found that straw mulch reduced soil temperature by 3-5°C during summer months, preventing heat stress in tomato plants.

Conversely, black plastic mulch increased soil temperature by 2- 4°C in spring, allowing earlier planting in cooler climates (Lamont, 2017). Recent studies have explored the performance of different mulch types under extreme temperature conditions. Wittwer (2018) and Ding et al. (2022) demonstrated that white plastic mulch outperformed black plastic in preventing heat stress during heatwaves, resulting in 15-20% higher marketable yields. This finding underscores the importance of selecting appropriate mulch materials based on projected climate scenarios.

Mulching represents one of the most widely adopted nature-based solutions among tomato farmers in Ghana. Adombilla et al. (2024) documented various mulching materials used, including rice straw, dried grass, and synthetic mulching materials, which have different impacts on soil characteristics and crop performance. Their study found that organic mulches boosted the soil's moisture-holding capacity by 22-35% compared to the control unmatched plots during dry spells, resulting in 28% higher tomato yields. Cover cropping, although less common than mulching, has shown promising results in experimental studies. Mensah (2023) evaluated leguminous cover crops (cowpea and mucuna) in tomato production systems in the Bono region and reported improvements in soil structure, water infiltration, and nitrogen availability. Specifically, Mucuna cover crops reduced soil erosion by 45% during heavy rainfall events and contributed to 15-20% improved tomato production compared to conventional plots.

Cover crops encompass a diverse range of plant species, each offering specific benefits for climate adaptation in tomato farming systems (Blanco-Canqui et al., 2015). Nitrogenfixing cover crops like hairy vetch (Vicia villosa) and crimson clover (Trifolium incarnatum) fix atmospheric nitrogen, reducing fertilizer requirements and associated global warming gas outputs (Poffenbarger et al., 2015). Grasses like cereal rye (Secale cereale) and oats (Avena sativa) excel at carbon sequestration and erosion control due to their extensive root systems (Finney et al., 2016). Recent research has focused on optimizing cover crop mixtures for multiple ecosystem services. Finney et al. (2016) demonstrated that diverse cover crop mixtures containing both legumes and grasses provided more consistent benefits across varying climate conditions than monocultures. For tomato production specifically, Kader et al., (2017) and Araki (1998) found that combinations of hairy vetch and cereal rye improved both nitrogen availability and soil structure compared to single-species plantings.

2.6.1.3 Conservation Tillage

Conservation tillage encompasses a range of practices that minimize soil disturbance and maintain crop residues on the soil surface. These practices include no-tillage, minimum tillage, strip tillage, and mulch tillage (Derpsch, 2003). The primary objective is to reduce soil erosion, retain soil water, and enhance soil quality and health, all of which are increasingly important under changing climate conditions. According to Hobbs et al. (2008) conservation tillage refers to tillage practices that leave a minimum of 30% crop residue covering the soil surface following planting operations. This definition has been widely adopted in agricultural research and extension programs. For tomato cultivation specifically, conservation tillage typically involves reduced soil disturbance during bed preparation and maintaining plant residues between rows (Mitchell et al., 2017).

Conservation tillage practices, involving reduced tillage and no-tillage systems, offer potential benefits for climate adaptation in tomato production. Owusu-Sekyere & Aladago (2023) reported that approximately 23% of tomato farmers practiced some form of conservation tillage, primarily motivated by reduced labour requirements and observed improvements in soil structure. However, the same study noted challenges related to weed management and initial yield reductions during the transition period. These findings suggest the need for integrated approaches that combine conservation tillage with other complementary practices, such as mulching and appropriate weed management strategies.

2.6.1.4 Integrated Soil Fertility Management

Integrated soil fertility management (ISFM) blends organic and inorganic fertilizers to maximize soil productivity and nutrient efficiency while maintaining soil health. Ouédraogo et al. (2017) documented various ISFM practices among tomato farmers in Ghana, including applying compost, animal manure, and crop residues in combination with judicious use of mineral fertilizers. A comparative study by Kyei-Mensah et al. (2019) found that tomato plots managed with ISFM approaches demonstrated greater resilience to rainfall variability compared to plots receiving only mineral fertilizers. Specifically, ISFM plots maintained 32% higher yields during seasons with below-average rainfall and showed reduced incidence of blossom end rot is a plant problem caused by not having enough calcium and inconsistent watering.

Despite such benefits, the adoption of ISFM practices faces several constraints. Yeboah et al. (2024) identified limited access to quality organic inputs, insufficient knowledge

about optimal combinations, and high labour requirements as key barriers to ISFM adoption among smallholder tomato farmers in Ghana. These limitations highlight the need to tackle both technological challenges and economic and social issues when working to advance nature-based soil management practices. Organic matter management is central to ISFM implementation in tomato production. Research by Adekiya et al. (2020) demonstrated that incorporating poultry manure at 10 t/ha significantly improved soil physical properties and crop yield under inconsistent rainfall distribution in the West African region. Similarly, Bationo et al. (2007) found that combining compost with reduced rates of mineral fertilizers improved tomato resilience to drought stress while maintaining comparable yields to conventional fertilization. The application of crop residues as mulch has shown particular promise for tomato cultivation under climate stress. Mulching helps retain water in the soil, controls soil temperature fluctuations, and prevents weed growth, all of which are crucial for tomato performance under erratic rainfall and temperature extremes (Mutetwa & Mtaita, 2014). Straw mulch reduced soil temperature fluctuations by 2-4°C and increased water use efficiency by 15-20% in tomato fields exposed to heat stress (ur Rehman et al., 2025). Balanced nutrient management is essential for optimizing tomato productivity under climate change. These three elements, nitrogen, phosphorus, and potassium, are essential for healthy plant function, with their availability and uptake often affected by climate-related stresses (File et al., 2023). Site-specific nutrient management was identified as an effective approach for addressing agricultural stresses, according to research by Zhang (2013). Based on soil testing, improved tomato yields by 15-25% compared to blanket fertilizer recommendations across diverse climate conditions. Micronutrient management has gained increased attention in ISFM for climate adaptation. Boron, zinc, and calcium deficiencies in tomatoes are often exacerbated by climate stresses, affecting fruit quality and yield stability
(Dimkpa & Bindraban, 2016).

2.6.2 Water Management Approaches

Efficient water management represents a critical adaptation domain for tomato production under climate variability. Rainwater harvesting systems have been evaluated across diverse contexts, from small-scale farm ponds to landscape-level approaches. Kahinda & Taigbenu (2011) documented how in-field rainwater collection systems in arid and semiarid zones boosted accessible water resources for tomato production by 30-45% during critical growth stages. Their comparative analysis of five water harvesting approaches revealed that combining micro-catchments with mulching provided the most cost-effective benefits for smallholder tomato producers.

Precision irrigation technologies have been widely studied for their adaptation benefits. Ćosić et al. (2015) conducted field experiments comparing drip irrigation regimes in tomato production and found that deficit irrigation strategies, where water application is strategically reduced during less sensitive growth stages, maintained 90-95% of potential yields while reducing water use by 25-30%. Their research demonstrated how precision irrigation could transform water constraints from a threat to an opportunity for improving water use efficiency. Some researchers have focused on nature-inspired water management approaches that mimic natural hydrological processes. Liang et al. (2019) evaluated subsurface water retention technology using membranes that create a moisture reservoir within the root zone of tomato crops. Their three-year field study showed that this biomimetic approach reduced irrigation requirements by 40-60% while maintaining comparable yields to conventional irrigation, suggesting significant potential for regions facing increasing water scarcity.

2.6.2.1 Rainwater Harvesting

Rainwater harvesting offers significant potential for addressing water scarcity challenges in tomato production. Kahinda & Taigbenu (2011) and Raimondi et al. (2024)

documented various rainwater harvesting techniques employed by farmers in Ghana's transition zone, including small farm ponds, contour bunds, and roof catchment systems. Their analysis revealed that access to harvested rainwater allowed farmers to bridge dry spells during critical crop development stages, reducing yield losses by 25-40% during seasons with irregular rainfall distribution.

Sturm et al. (2009) demonstrated that small-scale rainwater harvesting systems could supply 30-60% of irrigation water needs for tomato production in semi-arid regions, reducing dependency on groundwater resources that are increasingly vulnerable to change and variability impacts. Research by Huang et al. (2021) showed that farm ponds collecting runoff from 1-2 ha catchments could provide supplemental irrigation for tomato cultivation during dry spells, increasing yields by 50-100% compared to rainfed production. Combining rainwater harvesting with efficient irrigation systems, like drip irrigation systems, can additionally improve the effectiveness of water utilization. Oweis & Hachum (2006) reported water productivity improvements of 100-200% when harvested rainwater was applied through drip systems compared to traditional irrigation system methods.

Mensah (2025) found that approximately 18% of tomato farmers had implemented some form of rainwater harvesting, with adoption rates higher among farmers with previous experiences of crop failure due to drought. The same study identified significant constraints to wider adoption, including high initial investment costs, land tenure insecurity, and technical knowledge gaps. These findings highlight the need for financial assistance and technical guidance mechanisms to facilitate the implementation of rainwater harvesting systems among resource-constrained farmers.

2.6.2.2 Soil and Water Conservation Structures

Agricultural management practices that help preserve soil and water resources include tillage, crop rotation, and organic amendments. Conservation tillage minimizes soil disturbance, and no-till farming practices help preserve soil structure and organic matter content. According to a comprehensive review of 174 research studies, no-tillage systems resulted in soil organic carbon increases of 3.15 ± 2.42 tons of carbon per hectare across 20 years when compared to traditional tillage methods (Bai et al., 2019). Crop rotations that include legumes enhance soil nitrogen while diversifying root architectures and residue inputs. This diversity promotes soil biodiversity and carbon stabilization mechanisms. Carbon sequestration rates range from 0.2 to 0.6 metric tons of carbon per hectare annually (Uli et al., 2017). Organic amendments such as compost and biochar directly add carbon to soils while improving physical properties. Biochar applications have demonstrated carbon sequestration potentials of 0.4-2.2 tons C/ha/year, with residence times exceeding centuries for stable carbon fractions (Scotti et al., 2015; Shahhoseini et al., 2023).

Soil and water conservation encompasses a diverse set of practices designed to protect soil resources, prevent erosion, enhance water infiltration, and improve overall landscape functionality (Liniger & Critchley, 2008). These interventions range from physical structures like terraces and check dams to biological measures, including practices like cover cropping and agroforestry, through improving soil health and optimizing water management. Soil and water conservation practices offer multiple pathways to address both reducing climate change and adjusting to its effects.

Climate change intensifies the hydrological cycle, increasing the rate of severe weather precipitation and long-lasting water shortages (Werners et al., 2021). A participatory research study by Adombilla et al. (2024) identified farmer-led innovations in soil and water conservation, including modified ridge designs that channelled excess water away from tomato plants during heavy rainfall while retaining moisture during dry periods. These indigenous innovations demonstrated the importance of building upon local knowledge and practices when promoting nature-based water management approaches.

2.6.2.3 Efficient Irrigation Systems

Efficient irrigation systems represent another important component of water management strategies for tomato production. Asamoah et al. (2023) evaluated various lowcost irrigation options for smallholder tomato farmers in Ghana, including drip irrigation using recycled materials, clay pot irrigation, and gravity-fed systems utilizing harvested rainwater. Their analysis found that drip irrigation reduced water usage by 40-60% compared to traditional watering methods while improving yield stability during dry periods. Despite the potential benefits, the adoption of efficient irrigation systems among tomatoes remains limited. Key barriers include high initial costs, limited technical support, and unreliable water sources (Antwi-Agyei et al., 2021). These constraints highlight the requirement for comprehensive strategies that tackle both the technological and socioeconomic dimensions of irrigation adoption among smallholder farmers (Antwi-Agyei & Amanor, 2023; Atta-Aidoo et al., 2022).

Drip irrigation systems reduced water by 30-50% compared to surface irrigation methods while maintaining or improving tomato yields (Sammis, 1980). When combined with deficit irrigation strategies, water productivity increased by 60-80% (Patanè et al., 2011). Irrigation timing guided by sensors increased water use efficiency by 20-40% compared to fixed-interval irrigation in tomato production (Jones, 2004). Soil moisture sensors, coupled with weather-based evapotranspiration models, allow for precise water application based on actual crop needs. A study by Yaghi et al. (2013) found that subsurface drip irrigation further reduced water use by 15-25% compared to surface drip systems while increasing tomato yields by 10-15% due to reduced surface evaporation and improved root zone moisture distribution.

2.6.3 Agroforestry and Biodiversity-Based Approaches

Tomatoes grown in agroforestry systems with partial shade from trees showed 15-30% higher yields compared to open-field cultivation during extreme heat events (Tálamo et al., 2015). The microclimate modification provided by trees (reduced air temperature, increased humidity) can significantly mitigate heat stress impacts on tomato physiological processes. Windbreaks composed of native tree species reduced wind speeds by 30-50% and decreased evapotranspiration rates by 10-20% in vegetable production systems, including tomatoes (Cleugh, 1998). This protection becomes increasingly valuable as climate change intensifies drought conditions in many regions. Pumariño et al. (2015) found that tomato plants grown in agroforestry systems had 30-45% fewer pest incidents compared to monoculture systems, attributing this to increased natural enemy populations supported by the diverse habitat structure. Enhancing biodiversity within tomato production systems represents another category of nature-based solutions with adaptation benefits. Polyculture and intercropping systems have been extensively studied for their resilience advantages. Salgado et al. (2021) conducted field trials comparing tomato monocultures with various intercropping arrangements and found that tomato-legume intercrops demonstrated 15-20% higher resistance to drought stress and 30-35% lower pest incidence compared to monocultures. Their research attributed these benefits to improved soil microclimate, enhanced beneficial insect populations, and complementary resource use between crop species.

Agroforestry integration into tomato production systems has shown promise in regions experiencing increasing temperature extremes. Sida et al. (2018) documented how tomatoes grown in agroforestry systems with appropriate tree species experienced 3-5°C lower midday temperatures during heat waves compared to open-field production. Their research across three agroecological zones found that partial shading from tree components reduced flower abortion during extreme heat events by 40-60%, significantly improving yield stability during abnormal weather patterns.

Ecological pest management approaches that enhance functional biodiversity have demonstrated adaptation benefits beyond pest control. Pérez-Hedo et al. (2021) reviewed 42 studies examining how habitat management for beneficial insects affected tomato production under climate stress conditions. Their synthesis revealed that farms implementing ecological pest management showed 25-40% lower yield losses during heat waves compared to conventional pest management systems, with benefits attributed to improved pollination, reduced heat stress, and enhanced natural enemy populations. Alley cropping systems, where tomatoes are cultivated in the spaces between rows of nitrogen-fixing tree shrubs, offer multiple benefits for climate adaptation.

Abass et al. (2018) and Antwi-Agyei & Nyantakyi-Frimpong (2021) documented alley cropping systems in Ghana's transition zone utilizing Gliricidia sepium and Leucaena leucocephala, reporting improvements in soil fertility, microclimate regulation, and crop performance. Their study found that tomato plants grown in alley cropping systems showed 15-25% higher resilience to temperature extremes compared to those in open field conditions. In Ghana, Nyantakyi-Frimpong (2020) reported limited but growing adoption of hedgerows and living barriers, particularly among farmers with secure land tenure. These systems primarily utilized multipurpose species such as Moringa oleifera and Jatropha carcass, which provided additional benefits beyond climate regulation, including fodder, fuelwood, and income diversification opportunities. However, the same study identified concerns regarding competition for resources and space, particularly on small landholdings, suggesting the need for context-specific designs and species selection.

2.6.4. Intercropping and Companion Planting

Intercropping tomatoes with compatible crops represents a traditional practice with renewed relevance for climate adaptation. Antwi-Agyei and Nyantakyi-Frimpong (2021) documented various tomato intercropping systems in Ghana, including combinations with peppers, okra, and aromatic herbs. Their analysis revealed multiple benefits, including pest suppression, improved resource utilization, and risk spreading across different crop types.

A field experiment by Amponsah (2017) evaluated tomato-basil and tomato-marigold intercropping systems, finding significant reductions in pest damage (particularly from whiteflies and thrips) compared to tomato monocultures. Additionally, these intercropping's systems demonstrated 30-35% higher water use efficiency, suggesting improved resilience to water stress conditions. Despite these benefits, market-oriented tomato production increasingly favours monocropping approaches, influenced by commercial buyers' preferences for uniform quality and harvest timing (Derbe et al., 2024). This trend highlights tensions between ecological resilience and market integration, requiring innovative approaches that balance climate adaptation with economic viability.

2.6.5 Variety Selection and Management

While plant breeding is sometimes separated from nature-based solutions, some approaches to variety selection and management draw directly on natural diversity and processes. Participatory variety selection involving farmers in the evaluation of diverse tomato germplasm has been documented as an effective adaptation strategy. Van Etten et al. (2023) implemented a crowdsourced approach to tomato variety evaluation across 200 smallholder farms experiencing climate variability and found that this methodology efficiently identified locally adapted varieties with 30-45% better performance under stress conditions compared to commercially dominant varieties.

Exploration of wild tomato relatives for climate resilience traits has yielded promising results. Razali et al. (2018) examined drought tolerance mechanisms in wild tomato species and identified key physiological traits that could be incorporated into cultivated varieties through conventional breeding. Their controlled experiments with introgression lines demonstrated that wild-derived traits improved water use efficiency by 25-40% under drought conditions while maintaining acceptable yield and quality parameters.

Seed saving and local adaptation practices represent traditional nature-based approaches to climate adaptation. Veteto & Skarbø (2009) documented how traditional seed-saving practices among tomato farmers have developed locally adapted landraces with enhanced resilience to regional climate patterns. Their ethnographic research across four countries revealed that farmer-maintained tomato varieties often outperformed commercial varieties under local stress conditions, though formal evaluation of these benefits has been limited. Variety selection is most effective when integrated with complementary agroecological practices. Nicholls & Altieri (2018) demonstrated that combining drought-tolerant tomato varieties with mulching and reduced tillage had synergistic effects, improving water retention and yield stability beyond what either strategy achieved alone.

Similar synergies exist between variety selection and soil health management. Scotti et al. (2015) found that heat-tolerant tomato varieties grown in soils with high organic matter content showed 35% higher yields under heat stress compared to the same varieties grown in degraded soils. Broader landscape management can enhance the effectiveness of variety selection. Njekete (2025) demonstrated that pest-resistant tomato varieties performed better when grown in diversified agricultural landscapes with natural habitat patches, which supported natural enemy populations. This emphasizes the need to evaluate a variety of choices as part of the wider range of ecological benefits and functions that ecosystems provide.

2.7 Effectiveness of Nature-Based Solutions

2.7.1 Assessment of NbS Effectiveness

Evaluating how well nature-based solutions work requires consideration of multiple criteria, including agronomic performance, economic viability, and environmental sustainability. A comprehensive assessment by Owusu-Sekyere & Aladago (2023) found varying degrees of effectiveness across different NbS interventions. Their study revealed that integrated approaches combining multiple practices (e.g., mulching, rainwater harvesting, and intercropping) demonstrated greater resilience benefits than single interventions, highlighting the importance of holistic adaptation strategies.

Asamoah et al. (2023) documented yield stability as a key indicator of NbS effectiveness among tomato farmers in Ghana. Their analysis found that farms implementing comprehensive NbS approaches maintained 45-60% of their average yields during seasons with adverse climate conditions, compared to 20-30% for conventional farms. Similarly, Kyei-Mensah et al. (2019) reported improvements in fruit quality parameters, including reduced incidence of physiological disorders associated with climate stress, on farms utilizing natural soil amendments and water conservation practices.

From an economic perspective. Ampaire et al. (2017) analysed the governmental role of diverse adaptive techniques in Ghana's tomato sector, finding that many NbS demonstrated positive returns on investment over medium to long time horizons (3-5 years), despite higher initial implementation costs compared to conventional practices. These economic benefits are derived primarily from reduced input costs, yield stability, and disaster risk reduction, particularly for practices that build soil organic matter and improve water management.

2.7.2 Factors Influencing Effective Adoption of NbS

The adoption of nature-based solutions among tomato farmers is influenced by various factors operating at individual, household, community, and institutional levels Asare-Nuamah & Botchway (2019) identified farmer characteristics, including education level, farming experience, and risk perception, as significant predictors of adaptation behaviour. Their study revealed that farmers who considered climate change a serious concern and had previous experiences of climate-related crop losses also showed a greater tendency to implement nature-based adaptation approaches. Resource access represents another critical determinant of NbS adoption. Nyantakyi-Frimpong (2020) highlighted that access to land, labour, and financial resources significantly influenced farmers' capacity to implement certain naturebased solutions, particularly those requiring substantial initial investments or modifications to land.

Gender disparities in resource access further shaped adoption patterns, with femaleheaded households facing additional constraints despite often demonstrating greater interest in sustainable practices. Knowledge systems and information access also play crucial roles in NbS adoption. Abass et al. (2018) found that farmers who had access to agricultural extension services, climate information, and farmer-to-farmer learning networks demonstrated higher rates of NbS adoption compared to isolated farmers. The study further highlighted the crucial role indigenous knowledge plays in developing effective climate adaptation approaches, with many effective Nature-Based Solutions (NbS) representing hybridizations of traditional practices and scientific techniques.

2.8 Barriers and Enablers to Scaling Up NbS

2.8.1 Barriers in Nature-Based Adaptation Strategies

Despite the prospective benefits of nature-based solutions, various barriers limit their widespread adoption and scaling in various farmlands. Antwi-Agyei et al. (2021) identified policy and institutional factors, including limited integration of NbS in agricultural extension programs, misaligned incentive structures, and insufficient research support, as key constraints to scaling. Their analysis revealed that agricultural policies and support mechanisms in Ghana continue to prioritize input-intensive approaches over ecological alternatives, creating an unfavourable enabling environment for NbS.

Market factors represent another important consideration. (Owusu & Asumadu-Sarkodie (2016) documented how market requirements for standardized products, specific timing, and high volumes sometimes conflict with diversified, ecological production systems. Their study found that tomato farmers often faced trade-offs between climate resilience and market integration, particularly when selling to structured markets with strict quality specifications. Despite these barriers, several enabling factors support the scaling of NbS in the region. Owusu & Asumadu-Sarkodie (2016) highlighted the role of farmers' organizations and cooperatives in facilitating knowledge exchange, pooling resources, and creating market linkages for nature-friendly production.

2.8.2 Socioeconomic and Institutional Barriers in Nature-Based Solutions.

Resource constraints represent significant barriers to implementing nature-based solutions in many contexts. Partey et al. (2018) conducted comparative case studies of climate adaptation among tomato farmers in West Africa and identified how labour availability, land tenure security, and financial capital constrained the adoption of practices like agroforestry and composting despite farmer awareness of potential benefits. Their mixed-methods research revealed that female farmers faced particularly significant resource barriers, with 65% reporting labour constraints as the primary limitation to adopting recommended adaptation practices. Institutional and policy frameworks strongly influence adoption potential. Ampaire et al. (2017) analysed how governance arrangements affected the adoption of climate-resilient farming practices in East Africa through policy analysis and stakeholder interviews. Their research identified fragmented institutional mandates, disconnected policy processes, and misaligned incentives as critical barriers to scaling nature-based solutions despite supportive rhetoric in policy documents. They documented how agricultural, environmental, and climate change policies often operated in silos, creating contradictory signals for farmers and extension services.

Market barriers and opportunities significantly shape adaptation strategies. Sonnino & Marsden (2015) examined how supply chain structures encouraged the implementation of sustainable methods within tomato producers in Europe. Their comparative analysis of conventional and alternative food networks revealed that shorter supply chains with closer producer-consumer relationships provided better economic incentives and knowledge flows supporting ecological practices. They found that premium prices for sustainably grown tomatoes offset implementation costs of nature-based solutions in some market channels but not in conventional supply chains prioritizing standardization and volume.

2.8.3 Policy and Institutional Frameworks for NbS in Ghana

The integration of NbS in Ghana is influenced by various policy and institutional frameworks. Ghana’s 2021 National Climate Change Policy from the Ministry of Environment, Science, Technology, and Innovation formally acknowledges how ecosystembased strategies contribute to both adapting to climate change and reducing its impacts. However, Antwi-Agyei & Nyantakyi-Frimpong (2021) noted that the translation of this policy recognition into concrete support mechanisms for smallholder farmers remains limited, at the local level.

2.9 Theoretical Foundation of the Study

This section positions the research within an academic framework by explaining the theoretical underpinnings that guide the study. Various theoretical approaches have been proposed to explain how nature-based solutions to climate adaptation among tomato farmers in developing countries operate through adaptive mechanisms in response to climate variability.

The Sustainable Livelihoods Framework (SLF), developed by Scoones in 1998, is combined with Ostrom's 2009 Social-Ecological Systems approach to create an integrated analytical framework (Ostrom, 2009; Scoones, 2015). The SLF provides a holistic framework for understanding how farmers navigate and respond to external stressors, including climate variability, by leveraging different forms of capital (human, social, natural, physical, and financial) within specific vulnerability contexts and institutional environments. This framework helps to situate farmers' adoption of nature-based solutions within broader livelihood strategies and constraints. The Social Ecological System perspective complements this by emphasizing the dynamic interface where human communities and natural ecosystems meet and influence each other, of farming systems, recognizing that adaptation practices like NbS emerge from and influence these coupled systems. This integrated theoretical lens allows for a comprehensive analysis of how nature-based solutions are embedded within and shaped by complex social-ecological contexts, helping to identify leverage points for enhancing their adoption and effectiveness.

Additionally, the research draws on Innovation Diffusion Theory (Rogers, 2010) to comprehend the mechanisms by which nature-based solutions operate, as innovations are communicated, perceived, and adopted within farming communities. This theoretical grounding helps to explain variations in adoption patterns and identify elements that affect the adoption of Nature-based Solutions by tomato growers in the research region.

2.10 Knowledge Gaps

Studies have documented climate adaptation strategies among various crop farmers in Ghana; there remains insufficient research on how nature-based solutions specifically affect tomato production systems in the transition zone. Most NbS research focuses on staple crops like maize and rice rather than high-value perishable vegetables (Antwi-Agyei et al., 2021).

The biological and economic characteristics of tomato farming, including its susceptibility to temperature extremes, water stress, and pest pressures, require crop-specific adaptation research that current literature inadequately addresses. Existing studies often examine single adaptation practices in isolation, such as agroforestry or mulching, without analysing how farmers combine multiple nature-based approaches synergistically (AttaAgyepong et al., 2023).

Current literature lacks comprehensive assessments of the investment requirements, return periods, and public-private financing mechanisms necessary to promote NbS adoption among tomato farmers (Nyantakyi-Frimpong & Bezner-Kerr, 2015). This gap limits evidence-based policy formulation for agricultural development programs. Most adaptation studies measure adoption rates rather than livelihood outcomes. There is limited longitudinal research documenting how nature-based solutions affect household income variability, food security status, and economic resilience among vegetable farmers facing increasing climate variability (Falconnier et al., 2020).

The specific pathways through which NbS enhance or constrain livelihood diversification opportunities remain underexplored. While nature-based solutions theoretically contribute to multiple SDGs, including SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land), there is limited research quantifying these multidimensional impacts within specific farming communities (Seddon et al., 2020). Although studies highlight the potential of NbS in African agriculture (Seddon et al., 2020; Thorn et al., 2020), few have empirically assessed their effectiveness in the tomato farming system in Ghana's transitional zone.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Introduction

This chapter examines the research methodology and the area of study. The chapter explores the research approach and design for both quantitative and qualitative investigations, including the types, sources, and techniques employed for data collection. Additionally, it discusses the sampling process, the target population, sample size, sampling design, sample dimensions, and data analysis, along with the ethical considerations applied in field research management. Furthermore, the study provides a detailed overview of the research area's characteristics, including its geographical position and topography, regional climate conditions, and agricultural activities.

3.2 Study Area

3.2.1 Location and Geography

The Techiman North Municipal, with Tuobodom as its administrative center, is situated in Ghana's Bono East Region and encompasses roughly 986.4 square kilometers. Geographically, it falls within coordinates 7°35'N to 8°00'N latitude and 1°49'W to 2°30'W longitude, according to the Ghana Statistical Service (2021). The municipality is bordered by four districts: Kintampo South to the north, Nkoranza North on the eastern side, Techiman Municipal to the south, and Wenchi Municipal on the western boundary. The terrain features rolling hills with altitude variations between 180 and 300 meters above sea level. Multiple tributaries of the Black Volta River system, notably the Tano and Subin Rivers, flow through the region and serve as important water sources supporting local farming activities (Yiran & Stringer, 2017).

The study area in Techiman North Municipal was purposely chosen because this is where tomatoes have been grown for the target period. Four towns, namely Tuobodom, Aworowa, Ofuman, and Buoyem, within the Municipal area were selected for the study. These towns were selected because tomato farmers in those towns produce the largest quantities of tomatoes in the municipality (Nyantakyi 2022). The Municipality consists of 64 towns and villages in total, which encompass five key urban centers: Tuobodom, Offuman, Aworowa, Krobo, and Buoyem. where tomato production is high, having yields ranging from 13 metric tons to 23 metric tons per hectare. (Nyantakyi 2022).

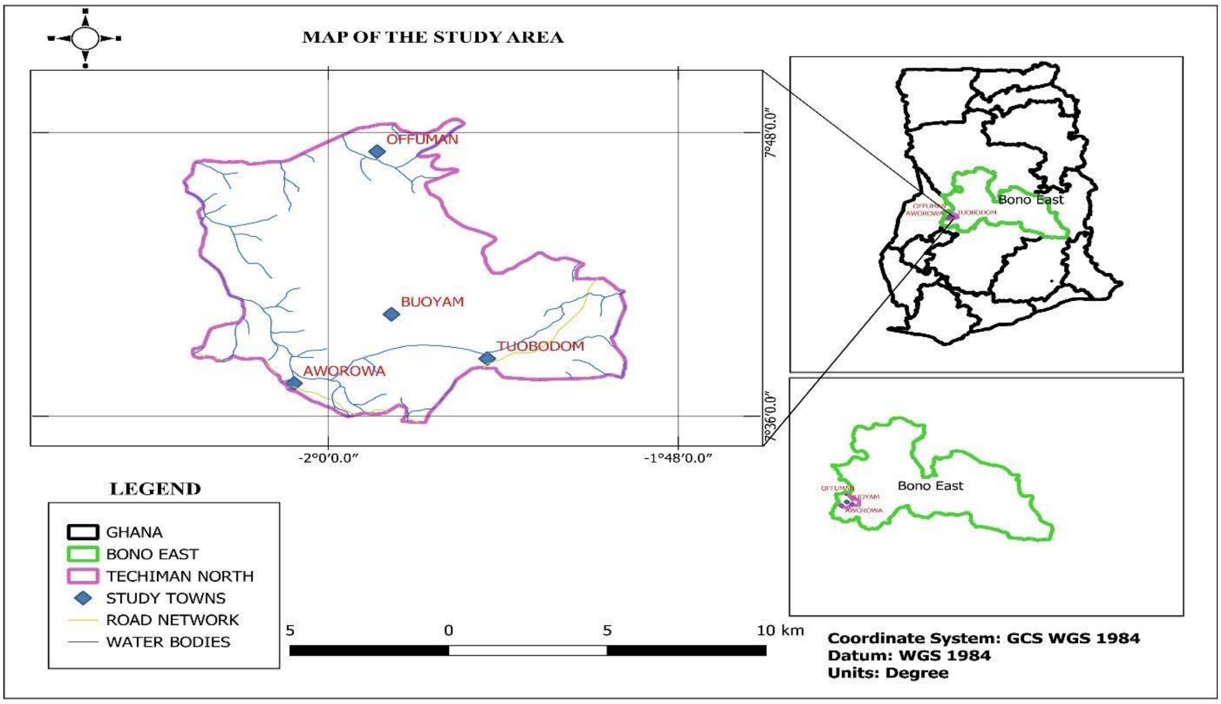


Figure 1.0: Map of Study Location

Source: Authors Construct 2025.

3.2.2 Vegetation and Climate

The Municipal has semi-equatorial and tropical savannah climate patterns, characterized by moderate to heavy precipitation. The primary rainy season occurs from April through July, and the minor from September to October, with a mean annual rainfall ranging between 1660mm and 1260mm. The only dry season, which is highly pronounced in the Savannah zone, starts in November and lasts until March. The district has semi-equatorial and tropical savannah climate patterns, characterized by moderate to heavy precipitation. The primary rainy season occurs from April through July. The region experiences its warmest temperatures, averaging around 30°C (86°F) during the March-April period, while cooler conditions of approximately 20°C (68°F) typically occur in August. High humidity levels persist year-round.

The topography of the municipal features is predominantly flat terrain with gentle rolling hills. The landscape consists of elevated areas and valleys, with the highest elevation reaching

579 meters near Buoyem. The lowest elevation sits at about 305 meters in the Krobo area in the southwestern section. Key waterways include the Tano River, which flows southward, and the Subin and Kar rivers, which run northward. These rivers and smaller waterways hold important cultural value for various ethnic communities living along their shores, with various traditional practices and beliefs associated with them. Additionally, it supports biodiversity with numerous fish species and riverine ecosystems.

3.2.3 Agricultural Activities

Agriculture serves as the primary economic force in the Techiman North Municipal, engaging approximately 70% of the active labour force (Ghana Statistical Service, 2021). The primary agricultural products grown in the area are maize, cassava, yams, plantain, and various vegetables, including tomatoes, which is one of the key vegetable crops. Tomato farming is particularly important for livelihood security and income generation in the municipality, with production concentrated in communities such as Aworowa, Krobo, Tuobodom, and Offuman (Kidido et al., 2017).

Tomato cultivation in the area is primarily rainfed, with some farmers practicing supplementary irrigation during the dry season (Yiran & Stringer, 2017). The crop is grown on both commercial and subsistence scales, with farm sizes ranging from 0.4 to 5 hectares. According to Owusu-Sekyere & Aladago (2023). Tomato farmers in the area have been significantly affected by climate variability, necessitating the adoption of various adaptation strategies, including nature-based solutions.

3.3 Research Design

This research employed a mixed-methods approach, integrating quantitative and qualitative methodologies to offer a thorough evaluation of nature-based strategies for adapting to climate variability among tomato farmers. As Tashakkori & Teddlie (2010) argue, mixed-methods research allows for triangulation of findings, providing more robust evidence than either approach alone. When combined, quantitative and qualitative data offer a more comprehensive insight into research problems compared to using either approach independently. The quantitative research employed both exploratory and descriptive methodologies.

A cross-sectional design allows researchers to collect both quantitative and qualitative data at a single point in time, creating a comprehensive snapshot of the phenomenon under study, which gives a comprehensive, holistic understanding of a complex phenomenon. This design also facilitates the knowledge of both the prevalence of specific climate adaptation strategies and the underlying rationales, challenges, and experiences of implementing naturebased solutions. The research is also an exploratory and descriptive analysis aiming to document existing practices and explore potential improvements in nature-based adaptation strategies.

3.4 Target Population for the Study

The population targeted was registered tomato crop farmers in the municipality. The respondents for the study were selected using purposive sampling, which involves selecting participants or cases according to particular criteria or characteristics such as age, experiences, etc, that align with the researcher's objectives. Participants were required to have hands-on experience and be capable of sharing specific instances of weather-related challenges that affected their tomato harvests in the past five years. Farmers with less than three years of experience were excluded because they may lack sufficient awareness of extended weather trends and how to adapt to them.

Nevertheless, the available population consisted of tomato farmers from four chosen communities (Tuobodom, Aworowa, Ofuman, and Buoyam). Report to the Municipal Agricultural Development Unit (MADU), there are approximately 3,500 tomato farmers in the municipality (Yong, 2023). The accessible population refers to the subset of the target population that researchers can realistically reach and from which they will actually select their sample participants.

3.5 Sample Size Determination

The quantitative survey sample size was calculated using Yamane's formula, as shown below (Adams et al., 2020):

$$n = \frac{N}{(1+N)(e)^2}$$

In this formula:

- n represents the required sample size
- N indicates the total population (3,500)
- e denotes the acceptable margin of error (0.05 for a 95% confidence interval). When values are inserted into the formula: $n = \frac{3500}{(1+3500)(0.05)^2}$

$$n = \frac{3500}{(1+3500)(0.0025)}$$

$$n = \frac{3500}{(1+8.75)}$$

$$n = \frac{3500}{(9.75)}$$

$$n = 359.8974359$$

$$n = 359.90$$

There was an adequate sample size at a 95% confidence level with 5% margin of error; the sample of 360 represents approximately 10.3% of the total population, which exceeds the minimum requirement calculated through Yamane's formula (358.97). The margin of error of ±5% is considered acceptable in social science research, providing a reasonable balance between statistical precision and practical feasibility. The 95% confidence level indicates that if the survey were repeated 100 times, approximately 95 times the results would fall within the specified margin of error. To compensate for possible non-participation and improve the study's representativeness, the calculated sample size was rounded up to 360 tomato farmers for the quantitative analysis. Additionally, the qualitative aspect involved conducting 10 comprehensive interviews with key stakeholders, comprising tomato farmers, agricultural extension workers, and community leaders.

3.6 Sampling Techniques

Purposive sampling was employed in this study, which entails choosing participants or cases based on particular criteria or characteristics that align with the research objectives. Participants were intentionally selected rather than randomly as tomato farmers involved in nature-based climate adaptation strategies. Tuobodom, Aworowa, Ofuman, and Buoyam communities were selected purposively because they are the leading producer of tomatoes in the municipality. Etikan (2016) explains that purposive sampling is appropriate when specific characteristics of a population are required for the study.

The study selected tomato farmers from Techiman North Municipal who were actively involved in tomato cultivation as either their main or supplementary farming activity. These participants needed to have practical experience and be able to provide concrete examples of climate-related difficulties that impacted their tomato crops over the previous five years. To ensure sufficient expertise with climate variability, only farmers with at least five continuous seasons of tomato production experience were included in the research. Those with fewer than three years of tomato farming experience were not considered, as they might not possess an adequate understanding of long-term weather patterns and adaptation requirements.

The research included participants aged 18 and above who held decision-making authority and control over agricultural practices on their land. Gender balance was intentionally maintained among participants, as research indicates that gender affects resource accessibility, decision-making authority, and the implementation of climate adaptation measures (Nyantakyi-Frimpong, 2020). To maintain research integrity and participant wellbeing, farmers currently involved in land ownership disputes or legal issues concerning their agricultural operations were not included in the study.

3.7 Data Collection Procedures and Instruments

The study utilized data from both primary and secondary sources. Primary data were gathered through interviews with key informants, specifically small-scale tomato producers within the municipality and officers of the crop research institute. Qualitative data were obtained through in-depth interviews, structured questionnaires, and direct field observation. Secondary data was sourced from academic journals, scholarly articles, organizational annual reports, and other relevant published materials.

To identify different nature-based adaptation strategies for climate variability among tomato farmers and assess the factors influencing their decisions, the researcher conducted direct interviews with participants. These interviews involved face-to-face meetings between researchers and farmers at the study location, incorporating extensive descriptive and practical observations. The data collection process also utilized structured questionnaires that included both closed-ended and open-ended questions.

To assess the effectiveness of different nature-based climate adaptation methods, researchers deliberately selected farmers who used various adaptation approaches and gathered data through direct interviews and structured questionnaires. The study employed descriptive surveys with experienced tomato farmers to create policy recommendations and guidance for improving nature-based climate adaptation strategies, specifically for tomato farmers in the municipality.

3.7.1 Primary Data Collection Methods

3.7.1.1 Questionnaire

A structured questionnaire (Appendix 1) was administered to collect quantitative data on farmers' socio-demographic characteristics, farming practices, experiences of climate variability, current nature-based adaptation strategies, and perceptions of nature-based solutions. Questionnaire surveys were essential for gathering standardized data from a large sample, which can be statistically analysed to identify patterns and relationships. Out of the 360 questionnaires distributed, 255 were completed, with a 70% response rate from the completed questionnaires. This response rate implies a strong representation of the targeted population and also enhances the reliability and generalizability of this study's findings. In this research, survey data will offer a comprehensive perspective on how tomato farmers in the Techiman North Municipal have implemented and evaluated the success of their adaptation approaches. The questionnaire was designed based on the research objectives, literature review, and preliminary field observations. It incorporated both closed-ended and open-ended questions to gather structured responses as well as more detailed, qualitative feedback and more detailed explanations. The questionnaires were translated into the local language, thus (Bono and Twi), for respondents to have a better understanding.

The questionnaire was administered through face-to-face interviews by trained field workers who had fluency in both English and the local language. As noted by Sarku et al. (2025) Face-to-face administration is preferable in rural settings where literacy levels might be low and where clarification might be needed for certain questions. Each interview took approximately 10-20 minutes to complete. Before administering the questionnaire, the enumerators will explain the aim of the study, ensure that respondents understand their rights (including the right to withdraw at any time), and obtain informed consent. The enumerators were trained to establish rapport with the participants, ask questions clearly and neutrally, and record responses accurately. Quality control measures, such as spot checks and daily debriefing sessions, were implemented to ensure the consistency and reliability of the data collection process.

3.7.1.2 Key Format Interviews

This interview was conducted with key informant farmers to gain detailed insights into the experiences, perspectives, and knowledge of tomato farmers regarding climate variability, adaptation strategies, and nature-based solutions in the study area. According to OwusuDaaku et al. (2023) In-depth key informant interviews allow researchers to explore complex topics in detail and understand the nuanced factors that influence individuals' decisions and actions. In this study, the interviews complemented the other data collection methods by providing deeper perspectives concerning the institutional, policy, regulatory, and sociocultural factors that influence climate adaptation efforts.

This diverse selection of tomato farmers in various towns ensures that the study captures a range of perspectives and expertise. The interviews explore participants' experiences, perceptions, and insights regarding climate variability impacts and the effectiveness of naturebased solutions. Each interview lasted approximately 10-25 minutes and was audio-recorded with participants' consent. Following Rubin & Rubin (2011) responsive interviewing approach, the interview guide is flexible, allowing for the exploration of emergent themes and issues.

3.7.1.3 Field Observations

Field observation constitutes a central component of the data collection strategy, providing direct, firsthand insights into the implementation and effects of nature-based solutions in the study area. Field observations were conducted on 24 tomato farms (6 from each community) to directly observe and document nature-based solutions being implemented. Field observations were employed as a primary data collection method to directly document and assess the current farming practices on nature-based adaptation strategies and environmental factors within the research location. According to the Routledge Handbook of Research, field observations provide researchers with a firsthand understanding of the context and allow them to document phenomena that participants might not mention in interviews or questionnaires (Adogame & Harvey, 2025).

In the context of this study, field observations were valuable for evaluating the actual implementation of nature-based solutions and other adaptation strategies on tomato farms. A structured observation protocol was developed to guide the field observations. The protocol was focused on key aspects such as soil management practices (e.g., mulching, cover cropping, agroforestry) for tomato production, water management techniques (e.g., rainwater harvesting, efficient irrigation systems), Implementation of nature-based solutions (e.g., riparian buffers, windbreaks, conservation agriculture) on tomato production, etc.

As Adogame & Harvey (2025) noted, repeated observations over time are essential for understanding the dynamic nature of agricultural practices and their relationship with climate variability. During the field observations, the following documentation methods were employed:

a. Field notes: descriptive and reflective notes were taken during each observation session to document observed practices, environmental conditions, and preliminary interpretations.

b. Photography: Photographs were taken (with farmers' consent) to visually document farming practices, adaptation strategies, and environmental conditions. Visual documentation is particularly valuable for capturing and communicating complex agricultural practices (Janssen et al., 2017).

A thorough review of documentation was carried out to gather contextual information, historical data, and policy frameworks on climate variability and adaptation in the field of study. Bowen (2009) explained that document analysis is particularly useful for providing background information, historical context, and tracking changes over time. The following types of documents were reviewed: Project reports from NGOs working on climate adaptation in the area, Academic studies, and research reports on changes in climatic activities and farming in Ghana. Also, a document review guide was developed to systematically extract relevant information from these sources.

A comprehensive review of academic research was undertaken to establish the study's theoretical and conceptual foundation and to position the research within the wider scholarly conversation regarding environmentally-based approaches for agricultural climate resilience. The literature review incorporated sources from peer-reviewed journal articles, academic books, conference proceedings, and grey literature, including working papers and technical reports. Relevant literature was accessed through academic databases, including Web of Science, Scopus, Science Direct, and Google Scholar.

3.8 Data Analysis and Presentation Techniques

The data was analysed using both qualitative and quantitative methods. Data from questionnaires and interviews were coded and analysed in the Statistical Package for Social Sciences (SPSS) version 20.0. Logistic regression analysis, sample t-test, and thematic analysis were also used to analyse the data. The general form of the logistic regression model is given as:

$$Log(\frac{p}{1-p}) = \beta_0+\beta_1X_1+\beta_2X_2+ \beta_3X_3 \ldots +\beta_{14}X_{14}$$

Where p is the probability of adopting the strategy, β_0 is the intercept, and $\beta_1, \beta_2, \beta_3 \ldots \beta_{14}$ are the regression coefficients for each factor, $X_1, X_2, X_3 \ldots X_{14}$. Logistic Regression Analysis helps to identify and quantify the influence of multiple predictor variables (X_1 to X_{14}) on farmers' binary adoption decisions (adopt vs. not adopt NbS strategies). Logistic regression is appropriate when the dependent variable is categorical. This will help researchers to understand which factors significantly predict adoption while controlling for other variables simultaneously. The binary dependent variable verifies the outcome variable, which is coded as 0 (non-adopter) and 1 (adopter). Frequency distribution confirms that only two categories exist. Logistic regression models the probability of an event occurring (adoption) on a scale from 0 to 1, which aligns with the binary nature of the decision. The logistic function ensures predicted probabilities remain bounded between 0 and 1, unlike linear regression, which can produce impossible values (<0 or >1).

Additionally, the one-sample t-test statistic is calculated as:

$$t = \left(\frac{\bar{X} - \mu_0}{s/\sqrt{n}}\right)$$

Where $\bar{X}$ is the sample mean (mean rating of an NbS strategy); μ_0 is the hypothesized mean (neutral test value of 3 on a Likert scale); s is the sample standard deviation, whilst “n” represents the sample size.

One-sample t-test helps to assess whether farmers' mean effectiveness ratings of NbS strategies differ significantly from a neutral position (Likert scale midpoint of 3). This test determines if farmers perceive strategies as significantly effective (mean > 3), ineffective (mean < 3), or neutral, providing evidence-based validation of strategy effectiveness

Descriptive statistics such as frequencies, bar charts, mean, and thematic analysis were used to identify the various nature-based climate variability adaptation strategies among tomato farmers. Descriptive statistics summarize and describe the basic features of the dataset. It provides a foundational understanding of sample characteristics, distribution of variables, and prevalence of different NbS strategies

Also, binary logistic regression analysis and thematic analysis for qualitative data were used to evaluate the factors that influence their choices of the identified nature-based adaptation strategies. To assess the effectiveness of the identified nature-based adaptation strategies employed by the tomato farmers, inferential statistics a sample t-tests, were used with a thematic analysis for qualitative data.

Finally, descriptive statistics and thematic analysis were used to develop recommendations and policies for scaling up effective and appropriate nature-based solutions to support climate adaptation measures among tomato farmers. Thematic analysis identifies recurring patterns, themes, and deeper contextual meanings in qualitative data from interviews and observations.

All interviews were transcribed verbatim, including pauses, emotions, and contextual notes. which compiled field observation notes with timestamps and environmental contexts, a master data file was organised by Farmer demographics (age, farm size, experience), Interview date and duration, observation type, and context. It provides rich, nuanced insights into farmers' experiences, motivations, and barriers that quantitative methods cannot capture. Thematic analysis complements quantitative findings by explaining the "why" behind adoption patterns and effectiveness perceptions. Thematic analysis will identify the key theme related to nature-based solutions against climate variability.

The analytical process began with repeated reading of all interview transcripts, including pauses, emotional markers, and contextual notes. This immersive phase allowed the research team to develop intimate familiarity with the data's depth and breadth, noting initial patterns and areas of significance related to nature-based solutions and climate variability.

Themes were independently coded on a subset of transcripts (typically 15-20% of the dataset) to establish coding consistency. Krippendorff's alpha coefficients were calculated to quantify inter-rater agreement, with values above 0.70 considered acceptable and above 0.80 indicating strong reliability. Discrepancies were discussed until consensus was reached, and coding guidelines were refined accordingly.

As recommended by Field (2024), visual representations such as tables, charts, and graphs are utilized to enhance the interpretation of descriptive statistics. Thematic analysis was used to analyse interviews, transcript discussions. Also, qualitative data from interviews, discussions, and field observations were analysed using thematic analysis.

3.9 Ethical Considerations

Ethical considerations are paramount in this research, particularly given the vulnerable position of many farmers in the face of climate challenges. Participants were provided with clear information about the purpose of the research, the nature of their participation, potential risks and benefits, and their right to withdraw at any time without penalty. Informed consent (Appendix 3) was obtained from all research participants before their involvement in the study. For illiterate participants, the information was explained verbally in the local language, and consent was documented through thumbprints or signatures of witnesses. Measures are taken to protect the confidentiality and anonymity of research participants. Personal identifiers were removed from data during analysis and reporting, and pseudonyms were used when quoting participants. Data was stored securely with password protection for electronic files and locked storage for physical documents.

Ethical approval for the research was obtained from the relevant institutional review board at the researcher's university (UENR Ethical Committee). Additionally, permission to conduct the research in the Techiman North Municipal area is obtained from the Municipal Assembly and traditional authorities in the selected communities. The research is conducted with sensitivity to local cultural norms and practices. Data collection approaches, timing, and language were adapted to ensure cultural appropriateness and respect for local customs. Local research assistants were engaged to provide guidance on cultural protocols and facilitate culturally sensitive interactions. In recognition of participants' contributions to the research, findings are shared with participating communities through community forums and simplified summary reports in the local language.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION OF FINDINGS

4.1 Overview

This chapter presents the results and discussion of the findings derived from both the quantitative and qualitative data collected from tomato farmers in the Techiman North Municipality. The analysis focuses on addressing the research objectives outlined in the first chapters of the research. Quantitative data were analysed using descriptive statistics, binary regression, and t-tests. In contrast, qualitative data were examined through thematic analysis to capture in-depth information from respondents on the phenomenon under study. The chapter begins with the presentation of the demographic characteristics of respondents to provide a background context for interpreting the results. This is followed by findings on the nature-based climate variability adaptation strategies employed by tomato farmers, the factors influencing their choice of these strategies, the perceived effectiveness of the strategies, and the challenges and outcomes associated with their implementation.

4.2 Socio-Demographic Characteristics of Respondents

Table 1 presents the analysed data on the socio-demographic characteristics of the 255 tomato farmers who were sampled in the Techiman North Municipality of Ghana. The data reflects a diverse population in terms of age, gender, education, and farming experience, offering a comprehensive perspective on the adoption and effectiveness of nature-based climate adaptation strategies. The results show that the majority of respondents (33.7%) were between the ages of 41 and 50 years, followed by those aged 31–40 years (28.2%) and 18–30 years (18.8%). Farmers aged 51–60 years made up 10.7%, while those above 60 years constituted 8.6% of the respondents. This age distribution suggests a strong presence of middle-aged farmers, who will combine both practical farming experience and openness to adaptation strategies, along with a meaningful representation from both younger and older age groups.

Additionally, the analysed data indicates a slightly higher representation of male respondents (52.9%) compared to female respondents (47.1%). This reflects a closed, and almost balanced, gender involvement in tomato farming activities within the municipality and underscores the active role both men and women play in agricultural production, particularly in the context of climate adaptation.

Also, on the educational background of the respondents, the highest proportion had completed Junior High School or Middle School (36.9%), followed by those with Senior High School or Secondary education (26.7%). Additionally, 12.9% had no formal education, 12.5%

had completed primary education, 5.9% had tertiary education, and 5.1% indicated "Other" forms of education. This indicates a population with generally low to moderate formal education, which has implications for the design and delivery of climate-related training programs that are accessible and easy to understand.

Moreover, the results showed that a significant number of respondents had between 11 and 20 years of experience (34.5%), followed by those with 5 to 10 years (29.0%). Farmers with less than 5 years of experience constituted 18.8%, while 17.6% had been farming for more than 20 years. This distribution suggests that the majority of respondents possess considerable experience in tomato farming, which is very impressive for evaluating the practical effectiveness and relevance of various adaptation strategies over time, although the majority had low to moderate formal education.

Table 1: Demographic Characteristics of Respondents

Variables	**Items**	**Frequency**	**Percentages**
Age	18-30	48	18.8
	31-40	72	28.2
	41-50	86	33.7
	51-60	27	10.7
	Above 60	22	8.6
	Total	255	100.0
Gender			
	Female	120	47.1
	Male	135	52.9
	Total	255	100.0
Education			
	No formal education	33	12.9
	Primary	32	12.5

	JHS/Middle School	94	36.9
	SHS/Secondary	68	26.7
	Tertiary	15	5.9
	Other	13	5.1
	Total	255	100.0
Experience			
	Less than 5 years	48	18.8
	5-10 years	74	29.0
	11-20 years	88	34.5
	More than 20 years	45	17.6
	Total	**255**	**100.0**

Source: Field Survey, 2025

4.2.1 Farm Level Characteristics of Tomato Farmers in Techiman North Municipal

Figure 2.0, Figure 3.0, and Figure 4.0 provide additional demographic information on the landholding patterns, land ownership arrangements, and income sources of the 255 tomato farmers surveyed in the Techiman North Municipality. These variables are very important in understanding the resource base and economic orientation of the farmers, which can influence their capacity and willingness to adopt nature-based climate adaptation strategies.

Figure 2.0 presents the land size that the respondents dedicated to tomato farming. The results revealed that out of the 255 respondents, the majority of respondents (38.4%) cultivated between 1 and 2 acres of land, followed by 27.1% who operated on 3 to 5 acres. A smaller proportion (20.0%) farmed on less than 1 acre, while only 14.5% cultivated more than 5 acres. This distribution implies that most tomato farmers in the municipality are not largescale producers but rather, small- to medium-scale. Their limited land size may affect the extent to which they can implement certain nature-based solutions, such as agroforestry or buffer zones. Additionally, it may influence their decisions based on cost-effectiveness and the efficiency of land use in the region. This because, farmers with limited land must choose solutions that do not reduce their crop area.

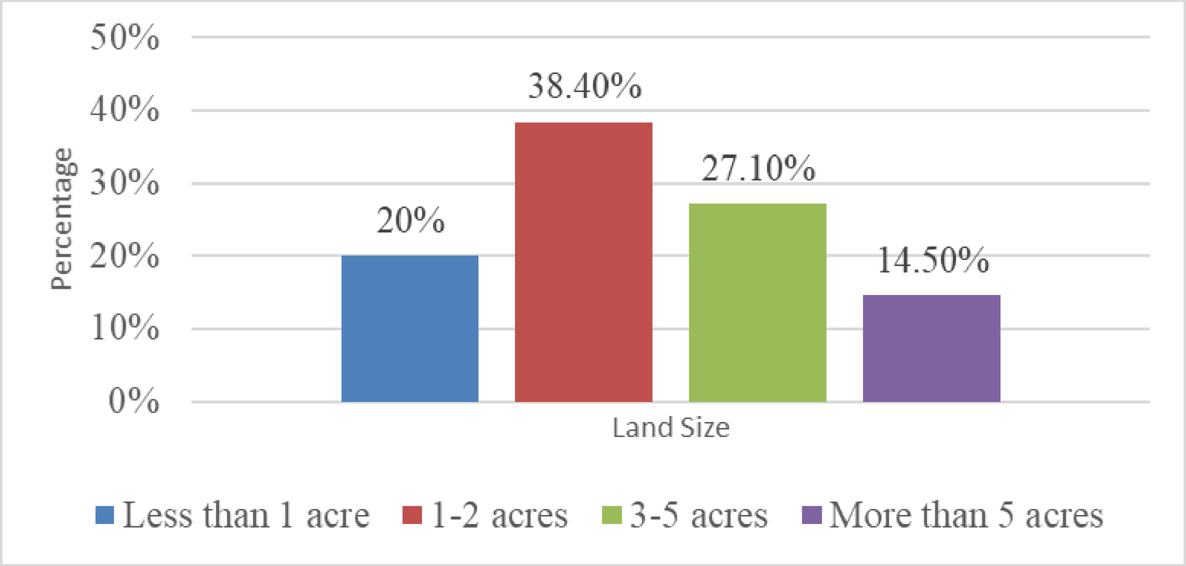


Figure 2.0: Land Size

Notwithstanding the analysed results, as graphically presented in Figure 3.0, revealed that, out of the 255 farmers, 31.0% of the farmers cultivated family land, making it the most common form of land access. This was followed by 20.8% who owned all their farmland, and 19.6% who had mixed ownership, thus owning some land while renting additional land. Additionally, 18.4% of respondents rented all their farmland, and 10.2% reported farming under other types of arrangements like sharecropping and caretaker farming. The predominance of family and rented land suggests a significant portion of farmers may have limited legal land tenure security, which can influence long-term investment decisions, including whether or not to adopt sustainable practices like nature-based solutions.

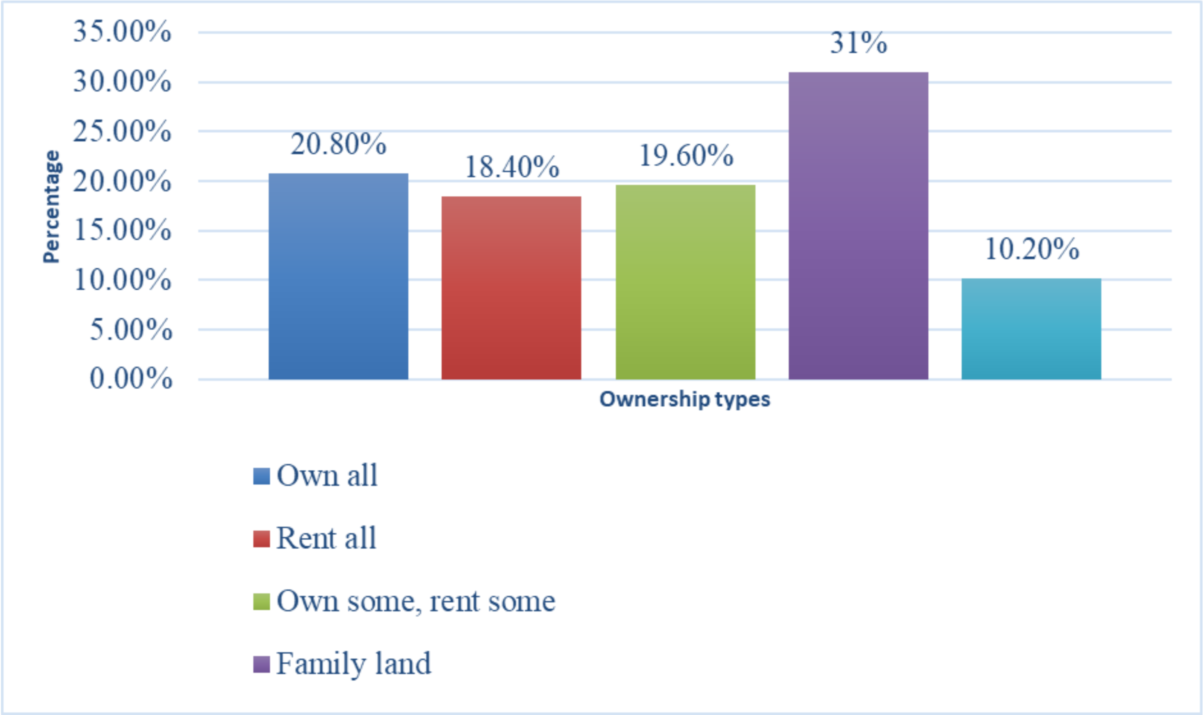


Figure 3.0: Farm Ownership

Lastly, the outcome of the study on the farm level characteristics, as presented in Figure 4.0, showed that a large majority of respondents (74.9%) indicated that tomato farming was their primary source of income, while 25.1% reported having other main sources of livelihood. This high level of economic dependence on tomato farming underscores the importance of ensuring the resilience and sustainability of tomato production in the face of climate variability. Farmers whose livelihoods depend directly on tomato farming may be more motivated to adopt effective adaptation strategies to safeguard their income.

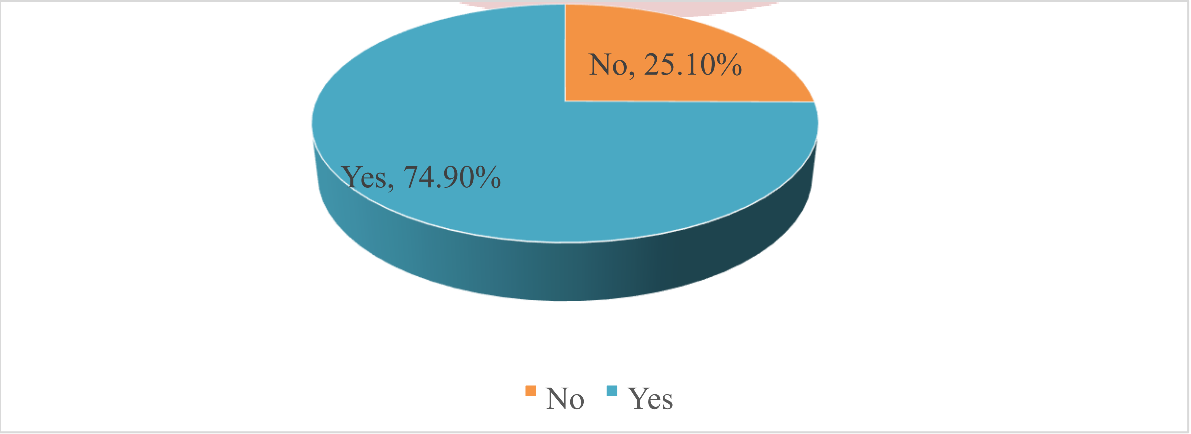


Figure 4.0: Primary source of Income

4.2.2 Climate Variability Awareness and Impact

Figure 5.0 presents the results on the awareness of climate variability and its perceived impact on tomato farming among respondents. The findings suggest a high level of climate change awareness and widespread experiences of climate-related variability in the Techiman North Municipality. The results in the table indicate a huge majority of farmers (86.3%) who reported noticing changes in climate patterns throughout their farming careers, while only 7.8% said they had not observed any changes, and a small proportion (5.9%) were unsure. This high level of awareness suggests that climate change is no longer an abstract concept for these farmers; rather, it is a lived reality that influences their day-to-day decisions. This finding is supported by interview feedback, where one female farmer stated, *"We no longer know when the rains will come. Sometimes they come too late, and other times they come and destroy everything."* Such statements underline the increasing unpredictability of weather patterns, which is making traditional farming practices less reliable.

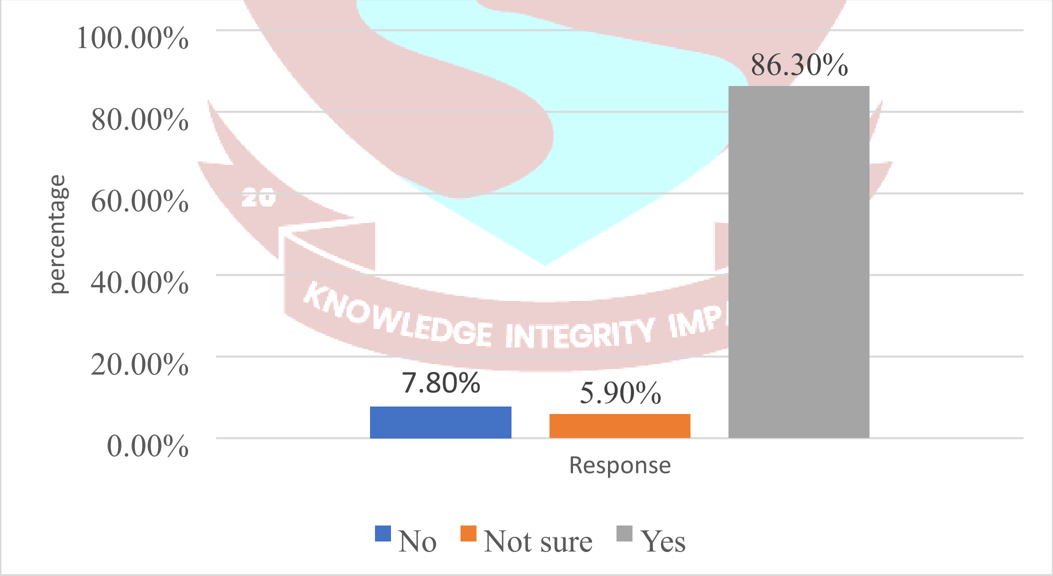


Figure 5.0: Awareness of any Climate Change Patterns

Also, the results presented in Table 2 revealed that the specific types of climate variability observed, with 42.4% of respondents indicating that they are experiencing increased temperatures, while 40.2% reported decreased rainfall. Other frequently observed patterns included shorter rainy seasons (39.6%), longer dry seasons (39.2%), unpredictable rainfall (38.8%), and more frequent storms (36.9%). Interestingly, 36.5% also reported instances of increased rainfall, indicating that the variability is not just about reduced precipitation but also erratic and inconsistent weather behaviour. The mean values for each of these observations range between 0.36 and 0.42, with standard deviations close to 0.49, indicating a fairly even spread of experiences across the sample. These observations align with some feedback from several farmers who noted that they can no longer rely on historical planting calendars. One respondent said, *"The weather has become confused. Last year, we planted early and lost everything. This year, we waited and still had problems."* This evidence reinforces the quantitative results and highlights the urgency for adaptive strategies.

Table 2: Climate Change Variability Observed by Farmers

Climate Change Variability Observed	Frequency (N)	Percentage (%)	Mean	Std. Dev.
Increased temperature	108	42.4	0.42	0.51
Decreased rainfall	103	40.2	0.40	0.49
Increased rainfall	93	36.5	0.36	0.48
Unpredictable rainfall	99	38.8	0.39	0.49
Longer dry seasons	100	39.2	0.39	0.49
Shorter rainy seasons	101	39.6	0.40	0.49
More frequent storms	94	36.9	0.37	0.48

Moreover, when asked about the severity of climate change impacts on their tomato production, a large portion of farmers reported significant effects. Specifically, from Figure

6.0, 38.0% described the impact as severe, and 16.5% considered it extremely severe. A further 30.6% classified the impact as moderate, while only 9.8% and 5.1% reported minor or no effects, respectively. These findings suggest that the majority of farmers are not only aware of climate variability but are also experiencing tangible disruptions to their productivity and livelihoods**.**

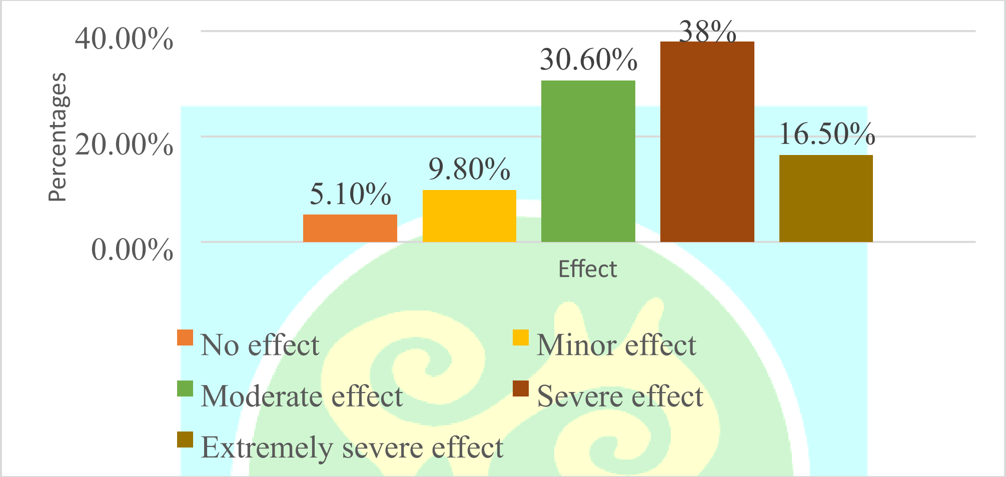


Figure 6: Climate Change Severity Impact on Tomato Production

4.2.3 Familiarity with Nature-Based Solutions

Table 3 provides insights into farmers' levels of familiarity with NbS as a concept and practice in the context of tomato farming. The findings reveal a mixed but leaning-towardpositive awareness landscape, with the majority of farmers having at least some knowledge of NbS, though a significant portion remain unaware or only vaguely informed. The results showed that (29.8%) indicated they were "somewhat familiar" with nature-based solutions. This group likely represents farmers who have heard about and perhaps attempted a few practices, but may not fully understand the term "nature-based solutions" as a formal concept. During interviews, some respondents expressed this indirectly. One farmer noted, *"I don't know if it's called that, but I do use compost and cover the soil with grass sometimes."* This highlights that while the terminology may be unfamiliar, the practices themselves are not entirely new to many farmers.

Another 23.9% of respondents stated they had “heard of it,” suggesting an introductory or superficial level of exposure. These farmers may have come across the concept through radio programs, extension officers, community training, or conversations with other farmers, but lack a deeper understanding or practical application. A 45-year-old farmer explained, *“I heard something on the radio about planting trees and using organic manure, but I’m not sure what it’s really about.”* Interestingly, a proportion of (25.5%) reported they had “never heard” of nature-based solutions. This lack of awareness is concerning, especially considering that these farmers are highly vulnerable to climate variability. Their unfamiliarity may stem from limited access to agricultural extension services, low literacy levels, or insufficient exposure to formal training sessions. One female respondent said, *“We have not had any training in my area. Most of us just do what we know from our fathers.”* This underscores the persistent gap in information dissemination, particularly in more remote or underserved communities.

On the other hand, 53 farmers (20.8%) identified as “very familiar” with NbS. These farmers are likely to be more engaged with training programs, farmer cooperatives, or partnerships with NGOs or government projects. Their responses were often confident and articulate. One respondent said, *“We were trained by an NGO on how to build contours and harvest rainwater. They explained it as a nature-based approach. I have used it for years.”* Such accounts demonstrate that where targeted support and education are available, farmers not only understand the concept but can apply it effectively. On the whole, the data shows that awareness of nature-based solutions is present but unevenly distributed, with nearly half of the farmers falling into the “somewhat familiar” or “heard of it” categories. This indicates an opportunity for capacity building and targeted awareness campaigns. The 25.5% who have never heard of NbS signal a clear information gap, which could hinder the broad adoption of sustainable farming practices. The presence of a smaller but informed group of “very familiar” farmers suggests that peer learning and demonstration farms could be leveraged to bridge this gap and encourage wider understanding and adoption.

Table 3: Familiarity with Nature-Based Solutions and Sustainability

Responses	Frequency	Percent
Heard of it	61	23.9
Never heard	65	25.5
Somewhat familiar	76	29.8
Very familiar	53	20.8
Total	255	100.0

Source: Field Survey, 2025

4.3 Nature-Based Climate Variability Adaptation Strategies Implementation by Tomato Farmers

Figure 7.0 presents the graphical representation of the distribution of the various naturebased solutions implemented by tomato farmers in the Techiman North Municipality. The results reveal that farmers are actively experimenting with a range of ecological strategies to adapt to climate variability, although adoption levels vary across specific practices. The most widely implemented NbS was "restoring natural vegetation around farms," adopted by 33.6% of respondents (n = 86). This may reflect farmers' recognition of the value of ecological integrity in stabilizing local microclimates and conserving moisture. Similarly, contour farming (32.4%) and green manure/organic fertilizers (31.6%) were also among the top three adopted practices. These practices are known to enhance soil fertility, reduce erosion, and support sustainable yields, which may explain their popularity. Agroforestry (30.5%) and intercropping (29.3%) also featured prominently, suggesting that farmers are increasingly integrating trees and diverse crops into their farming systems. These approaches not only provide resilience to erratic rainfall and extreme temperatures but also support biodiversity and economic diversification.

Other widely adopted practices include; creating buffer zones near water bodies (28.5%), creating farm ponds for water storage (27%), constructing vegetative barriers against winds (26.6%), composting (26.6%) crop rotation (26.6%), mulching (26.2%), cover cropping (26.2%) and rainwater harvesting (26.2%). Although these practices were adopted by slightly fewer respondents (between 26.2% and 27%), they still reflect a strong awareness of climateresponsive agricultural techniques. For example, rainwater harvesting and farm ponds address water availability during prolonged dry spells, while mulching and composting improve soil structure and water retention. Qualitative feedback from farmers also supports these findings.

One farmer noted, "*We use tree leaves and plant remains to protect the soil; it helps us when the rains delay."* Another explained, *"We created small ponds to store water; it's not perfect, but it helps during the dry weeks."* On the whole, the data suggest that tomato farmers are implementing a mix of traditional and modern ecological practices to enhance their resilience to climate change. The relatively balanced adoption rates across most strategies indicate that farmers are open to using multiple approaches, depending on resource availability, land type, and technical support. This reflects a growing capacity within the community to respond to climate variability through nature-based methods.

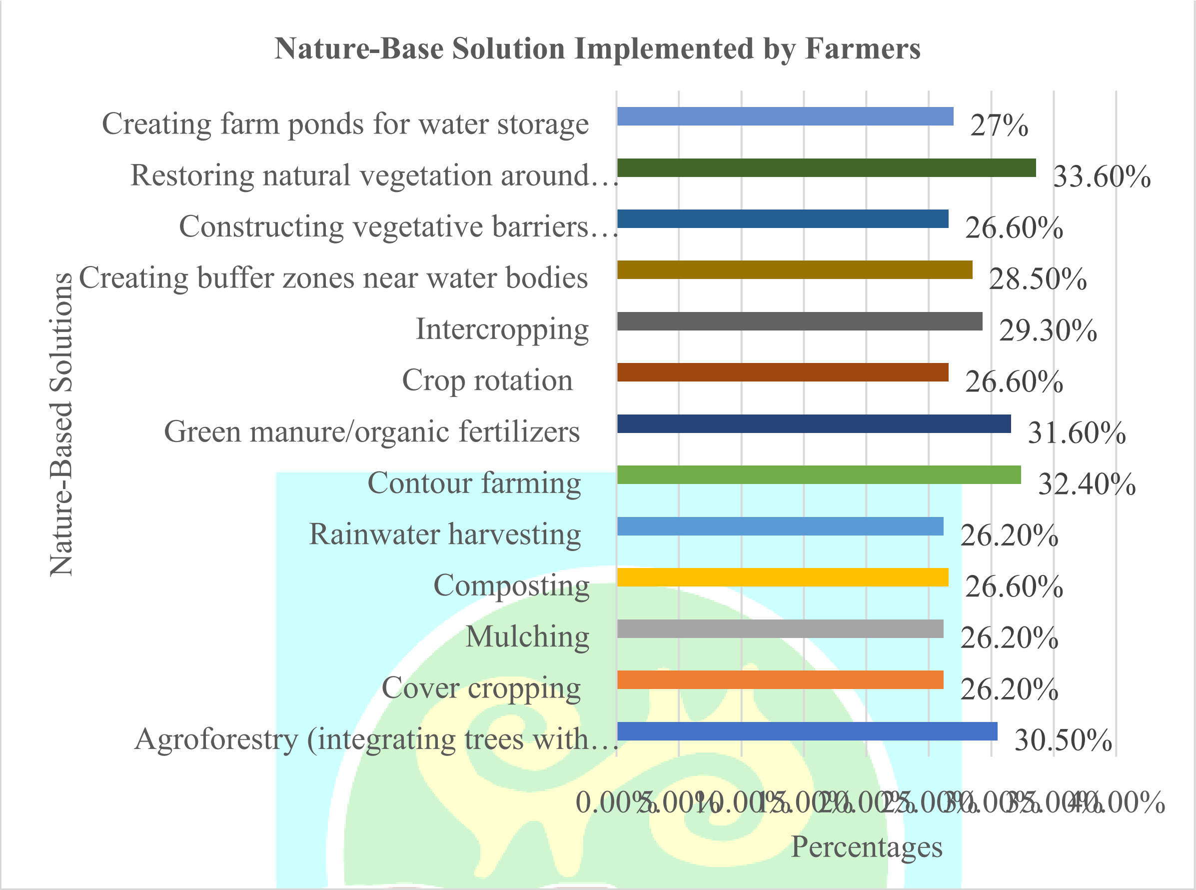


Figure 7: Nature-Based Solution Implemented by Farmers.

4.4 Factors Influencing Farmers' Choice of Nature-Based Climate Adaptation Strategies

4.4.1 Factors Influencing Farmers' Choice for Agroforestry

The results of the binary logistic regression analysis for the adoption of agroforestry (Table 4) showed that none of the individual factors significantly influenced farmers' decisions at the 5% level of significance. However, some variables approached significance and offer meaningful insights when considered alongside qualitative data. For instance, market demand (p = 0.085) negatively influenced adoption, implying that farmers who are driven by market trends were less likely to adopt agroforestry. This aligns with what several farmers mentioned during interviews, that agroforestry takes a long time to yield marketable returns and may not suit their urgent income needs. One respondent remarked, "*Agroforestry is good, but we don't get money from trees quickly, so we just focus on tomatoes.*" Similarly, the perception of less labour requirement (p = 0.076) had a positive, though not statistically significant, effect.

This suggests that those who view agroforestry as manageable within their labour constraints may be more likely to adopt it. However, in qualitative responses, others highlighted the contrary, with a female farmer stating, *"You need time and extra hands to maintain trees along with tomatoes, and not everyone has that…."* The overall lack of significant predictors suggests that agroforestry adoption may be shaped more by long-term vision, land tenure issues, or environmental consciousness factors that are not always captured quantitatively but were evident in qualitative discussions.

Table 4: Factors Influencing Farmers' Choice for Agroforestry

Factors	B	Exp(B)	Sig.
Investment cost	.049	1.050	.884
Profitability	-.140	.870	.687
Market demand	-.663	.516	.085
Less labour	.563	1.755	.076
Training Availability	.112	1.119	.719
Complexity	-.065	.937	.844
Compatibility	-.483	.617	.163
Proven effectiveness	.141	1.151	.695
Traditional beliefs	.250	1.284	.449
Peer influence	.107	1.113	.733
Government Polices	.145	1.156	.673
Access to Info	.024	1.024	.944
Environmental Benefit	.115	1.122	.723
Sustainability	.313	1.367	.347

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B))

4.4.2 Factors Influencing Farmers' Choice for Cover Cropping

Table 5 presents the regression results on the influential factors of cover cropping strategy. The results revealed that two factors, environmental benefit (p = 0.057) and sustainability (p = 0.056), were nearly significant but had negative relationships with adoption. This is somewhat counterintuitive, as one would expect these considerations to encourage adoption. However, insights from the interviews provide clarity. Several farmers indicated that while they recognize the environmental value of cover cropping, they see it as a luxury rather than a necessity. As one farmer put it, *"We hear it helps the soil, but we need quick results. Sometimes it feels like wasting land."* This view may explain why farmers who claim to value sustainability are, in practice, hesitant to adopt cover cropping. Additionally, peer influence emerged close to positive (p = 0.063), suggesting that social dynamics significantly shape adoption behaviour. This was echoed in the qualitative responses, with one farmer noting, *"I saw my neighbour using some kind of leaf cover, and when his tomatoes did well, I also tried it."* This reinforces the role of informal knowledge transfer and community-level trust in influencing farmers' decisions. The integration of these findings reveals that even when statistical relationships are not strong, the underlying narratives and perceptions significantly influence how farmers engage with nature-based solutions.

Table 5: Factors Influencing Farmers' Choice for Cover Cropping

Factors	**B**	**Exp(B)**	**Sig.**
Investment cost	.383	1.466	.269
Profitability	.556	1.743	.111
Market demand	-.404	.668	.297
Less labour	-.175	.839	.614

Training Availability	.173	1.189	.598
Complexity	-.030	.971	.933
Compatibility	-.068	.934	.846
Proven effectiveness	.187	1.206	.621
Traditional beliefs	.051	1.052	.884
Peer influence	.600	1.822	.063
Government Polices	-.286	.752	.453
Access to Info	-.338	.713	.349
Environmental Benefit	-.720	.487	.057
Sustainability	-.767	.464	.056

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B))

4.4.3 Factors Influencing Farmers' Choice for *Mulching*

The regression analysis results for the adoption of mulching (Table 6) indicate that none of the tested factors had a statistically significant effect on farmers' likelihood of adopting the practice. All p-values were above the conventional 0.05 threshold, suggesting that no single factor independently explains mulching adoption in the model. However, some patterns, when viewed alongside qualitative data, offer useful insights. For example, investment cost (p = 0.162, Exp(B) = 1.597) and market demand (p = 0.145, Exp(B) = 0.560) showed moderate, though non-significant, influence. Farmers who perceived mulching as affordable were somewhat more likely to adopt it, while those influenced by market demand were less likely to do so, possibly because mulching is not directly linked to market profitability, but rather to soil health and moisture retention. During interviews, several farmers expressed practical motivations for using mulching, with one explaining, *"When I mulch, I don't water every day. It saves water and time, especially when the sun is too hot."* This reflects the functional benefit of mulching rather than economic incentives. Another farmer said, *"I saw others doing it, but I wasn't sure if it would help,"* suggesting that uncertainty and lack of strong peer endorsement may also limit its widespread use. While no single factor statistically predicted adoption, the qualitative responses highlight that perceived usefulness, especially under climate stress, may be the driving force, something not easily captured in quantitative models.

Table 6: Factors Influencing Farmers' Choice for Mulching

Factors	**B**	**Exp(B)**	**Sig.**
Investment cost	.468	1.597	.162
Profitability	.362	1.436	.292
Market demand	-.579	.560	.145
Less labour	-.151	.860	.658
Training Availability	-.031	.970	.925
Complexity	-.042	.959	.904
Compatibility	-.278	.757	.425
Proven effectiveness	.071	1.074	.850
Traditional beliefs	-.172	.842	.625
Peer influence	.309	1.362	.337
Government Polices	-.435	.647	.256
Access to Info	-.126	.881	.717
Environmental Benefit	-.136	.872	.690
Sustainability	-.085	.919	.811

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B)).

4.4.4 Factors Influencing Farmers' Choice for *Composting*

The results presented in Table 7 showed that the regression model yielded one statistically significant factor: government policy (p = 0.052, Exp (B) = 0.454). Interestingly, the negative relationship suggests that those who considered government policy were less likely to adopt composting. This could indicate that either composting is not widely promoted by local agricultural authorities or that farmers perceive existing policies as inadequate or irrelevant. In interviews, one farmer noted, *"We hear composting is good, but nobody shows us how to do it properly. The extension officers talk more about fertilizers."* This suggests a disconnect between government messaging and farmers' practical support needs. Another possible explanation is scepticism towards formal interventions, as another respondent shared, *"Government people come and go. We rely more on what our fellow farmers show us."* Apart from that, profitability (p = 0.104) was negatively associated with composting. This may indicate that farmers focused on short-term gains may avoid composting due to the time, effort, or uncertainty involved in producing and applying organic matter. Nevertheless, qualitative insights pointed to a growing interest in composting among farmers who have observed its soil-improving effects firsthand. One farmer mentioned, *"Since I started using compost, my soil has improved. I get better tomatoes now, even when the rains are not enough."* These narratives reveal that while the statistical model does not strongly identify predictive factors, experiential knowledge and peer influence remain important drivers of adoption in practice.

Table 7: Factors Influencing Farmers' Choice for Compositing

Factor	B	Exp(B)	Sig.
Investment cost	.398	1.489	.239
Profitability	-.642	.526	.104
Market demand	-.282	.754	.460
Less labour	-.108	.898	.749

Training Availability	.185	1.204	.567
Complexity	-.032	.969	.928
Compatibility	-.065	.937	.850
Proven effectiveness	.394	1.482	.285
Traditional beliefs	-.104	.901	.769
Peer influence	.206	1.229	.527
Government Polices	-.789	.454	.052
Access to Info	.106	1.112	.755
Environmental Benefit	-.157	.855	.657
Sustainability	-.442	.642	.241

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B)).

4.4.5 Factors Influencing Farmers' Choice for Rainwater Harvesting

From Table 8 below, the binary logistic regression analysis for rainwater harvesting revealed one statistically significant factor. Thus, training availability (p = 0.040, Exp(B) = 1.919). This result suggests that farmers who had access to training were nearly twice as likely to adopt rainwater harvesting compared to those who did not. This finding is reinforced by qualitative accounts, where farmers emphasized the importance of practical exposure and guidance in understanding how to set up and maintain water collection systems. One farmer noted, *"I only started collecting rainwater after the extension officer explained it and showed us how to build a simple tank using barrels.* "This highlights the effectiveness of extension services and structured learning opportunities in encouraging technology adoption. Another factor, investment cost (p = 0.061), showed a positive relationship with adoption (Exp(B) = 1.872), indicating that those who perceived the practice as financially manageable were more likely to adopt it. However, many farmers still expressed concern about affordability. As one interviewee put it, *"Rainwater systems are good, but not everyone can buy tanks or build gutters."* The other variables in the model were not statistically significant, though some, such as less labour and sustainability, showed positive trends. These findings suggest that while awareness of benefits exists, access to training and affordability remain critical enablers of adoption.

Table 8: Factors Influencing Farmers' Choice for Rainwater Harvesting

Factors	**B**	**Exp(B)**	**Sig**
Investment cost	.627	1.872	.061
Profitability	.153	1.165	.666
Market demand	.081	1.084	.826
Less labour	.389	1.476	.257
Training Availability	.652	1.919	**.040***
Complexity	.381	1.463	.256
Compatibility	-.517	.596	.169
Proven effectiveness	-.007	.993	.985
Traditional beliefs	.389	1.475	.259
Peer influence	-.317	.728	.363
Government Polices	.178	1.195	.621
Access to Info	.121	1.129	.730
Environmental Benefit	.098	1.102	.777
Sustainability	.392	1.480	.260

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio

(Exp(B)).

4.4.6 Factors Influencing Farmers' Choice for Contour Farming

Table 9 shows the results of the factors influencing contour farming among the farmers. None of the factors reached statistical significance. However, a few variables approached significance and are worth discussing. Notably, the perception of proven effectiveness (p = 0.071, Exp(B) = 0.485) had a moderately negative influence on adoption. Government policies (p = 0.073, Exp(B) = 1.799) and sustainability (p = 0.076, Exp(B) = 0.518) also approached significance. While policy support showed a positive association, the negative sign for sustainability suggests some farmers may not associate contour farming with longterm viability, possibly due to lack of visible benefits or labour demands. In interviews, some farmers described contour farming as labour-intensive and unfamiliar, with one stating, *"If we had machines or more people, maybe we could try, but doing it by hand is not easy."* These findings suggest that contour farming remains underutilized, largely due to limited awareness, lack of technical assistance, and a disconnect between its perceived sustainability and actual

adoption behaviour.

Table 9: Factors Influencing Farmers' Choice for Contour Farming

Factors	**B**	**Exp(B)**	**Sig**
Investment cost	-.011	.989	.974
Profitability	-.420	.657	.230
Market demand	-.333	.717	.350
Less labour	-.145	.865	.663
Training Availability	-.456	.634	.163
Complexity	-.019	.981	.953
Compatibility	.128	1.136	.695

Proven effectiveness	-.723	.485	.071
Traditional beliefs	-.162	.850	.631
Peer influence	-.188	.829	.557
Government Polices	.587	1.799	.073
Access to Info	.187	1.205	.556
Environmental Benefit	.050	1.051	.876
Sustainability	-.659	.518	.076

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B))

4.4.7 Factors Influencing Farmers' Choice for Organic Fertilizers

The logistic regression results show that government policies significantly influenced the adoption of organic fertilizers (p = 0.025, Exp(B) = 0.421), and in a negative direction (See Table 10.0). This implies that farmers who considered government policies were less likely to adopt organic fertilizers, which is a noteworthy and concerning trend. During interviews, farmers expressed disillusionment with the lack of support or incentives from government programs regarding organic inputs. One farmer remarked, *“We hear the government wants us to go organic, but they still promote chemical fertilizers. There is no real support or price reduction.”* This contradiction may contribute to the negative association observed in the model. Moreover, complexity (p = 0.060) and proven effectiveness (p = 0.067) were also near significance, suggesting that those who viewed organic fertilizers as complex or questioned their effectiveness were less likely to adopt them. In line with this, a few farmers stated that composting and organic practices were “too much work” or “not strong enough” compared to chemical fertilizers. As one farmer explained, *“I tried compost, but the results were slow. With fertilizer, I see results in a week.”* Others, however, believed in the long-term benefits but lacked technical know-how. A farmer added, *“If someone would teach us how to* *do it well, I think more of us will switch."* These insights suggest that policy inconsistencies, lack of demonstration, and scepticism about performance all contribute to low uptake of organic fertilizers, despite rising awareness of their environmental and soil benefits.

Table 10: Factors Influencing Farmers' Choice for Organic Fertilizers

Factors	B	Exp(B)	Sig
Investment cost	.121	1.129	.719
Profitability	-.028	.973	.936
Market demand	.022	1.023	.950
Less labour	-.086	.918	.795
Training Availability	-.145	.865	.650
Complexity	.607	1.835	.060
Compatibility	.466	1.593	.145
Proven effectiveness	.648	1.911	.067
Traditional beliefs	.536	1.710	.097
Peer influence	-.028	.973	.930
Government Polices	-.864	.421	**.025***
Access to Info	-.457	.633	.189
Environmental Benefit	-.091	.913	.785
Sustainability	.336	1.399	.312

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B))

4.4.8 Factors Influencing Farmers' Choice for Crop Rotation

Based on the results presented in Table 11, the regression model for crop rotation did not show any statistically significant predictors. None of the 14 factors reached the 5% threshold, suggesting that the adoption of this practice may not be driven by any single factor but possibly by routine knowledge, tradition, or ecological necessity. However, qualitative insights reveal that crop rotation is seen by many as a basic and traditional practice, rather than a strategic or innovation-driven approach. One respondent commented, *“We rotate because that’s how our fathers did it… to avoid pests and sickness.”* This cultural embeddedness could explain why variables like profitability, training availability, or government policy did not significantly influence adoption. Another farmer noted, *“Sometimes we don’t even call it crop rotation…we just change what we plant when the land looks tired.”* This suggests that for many, crop rotation is not a planned strategy but a practical response to changing soil conditions, making it difficult to link adoption to structured influencing factors. The quantitative results confirm that, unlike other nature-based solutions that require specific inputs or skills, crop rotation may be too ingrained or informally practiced to be significantly predicted by the measured factors.

Table 11: Factors Influencing Farmers' Choice for Crop Rotation

Factors	B	Exp(B)	Sig
Investment cost	-.571	.565	.130
Profitability	-.387	.679	.290
Market demand	-.312	.732	.406
Less labour	.039	1.040	.908
Training Availability	.247	1.280	.440
Complexity	.077	1.080	.821
Compatibility	-.181	.835	.605
Proven effectiveness	.204	1.226	.580
Traditional beliefs	.025	1.025	.943
Peer influence	-.391	.676	.251

Government Polices	-.153	.858	.670
Access to Info	-.278	.757	.429
Environmental Benefit	.281	1.325	.395
Sustainability	.120	1.128	.729

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B)).

4.4.9 Factors Influencing Farmers' Choice for Intercropping

In the model for intercropping, traditional beliefs emerged as a statistically significant factor (p = 0.019, Exp(B) = 2.185), meaning that farmers who identified with traditional beliefs were more than twice as likely to adopt intercropping (See Table 12). This finding is strongly supported by qualitative data. Many farmers described intercropping as a “passeddown” method rooted in ancestral farming knowledge. One farmer shared, *“In our culture, we’ve always grown maize with beans or tomatoes with okra. It’s how we preserve the soil and feed the family.”* This reflects a deep cultural embeddedness of the practice, particularly in indigenous farming systems where biodiversity and resource use efficiency are naturally integrated. Another farmer explained, “*We don’t see intercropping as new… It’s something that works for small lands and keeps pests away.* These results show that intercropping is a rare case where traditional belief aligns well with ecological sustainability, and policy efforts could be more effective if they embrace and build upon local wisdom rather than introducing external systems as replacements.

Table 12: Factors Influencing Farmers' Choice for Intercropping

Factors	B	Exp(B)	Sig
Investment cost	-.092	.912	.797
Profitability	.459	1.582	.172

Market demand	-.231	.794	.531
Less labour	-.263	.769	.453
Training Availability	.357	1.429	.266
Complexity	-.462	.630	.201
Compatibility	.554	1.740	.095
Proven effectiveness	.521	1.684	.157
Traditional beliefs	.782	2.185	**.019***
Peer influence	.432	1.540	.182
Government Polices	.523	1.686	.129
Access to Information	-.584	.558	.111
Environmental Benefit	.408	1.504	.220
Sustainability	-.586	.556	.117

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B)).

4.4.10 Factors Influencing Farmers' Choice for Buffer Zone

The logistic regression results for the adoption of buffer zones (Table 13) revealed that none of the variables tested had a statistically significant effect on adoption. However, a few factors approached significance and offer important contextual insights. Investment cost (p = 0.153) and government policy (p = 0.100) showed negative associations with adoption, suggesting that farmers who were concerned about the financial burden or who considered government influence were less likely to adopt buffer zones. During interviews, farmers expressed that setting aside land for buffer zones often feels like a ‘loss’ of productive space. One farmer explained, *“We already have small land. Leaving space for bushes or grass means planting fewer tomatoes.”* Others mentioned that government extension services rarely promoted or explained the purpose of buffer zones. As one respondent noted, *"We only hear about buffer zones when they talk about forests, not small farms like ours."* These insights suggest that although buffer zones are an important nature-based solution for water protection and biodiversity, a lack of awareness and land pressure hinder their practical implementation.

Table 13: Factors Influencing Farmers' Choice for Buffer Zone

Factors	B	Exp(B)	Sig
Investment cost	-.527	.590	.153
Profitability	-.284	.753	.423
Market demand	.123	1.130	.727
Less labour	-.458	.632	.184
Training Availability	.204	1.226	.518
Complexity	-.076	.927	.822
Compatibility	.214	1.238	.519
Proven effectiveness	.025	1.025	.947
Traditional beliefs	-.398	.672	.261
Peer influence	-.067	.936	.837
Government Polices	-.615	.541	.100
Access to Information	-.375	.687	.278
Environmental Benefit	.122	1.130	.709
Sustainability	-.285	.752	.426

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B))

4.4.11 Factors Influencing Farmers' Choice for Vegetative Barriers

In the case of vegetative barriers as presented in Table 14, environmental benefit was the only statistically significant factor (p = 0.017, Exp(B) = 0.391), but interestingly, it had a negative effect on adoption. This implies that farmers who considered environmental benefits were less likely to adopt vegetative barriers, possibly due to a disconnect between the perceived purpose of the practice and its practical utility. Several farmers described vegetative barriers as being more beneficial for large, sloped lands or erosion-prone areas rather than for the flat or semi-flat tomato plots common in Techiman. One farmer shared, *"We don't see the point of planting grass to block water when the land is already flat."* This perception may explain why awareness of environmental benefits is not translating into adoption. Additionally, factors such as complexity (p = 0.121) and compatibility (p = 0.156) negatively associated, reinforcing the idea that tomato farmers in Techiman view vegetative barriers as too complicated or ill-suited to their land characteristics.

Table 14: Factors Influencing Farmers' Choice for Vegetative Barriers

Factors	B	Exp(B)	Sig
Investment cost	.366	1.443	.284
Profitability	-.233	.792	.531
Market demand	-.345	.709	.368
Less labour	-.089	.915	.793
Training Availability	.315	1.371	.329
Complexity	-.582	.559	.121
Compatibility	-.523	.593	.156
Proven effectiveness	.086	1.089	.818
Traditional beliefs	.050	1.051	.886
Peer influence	.131	1.140	.697
Government Polices	-.010	.990	.977
Access to Information	-.359	.698	.322
Environmental Benefit	-.938	.391	**.017***

Sustainability	-.016	.985	.966

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B))

4.4.12 Factors Influencing Farmers' Choice for Restoring Vegetation

The results on restoring natural vegetation, as presented in Table 15, showed no statistically significant predictors, but peer influence (p = 0.063, Exp(B) = 1.752) came close. This suggests that farmers who observe others engaging in vegetation restoration are more likely to do the same. In the interviews, some farmers mentioned community efforts or NGOled training sessions that encouraged replanting trees and native species. One farmer noted, *"We were told to leave some parts of the land for native plants and trees to grow back, and I saw it worked for someone in my village."* While other factors, such as proven effectiveness (p = 0.150) and environmental benefit (p = 0.134) also showed the overall lack of statistical significance may indicate that restoring vegetation is seen more as a conservation effort rather than a direct farming benefit. As such, it may not rank highly in individual farmers' decisionmaking unless supported by communal programs or external incentives.

Table 15: Factors Influencing Farmers' Choice for Restoring Vegetation

Factors	**B**	**Exp(B)**	**Sig**
Investment cost	.252	1.286	.432
Profitability	.086	1.090	.795
Market demand	.227	1.255	.497
Less labour	.292	1.339	.353
Training Availability	-.249	.780	.421
Complexity	.227	1.255	.471
Compatibility	.055	1.056	.864
Proven effectiveness	-.537	.584	.150

Traditional beliefs	.079	1.082	.804
Peer influence	.560	1.752	.063
Government Polices	-.066	.936	.845
Access to Information	-.184	.832	.573
Environmental Benefit	-.493	.611	.134
Sustainability	-.084	.920	.804

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B).

4.4.13 Factors Influencing Farmers' Choice for Farm Ponds

Finally, the analysis for farm ponds (Table 16) revealed three statistically significant factors: profitability (p = 0.039), complexity (p = 0.043), and proven effectiveness (p = 0.056). Profitability had a strong positive effect (Exp(B) = 2.007), indicating that farmers who believed farm ponds would increase income were twice as likely to adopt them. Complexity and proven effectiveness were also significant, though complexity had a positive influence (Exp(B) = 1.946), and proven effectiveness showed a negative relationship (Exp(B) = 0.417). These somewhat conflicting results suggest that while some farmers perceive ponds as worthwhile despite being complex, others may remain sceptical of their true value. In interviews, farmers frequently mentioned the usefulness of ponds for irrigation during dry spells. One respondent shared, *"When the rains stop early, those with ponds still get tomatoes. That's why I want to build one too."* However, others mentioned challenges such as construction costs, maintenance, and lack of technical support. *"Digging a pond is not easy. And if it dries up or collapses, it's a waste*," one farmer explained. These findings suggest that while farm ponds are widely recognized as potentially profitable, practical barriers and risk perceptions limit widespread adoption. It also reinforces the need for hands-on training, financing schemes, or community-level infrastructure support.

Table 16: Factors Influencing Farmers' Choice for Farm Ponds

Factors	B	Exp(B)	Sig
Investment cost	.307	1.359	.376
Profitability	.697	2.007	**.039***
Market demand	.412	1.509	.245
Less labour	-.276	.759	.448
Training Availability	-.323	.724	.343
Complexity	.666	1.946	**.043***
Compatibility	-.358	.699	.328
Proven effectiveness	-.875	.417	.056
Traditional beliefs	-.594	.552	.111
Peer influence	-.267	.765	.444
Government Polices	.176	1.193	.622
Access to Information	.027	1.027	.939
Environmental Benefit	.047	1.049	.887
Sustainability	.345	1.412	.332

Source: Field Survey, 2025. Coefficient (B); significance level (p-value); Odds ratio (Exp(B))

4.5 Effectiveness of Nature-Based Adaptation Strategies Implemented by Tomato Farmers

Table 17 presents farmers' perceptions of the effectiveness of various nature-based climate variability adaptation strategies they have implemented. The assessment was conducted using a one-sample t-test, comparing the average effectiveness score of each strategy to a neutral benchmark value of 3 on a five-point Likert scale (1 = Very ineffective, 5 = Very effective). The midpoint value of 3 was adopted as a neutral reference point, consistent with established practice in perception studies where the aim is to determine whether respondents' ratings are significantly more positive or negative than neutrality (Boone & Boone, 2012; Adzawla et al., 2019; Tega & Bojago, 2023). To enhance interpretative depth, these subjective ratings were further contextualized using established tomato yield benchmarks in Ghana. According to the Ministry of Food and Agriculture (MOFA, 2022), the national average tomato yield is approximately 10.6 t/ha, while regional best-practice yields can reach up to 16.2 t/ha. In this study, mean scores above 3 were interpreted as perceptions that the respective adaptation strategy could potentially achieve or exceed the national average yield, whereas mean scores below 3 suggested perceived ineffectiveness relative to this benchmark. The results reveal that most strategies were perceived as moderately effective, with only one, crop rotation, rated significantly below average. None of the strategies was rated significantly more effective than the neutral point at the 5% significance level. Among the strategies assessed, agroforestry and composting recorded the highest average effectiveness ratings (Mean = 3.11 each), although these were not statistically significant (p = .215 and p = .182, respectively).

Despite the lack of statistical significance, qualitative data from farmer interviews indicated that these strategies were valued for their long-term benefits. One farmer explained, *"When we plant trees around the farm, the soil does not dry too fast, and the wind is not too strong. It protects the crops."* Similarly, composting was appreciated for its role in improving soil fertility, especially among farmers who had limited access to chemical fertilizers. As one respondent noted, "*I use compost from animal waste and food leftovers. It helps my tomatoes to grow well without spending too much money."* These narratives support the idea that some farmers perceive these strategies as beneficial, even if the statistical evidence does not confirm a strong overall consensus.

Other strategies, such as cover cropping (Mean = 3.07), rainwater harvesting (Mean = 3.08), buffer zones (Mean = 3.10), and vegetative barriers (Mean = 3.04), also had average effectiveness ratings slightly above 3, but with p-values greater than 0.05, suggesting these were not significantly different from neutral. However, qualitative responses indicate that these methods are context-dependent. For instance, while rainwater harvesting is useful during the dry season, its impact is limited by the scale of storage available. One farmer lamented, *"I tried to harvest rainwater, but the tank is small. It helps for a short time, but not enough."* Similarly, farmers recognized the potential of cover cropping but mentioned difficulty maintaining ground cover during the dry season when weeds die off quickly. Also, strategies such as mulching (Mean = 2.96), organic fertilizers (Mean = 2.98), intercropping (Mean = 2.99), and farm ponds (Mean = 2.91) were rated close to the neutral mark, with no statistical significance. Though not rated poorly, these strategies may not have produced consistently noticeable results for the farmers. Some attributed this to the lack of proper training or technical support in implementation. One farmer shared, *"We were told to mulch the soil, but I don't always know which materials are best or how thick to apply them."* This highlights the importance of not just promoting these practices but also ensuring that farmers know to implement them effectively.

Interestingly, crop rotation was the only strategy that had a mean effectiveness rating significantly below the neutral value of 3 (Mean = 2.78, p = .015). This suggests that farmers generally perceived this strategy as less effective, possibly due to short-term yield losses or limitations in land size, which prevent proper rotation. One farmer commented, *"I cannot rotate crops because I have only one piece of land. If I stop planting tomatoes there, I will lose my income."* These words illustrate the practical constraints that limit the feasibility and perceived value of certain strategies, regardless of their theoretical benefits. Moreover, the strategy of restoring natural vegetation around farms received a neutral mean score of 3.00 with an insignificant p-value (p = .965), indicating that farmers neither strongly agreed nor disagreed on its effectiveness. This may reflect limited understanding or delayed benefits associated with ecological restoration. A few farmers mentioned that while planting trees and allowing natural vegetation to grow seemed environmentally beneficial, they were unsure how it directly improved yields in the short term.

Table 17: Effectiveness of Nature-Based Solutions Implemented by Farmers

Nature-Based Solutions	Mean	Std. Dev	T-Values	Sig(2-tailed)	Std. Error Mean
Agroforestry	3.11	1.407	1.244	.215	.088
Cover cropping	3.07	1.425	.834	.405	.089
Mulching	2.96	1.426	-.482	.630	.089
Composting	3.11	1.354	1.338	.182	.085
Rainwater harvesting	3.08	1.396	.940	.348	.087
Contour farming	3.05	1.360	.552	.582	.085
Organic fertilizers	2.98	1.451	-.215	.830	.091
Crop rotation	2.78	1.458	-2.443	.015	.091
Intercropping	2.99	1.399	-.134	.893	.087
Buffer zones	3.10	1.434	1.089	.277	.090
Vegetative barriers	3.04	1.386	.451	.652	.087
Restoring vegetation	3.00	1.432	.044	.965	.090
Farm ponds	2.91	1.420	-.968	.334	.089

Source: Field Survey, 2025

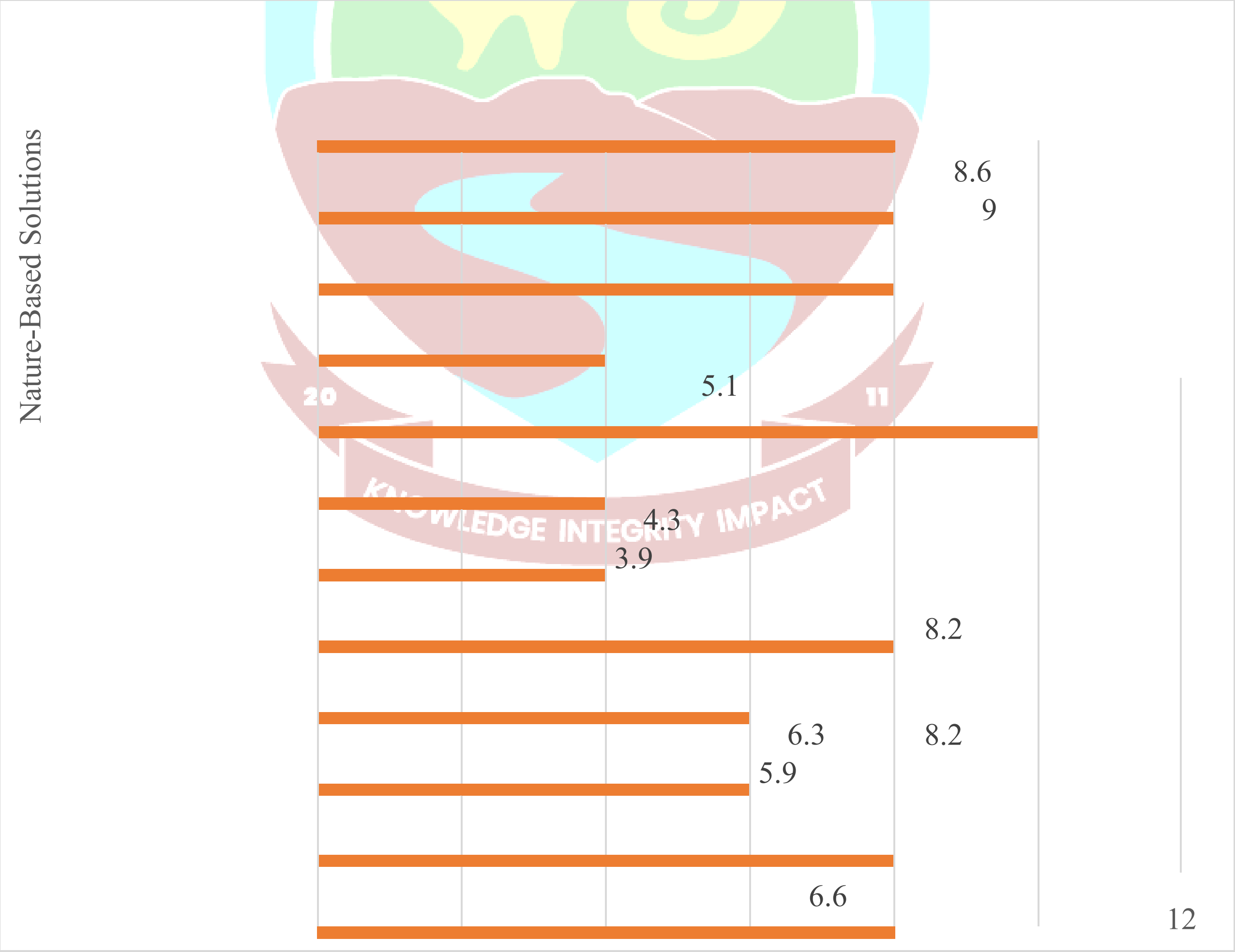
4.5.1 Best Nature-Based Solution for Tomato Farming

Figure 9.0 presents the graphical representation of the distribution of responses regarding what farmers considered the best nature-based solution (NbS) for addressing climate variability in tomato farming. The results show that while no single strategy overwhelmingly dominated, some practices were favoured more than others, reflecting farmers' practical experiences, environmental context, and farming priorities.

Mulching emerged as the most preferred nature-based solution, identified by 25 farmers (9.8%). This preference is likely tied to its simplicity, affordability, and immediate impact on soil moisture retention and weed control. During interviews, several farmers highlighted mulching as both cost-effective and practical. One respondent noted, *“With the dry season getting longer, mulching is what helps my tomatoes survive. I use maize husks and dry grass…it’s cheap and works fast.”* Another added, *“It’s something we can do ourselves without needing machines or money.”* This underscores mulching’s reputation as a low-input, high-impact solution among smallholder farmers.

Closely following were vegetative barriers (9.0%) and rainwater harvesting (9.0%), each mentioned by 23 farmers. Farmers valued vegetative barriers for preventing wind erosion and protecting crops, especially in areas with exposed or sloped land. Rainwater harvesting was appreciated as a buffer during erratic rainfall, especially in communities where dry spells and delayed rains are increasingly common. One farmer explained, *“I built a small catchment with help from an NGO. When there’s no rain for weeks, I use the stored water on my farm. It has saved my crops more than once.”*

Agroforestry and restoring vegetation were each selected by 22 farmers (8.6%). These strategies align with broader ecological restoration goals and are often seen as solutions that improve both soil fertility and microclimate over time. Farmers who chose agroforestry typically spoke about long-term resilience. One remarked, *“The trees I planted years ago now protect the soil and keep the farm cooler. It's slow, but worth it.”* Additionally, other frequently cited practices included contour farming (8.2%) and farm ponds (8.2%), both selected by 21 farmers. These methods are particularly useful on sloped lands or in waterscarce areas. Contour farming was praised for reducing runoff and maintaining soil structure, while farm ponds provided a water source during irregular rainfall. However, both were also described as labour -intensive, and some farmers noted they had to seek help or support to implement them effectively. Furthermore, lower preference was observed for cover cropping (5.9%), organic fertilizers (5.1%), and irrigation systems (4.3%). The lower rankings for these strategies may be due to resource constraints or knowledge gaps. For example, irrigation systems may require equipment or capital investment that smallholder farmers often lack. One farmer expressed, *"I would like to use drip irrigation, but the materials are too expensive for me."* Similarly, while organic fertilizers are widely accepted in principle, farmers sometimes face challenges in sourcing raw materials or ensuring consistency in compost quality. Furthermore, intercropping, identified by only 10 farmers (3.9%), had the lowest frequency. Though intercropping is widely recommended by agricultural experts for improving biodiversity and maximizing land use, its complexity in management and harvesting may reduce its appeal. A respondent explained, "I tried intercropping with maize, but it made weeding difficult and reduced the space for my tomatoes." These findings highlight the importance of aligning promotion efforts with farmers' capacities and offering support mechanisms that make more complex practices feasible.



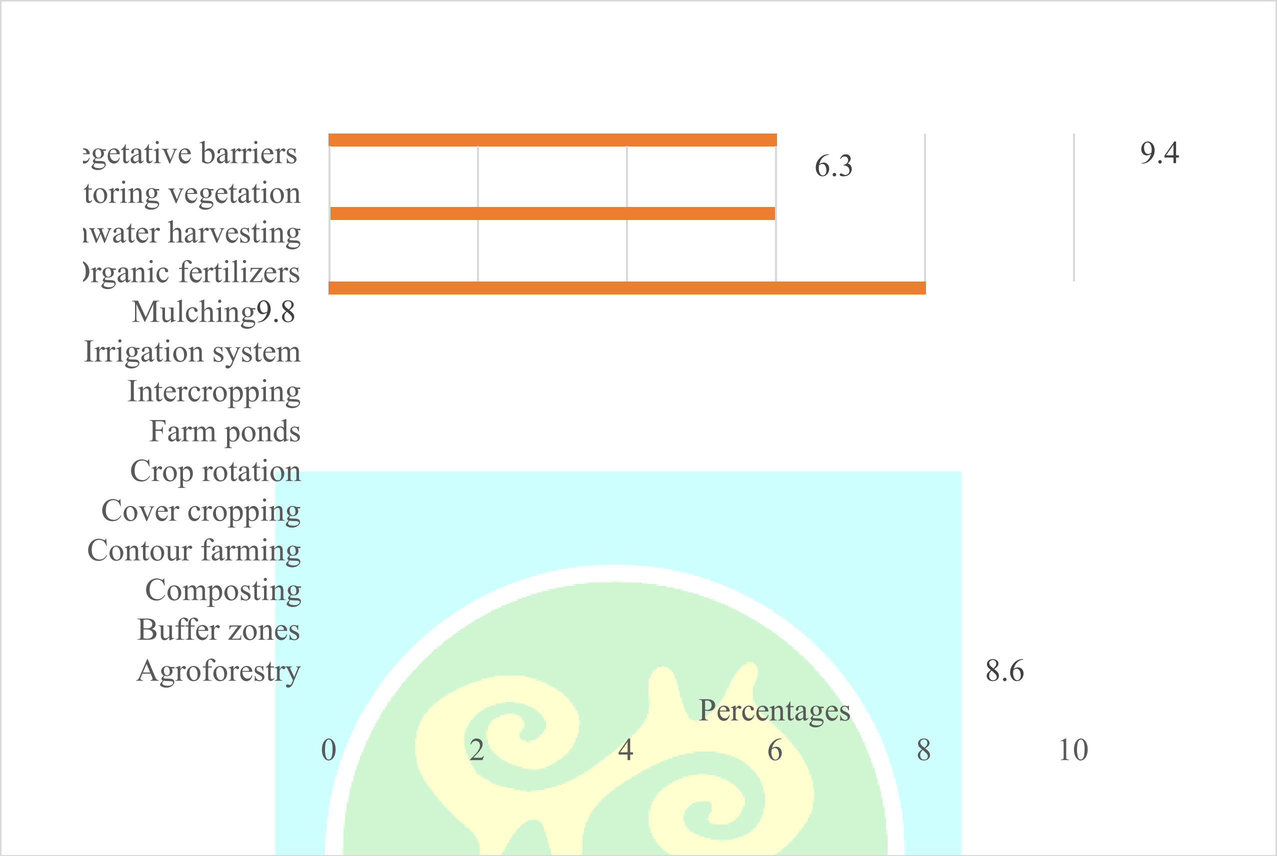


Figure 8: Best Nature-Based Solution for Tomato Farming

4.5.2 Nature-Base Solution Success, Duration of Use, Motivations for Use & Sustainability.

Figures 9, 10.0, and 11.0 present farmers' experiences and perceptions of the success, duration, motivation, and sustainability of nature-based climate adaptation strategies in tomato farming. The results showed that the majority of the farmers surveyed (73.8%) reported that the nature-based solutions (NbS) they implemented in tomato production were successful, while 26.2% indicated that their efforts had not yielded satisfactory results (See Figure 9.0). From the interviews, those who perceived their strategies as successful often cited improved soil quality, reduced input costs, and resilience to erratic rainfall as reasons. One farmer explained, *"Since I started using compost and planting cover crops, I don't have to buy fertilizer all the time. My tomatoes are doing better, even when the rains are not regular."* On the other hand, farmers who found their nature-based solutions unsuccessful mostly attributed it to lack of proper training or inconsistent implementation. A respondent shared, *"They told us to mulch and use organic manure, but I didn't get enough materials or help. It didn't work the way I expected."*

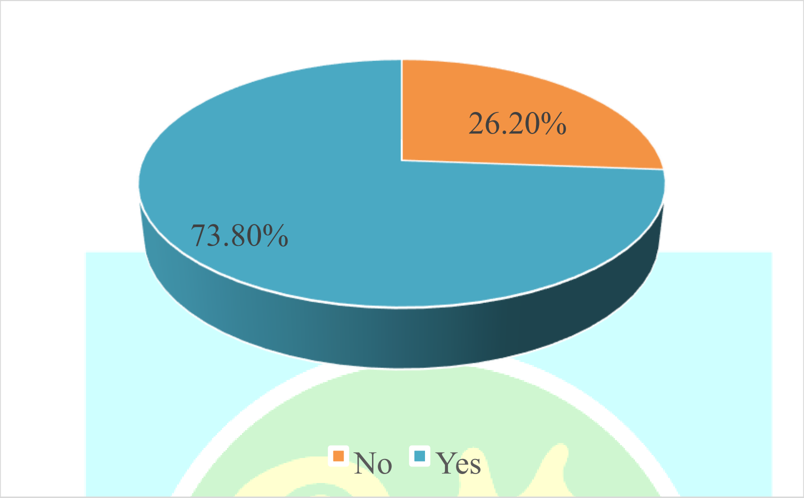


Figure 9: Success of Nature-based Solution in Tomato Farms

Also, the analysed results, as presented in Figure 10.0, showed that the responses were relatively evenly distributed in terms of duration of usage of the strategy. Thus, while 21.9% of respondents have been using nature-based solutions for less than one year, a notable 21.5% have used them for more than 10 years. The rest fall within mid-term usage: 16.8% for 1–3 years, 20.7% for 4–6.

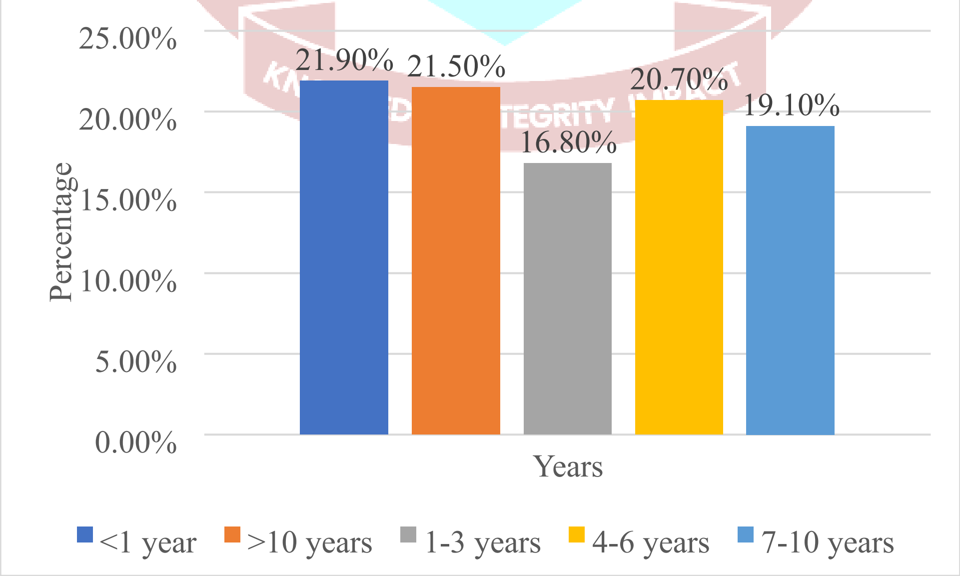


Figure 10: Duration of Implementing Nature-based Solution

Additionally, the farmers were asked to indicate their source of motivation or what motivated them to adopt nature-based solutions (NbS) in their tomato farming. The results, as shown in Figure 11.0, revealed a multi-layered set of motivations, reflecting both individual experiences and external influences. The top three motivators were: knowledge from other farmers (32.8%), advice from agricultural extension officers (31.6%), and personal observation of climate change (31.3%). This suggests that peer learning, formal agricultural support, and direct personal experience all play equally strong roles in influencing farmer behaviour. Many farmers credited peer-to-peer learning as their first source of practical information. One respondent explained, *"It was my friend in the next village who started using compost and mulching. I saw how healthy his tomatoes were and decided to try it. We learn more from each other than from books."* This insight emphasizes the importance of local farmer networks and community observation in driving the adoption of new practices.

Closely tied to this is the role of agricultural extension officers, with 31.6% of farmers acknowledging their advice as a motivating factor. For some farmers, this formal support helped translate complex climate adaptation strategies into simple, practical actions. A farmer noted, *"When the extension officer came, he explained how planting trees and cover crops could protect the soil. He even showed us how to do it. That's when I started taking it seriously."* However, a few respondents also indicated that such services were not consistent across all communities, highlighting a need for more regular extension engagement. Another driver was personal observation of changing weather patterns, reported by 31.3% of respondents. Farmers frequently mentioned experiencing unusual rainfall patterns, prolonged drought, or higher temperatures as triggers for change. One participant described, *"In the past, we used to know when the rain would come. Now, it comes too late or too heavy. I realized I had to do something different… that's why I tried mulching and building a small pond."* This direct connection between lived climate experience and adaptation behavior supports the argument that farmers are not passive recipients of knowledge but are actively responding to environmental changes.

In addition, media (radio, TV, newspapers) were cited by 31.3% of farmers as a source of motivation. Radio programs, in particular, were commonly referenced during interviews. One farmer shared, *"There's a farming program on the local radio every Tuesday. That's where I first heard about composting and using trees to stop wind. It makes a lot of sense."* This suggests that accessible, local-language media play a powerful role in disseminating agricultural innovations. Other important motivators included traditional knowledge (30.1%), government programs (30.9%), cost savings (27.0%), training workshops (29.3%), and NGO interventions (25.4%). Traditional knowledge, for instance, was often blended with modern practices. A farmer stated, *"My grandfather used to leave grass around the crops to keep the soil cool. Now I know that's called mulching, and it still works." Similarly, some farmers* described NGO-led training as critical: *"The NGO gave us training and even small equipment to try contour farming. Without that, I wouldn't have started."* Collectively, these findings reveal that the decision to adopt nature-based solutions is rarely based on a single factor. Instead, it is shaped by a combination of experiential learning, peer influence, institutional support, cultural knowledge, and economic considerations. This implies that future efforts to promote NBS adoption must adopt a multi-channel approach, leveraging farmer-to-farmer education, mass media, traditional wisdom, and targeted technical support.

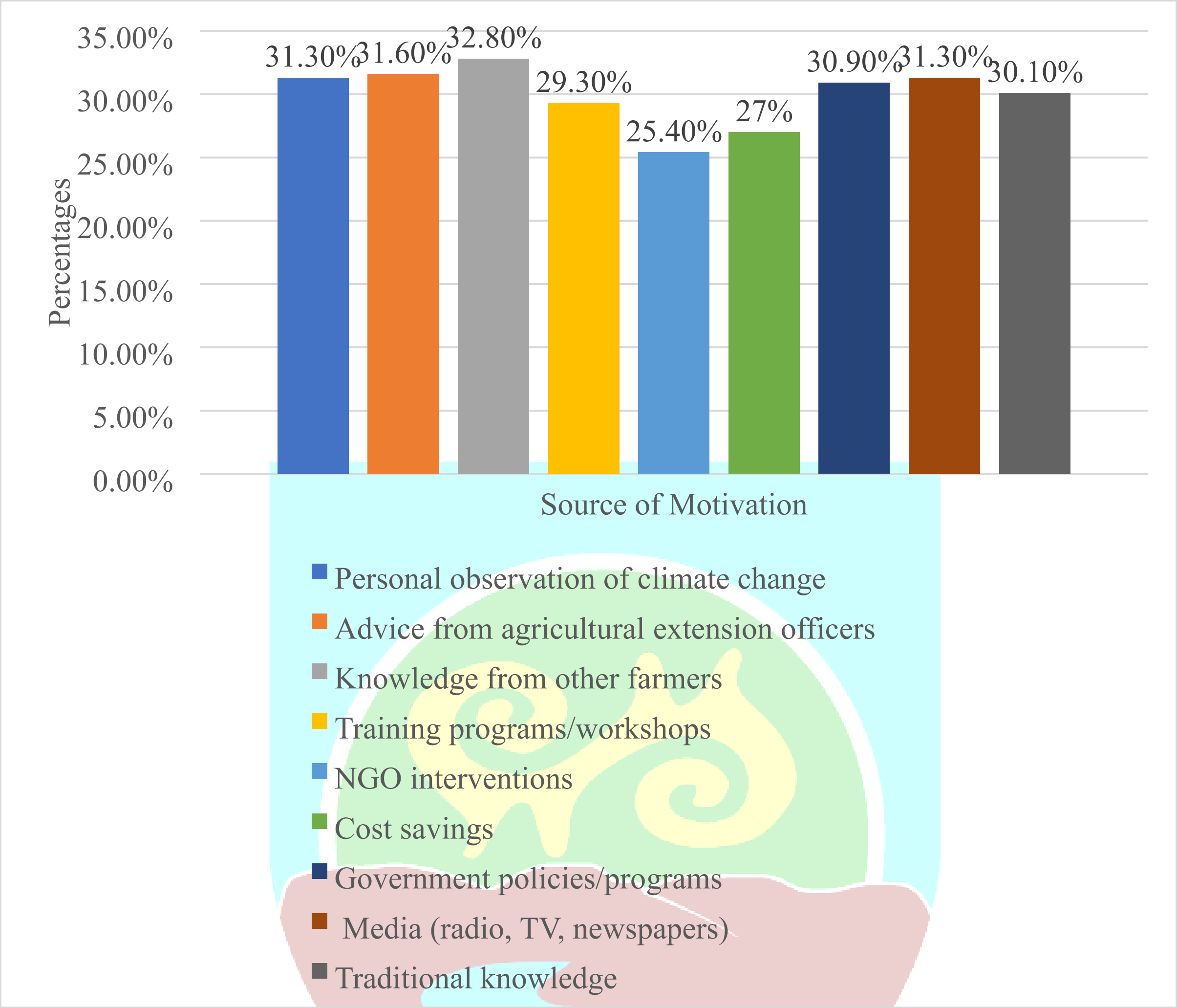


Figure 11: Source of Motivations for Using NbS

The final section of results presented in Figure 12.0 explores how farmers perceive the sustainability of the nature-based strategies they have implemented in their tomato farming. The responses indicate a generally positive outlook, with 45.7% describing their NbS methods as “fairly sustainable”, and 35.2% rating them as “very sustainable.” Only 19.1% of farmers considered their strategies to be “not sustainable.”

For many farmers who rated their NbS as “very sustainable,” the defining feature was the ability to reuse local materials, reduce costs, and maintain soil health over time. One farmer explained, *“I use compost and plant cover crops because I don’t have to buy anything.*

Even if the market is bad or fertilizer is expensive, I can still farm." This view reflects a strong appreciation for low-input, locally sourced methods that align with resource-constrained farming realities in Ghana. Another respondent who practiced agroforestry and intercropping commented, *"Once the trees grow, I don't need to do much. They protect the crops and the land. I think this method will last for many years."* This statement illustrates how some farmers link sustainability not only to immediate benefits but to long-term ecological resilience, a key principle in nature-based approaches. Those who rated their strategies as "fairly sustainable" often described some success, but also mentioned challenges that limit consistent or full-scale implementation. For example, one farmer stated, *"Using organic fertilizer works, but it takes time to prepare. Sometimes, I'm too busy during the planting season."* Another added, *"Mulching helps a lot, but when the dry season is long, the materials get scarce."* These responses reveal that even when strategies are effective, their sustainability may be affected by labour demands, resource availability, or time constraints.

In contrast, the 19.1% of respondents who viewed their methods as "not sustainable" expressed concerns about labour intensity, cost, or land limitations. One farmer explained, *"Contour farming is good, but I need help to dig and shape the land. Doing it alone every season is not realistic."* Another remarked, *"I tried creating a small pond, but during the dry season it dries up too fast, and I don't have the means to expand it."* These cases highlight the practical barriers that can undermine sustainability, even when the strategy is conceptually sound. Importantly, several farmers emphasized that the sustainability of these practices depends heavily on external support, such as training, access to tools, and cooperative labour. One farmer summarized this perspective well: *"If we get continued training and group work support, these methods will be easy to keep doing. But if we're left alone, many will stop."*

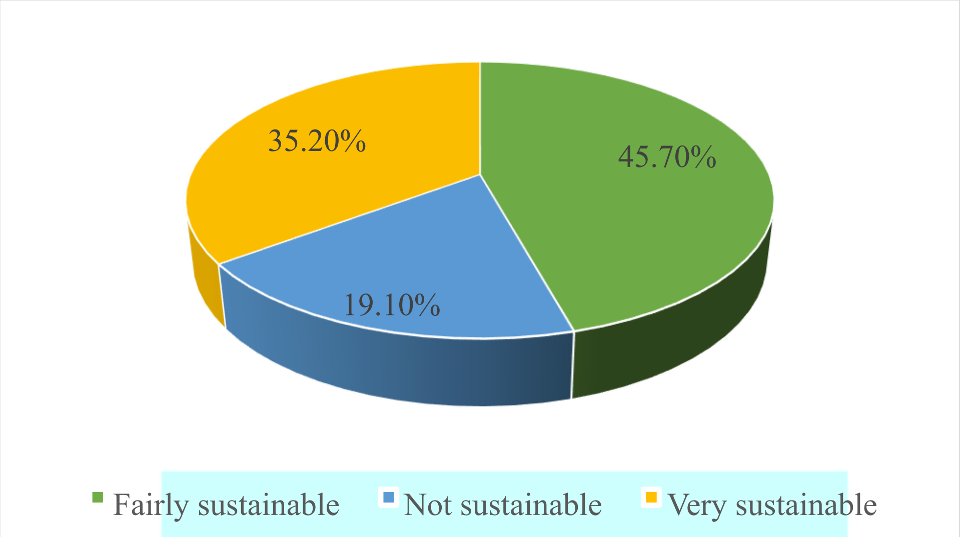


Figure 12: Sustainability of Nature-based Solutions

4.5.3 Outcomes and Challenges of Nature-Based Solutions

4.5.3.1 Outcomes of Nature-Based Solutions

Table 18 presents the outcomes of implementing nature-based solutions (NbS) in tomato farming, as reported by the 255 surveyed farmers. The values reflect whether each farmer experienced specific benefits or not (coded as binary responses), with the mean representing the proportion of farmers who reported experiencing each outcome. The results show moderate levels of reported benefits, with no single outcome overwhelmingly endorsed, and a notable percentage of farmers indicating no observable positive effects. The most commonly reported outcomes were reduced production costs, better resilience to extreme weather, and additional income sources, each reported by 37% (Mean = 0.37) of respondents. These findings suggest that a subset of farmers is beginning to experience tangible benefits beyond immediate yield, particularly in terms of economic stability and climate adaptation. For instance, reduced input use through composting and mulching was highlighted in interviews as a major cost-saving measure. One farmer explained, *"I don't buy fertilizer anymore. I make compost myself, and it has helped me save money."* Moreover, the study revealed that several farmers noted improvements in how their farms withstand irregular rainfall and harsh weather.

One respondent shared, *"Since I started using buffer zones and planting trees, the strong winds don't damage my crops like before."* Similarly, the opportunity to earn additional income, for example, from selling compost or surplus crops due to better yields, was seen as a welcome outcome by some.

Additionally, improved crop quality and reduced pest problems were also moderately reported, each by 34% of farmers (Mean = 0.34). A number of farmers attributed this to using organic inputs and improved soil management. One participant remarked, *"I used to spray chemicals, but now I use neem and compost, and the tomatoes are healthier and last longer after harvest."* These outcomes point to potential health and environmental benefits that go beyond economic concerns. Other outcomes such as better water retention (Mean = 0.33), increased crop yield (Mean = 0.31), and improved soil fertility (Mean = 0.30) were reported by slightly fewer farmers. Though these are expected ecological outcomes of many naturebased solutions, their modest ratings may reflect either the slow pace at which benefits manifest or variability in how effectively the practices are applied. For instance, a farmer who had just started using compost said, *"They say compost makes the soil better, but I think I need more time to see the difference."* This suggests that short-term adoption may not yet yield measurable agronomic results, even though the foundation has been laid.

Surprisingly, farmers with mean value (Mean = 0.39) reported no positive outcomes observed, making this the most selected response. This figure highlights a critical concern: that despite widespread promotion of NbS, a significant number of farmers may be failing to see results, either due to poor implementation, lack of knowledge, resource limitations, or unrealistic expectations. One disillusioned farmer expressed, *"I tried mulching and even made compost, but I didn't see any big change in yield or income."* This underlines the importance of follow-up training, contextual adaptation, and ongoing support to ensure nature-based solutions translate into real-world benefits.

Table 18: Outcomes of Nature-Based Solutions

Variables	N	Mean	Std. Dev.
Improved soil fertility	255	.30	.460
Increased crop yield	255	.31	.463
Better water retention	255	.33	.469
Reduced pest problems	255	.34	.475
Improved crop quality	255	.34	.475
More stable income	255	.345	.4763
Reduced production costs	255	.37	.483
Better farm resilience to extreme weather	255	.37	.483
Additional income sources	255	.37	.484
No positive outcomes observed	255	.39	.489

Source: Field Survey, 2025

4.5.3.2 Challenges of Nature-Based Solutions

Table 19 presents the challenges reported by tomato farmers in implementing nature-based solutions to address climate variability. Each item was measured as a binary variable (1 = yes, 0 = no), and the means represent the proportion of farmers who identified each issue. The data reveal a broad range of obstacles, with no single challenge dominating, but all playing meaningful roles in limiting the effective application and outcomes of nature-based solutions practices. The most frequently reported challenge was time constraints, with a value of (Mean = 0.33). This suggests that even when farmers are willing to adopt sustainable practices, the demands of day-to-day farm activities may leave them with insufficient time to properly implement techniques such as mulching, composting, or rainwater harvesting. Illustratively, one farmer explained, *“I know how to prepare compost, but during the planting season, I just* *don't have the time to gather the materials and wait for it to be ready."* This challenge may explain why some expected outcomes, such as improved soil fertility or increased yield, were not observed by all farmers.

Also, high cost had a mean of 0.31, confirming that although many NbS practices are promoted as low-cost or cost-saving, certain components, such as building farm ponds, acquiring planting materials for vegetative barriers, or setting up simple irrigation systems, still require upfront investment. A farmer shared, *"They said we could build a water storage pond, but digging it and lining it costs money I don't have*. Moreover, the outcome of the study shows that limited land had a mean of 0.29. Also, no local support mean value of 0.29. These challenges reflect both structural limitations and social dynamics. For example, small land sizes may prevent farmers from rotating crops or setting aside areas for agroforestry. Cultural norms and traditional beliefs can also affect how willing farmers are to adopt new techniques. One farmer said, *"Some people in my community believe certain methods, like planting trees in the middle of the field, are a waste of space or even bad luck."* A lack of localized support, whether from agricultural extension officers, local cooperatives, or NGOs, can leave farmers feeling isolated or unsure about how to sustain newly adopted practices. Notwithstanding, lack of knowledge, labour intensity, and uncertainty each had a mean value of 0.27. These findings emphasize the knowledge gap and practical difficulties that often accompany transitions to new agricultural systems. Farmers unfamiliar with compost ratios, planting patterns for contour farming, or organic pest control techniques may either misuse or abandon practices altogether. A respondent noted, *"I tried to mulch but did it wrongly, and the termites increased instead of reducing. No one came to show me how to do it right."* Also, the challenge of labour intensity is particularly relevant in a smallholder context where family labour is limited, and hiring external help is expensive. Practices like contour farming, building vegetative barriers, and composting can be labour-demanding. A farmer stated, *"Doing these things alone is hard. You need help, and it takes time away from other work."* Similarly, uncertainty about results discourages long-term commitment. Several farmers expressed that they were unsure whether nature-based solutions would truly work for them or offer better results than conventional methods. This lack of confidence reduces motivation to invest the time or resources required for consistent application

Table 19: Challenges of Nature-Based Solutions

Variables	N	Mean	Std. Dev.
Lack of knowledge	255	.271	.4451
High cost	255	.31	.463
Labor intensive	255	.27	.443
Time constraints	255	.33	.469
Limited land	255	.29	.453
Uncertainty	255	.27	.447
No local support	255	.29	.453
Cultural barriers	255	.29	.453

Source: Field Survey, 2025.

4.6 Recommendations for Scaling Up Effective and Appropriate Nature-Based Solutions to Support Climate Adaptation Measures

This section of the chapter presents the results of the recommendations made in the interviewed participants regarding how to scale-up nature-based solutions among tomato farmers in Techiman North Municipality. From the analysis, three major themes emerged;

Theme 1: Need for Continuous Capacity Building and Farmer Training

A consistent theme that emerged from the interviews was the need for ongoing training and practical support to ensure farmers understand how to implement nature-based solutions effectively and sustainably. Many farmers who had attempted practices like composting, mulching, or rainwater harvesting expressed uncertainty or admitted to trial-and-error approaches due to a lack of technical guidance.

> *"I was told to use compost, but nobody showed me how to prepare it well. I just put things together, and sometimes it smells bad or doesn't break down properly." (Male farmer, 41 years from Aworowa).*

Another participant also said:

> "*When the NGO came to train us, we started using vegetative barriers, and we saw improvements. But now they are gone, and we are forgetting how to do it well." … Female farmer, 36 years, Tuobodom.*

Another added:

> *"We need more frequent visits from extension officers. They come once in a while and don't reach everyone." Male farmer, 50 years, Buoyem)*

This theme reflects the importance of institutionalizing farmer education through regular field demonstrations, mobile training units, and peer-to-peer learning models. Continuous support is necessary, especially for low-literacy farmers, to transition from surface-level awareness to mastery of climate-resilient practices.

Theme 2: Access to Local Resources and Financial Support

Many farmers emphasized that while they are willing to adopt nature-based solutions, they often lack access to necessary resources such as tools for digging contour ridges, organic materials for composting or mulching, and even land for practices like crop rotation or agroforestry. Illustratively, some farmers said:

> *"I wanted to build a small pond, but digging it requires help and money. I cannot afford it alone." … (Female farmer, 44 years, Offuman)*
>
> *"Sometimes, the materials like leaves for mulching are not easy to get, especially in the dry season." …(Male farmer, 38 years, Tuobodom)*

> *"We heard about tree planting, but where is the land? My farm is already small."* … *(Female farmer, 30 years, Krobo)*

These responses from some farmers depict recommendations that future programs include resource packages, subsidized inputs, or community-based equipment hubs, where tools and materials can be shared. These support systems would make it more feasible for farmers to practice and sustain nature-based solutions across different seasons and land conditions.

Theme 3: Building Local Structures and Community Engagement for Sustainability

Several respondents highlighted the need to engage local farmer groups, traditional leaders, and cooperatives to improve coordination, monitor progress, and embed climate practices into the culture of farming in the municipality. Farmers expressed that communitybased action could be more effective than relying solely on external organizations.

> *"If the chiefs and opinion leaders support it, more people will follow. Some people wait to see what others are doing."* … *(Male farmer, 55 years, from Aworowa)* *"We need a local team, like lead farmers who can teach and monitor others. Not every time should we wait for outsiders."* … *(Female farmer, 33 years, from Offuman)* *"When we form groups and learn together, it's easier to remember and apply.*
>
> *Alone, you forget things quickly."* … *(Male farmer, 47 years, from Tanoboase)*

This theme emphasizes that scaling nature-based solutions requires localized governance structures, such as community climate committees, farmer champions, and integration of climate practices into local norms and agricultural associations. Such efforts can foster ownership, continuity, and peer-driven accountability.

The themes that emerged from the analysis revealed that to successfully scale up naturebased solutions, the focus should go beyond simply introducing the practices, as farmers in Techiman North Municipal demand, regular, practical training and follow-up, material and financial support that makes adoption feasible, and locally rooted community systems to reinforce continuity and shared responsibility. These findings suggest that government and development partners should adopt a holistic, farmer-centered policy framework that prioritizes capacity, access, and ownership.

4.7 Discussion of Findings

The goal of this study was to explore the nature-based climate variability adaptation strategies employed by tomato farmers in the Techiman North Municipal of Ghana. The study specifically aimed to identify the types of nature-based solutions adopted, the factors influencing their choice, assess the perceived effectiveness of those strategies, and finally develop recommendations to support their adoption and upscaling.

The first objective of the study sought to identify the various nature-based climate variability adaptation strategies adopted by tomato farmers to cope with unpredictable weather conditions and climate stress. The study found that farmers implemented a wide range of strategies, including restoring natural vegetation, contour farming, green manure or organic fertilizer, agroforestry, intercropping, buffer zone, farm ponds, composting, mulching, crop rotation, cover cropping, and rainwater harvesting. Farmers particularly rated mulching, rainwater harvesting, vegetative barriers, and agroforestry as the most effective strategies. One farmer stated, *"Mulching has helped me survive dry spells without watching all my tomatoes die,"* confirming that it plays a critical role in maintaining soil moisture and reducing plant stress during hot conditions. These findings imply that tomato farmers are not passive recipients of climate impacts, but active agents adopting practices tailored to their environmental and socio-economic conditions. The widespread use of mulching and rainwater harvesting reflects an emphasis on low-cost, accessible solutions that also improve soil and water conservation. The findings are largely consistent with the literature. Adombilla et al. (2024) reported widespread use of organic mulches such as dried grass and rice straw among tomato farmers in Ghana, showing improvements in soil moisture retention and crop yield. Similarly, Kahinda and Taigbenu (2011) and Raimondi et al. (2024) documented how rainwater harvesting reduced yield losses by up to 40% during periods of erratic rainfall in Ghana's transition zone. Antwi-Agyei et al. (2021) also noted that mulching, agroforestry, and composting are part of integrated soil fertility strategies that are gaining traction among smallholder tomato farmers for their climate resilience benefits. However, the relatively high adoption rate of buffer zones and vegetative barriers contrasts with findings by NyantakyiFrimpong (2020), who reported low uptake of such strategies due to land constraints in areas of high population density. This contradiction may stem from land availability in Techiman North compared to more densely populated regions. It may also reflect localized knowledge systems and farmer cooperatives that promote ecosystem-based practices, as suggested by. Owusu and Asumadu-Sarkodie (2016) highlighted that communal efforts often ease resource constraints and facilitate the adoption of spatially demanding strategies.

Following the first objective, the second aimed to understand what influenced their choices of identified nature-based adaptation strategies among tomato farmers in selecting specific adaptation practices over others. The findings show that different factors influence the adoption of specific practices. For instance, rainwater harvesting was significantly influenced by access to training ($p = 0.040$), while farm ponds were influenced by profitability ($p = 0.039$) and perceived complexity ($p = 0.043$). Intercropping was strongly influenced by traditional beliefs ($p = 0.019$). In contrast, government policy had a significant negative influence on the use of organic fertilizers ($p = 0.025$), suggesting that some institutional frameworks may unintentionally discourage beneficial. The implications of these results are profound. Thus, the adoption of nature-based solutions is not solely a function of climate awareness or farm size, but is deeply embedded in local belief systems, perceptions of economic benefit, and availability of extension services. For example, a farmer who was interviewed stated, "*If the government won't support compost, I will just burn the waste…it's* *faster.”* These findings align with Rogers’ Diffusion of Innovation theory (Rogers 2010) which posits that adoption decisions are shaped by perceived attributes of innovations and social systems. Also, Abass et al. (2018) found that training, extension services, and traditional practices jointly influence farmers’ behaviour towards nature-based solutions among the farmers. However, these findings contradict earlier works by Antwi-Agyei et al. (2021), who found government policies to be significant facilitators, not barriers, to the adoption of green manure in northern Ghana. One possible explanation could be contextual policy misalignment, as Antwi-Agyei & Nyantakyi-Frimpong (2021) noted that while national climate policies exist in Ghana, their translation into local-level support systems remains poor. Another reason could be market-induced constraints, such as the commercialization of tomato production in certain districts that push farmers towards conventional rather than ecological inputs, as reported by Sonnino & Marsden (2015). Furthermore, the third objective assessed how well the adopted strategies performed from the perspective of the farmers. The analysis showed that most strategies were perceived as moderately effective. Only crop rotation was significantly rated as less effective (Mean = 2.78, p = .015). Practices such as composting, rainwater harvesting, and buffer zones had the highest mean scores (above 3.08), indicating a positive perception of their outcomes. Though strategies like mulching, farm ponds, and intercropping had lower ratings (below 3), interviews revealed that their practical benefits were appreciated. A female farmer noted, “*Compost makes the soil rich, and the plants grow strong even with little water.”* These findings imply that effectiveness is not always accurately captured by quantitative scoring alone; it is shaped by context, ease of use, and immediate returns. The fact that over 73.8% of respondents found their strategies successful reflects a broader acceptance of these interventions as viable adaptation tools. These findings are consistent with Kyei-Mensah et al. (2019), who found that farms applying natural soil amendments and water conservation practices like compost and mulching had improved yields and fruit quality under climate stress. Similarly, Asamoah et al. (2023) reported that comprehensive nature-based interventions (like combining mulching and intercropping) maintained up to 60% of average yields during adverse seasons. Similarly, Owusu-Sekyere and Aladago (2023) found that integrated Nature-based Solutions (NbS), such as combining mulching, rainwater harvesting, and intercropping, provided greater resilience benefits than single interventions, emphasizing the importance of holistic adaptation strategies. Brooks et al. (2013) also emphasize that local definitions of effectiveness must account for perceived risk reduction and co-benefits, such as soil health or pest control. Contrastingly, crop rotation's poor effectiveness rating diverges from Uli et al. (2017), who found crop rotations to improve soil structure and yield resilience in diversified systems. Similarly, Liniger and Critchley (2008) advocated rotation as a key soil and water conservation measure. The divergence may be due to a lack of enforcement of rotation best practices or short-term focus among tomato producers who rely on consistent market availability and may rotate crops only within short timeframes. Furthermore, Ddamulira et al. (2021) in Uganda observed that tomato farmers often repeat crops due to market pressure, undermining the benefits of crop rotation. These contextual factors may explain the low effectiveness observed in this study.

Lastly, the final objective focused on drawing practical insights and proposing strategies for the broader implementation of effective nature-based solutions. Key recommendations from the field include; continuous training and support, especially for composting, rainwater harvesting, and mulching, enhancing farmer-to-farmer education, which was the most cited motivator for adoption (32.8%), integrating local knowledge systems, since strategies like intercropping are culturally rooted, and addressing barriers such as high cost (31%), lack of land (29%), and limited institutional support. These findings emphasize the need for contextsensitive scaling strategies that account for resource constraints, knowledge gaps, and sociocultural dynamics. One farmer lamented, *"If I had land and some training, I could have done more with the rainwater I collect."* The recommendations are aligned with literature by Antwi-Agyei and Nyantakyi-Frimpong (2021), who advocated for integrating indigenous knowledge with formal policies in Ghana. Similarly, Antwi-Agyei et al. (2021) added that there is a need for policy reform to ensure alignment of agricultural extension services with ecological practices. Purcell (2020) also stresses that successful community-based adaptation requires participatory processes and sustained institutional support.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

This chapter presents a summary of the study, including its objectives, methodology, and key findings. It also provides conclusions drawn from the findings. It offers practical recommendations for enhancing the adoption and scaling of nature-based climate adaptation strategies among tomato farmers in Techiman North Municipal, Ghana. The chapter ends with implications for practice and suggestions for further studies.

5.2 Key Findings

The demographic characteristics of the respondents showed that the majority of the farmers were between 31–50 years and had moderate to low formal education. Most farmers had more than 10 years of farming experience and operated on small to medium-sized farms (1–5 acres). Over 74% of respondents reported that tomato farming was their primary source of income, which shows the importance of improving resilience in this sector.

The first objective aimed to identify the nature-based climate adaptation strategies adopted by tomato farmers. The findings revealed that the most commonly adopted strategies were restoring vegetation, contour farming, organic fertilizers, agroforestry, and intercropping, among others.

The second objective assessed the factors influencing the adoption of these strategies. It was found that adoption was driven by factors such as training, profitability, and traditional beliefs, while government policies negatively influenced the uptake of certain strategies like composting and organic fertilizer.

The third objective assessed the effectiveness of the strategies. Agroforestry, Composting, Buffer zones, and Rainwater harvesting were perceived as moderately effective, while crop rotation was the only strategy significantly rated as slightly effective (mean = 2.78, p = 0.015).

The final objective focused on generating recommendations to scale up effective strategies. Key suggestions included continuous farmer training, promoting peer learning, integrating indigenous knowledge, and addressing land and financial constraints.

5.3 Conclusion

The study concludes that tomato farmers in Techiman North Municipal actively adopt a diverse range of nature-based adaptation strategies to cope with climate variability. These strategies are not randomly chosen but are shaped by factors such as environmental suitability, perceived effectiveness, and socio-cultural values. The findings also show that strategies like mulching, composting, and rainwater harvesting are perceived to be among the most effective. However, challenges such as policy disincentives, high implementation costs, and limited land ownership pose barriers to broader adoption. The negative role of policy in influencing certain strategies suggests a need for better alignment between national programs and the actual needs of local farmers. Finally, it is evident from the findings that farmers prefer lowcost, accessible, and proven solutions. Their continued use of nature-based practices despite constraints indicates strong potential for scaling up such strategies, particularly when supported by training and institutional backing.

5.4 Recommendations

Based on the findings from the study, the following recommendations were made;

1. Extension services should prioritize by strengthening farmers' training and support Services: Capacity building for tomato farmers and training should be practical and tailored to farmers’ literacy levels. Special attention should be given to composting, mulching, and water conservation techniques like rainwater harvesting.

2. There should be promotion of farmer-to-farmer learning platforms: Given that peer influence was a strong driver of adoption, farmer exchange programs and demonstration plots should be introduced by the government and various stakeholders to allow successful farmers to share experiences and teach others.
3. Government and various non-governmental organizations should align agricultural policies with local realities. This will actively support nature-based practices such as organic fertilizers and composting, which are currently hindered by policy disincentives. This includes providing subsidies or incentives and integrating such practices into agricultural extension programs.
4. Provision of financial and technical incentives: Government and local banks should establish funding mechanisms such as microcredit schemes or grants to help farmers overcome the initial costs of adopting effective but capital-intensive strategies like farm ponds and cover cropping.

5.5 Practical Implications

The results of this study have important practical implications. First, it confirms that farmers are willing to adopt sustainable climate adaptation strategies, provided they receive the right information and support. Institutions involved in agriculture and environmental management should integrate nature-based solutions into local development plans. Secondly, the study shows that effectiveness is not only about technical success but also about accessibility, cultural acceptance, and economic feasibility. Thus, any scaling-up strategy must consider not just the environmental benefits but also the socio-economic realities of smallholder farmers. Lastly, recognizing the value of indigenous knowledge and informal farmer networks is crucial. These systems can serve as powerful tools for accelerating the spread of sustainable practices in rural communities.

5.6 Suggestions for Further Studies

Future research should explore the long-term economic and environmental impacts of nature-based adaptation strategies on tomato farming, how specific policies at the municipal, district, and national levels affect the adoption of these strategies, and the role of gender and youth in promoting or hindering the adoption of nature-based solutions. Also, comparative studies across different districts or regions to assess how geographical and cultural factors shape adaptation responses would be helpful.

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LIST OF APPENDICES

Appendix 1 Questionnaires

UNIVERSITY OF ENERGY AND NATURAL RESOURCES SUNYANI

SCHOOL OF GRADUATE STUDIES DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

<u>QUESTIONNAIRES FOR TOMATO FARMERS IN TECHIMAN NORTH MUNICIPAL, GHANA</u> RESEARCH TITLE:

ASSESSING NATURE-BASED SOLUTIONS TO CLIMATE VARIABILITY ADAPTATION STRATEGIES AMONG TOMATO FARMERS IN TECHIMAN NORTH MUNICIPAL, GHANA

Dear Respondents,

I am **George Frimpong Enchill,** a postgraduate student of the above university. As part of our academic requirement, I am conducting research on: Assessing nature-based solutions to climate variability adaptation strategies among tomato farmers in Techiman North Municipal, Ghana. You are kindly requested to fill out this questionnaire, indicating your honest responses. Your responses will help develop better responses to nature-based climate adaptation strategies for farmers across Ghana. I assure you that any information provided will remain confidential and be used solely for academic purposes. Thank you for your valuable time and cooperation.

(Please tick and specify where appropriate)

SECTION A: DEMOGRAPHIC INFORMATION

1. Age: [ ] 18 - 30 [ ] 31- 40 [ ] 41-50 [ ] 51-60 [ ] Above 60
2. Gender: [ ] Male [ ] Female
3. Highest level of education: [ ] No formal education [ ] Primary [ ] JHS/Middle School [ ] SHS/Secondary [ ] Tertiary [ ] Other (Please specify): __________________
4. Farming Experience:
   [ ] Less than 5 years [ ] 5-10 years [ ] 11-20 years [ ] More than 20 years
5. Land Size Dedicated to Tomato Farming:
   [ ] Less than 1 acre [ ] 1-2 acres [ ] 3-5 acres [ ] More than 5 acres

SECTION B: CLIMATE VARIABILITY AWARENESS AND IMPACTS

6. Have you noticed any changes in climate patterns over your farming career?
   [ ] Yes [ ] No [ ] Not sure
9. If yes, which climate changes? Variability, have you observed? (Check all that apply)
   - [ ] Increased temperature
   - [ ] Decreased rainfall
   - [ ] Increased rainfall
   - [ ] Unpredictable rainfall patterns

[ ] Longer dry seasons
[ ] Shorter rainy seasons
[ ] More frequent storms [ ] Other (Please specify): ________________

10. On a scale of 1-5, how severely have these climate changes affected your tomato production?
[ ] 1 (No effect)
[ ] 2 (Minor effect)
[ ] 3 (Moderate effect)
[ ] 4 (Severe effect)
[ ] 5 (Extremely severe effect

SECTION C: AWARENESS AND IMPLEMENTATION OF NATURE-BASED SOLUTIONS AND SUSTAINABILITY

11. Are you familiar with the term "nature-based solutions"?
[ ] Yes, very familiar
[ ] Somewhat familiar
[ ] Have heard of it but not sure what it means
[ ] No, never heard of it

12. After reading this brief explanation: "Nature-based solutions are actions that work with and enhance natural systems to address social and environmental challenges," which of the following nature-based solutions have you implemented on your farm? (Check all that apply)
[ ] Agroforestry (integrating trees with crops)
[ ] Cover cropping
[ ] Mulching
[ ] Composting
[ ] Rainwater harvesting
[ ] Contour farming
[ ] Green manure/organic fertilizers
[ ] Crop rotation [ ] Intercropping
[ ] Creating buffer zones near water bodies
[ ] Constructing vegetative barriers against winds
[ ] Restoring natural vegetation around farms
[ ] Creating farm ponds for water storage
[ ] Other (Please specify): ________________

13. For each nature-based solution you have implemented, please rate its effectiveness in addressing climate variability challenges: ***(Please use: 1=Not effective, 2=Slightly effective, 3=Moderately effective, 4=Very effective, 5=Extremely effective*** a. ___ Agroforestry
b. ___ Cover cropping
c. ___ Mulching
d. ___ Composting
e. ___ Rainwater harvesting f ---- Irrigation system
g. ___ Contour farming
h. ___ Green manure/organic fertilizers

i. ___ Crop rotation
j. ___ Intercropping
k. ___ Creating buffer zones
l. ___ Vegetative barriers
m. ___ Restoring natural vegetation n ___ Farm ponds

15. Which of this nature-based solution is the best for your tomato farming

[ ] Agroforestry (integrating trees with crops)
[ ] Cover cropping
[ ] Mulching
[ ] Composting
[ ] Rainwater harvesting
[ ] Irrigation system
[ ] Contour farming
[ ] Green manure/organic fertilizers
[ ] Crop rotation [ ] Intercropping
[ ] Creating buffer zones near water bodies
[ ] Constructing vegetative barriers against winds
[ ] Restoring natural vegetation around farms
[ ] Creating farm ponds for water storage

16. Which factors influence your choice of your nature-based solution adaptation strategies

(tick at least two)

[ ] Initial investment costs
[ ] Expected economic returns/profitability
[ ] Market demand for sustainably produced tomatoes
[ ] Less Labor requirements
[ ] Availability of training and extension services
[ ] Complexity of implementing the practice
[ ] Compatibility with the existing farming system
[ ] Observable results/proven effectiveness
[ ] Traditional beliefs and practices
[ ] Peer influence/recommendations
[ ] Government policies and regulations
[ ] Access to relevant information
[ ] Environmental benefits
[ ] Long-term sustainability

17. Is your nature-based solution successful in your tomato farming?

[ ] Yes [ ] No

18. What motivated you to adopt these nature-based solutions? (Check all that apply)

[ ] Personal observation of climate changes
[ ] Advice from agricultural extension officers
[ ] Knowledge from other farmers
[ ] Training programs/workshops
[ ] NGO interventions

[ ] Cost savings
[ ] Government policies/programs
[ ] Media (radio, TV, newspapers)
[ ] Traditional knowledge
[ ] Other (Please specify): ________________

19. How long have you been implementing these nature-based solutions?
[ ] Less than 1 year [ ] 1- 3 years [ ] 4- 6 years [ ] 7- 10 years [ ] More than 10 years.

20. How sustainable is your nature-based solution method in your tomato farming
[ ] Very sustainable [ ] Fairly sustainable [ ] Not Sustainable

SECTION D: OUTCOMES AND CHALLENGES OF NATURE-BASED SOLUTIONS

21. What positive outcomes have you observed after implementing nature-based solutions? (Check all that apply)
[ ] Improved soil fertility
[ ] Increased crop yield
[ ] Better water retention
[ ] Reduced pest problems
[ ] Improved crop quality
[ ] More stable income
[ ] Reduced production costs
[ ] Better farm resilience to extreme weather
[ ] Additional income sources
[ ] Other (Please specify): ________________
[ ] No positive outcomes observed

22. What challenges/barriers have you faced in implementing nature-based solutions? (Check all that apply)
[ ] Lack of knowledge/technical expertise
[ ] High initial implementation costs
[ ] Labor intensiveness
[ ] Time constraints
[ ] Limited land availability
[ ] Uncertain results/benefits
[ ] Lack of support from local authorities
[ ] Cultural/traditional barriers [ ] Other (Please specify): ________________

SECTION E: POLICY RECOMMENDATIONS FOR SCALING UP NATUREBASED SOLUTIONS AND INSTITUTIONAL AND GOVERNANCE

Technical Support and Extension

23. What type of technical support is most needed? (Rank 1-5) ○ On-farm demonstrations: ___ ○ Training workshops: ___ ○ Digital/mobile advisory services: ___ ○ Peer farmer networks: ___ ○ University/research partnerships: ___

24. Which policy interventions are most important? (Rank 1-5)
a. National climate adaptation strategy: ___

b. Agricultural extension reform: ___
c. Environmental regulations: ___
d. Land use planning: ___
e. Water resource management: ___

25. Which institutions should lead scaling efforts? (Check all that apply)

a. ☐ Ministry of Agriculture
b. ☐ Environmental agencies
c. ☐ Research institutions
d. ☐ Farmer organizations
e. ☐ NGOs
f. ☐ Private sector
g. ☐ International development partners
h. ☐ Local government

26. What capacity building is most needed? (Rank 1-5) ○ Farmer education and training: ___ ○ Extension agent capacity: ___ ○ Research institution strengthening: ___ ○ Policy maker awareness: ___ ○ Private sector engagement: __

This information is gathered and will be used by George Frimpong Enchill
MPhil Environment, Water and Sustainability
Candidate UENR. Date:…......................... Signature…......................................

Thank you for your cooperation

Contacts/Phone Number: 0248719333/ 0208870508 **E-mail:** georgefrimpongenchill@gmail.com

Appendix 2 Key informant interview for tomato farmers

Interview Guide: For Tomato Farmers

Good morning/afternoon. My name is **George Frimpong Enchill,** and I am a graduate student conducting research on how tomato farmers in Techiman North Municipal are adapting to climate changes using nature-based solutions. This interview is part of my MPhil thesis research. Your participation is voluntary, and all information shared will be kept confidential. The interview will take approximately 10-30 minutes. May I have your permission to proceed and record this conversation for research purposes only?

Respondent Background

- **Name:** ________________ (Optional/Anonymous)
- **Age:** ________________
- **Gender:** ________________
- **Years of farming experience:** ________________

1. Have you noticed any changes in weather patterns over the years you've been farming? 2. What specific changes have you observed? (Probe: rainfall patterns, temperature, dry seasons, etc.)
3. What nature-based management practices do you use during dry periods in your tomato farming
4. How do you protect your crops during extreme weather events?
5. Do you implement nature-based solutions in your tomato farming
6. What factors influence your choice of the nature-based
7. Is your nature-based solution implemented in your farm effectively 8. What would encourage you to adopt more nature-based farming approaches?
9. What support do you need to implement nature-based solutions?
10. Have you received training on climate-smart agriculture or nature-based farming?
11. What kind of support do you receive from government agricultural extension services?
12. What should the government and organizations do to support you?
13. What specific policy changes would most encourage you to adopt nature-based solutions?
14. What are the biggest opportunities for scaling up nature-based solutions in your area?
15. Do you have any additional comments or recommendations?

Appendix 3 Participant Consent Form

PARTICIPANT CONSENT FORM FOR TOMATO FARMERS IN TECHIMAN NORTH MUNICIPAL

MPhil Research Study

Research Title: Assessment of Nature-Based Solutions to Climate Variability and Adaptation Strategies Among Tomato Farmers in Techiman North Municipal, Ghana
Principal Investigator: George Frimpong Enchill
Institution: University of Energy and Natural Resources
Department/School: Department of Environmental Management
Supervisor: Dr. Mary Antwi & Dr David Adu Poku
Contact Information: georgefrimpongenchill@gmail.com, 0248719333

INVITATION TO PARTICIPATE

You are being invited to participate in a research study as part of an MPhil thesis. Before deciding whether to participate, you must understand the purpose of the research and what it entails.

Purpose of the study

The main objective of the research was to assess the nature-based climate variability adaptation strategies used by tomato farmers in Techiman North Municipal.

If you agree to participate, you will be asked to:

- Complete a questionnaire that will take approximately 30 minutes • with a few follow-up questions, interviews

VOLUNTARY PARTICIPATION

Your participation in this research is entirely voluntary. You may:

- Decline to participate without providing a reason
- Withdraw from the study at any time without penalty
- Skip any questions you prefer not to answer
- Request that your data be removed from the study (up until [specify deadline, e.g., data analysis begins])

CONFIDENTIALITY AND DATA PROTECTION

Your privacy and confidentiality will be protected through the following measures:

Data Collection:

- All responses will be kept strictly confidential
- Your name will not be used
- Only the research team will have access to your responses

Data Use:

- Your responses may be quoted anonymously in the thesis and related publications
- No identifying information will be included in any reports
- Aggregate data may be shared with the academic community through publication.

CONSENT STATEMENT

I have read and understood the information provided about this research study. I have had the opportunity to ask questions, and any questions I have asked have been answered to my satisfaction.

I understand that:

- My participation is voluntary
- I can withdraw at any time without penalty
- My responses will be kept confidential
- The data will be used for the purposes outlined above

By proceeding with the questionnaire, I confirm that:

☐ I am 18 years of age or older
☐ I have read and understood the information about this study
☐ I voluntarily consent to participate in this research

☐ I understand that I can withdraw my participation at any time
☐ I consent to the use of my anonymized data for the purposes described above
☐ I would like to receive a summary of the research findings *(optional)*

Participant Name: __________________________ **Date:** _____________

Participant Signature: __________________________

Please keep a copy of this form for your records.

For Researcher Use Only:

Researcher Name: __________________________

Researcher Signature: __________________________ **Date:** _____________

Appendix 4 Interview with Tomato Farmers

YOKOHAMA TYRES