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SUSTAINABILITY OF FARMER-LED IRRIGATION SYSTEMS UNDER CLIMATE CHANGE IN THE UPPER EAST REGION OF GHANA

ABARIKE, APUSWIN MERCY

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ABARIKE, APUSWIN MERCY (MPhil DEVELOPMENT STUDIES)

(UDS/DES/0001/19)

A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENT AND SUSTAINABILITY SCIENCES, FACULTY OF NATURAL RESOURCES AND ENVIRONMENT, UNIVERSITY FOR DEVELOPMENT STUDIES, TAMALE GHANA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN ENVIRONMENTAL MANAGEMENT AND SUSTAINABILITY

MARCH, 2026

DECLARATION

STUDENT'S DECLARATION

I hereby declare that this thesis is the result of my original work and that no part of it has been presented for another degree at this University or elsewhere.

Candidate's Signature: ………………………….. **Date: 24/03/2026**

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SUPERVISORS' DECLARATION

We hereby declare that the preparation and presentation of the thesis were supervised under the guidelines on thesis supervision laid down by the University for Development Studies.

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ABSTRACT

Farmer-led irrigation (FLI) plays a critical role in food security, livelihoods, and rural development in the Upper East Region (UER) of Ghana, and contributes to the achievement of Sustainable Development Goals (SDGs) 1,2,5,6 and 13. However, its long-term sustainability under climate change remains insufficiently understood. This study evaluates the sustainability of FLI systems in the UER, focusing on environmental, economic and social dimensions, including gender relations. A mixed-methods approach was employed, combining qualitative data from 33 key informant interviews and 20 focus group discussions with quantitative cross-sectional survey data from 250 FLI practitioners. The study examined the development trend of FLI systems, effects of climate change on FLI, adaptation strategies , and the sustainability potential of different FLI systems. The findings indicate that FLI enhances agricultural productivity and livelihoods by enabling dry-season cultivation and mitigating risk associated with rainfall variability. FLI systems are transforming in response to climate stress, with increased adoption of motorised groundwater systems, despite high capital cost. Manual and gravity-fed systems exhibit lower ecological footprints. Supplementary and pump-based irrigation systems are more economically viable, while manual systems are more socially inclusive. The decomposition analyses shows that gender disparities are largely driven by unequal access to land and other resources rather than differences in returns. This suggest that targeted support could reduce the gap. The Major challenges of FLI include limited access to credit, marketing issues, and climate change effects, including increased evapotranspiration, biodiversity loss and water scarcity. The study concludes that sustainability outcomes vary across FLI systems and are shaped by technology type, water source, gender and institutional support. A sustainability pathway framework for FLI is proposed, emphasising system-specific interventions, collective organisation of irrigation practitioners, gender-responsive support, and investments in water efficient irrigation technologies through government and NGO support.

DEDICATION

I dedicate this work to the Abarike and Nbila families.

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LIST OF ACRONYMS

BCR - Benefit Cost Ratio
CAPI - Computer-Assisted Personal Interview
FLI - Farmer-led Irrigation
FGD - Focused group discussion
GASSIP - Ghana Agricultural Sector Investment Programme
GCAP - Ghana Commercial Agricultural Programme
HDDS - Household Dietary Diversity Scores
IAASTD - Assessment of Agricultural Knowledge, Science and Technology for Development
ILSSI - Innovations Lab for Small Scale Irrigation
KII - Key Informant interview
MMDAs - Metropolitan, Municipal, and District Assemblies
MESTI - Ministry of Environment Science Technology and Innovations
MOFA - Ministry of Agriculture
NGO - Non-governmental Organization
NRGP - Northern Rural Growth Programme
OB = Oaxaca Blinder
OLS - Ordinary Least Squares
RIF - Recentred Influence Function
SDGs - Sustainable Development Goals
UER - Upper East Region
UNFCCC - United Nations Framework Convention on Climate Change
VSLA - Village Savings and Loans Associations
PGW - Pump Groundwater
PSW - Pump Surface water

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Agriculture is a vital component of Ghana's economy and the primary livelihood for many people, employing 65.2% of rural dwellers in Ghana (Ghana Statistical Service, 2018;Yeboah & Kyeremeh, 2021) .In Ghana's Upper East Region (UER), it plays a crucial role in sustaining rural communities and contributing to the nation's food security (Ampadu *et al*., 2019; Antwi-Agyei *et al*., 2013; Osarfo *et al*., 2016) .

Farmers in the UER face ongoing challenges from unpredictable rainfall, temperature fluctuations, and other climate extremes. Droughts, dry spells, and considerable flooding especially during the peak of the rainy season in August and September, affect crop yields and threaten livelihoods (Ampadu *et al*., 2019;Kasei, 2010; Fontaine *et al*., 2019), . These climate variations have severe implications for food security and general welfare of the population.

Irrigated agriculture has long played a crucial role in supporting people in Ghana's dry savannah regions, helping farmers adapt to climate change and variability (Ampadu *et al*., 2019; Fontaine *et al*., 2019) . Expanding irrigation systems is increasingly recognised globally as a key climate adaptation strategy, particularly for improving the productivity of underperforming rainfed croplands, reducing crop exposure to heat and water stress, and enhancing resilience to climate extremes (Rosa,2022). Countries that depend on agriculture for socio-economic development risk compromising food security and rural livelihoods if irrigation development is not integrated into their national climate adaptation strategies (MOFA, 2011). Expanding irrigation systems has been identified as a critical climate adaption

Irrigation is vulnerable to climate variability and change because it relies on surface and groundwater, which depends on rainfall for recharge (Mahe *et al*., 2013). Conversely, irrigation contributes to climate change by directly and indirectly emitting greenhouse gases (Yang *et al*., 2023).

According to the Intergovernmental Panel on Climate Change (IPCC, 2023), increasing weather and climate extremes are already exposing millions of people to acute food insecurity and reduced water security, particularly in regions with significant development constraints such as Sub-Saharan Africa. Future water resource availability in the Volta basin in West Africa remains uncertain, with projections spanning a wide range of possible futures (Mul *et al*., 2016). Rivers and streams in the West African subregion are drying up due to siltation and unsustainable use (Dittoh *et al*., 2013), and climate change is expected to worsen water stress and scarcity in the Volta Basin, particularly in northern Ghana (Kasei, 2010). In this context, sufficient water resources and suitable land remain essential for agricultural growth, supporting recommendations for continued investments in irrigation development in Ghana (Akudugu *et al*., 2016; Kyei-Baffour & Ofori, 2006; Namara, 2011).

Irrigation systems can be categorized by scale into large, medium and small systems, and by management into formal or informal systems (Abric *et al*., 2011). Formal irrigation in Ghana dates back to the 1960s, with earth dams and dug-outs constructed across the Guinea, Sudan and Coastal Savannah belts to provide water for domestic use, livestock and for dry-season farming (MOFA, 2011; Baba, 2016). These systems are managed by the government, non-governmental organizations (NGOs) or donor agencies, and serve multiple households (Namara *et al*., 2010).

Large-scale schemes in West Africa have generally been unsuccessful due to top-down decision-making, low financial sustainability, and poor water-use efficiency (Ofosu, 2011;Dittoh *et al*., 2013; Woodhouse *et al*., 2017). From the 1980s, attention shifted towards small-scale schemes, which proved more profitable and effective (Dittoh *et al*., 2013; Woodhouse *et al*., 2017). Informal or farmer-led irrigation (FLI) is comprised mostly of small holder irrigation practitioners cultivating between 0.5 to 2 ha of land. Farmers source water from rivers, streams, lowlands or flood plains, groundwater or wastewater, and finance their activities independently while adopting simple technologies for water storage, conveyance and application (De Fraiture & Giordano, 2014; Wiggins & Lankford, 2019; MOFA, 2011; Namara *et al*., 2010). FLI is entrepreneurial, market-oriented, and more efficient than formal schemes due to better local control over resources and decision-making, as well as its self-financing nature (Ofosu, 2011).

FLI is practiced in urban, peri-urban, and rural areas, inland valleys and flood plains, around small reservoirs, streams, rivers and areas with access to groundwater. Its expansion has dominated the last two decades as, government-led irrigation systems has declined (Ofosu, 2011) . The exact area under FLI in Ghana and the Upper East Region is unknown (Dittoh, Bhattarai, *et al*., 2013). However, MOFA, (2019) estimates it at approximately 189,000 ha since 2015, while area under the formal sector which was 11,000 as at 2015 increased to almost 13,000 hectares. In the Volta basin irrigation grew at 5% annually and is expected to more than double by 2025 (Ofosu ,2011).

Sustainable irrigation seeks to enhance crop production, improve soil health, efficiently use water, and protect the ecosystem. Integrated irrigation systems play a crucial role in ensuring the sustainability of irrigated agriculture (Adams *et al.*, 2020), while reducing costs and increasing profitability. Equity in water sharing is essential: the benefits and cost of water use must be distributed fairly, and water should be delivered at the right time, place and quality according to availability and need (Cai *et al.*, 2003; Li *et al.*, 2020).

Existing studies on small scale irrigation in Ghana largely emphasises productivity and economic outcomes, with limited attention to the integrated assessments of environmental sustainability, social equity and long-term resource implications, particularly in semi-arid regions such as the Upper East Region.

1.2 Problem Statement

Irrigated agriculture plays a crucial role in food security, employment, and poverty alleviation, particularly in arid and semi-arid regions of Asia and Africa *(*Akudugu *et al.*, 2016; Ahmed *et al.*, 2022). Informal irrigation by smallholder farmers outperforms the formal sector in various ways, including employing more people, cultivating more food, increasing area cultivated and producing more food (Dittoh *et al.*, 2013; MOFA, 2021; Ofosu, 2011). However, the irrigation agenda of governments and donors in SSA, including Ghana, seems to ignore farmers' initiatives in developing irrigation in the sub-region, despite farmers making substantial investments in productive assets in agriculture (Woodhouse *et al*., 2017).

Climate change is creating significant challenges for water availability in irrigation, with projections indicating both unfavourable climate trends (Niang *et al*., 2014), and uncertainty regarding future water resource availability in the Volta basin in West Africa (Mul *et al.,* 2016b; Yang *et al*., 2023). Recent studies further project increasing crop water demand and irrigation requirements across West Africa alongside declining water availability in many areas, suggesting increasing pressure on irrigation water resources under climate change (Gbode *et al*., 2022). These pressures encourage increased adoption and expansion of irrigation technologies by farmers. However, unregulated expansion of cultivated areas and intensive practices in informal irrigation could harm the environment as noted by Akudugu *et al*., (2016) and exacerbate resource inequalities. This, together with limited application of science and technology, and the declining availability and quality of, land, places the sustainability of FLI in the UER at risk. This may slow progress towards achieving Sustainable Development Goals (SDGs) 1, 2 and 13.

This research therefore sought to understudy the farmer-led irrigation systems in the Upper East Region, the effects of climate change on farmer-led irrigation and adaptation strategies used by farmers, and to analyse the economic, social and environmental sustainability potential of the farmer-led systems to come out with viable models to assist its sustainability. The research also examined the roles of different genders in FLI.

1.3 Main Research Question

What is the sustainability potential of farmer-led irrigation (FLI) systems in the Upper East Region under climate change?

1.3.1 Specific research questions

The following are the specific research questions:

1. What are the FLI systems in the Upper East Region (UER), and how have they developed over the past 30 years?
2. What are the productivity levels of farmer-led irrigation (FLI) systems in the UER, and what is their potential for upscaling?
3. What are the productivity gaps between men and women farmer-led irrigation (FLI) practitioners in the UER?
4. What are the challenges and constraints of FLI systems in the UER?
5. What are the environmental, social, and economic sustainability potentials of FLI systems in the UER?
6. What are the adaptation strategies of farmer-led irrigation practitioners in the UER to the effects of climate change?

1.4 Main Research Objective

The main objective of the research is to evaluate farmer-led irrigation (FLI) systems in the Upper East Region (UER), for their sustainability potential under climate change.

1.4.1 Specific research objectives

The specific objectives were:

1. To examine FLI systems and their development trend for the past 30 years in UER.
2. To evaluate FLI systems with respect to their productivity and upscaling potential.
3. To estimate productivity gap between men and women FLI practitioners.
4. To analyse challenges and constraints of FLI systems in the UER.
5. To assess the environmental, social, and economic sustainability potential of FLI systems.
6. To study the adaptation strategies of farmer-led irrigation practitioners to the effects of climate change.

1.5 Scope of the Study

The study specifically focused on the Upper East Region of Ghana, limiting its generalizability to other regions. It examines FLI sustainability during the dry season, overlooking potential impacts in other seasons. The research considered temperature and precipitation changes but does not thoroughly address other climate variables. Constraints related to sample size may affect the robustness of findings. Additionally, policy support, institutional capacity, and governance issues are not fully accounted for in the study.

1.6 Justification for the Study

Irrigation is a major means of increasing food production in arid and semi-arid areas, especially amid climate change. However, it faces challenges such as water and land scarcity and environmental impacts. The Upper East Region (UER) of Ghana is characterised by a dry climate and unpredictable rainfall, making it a clear example of the challenges faced in arid and semi-arid areas.

Farmer-led Irrigation (FLI) systems are crucial for crop production, income generation and poverty reduction among smallholder farmers. However, their unregulated nature, and use of pumps and chemicals poses risks such as contamination of water, groundwater depletion, disruption of natural hydrological cycles and, biodiversity loss. Continued use of fossil-fuel pumps also contributes to greenhouse gas emissions.

While there are several studies on small-scale irrigation and hence FLI, they often emphasise their economic gains (Osewe *et al*., 2020; Wiggins & Lankford, 2019) and overlook the environmental and social sustainability issues related to FLI. This study provides historical trends for understanding the development of FLI systems to inform regulatory needs. It also gives information on challenges and constraints to guide targeted interventions along the irrigation value chain, as well as a sustainability assessment (evaluating environmental impacts, social equity, and economic viability) to inform better management. It also provides information on adaptation strategies employed by practitioners in responses to the effects of climate change. Recommendations from this study can guide climate-smart interventions, resource allocation, and capacity-building efforts for essential policy and regulatory frameworks to mitigate risks associated with FLI systems for sustainable development.

1.7 Organization of the Thesis

The thesis is organized into five chapters. Chapter one is the introduction which identifies a research gap and establishes the problem and research questions.

Chapter two presents the conceptual framework and literature review on irrigation typologies, farmer-led irrigation and its importance, challenges of farmer-led irrigation, perceptions on the effects of climate change on farmer-led irrigation and adaptation strategies to these effects and ends with sustainability measures in relation farmer-led irrigation.

Chapter three discusses the methodology of study. It provides information on the study area, research design, the sampling procedure, data gathering techniques, data analysis and ethical considerations of the research.

Chapter four presents the results and discussions from the analysis of data collected under various objectives of the study. It begins with the demographic characteristics of respondents, followed by the development trends of farmer-led irrigation (FLI). The chapter then evaluates the productivity of FLI systems, examines productivity differences between men and women, and the challenges of FLI. Additionally, it explores the sustainability potential of FLI systems and the adaptation strategies of FLI practitioners in the Upper East Region (UER).

Chapter five presents a summary of the findings of the study, along with conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The sustainability of farmer-led irrigation (FLI) systems in the Upper East Region (UER) of Ghana is a critical concern, particularly in the face of climate change. As global temperatures rise and weather patterns become increasingly erratic, the resilience and viability of FLI practices come under scrutiny. In this literature review, we delve into existing research, synthesize knowledge, and identify gaps related to FLI systems. By examining historical trends, challenges, and adaptation strategies, we seek to inform evidence-based policies and practices that enhance FLI sustainability in the UER.

2.2 Conceptual Framework

This study sought to understudy the sustainability of farmer-led irrigation systems in the UER in the face of climate change. The conceptual framework provides a structure to understand the key components, relationships, and influencing factors in the sustainability of FLI.

Key Components:

Farmer-Led Irrigation Systems: These are community-based or individual irrigation systems managed and operated by local farmers. They include various types of irrigation practices, such as surface and groundwater irrigation using various techniques of lifting, conveying and applying water to crops and providing other resources with or without assistance from external sources.

Sustainability: Sustainability is the capacity of farmer-led irrigation systems to maintain their function and adapt to changing conditions while promoting economic, social, and environmental well-being. It encompasses environmental soundness of systems, social equity, and economic viability.

Climate Change: Climate change refers to long-term alterations in temperature, precipitation, and weather patterns due to factors like greenhouse gas emissions. In the context of this study, it encompasses changes in rainfall patterns, temperature, and extreme weather events.

Key Relationships and Factors:

Economic Viability: The economic viability of farmer-led irrigation systems is influenced by factors such as crop yields, income generation, and cost-effectiveness. It is affected by climate change through changes in water availability, growing seasons, and crop choices.

Social Equity: Social equity in these systems pertains to equitable access to resources and benefits among different community members, including men and women. Climate change can affect social equity through altered resource distribution and access disparities.

Environmental Soundness: Environmental soundness relates to the ecological impact of irrigation practices, including water use efficiency, soil quality, and biodiversity.

Climate change can impact this dimension through changes in local ecosystems and resource availability.

Influencing Factors:

Water Availability and Quality: Climate change can affect the availability and quality of water resources, potentially leading to shortages and water stress in farmer-led irrigation systems.

Crop Diversity and Adaptation: Farmers' choices of crop types and varieties and adaptation strategies are influenced by climate change impacts on crop suitability and resilience.

Governance and Management: Effective governance and management structures at various levels of society, especially at the community level, play vital roles in ensuring the sustainability of farmer-led irrigation systems under changing climatic conditions.

Local Knowledge and Innovation: Local knowledge and innovative practices by farmers can contribute to adapting and mitigating the impacts of climate change in irrigation.

The research study is conceptualized as given in the following framework (Figure 2.1). It is important that there is classification of the different types of FLI systems from the start and to obtain information on their distribution and development over time. This approach enables us to evaluate the economic, social, and environmental sustainability of each system within existing constraints and propose viable models for sustainable FLI systems.

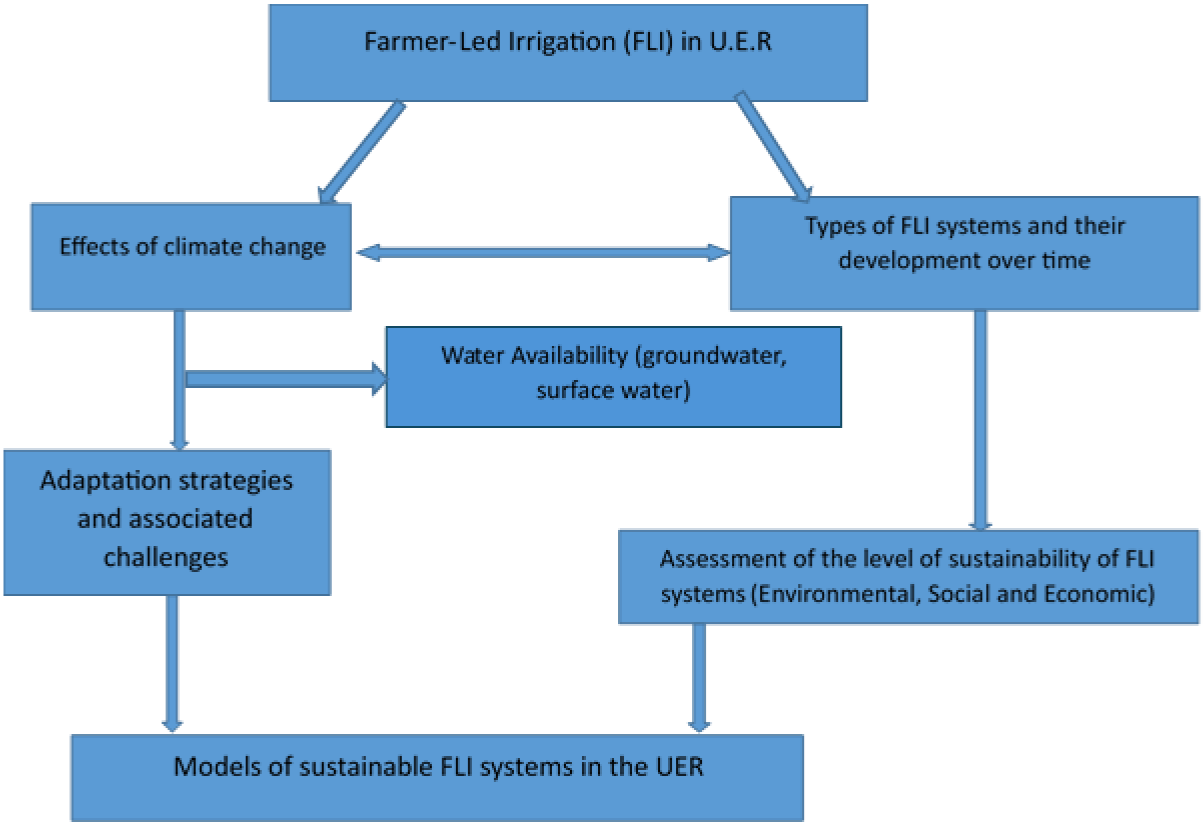


Figure 2.1: Conceptual Framework for Farmer-Led Irrigation

Source: Field Survey (2022)

2.3 Irrigation Typologies

Irrigation refers to the act of providing the right quantity and quality water at the right time for crop production from various sources and using various technologies/methods in order to enhance availability of food. Irrigated agriculture has been a major intervention used in addressing water challenges affecting food production in areas characterised by unreliable rainfall patterns. Previous studies demonstrate that irrigated agriculture increases food production and secures rural and urban household incomes

(Akudugu *et al*., 2021; Ofosu, 2011). Apart from this, it is widely acknowledged as an effective climate adaptation strategy to reducing farmers' vulnerability to rainfall variability and climate-induced shocks.

Namara *et al*., (2010) categorized irrigation systems into two broad classes thus, conventional and emerging systems. The former refers to systems mainly initiated and developed by Government and non-governmental organizations (NGOs), communities or individuals over several years. Under this system specific typologies are public surface irrigation systems, small reservoirs, wastewater irrigation, recession agriculture or residual moisture irrigation, and shallow groundwater irrigation in the coastal areas based on traditional lifting technologies. Emerging systems, in contrast, refer to farmer- or private initiated systems, developed either autonomously or with support from the government and/or NGOs. Examples of these systems are groundwater pumping systems, river or stream pumping systems, public/private partnership-based systems, out-grower systems, lowland/inland valley rice water capture systems, and private small-reservoirs systems. Similarly, the African Union Commission (2020) groups farmer-led irrigation based on the scale of management, distinguishing between individual and community-based irrigation systems. A more recent study by Weerahewa *et al*. (2022), adopt a resource-based perspective, classifying irrigation systems based on their major sources of water. This study distinguishes rainwater harvesting, from groundwater -based and surface water-based systems, and show that degradation processes vary across typologies due to climate variability, sedimentation, weakening institutions, and insufficient maintenance support. Together the above studies suggest that irrigation systems are shaped not only by institutional arrangements and management scale but also by water resource dependence and long-term governance conditions.

Irrigation system may therefore be more comprehensively classified using three interrelated dimensions: (i) source of irrigation water (surface water from dams, rivers and dugouts; groundwater from shallow or deep wells; and harvested or floodwater systems), (ii) water abstraction mechanisms (gravity flow, mechanized or manual pumps, and bucket and rope technologies), and (iii) field application methods such as flood, furrow, sprinkler and drip irrigation. Technological advancement, especially drip irrigation enhanced through automation, and the use of microcontrollers sensors, and integrated systems have substantially improved water-use efficiency, with reported water savings ranging between 18% and 75% (De Wrachien et al., 2013; Guerbaoui et al., 2013; Velasco-Muñoz et al., 2019) depending on management practices However, there is uneven access to these improved technologies with wealthier farmers benefiting more. while poor farmers face challenges such as financial constraints, weak supply chains, market volatility and limited institutional support (Namara et al., 2014).

The above shows a shift by researchers from viewing irrigation systems primarily as technological or institutional arrangements, to understanding them as socio-ecological systems shaped by how they are managed, environmental changes, and farmer agency. This highlights a need for context specific analysis of farmer-led irrigation sustainability in semi-arid regions such as northern Ghana Despite the growing body of literature on irrigation typologies and technological advancements, researchers have largely examined irrigation systems either from institutional and developmental perspectives, management scale, or hydrological and environmental standpoints. There is insufficient attention on how these dimensions interact in FLI systems, especially in semi-arid African contexts where irrigation development is largely self-driven and shaped by economic and environmental challenges. Empirical evidence on the sustainability of farmer-led irrigation systems in northern Ghana, considering how they are managed, the water sources they depend on, and the role farmers play in decision making, is still limited.

2.4 Irrigation Interventions

Investing in agricultural water management is widely accepted as a major driver of transformation of agricultural and poverty reduction in developing economies (World Bank, 2008; Ahmed et al., 2022). These Interventions include improved rainwater management, community based small irrigation schemes, groundwater irrigation development, and promotion of the use of improved irrigation technologies. Early assessments by the World Bank, (2008) highlights that irrigation investments also indirectly, stimulates broader economic growth by reducing production costs, lowering local food prices, and improving real net incomes through multiplier effects within rural non-farm economies.

Recent interventions have increasingly shifted towards supporting FLI development in sub-Saharan Africa, with multilateral donors and development agencies now promoting irrigation expansion as a strategy to expand irrigation coverage, improve household food security, and alleviate rural poverty (Harmon *et al*., 2023). This shift shows the growing recognition of farmer agency and the role of private investment in irrigation development. Unlike formal large-scale irrigation schemes that were primarily state-led, FLI development approaches acknowledge farmers as key drivers of irrigation expansion through Smale-scale technological innovations and investments in accessing water. Despite this shift in development thinking, caution needs to be taken to ensure that donor-supported irrigation programmes do not indirectly reinforce existing structural inequalities. This bias may occur if programme and resource allocation favour commercially oriented large-scale producers who often have more influence and better connections with policymakers and donor agencies to the disadvantage of the resource poor farmers.

In Ghana, successive governments and development partners have pursued investments in several agricultural related interventions that emphasize irrigated agriculture as a strategy to secure agricultural livelihoods and enhance incomes along the related value chains. Programmes such as the Northern Rural Growth Programme (NRGP), the Ghana Commercial Agricultural Programme (GCAP), and the Ghana Agricultural Sector Investment Programme (GASIP) have all had irrigation as an integral component within broader strategies to stimulate pro-poor agricultural growth, improve market access and enhance food security and livelihoods. The most recent drive towards irrigated agriculture is the One-Village-One-Dam (1V1D) initiative, which sought to expand small-scale water harvesting infrastructure to support year-round crop production, livestock rearing and domestic use.

Most of these investments have, however, not yielded the desired results in terms of productivity, sustainability and livelihood improvement (MOFA, 2011; Namara *et al*., 2010).

The literature highlights that though irrigation interventions are widely recognised as a means of improving agricultural productivity, food security and rural livelihoods, their effectiveness in supporting small-holder farmers depends on equitable access, sustainable management and institutional support.

2.5 Farmer-Led Irrigation Development

Farmer-led irrigation development (FLID) is a process where farmers assume a driving role in improving their water use for agriculture by bringing about changes in knowledge production, technology use, investment patterns, market linkages, and in the governance of land and water mostly as individuals, but sometimes in small groups (Lefore *et al*., 2019; Woodhouse *et al*., 2017; Harmon *et al*., 2023). Conventional irrigation schemes on the other hand are initiated and managed by governments or development agencies, while FLID developed through farmer-led investments and innovations. It is a process, in which farmers interact with many actors including neighbouring farmers, agro-dealers and traders, craftspeople, agriculture extension agents and irrigation engineers, administrative authorities, policymakers, civil society and development aid agents (Woodhouse *et al*., 2017). These reports emphasize farmer agency, and highlight their role in shaping irrigation development.

There is variation in FLI practices across the world due to practitioner’s use of locally adapted irrigation and water management techniques. Initiatives of farmer-led irrigation practitioners include furrow irrigation in mountainous areas, the use of shallow groundwater in valley bottoms, petrol, diesel, and solar pumps to lift water from surface and groundwater sources. Additionally, wastewater is used in urban and peri-urban areas (Woodhouse *et al*., 2017). Watering cans or buckets, used either alone or in combination with motorized pumps, are the most common technologies used in both rural and peri-urban areas. These initiatives by farmers reflect the environmental, and socio-economic constraints they encounter, as well as their adaptive capacities. Earlier studies in the Upper East Region (UER) of Ghana, such as Barry *et al.,* (2010) indicate that smallholder farmers in the Atankwidi and Anayere catchments of the Volta Basin began developing their own irrigation systems in the late 1980s by abstracting shallow groundwater in the lowlands and from the dry riverbeds manually and later with motorised pumps.

Previous studies portray FLI as a flexible and responsive alternative to centrally planned irrigation systems. For example, it is argued that FLI has positive and significant effects on the per capita net crop incomes of small-holder private irrigation practitioners, as their use of technologies, generate relatively higher productivity and profitability, while also creating employment opportunities for both Men and Women (Ofosu, 2011; Osewe et al., 2020). This was attributed to farmers operation of relatively small farm sizes, which allows them to manage water and other farm inputs more intensively to improve yields. Similarly, Harmon *et al*. (2023) suggest that FLI emerged in response to the failure of conventional systems and neoliberal structural adjustment policies that reduced public investment in irrigation. They further suggest that the success of farmer-led initiatives attracted attention of multilateral donors, who now promote and fund its expansion especially in Sub-Saharan Africa.

The importance of FLI is also linked to the autonomy FLI practitioners have in controlling resources and making decisions. This prevents them from encountering some of the problems experienced by farmers in large-scale irrigation schemes. This autonomy has contributed to the rapid spread of FLI in northern Ghana over the last two decades (Ofosu, 2011). This suggest that a better understanding of farmers' irrigation initiatives can generate benefits that are widely distributed among the rural population and sustained over the medium to long term (Woodhouse *et al*., 2017).

The literature places emphasis on the economic and livelihood benefits of FLI. Not much attention is given to FLI interacts with water resource availability, or the environmental conditions needed to sustain these systems over the long-term. Addressing these issues is essential for understanding whether FLI is a sustainable way means of intensifying agriculture especially in water scarce semi-arid areas.

In summary, previous studies point to the fact that FLI development was initiated by farmers to overcome limitations of conventional state-led irrigation systems and reduced public investment in irrigation infrastructure. Recently, development agencies, recognizing their potential, are now increasingly supporting FLID as a strategy to expand irrigation and strengthen rural livelihoods.

2.6 Productivity and Upscaling Potential of Irrigation Systems

Productivity of irrigation systems can be assessed based on the amounts of water used and output of crops produced under it. Agricultural water productivity is a partial productivity measure expressed as a ratio of crop yield to the amount of water withdrawn, applied, or consumed, typically measured for a particular crop at the field or farm level (de Jong et al.,2020; Chatzimichael *et a*l, 2020). According to earlier studies it reflects the amount or economic value of agricultural production obtained per unit of water used. (Clemmens and Molden, 2007). The above imply that FLI systems that produce higher yields or economic returns from a particular crop with relatively lower water inputs are more efficient and sustainable.

Africa has significant development potential for both large- and small-scale irrigation due to availability of water and land (You *et al*., 2011). Similarly, Baldwin & Stwalley, (2022) suggest that irrigation and FLI in particular have a potential of being upscaled in Ghana because of availability of surface and groundwater resources. Scaling up irrigation technologies can enhance agricultural productivity and hence contribute to reduce reliance on imported agricultural goods in Ghana. The relatively unregulated characteristics of farmer-led irrigation enables quick adoption of technology and farmers adaptation to changing circumstances with no or minimal government interference (Mati, 2023). As a result, pump irrigation systems, including motorized, treadle, and solar-powered pumps, have been increasingly adopted by smallholder farmers in SSA (Kamwamba-Mtethiwa *et al.,* 2016). Upscaling of irrigation systems (expanding to more clients in each geographical area, or replication, from one geographical area to another) is a complex process that may be affected by a range of factors (environmental, social or economic) that influence it. Successful upscaling of irrigation for instance depends on factors such as availability of water, suitable land , labour, government/donor support, energy and cost of equipment (Dittoh, 2020; Shah et al., 2020).

The availability of land, water and labour in Sub-Saharan Africa provides favourable conditions for the upscaling of FLI as a strategy to improve agricultural productivity, livelihoods and enhancing food security. However, the sustainability of FLI requires an understanding of the local environmental, economic and institutional factors that influence its development especially in semi-arid areas such as the UER of Ghana.

2.7 Challenges of Farmer-led Irrigation

2.7.1 Institutional, financial and household challenges

Although farmer-led irrigation development is recognized and considered a key strategy to expand irrigated agriculture, in many developing economies, De Bont *et al.* (2019) report challenges relating to non-recognition and support by government policies and programmes. This lack of policy recognition can limit FLI practitioner's access to technical support (extension), financial services, and infrastructure needed to sustain irrigation development. According to Joachim & Matekere, (2018), farmer-led irrigation in Tanzania is bedeviled with challenges such as inadequate and affordable long-term funding, limited involvement of private sector actors in irrigation projects, weak farmer associations for collective action, insufficient knowledge of efficient irrigation practices, market access, and land tenure insecurity.

In Ghana, similar challenges occurring at multiple levels of the agricultural system have been observed. Minh *et al*. (2020) grouped these challenges into value chain and household level. At the value chain level challenges include underdevelopment, complex financial regulations, and limited access to credit. Low demand perception of irrigation equipment suppliers, a focus on rainfed crops by both farmers and policy makers, weak actor linkages, and financial constraints, limit growth and expansion into high-risk irrigation equipment markets.

Challenges at the household level according Balana *et al.* (2020) include low levels investment capacity of farmers, high initial costs associated with pumps, and rising energy cost. Additionally, most farmers according to Martey *et al*. (2023) find it difficult to make accurate decision on when and how much water to apply to their irrigated crops. Accurate decision on this is however very essential for sustainable water use and sustainability of FLI.

The above studies examined constraints of irrigation in general without explicit consideration of how climate change (through water scarcity, erratic rainfall and shifting cropping patterns) may exacerbate them. There is a need to understand the combined influence these challenges mentioned in literature alongside to climate change, on the resilience and sustainability of various FLI systems in semi-arid areas.

2.7.2 Climate Change and Irrigation

This section explores how climate change affects irrigation, and the strategies employed by FLI practitioners to adapt and build resilience in local FLI systems. Climatic changes that influencing surface or groundwater water availability, pose additional risks to sustainability of irrigation

2.7.2.1 Effects of climate change on irrigation

The effects of climate change vary by location depending on local climate, water availability and farming practices. In Africa, i climate change is anticipated to increase water stress and expand arid and semi-arid areas (Kasei, 2010). These changes will affect irrigation development in areas where agriculture is heavily rainfed.

In Ghana, climate variations pose a significant constraint to the development of the food and agriculture sector, including fisheries (MESTI, 2013). Increasing variability of rainfall results in recurrent and longer dry spells that delay and shorten the growing seasons, while intense rainfall events cause flash floods that destroy crop, and degrade the soil/land. These changes impact food production through changes in agro-ecological conditions and affect household incomes and livelihoods withing farming communities.

Climate change is projected to reduce annual rainfall, runoff, and groundwater recharge in the Volta Basin by the mid-21st century according to McCartney *et al*. (2012), and potentially lead to a four-fold rise in unmet irrigation demand. In Ghana and especially in the semi-arid northern parts, rising temperatures will increase crop evapotranspiration rates and hence water demand for irrigation (MESTI, 2013) . This implies increased competing for water for irrigation and other uses. Rising temperature may also reduce water storage in surface water systems (reservoirs, rivers) and affect the reliability of irrigation infrastructure in the tropics (Khaoma & Ngaira, 2007).

The IPCC (2023) emphasises that regions and populations with considerable development constraints, such as many communities in Africa, are particularly vulnerable to climate hazards. Increasing weather and climate extremes are already exposing many people to acute food insecurity and reduced water security. These impacts affect livelihoods, infrastructure, health and food production. Small-scale food producers, low-income households, and women are disproportionately affected. This highlights the interdependence of human and ecosystem vulnerability especially in regions where livelihoods are climate dependent.

Climate change according to the above literature is likely to increase pressure on irrigation systems by reducing water availability and also increasing irrigation water demand. An understanding of how climate variability interacts with different irrigation systems and affects the livelihoods of men and women in farming communities is however limited.

2.7.2.2 Adaptation to climate change

As climate change increasingly threaten agriculture, developing affect adaptive strategies has become very necessary. Effective adaptation according to Abarike *et al.* (2018), and Abass *et al*. (2018) must consider farmers' knowledge and perceptions of climate change, their copping and adaptation measures and the challenges they face in implementing new strategies. Irrigation as a key adaptation measure helps farmers to manage rainfall variability and reduce vulnerability of their crops and livelihoods. By providing a more reliable source of water, irrigation also provides opportunities for integrated farming faming systems that combine crop production with livestock, aquaculture, or poultry, thereby promoting efficient resource use and nutrient recycling. According to Basavanneppa and Gaddi (2020), integrated farming systems in irrigated ecosystems have been shown to enhance farm productivity, reduce production costs, and improve household income while meeting diverse household needs such as food, fodder and fuel. Irrigation scheme planning that combines crops with livestock or aquaculture can improve resource efficiency and enhance the sustainability of irrigation systems by promoting nutrient recycling and diversified income sources.

More recently, the concept of climate-Smart Agriculture (CSA) is widely recognised as an approach that integrates climate adaptation, mitigation and food security objectives in agricultural development strategies. CSA enhances the resilience of agricultural systems by improving soil health, increasing water and nutrient use efficiency, stabilising yields and reducing emissions of GHGs (Mallappa & Shirur, 2021). In this context, irrigation technologies and water management practices are often considered key components of climate resilient agricultural systems. Climate change continues to affect agricultural productivity as reported by the IPCC (2023) which noted that climate change has already slowed global agricultural productivity growth over the past 50 years, with negative impacts concentrated in mid- and low-latitude regions, including Africa. Adaptation strategies such as irrigation, soil moisture conservation, and the use of drought-tolerant crops are therefore critical to sustaining agricultural production and water security under changing climatic conditions.

Ghana as a country has taken significant steps to address climate change through its policies and strategies. Key climate change policy frameworks include the National Climate Change Policy and the Climate-Smart Agriculture Investment Plan. These initiatives promote climate-smart agricultural practices, and aim to strengthen agricultural value chains, and improve food security and employment opportunities.

Research and development initiatives have also contributed to the promotion of adaptation technologies. For instance, drought tolerant and early maturing crop varieties have been developed by research institutions to help farmers adapt to the shortened growing season (Tambo, 2016). Similarly Barry *et al*. (2010), reported the provision of rope pumps for abstraction of shallow groundwater to Smale-scale farmers in the Upper West Region of Ghana to support their irrigation activities by ProNet (a non-governmental organization) Additionally soil water monitoring tools such as the Wetting Front Detector (WFD) have been developed to help farmers overcome problems associated with irrigation scheduling and enhance efficient use of water on their irrigated fields. Despite these technological and policy innovations, adoption is still low. According to Martey *et al*. (2023), although farmers are aware of the benefits of the Wetting Front detectors (WFDs), they are unable to adopt because of its cost. This implies that the success of climate adaptation technologies depends not only on their technical effectiveness but also on their affordability, and accessibility.

The literature highlights the important role irrigation in climate change adaptation, particularly in strengthening the resilience of agricultural systems to rainfall variability and water stress. Existing literature however tends to focus on either technological innovations or on broader policy frameworks. Relatively less attention is given to how these strategies are incorporated into FLI systems.

2.8 Sustainability of Irrigation Systems

2.8.1 Concept and dimensions of sustainability

Sustainability is a key concept used by social scientists interested in the interactions between human society and the environment. The most frequently cited definition is from the Brundtland Commission (1987), which defines sustainable development as meeting present needs without compromising the ability of future generations to meet their own needs (Mensah, 2019). Although this definition is widely accepted, the interpretation of sustainability varies across disciplines and policy context.

Sustainability is often explained through three interconnected pillars: environmental conservation, social equity, and economic viability. These pillars emphasise that development outcomes cannot be considered sustainable unless the ecosystems are maintained, livelihoods secured and economic activities remain viable through generations. The multidimensional nature of sustainability allows it to be examined across a broad range of disciplines such as business administration, chemistry and beyond (Mensah, 2019) . In the context of water resources management, sustainability involves maintaining a balance between meeting human water needs and the preservation of water resource systems (Cai et al., 2001b). In river basins where irrigation represents the major water use, achieving such a balance is very important. It requires meeting the current agricultural water demands while mitigating or preventing negative environmental consequences such as water depletion, disruption of aquatic ecosystems.

People from different academic fields tend to emphasise different dimensions of sustainability. Environmental sustainability "seeks to improve human welfare by protecting the sources of raw materials used for human needs and ensuring that the sinks for human wastes are not exceeded, in order to prevent harm to humans" (Goodland,1995). This perspective emphasizes protection of ecosystems to maintain human welfare in the long term. Development oriented research, on the other hand focusses on the immediate livelihood pressures faced by households. Ensuring environmental quality sometimes conflicts with the welfare objectives of households whose primary concern is to meet their basic needs (Hanley et al., 2007). In this context farmers may adopt practices that increase production in the short term but have negative environmental consequences. According to Kassam & Friedrich (2012) , future farming needs to be multi-functional and at the same time ecologically, economically and socially sustainable so that it can deliver ecosystem goods and services as well as livelihoods to producers and society.

Sustainability is context or site specific, occurring at farm, and community levels, but influenced a lot by what happens at higher levels such as that of national policies and institutional arrangements (Anderson *et al*., 1997). These authors further noted that negative interactions among the components of sustainability occurs in many low-income countries, where poverty and ecological degradation are closely linked. In parts of West Africa, for example, population pressures and low incomes force farmers to cultivate environmentally fragile and marginal land. Ensuring ecological sustainability without solving the problems of poverty and population pressure on land is impossible (World Bank 1992).

With regards irrigation, sustainability has been conceptualised in terms of ability of irrigation systems to maintain agricultural productivity while protecting environmental resources. Ahmed (2014), for instance, defined sustainability as "the ability of an irrigation system to sustain crop yields using the optimum cropped area and water consumption to realize the economic viability of the irrigation system without a decline in soil quality and environment."

The above perspectives suggest sustainability to be understood as a dynamic interaction between ecological processes, livelihoods strategies and institutional conditions. This is very important to consider for irrigation as water use decisions affect agricultural production, ecosystem health and rural livelihoods.

2.8.2 Sustainability of Farmer-led irrigation systems

From the perspective of farmers' , irrigation is considered sustainable when it provides uninterrupted access to water and generates sufficient returns relative to the cost of production. According to Borsato *et al*. (2020), this perspective often overlooks environmental externalities. However, from the viewpoint of water resources, irrigation is sustainable if it does not deplete freshwater stocks or environmental flows. That is when water withdrawals are not higher than the capacity of natural systems to replenish them. Borsato et al (2020) suggest that sustainable irrigation must meet these conditions:

(1) prevent depletion of water stocks by maintaining withdrawal rates below those of natural replenishment;

(2) prevent losses of aquatic habitat and irreversible degradation of ecosystems due to withdrawals from water bodies; and

(3) prevent other types of environmental damage (such as soil salinization) that result in the loss of ecosystem services and functions.

Sustainable use of natural resources is critical for sustainable livelihoods, and it has a direct impact on the improvement of natural capital. According to the IAASTD, (2009), the absolute number of small farms is increasing in a number of countries in Asia and Africa due to further subdivision of landholdings and expansion of agricultural land into new areas. Despites the important role of smallholder irrigation in improving food security, they can contribute to environmental degradation, particularly when practiced under increasing population pressure and with scarce suitable land, involving shortened fallow periods and expansion of cropland areas into unsuitable environmental situations. Both poor and the rich resource users impact negatively on the environment. Where access to resources is easy and extraction is not capital-intensive, poor people may overuse natural resources in response to vulnerability. Similarly, where extraction is highly capital intensive, the rich tend to have the greatest environmental impact (IAASTD, 2009). Accelerated investments in smallholder irrigation could cause significant risks to the environment and human health if not properly managed within the context of landscape and other water use needs (Lefore et al., 2019). In northern

Ghana, limited availability of shallow groundwater resources requires careful on-farm water management with the conjunctive use of groundwater and surface water sources to enable irrigation throughout the dry season (Worqlul et al., 2018).

Technological advancement also contributes to sustainability discussions of FLI. The rising availability of affordable water abstraction technologies such small pumps in Africa creates a risk of rapid depletion of groundwater resources if not properly regulated. For example, small-scale irrigation may introduce environmental risk to human, animal, and aquatic biota health through contamination of soil and water resources with agrochemicals and organic waste (Huang et al., 2006). According to Wiggins & Lankford, (2019), much of the irrigation expansion since 2000 is led by smallholders. Significant knowledge gaps about how efficiently water is used and consumed however, is limited.

The literature shows that the sustainability of FLI systems cannot be assessed solely based on water availability or agricultural productivity. Instead, it depends on the interaction between economic incentives, environmental limits and institutional arrangements that govern water use. It is therefore very important to understand these interactions especially in semi-arid regions.

2.8.3 Strategies for enhancing sustainability of irrigation systems

In recent years development agencies have adopted approaches that seek to address poverty while protecting natural resources. This is based on the view that natural resources can be managed in ways that generate immediate benefits for local communities whilst sustaining long-term local and global environmental values (Sayer & Campbell, 2003). In relation agriculture, these approaches emphasise improving livelihoods while ensuring that water and land resources are used in ways that sustain them. This perspective is reinforced in global development frameworks. The adoption of the Agenda for Sustainable Development and its Sustainable Development Goals (SDGs) in 2015, confirms a renewed international commitment to sustainability, in the world up to 2030 (Heinrichs, 2019). An earlier global development initiative "the Millenium Development Goals (MDGs) "also emphasised sustainability. A major target of MDG 7 was to integrate the principles of sustainable development into national policies and programs and reverse the loss of environmental resources. Many regions including Africa, have reduced their consumption of ozone-depleting substances, and the proportion of protected terrestrial and marine areas has increased globally.

According to Mensah *et al.* (2020), many agricultural practices of Ghanian farmers contribute to improve soil health and resource sustainability. Some of these practices are crop rotation, crop diversification, agroforestry mulching, cover cropping and leaving crop residue on the farms. These practices can strengthen farmers' capacity to withstand climate stress by improving soil structure and nutrient availability. Similarly, the use of renewable energy sources such as solar and hydro powered irrigation pumps can contribute to reducing the carbon foot print of irrigation. (Durga *et al*., 2024; Boon *et al*., 2020). The promotion and adoption of renewable energy technologies for irrigation are however currently low in many developing countries (Boon *et al*., 2020).

Apart from the farm level practices above, there are regional and international initiatives that support sustainable irrigation development. According to CGIAR (2019), the Alliance for a Green Revolution in Africa (AGRA), with support from development partners such as the World Bank and African Development Bank (AfDB), made a commitment to promote irrigation technologies for small-scale farmers across the continent. The World Bank, pledged to provide African governments with up to USD 9 billion for irrigation development in African countries. Some elements of commitment to this can be seen through the various irrigation and climate smart-smart agriculture initiatives supported by international development agencies. For instance, AGRA in Mali in relation to this issued a call for concept notes for grant application promoting small-scale irrigation and green energy mechanization models in July 2023.

Research institutions play an important role in supporting irrigation development. The International Water Management Institute (IWMI) conducts research on sustainable soil and water management and provides policy advice to improve agricultural intensification.

Multi-stakeholder processes are also a mechanism for addressing water sustainability issues. These include innovation platforms, multi-stakeholder dialogues, or learning alliances that bring researchers, policy makers and practitioners together (Minh et al., 2020). Examples in Ghana include the Multi-Stakeholder Process for Policy Formulation and Action Planning (MPAP) and the Accra Working Group on Urban and Peri-Urban Agriculture (AWGUPA), which facilitated strategic partnerships and improved research-policy dialogues. These initiatives led to the official recognition of irrigated urban and peri-urban agriculture as an important component of urban food security. Similar innovation Platforms such as the West African Agricultural Productivity Programme (WAAPP) and the International Centre for development-oriented Research in Agriculture (ICRA) also engage interest groups such as farmers to disseminate technologies for adoption.

Namara *et al.* (2011) provided several recommendations to revitalize Ghana's irrigation sector, including supporting emerging irrigation systems and enhancing capacity building. Efforts have been made to implement these recommendations, but progress appears mixed. For instance, there has been an increase in efforts to support improved irrigation practices and technologies for small holder farmers especially involved in FLI. However, comprehensive national integration of these systems into the irrigation development agenda remains incomplete (Dittoh, 2020). Though there are efforts to promote the use of groundwater for irrigation, there is no detailed database of groundwater resources by region and agro-ecological zones. Training programs have been implemented to build capacity of technical staff and farmers, but their scale needs further expansion. The Ghana Irrigation Development Authority in its new strategies has incorporated FLID in its planning and production processes as one of the main business areas for promotion (GIDA, 2017).

These actions reflect a growing recognition of the role of FLI and small-scale technologies in addressing agricultural productivity and climate resilience challenges in Africa.

Previous studies have also examined how irrigation systems can be managed to enhance agricultural productivity while safeguarding environmental resources. A systematic review by Vallejo-Gómez *et al.* (2023) examined different types of smart irrigation systems that apply artificial intelligence in agricultural water management. Their review concluded that smart irrigation systems generally improve irrigation efficiency and timing of water application compared to conventional systems. They, however, highlighted the need for more research on the economic and environmental sustainability of these smart systems. Improving irrigation sustainability also requires better water management practices. An earlier report by Borsato *et al.* (2020) suggest that irrigation technologies and management strategies that improve efficiency of water use are essential particularly in water scarce regions. An example of such strategies is the adoption of deficit irrigation which reduces water applications while maintaining acceptable crop yields. Similarly, water productivity in agriculture can be improved through different pathways that include small-scale water management practices, modern irrigation technologies and soil water conservation measures (Ali &Talukter, 2008, Molden *et al*., 2007 in Antunes *et al*., 2017). In addition to technological and management interventions, social inclusion is increasing recognized as an important component of sustainable irrigation development. Uprety *et al*., (2022) emphasised the importance of enhancing gender equity, social inclusion, and poverty reduction in FLI systems and proposed a systems approach to sustainable and inclusive FLI development.

2.8.4 Methods for assessing the sustainability of irrigation systems

In arid or semi-arid basins where irrigation is the dominant water use, sustainability of irrigation systems can be measured using different indicators related to water supply system, environmental integrity, equity in water sharing, and economic acceptability (Cai *et al*., 2001b).

In relation to the water supply system, the factors considered are its reliability, reversibility, and vulnerability. Reliability is the ability of the system to consistently provide adequate and dependable water supply for irrigation over time. This ensures that water is available when needed for agricultural production. Reversibility refers to the ability of the water supply systems to adapt or switch between water sources or management strategies in response to changing conditions. Vulnerability of the system on the other hand refers to the susceptibility of the system to external stressors, risks, and potential failures that can disrupt water supply. These stressors may include natural disasters, infrastructure failures, climate change, and resource constraints.

Environmental system integrity is mainly concerned about sustainability of water use patterns. Water balance evaluation considers the availability of water resources, their variability and the patterns of water consumption. Water productivity, generally defined as the ratio of the net benefits obtained from an agricultural system to the amount of water required to produce those benefits (Molden *et al*., 2010) . It is a key factor to consider when determining sustainability of irrigated agricultural systems.

Equity in water sharing: Refers to the fair and just allocation of water resources among different users in an irrigated area. It ensures that all individuals, communities, and entities have access to an equitable share of water for their respective needs, without discrimination, and in a manner that considers environmental, economic and social, factors. Equity in water sharing is crucial to prevent conflicts, promote social justice, and support sustainable water resource management.

Economic acceptability: Refers to evaluating whether a particular project, program, or investment in an irrigated area is economically justifiable and financially viable. Economic acceptability is a critical aspect of decision-making in water resource management, as it helps determine the financial feasibility and sustainability of irrigation projects. It requires that the cost of irrigation does not exceed the value of the marginal productivity of irrigation with respect to the baseline of rain-fed production (Borsato *et al.*, 2020) . At the farm level economic viability is the ability of farms to maintain profitability, stability and productivity over time. (Slavickienė & Savickienė, 2014). Profitability is calculated by comparing revenue and cost, either as a difference, a ratio, or as a proxy by income variables such as farm income (Latruffe *et al.*, 2016).

Social sustainability indicators are often difficult to measure because they involve qualitative aspects of well-being Latruffe *et al*. (2016) . These indicators can be considered at two levels:

- Social sustainability that matters at the level of the farm community. This is related to the well-being of the farmers and their families.

- Social sustainability that matters at the level of society. This is related to society’s demands, depending on its values and concern.

In relation to well-being of farmers, Van Cauwenbergh *et al.* (2007) considered quality of life as a social theme and separated it into physical well-being (indicators related to labour conditions and health) and psychological well-being (indicators related to education, gender equity, family access to infrastructures and services, and the farmer’s feeling of independence).

Gender equity has also become an important component of social sustainability of irrigation systems. Women often face challenges in accessing productive resources and controlling farm assets in small-scale irrigation systems. Using the Women’s Empowerment in Agriculture Index (WEIA), Bryan & Garner (2020) assessed the impact of irrigation interventions on women’s empowerment in the UER of Ghana. They found that irrigation interventions can expand women’s access to technologies such as motor pumps, and enhance their participation in agricultural production, and income decisions, and time use. The WEAI measures empowerment across five domains: participation in agricultural production decisions, access and decision-making power over productive resources, control over the use of income, leadership in the community and time allocation (Muriel et al., 2019). Women's empowerment in farmer-led irrigation development involves enhancing women's resources, agency (ability to make strategic life choices), and achievements (improvements in well-being outcomes) according to (Bryan & Mekonnen, 2023) .

The literature shows that sustainability of irrigation systems requires considering multiple interrelated dimensions. Indicators such as the reliability and vulnerability of water supply systems, environmental system integrity, equity in water sharing and economic acceptability provide a useful basis for evaluating sustainability of irrigation systems. In addition, economic viability, farmer well-being and gender equity influences how irrigation benefits are sustained and distributed among users. This therefore suggest that sustainability of irrigation systems cannot be assessed using a single indicator but requires a combination of environmental, economic and social measures.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

The study was conducted in the Upper Region of Ghana located in the north-eastern corner of the country between longitude 00 and 10 West and latitudes 100 30"N and 110N. It is bordered to the north by Burkina Faso, the east by the Republic of Togo, the west by the Sisala East district of the Upper West region and the south by West Mamprusi in Northern Region. The land is relatively flat with a few hills to the East and southeast. The total land area is about 8,842 sq km, which translates into 2.7 per cent of the total land area of the country.

This region is selected because a lot of farmer-led irrigation is practiced, it experiences extreme weather events such as very high temperatures especially during the dry season, and droughts and floods during the raining season. It is the region with the largest and the most advanced irrigation infrastructure in Ghana and is characterized by shallow and accessible groundwater resources (Anayah et al., 2013; Dittoh, Awuni, et al., 2013). Figure 3.1 shows a map of the UER and the study sites for this research.

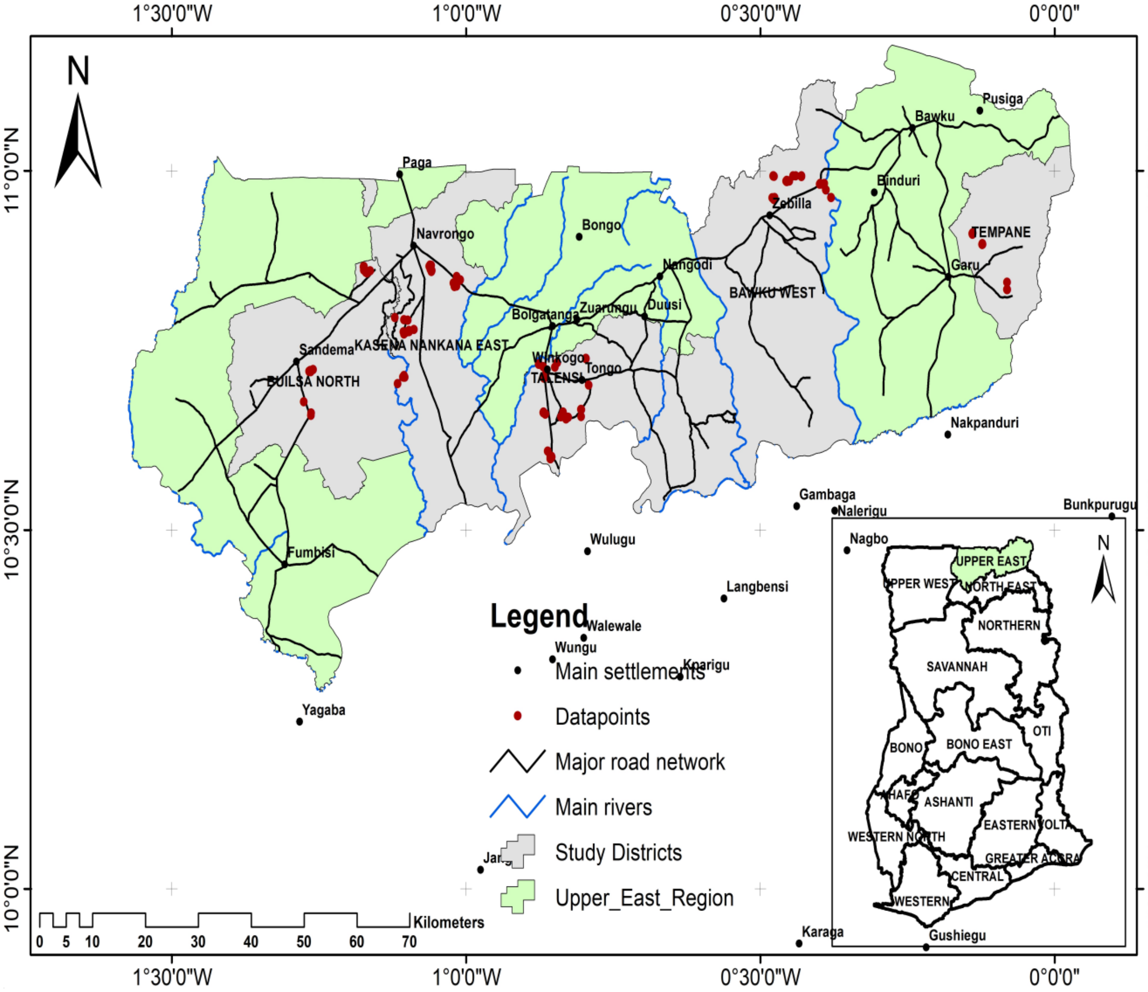


Figure 3.1: MAP of Upper East Region showing study Districts

Source: Author construct 2022

Soil and drainage: The area's soil is referred to as "upland soil," primarily formed from granite rocks. It is mostly coarse grained, shallow, and has low levels of organic matter and soil fertility. One issue is erosion. Soils in valley regions range from saline clays to sandy loams. Although they are more difficult to till and more vulnerable to flooding and seasonal waterlogging, they have a higher natural fertility. The White and Red Volta, and Sissili Rivers are the primary sources of drainage (UE Regional Coordinating Unit, 2003).

Vegetation: The native vegetation is savannah woodland, which is made up of small, dispersed trees that can withstand dryness and grass that burns during the long dry season from sunburn or bushfires. Due to considerable human intervention with ecology, conditions are now almost semi-arid. The acacia, boabab, dawadawa, and sheanut are the most popular economic trees (UE Regional Coordinating Unit, 2003).

Climate: There is one rainy season, which runs from May/June to September/October. The average yearly rainfall is between 800 and 1,100 millimetres. The pattern and duration of the rains are irregular. From November to the middle of February, there is a protracted dry season that is marked by harmattan winds that are dry, chilly, and dusty. During this season, nighttime lows can reach as low as 14 degrees Celsius, while daily highs can reach above 35 degrees Celsius. However, there is relatively little humidity, which makes the high temperature less uncomfortable (UE Regional Coordinating Unit, 2003).

Economic activities: The three primary industries in the area are forestry, hunting, and agriculture. Approximately 80% of people who are economically active work in agriculture. The primary crops include sorghum, millet, guinea-corn, maize, groundnuts, beans, and tomatoes and onions for the dry season. The cultivation of livestock and poultry is another widespread agricultural practice among the local populace. The two biggest irrigation projects owned by the government are Vea and Tono, which span 850 and 2,490 hectares, respectively, and employ over 6,000 small-scale farmers in the area. Water for home and agricultural use is provided via rivers, streams, and other water-retaining facilities (dams and dugouts), totaling approximately 220 (UE Regional Coordinating Unit, 2003).

3.2 Sampling Method

A multistage sampling technique was used for this study. This was done using both probability and non-probability sampling techniques to sample respondents for the study. First the study municipalities/districts were purposively sampled from the region based on the dominance of FLI systems such as shallow groundwater irrigation, and surface water irrigation. The Departments of Agriculture (DoA) in each selected district, provided an exhaustive list of villages and the irrigation systems practiced. These villages were then grouped based on the FLI systems practiced. Secondly the cluster sampling technique was used with the identified FLI system serving as clusters from which one to three (1-3) communities per FLI system were selected. In all twenty-four (24) communities were selected by simple random sampling from five districts in the region. From these 24 communities, ten (10) of them were also selected by simple random sampling for focus group discussions (FGDs). Purposive sampling was used to select key informants for interview. They comprised of stakeholders in the study area whose work is related to irrigation or have knowledge on the subject matter. People in this category included key officials of the Ghana Irrigation Development Authority, District Directors and Agricultural Extension Agents of Department of Agriculture of the selected Districts, agricultural input and equipment dealers, vegetable traders, community leaders (chiefs/subchiefs/assembly members/unit committee chairpersons, women's group leaders, farmers group leaders). A total of 33 Key informants were interviewed as in Table 3.1below.

Table 3.1: Distribution of key informant respondents for the study

Type of Respondent	**Number**
Agric extension agents	8
Traditional leaders	9
Women's group leader	3
Assembly member/Unit committee chair	4
Input dealers	4
Traders	5
Total	**33**

Source: Field Survey (2022)

With the assistance of some of the key informants at the community level, participants for the focus group discussions (FGDs) were identified and meeting dates scheduled. Participants for the FGDs ranged between 6-12 members per group with the male groups having a greater number of participants. In total, 171 individuals participated in the FGDs as in Table 3.2 below.

Table 3.2: Distribution of participants for focus group discussions

Community	FGD ID	Number of males	Number of Females	Total
Pwalugu	1 & 2	8	6	14
Pusunamoo	3 & 4	8	5	13
Kulogo	5 & 6	7	5	12
Winkogo	7 & 8	12	5	17
Yarigu	9 & 10	12	8	20
Goo	11 & 12	12	6	18
Teshi	13 & 14	12	6	18
Doba	15 &16	12	8	20
Bubolzugu	17 &18	12	8	20
Burankuan	19 &20	12	7	19
Total		**107(62.5%)**	**64(37.4%)**	**171(100%)**

For each community, the first FGD ID is for males and the second is for females
Source: Field Survey (2022)

As shown in Table 3.3 below, three hundred and fifteen respondents were sampled and interviewed. However, data for two-hundred and fifty (250) farmer-led irrigation practitioners and fifty (50) non practitioners was used for analysis. The remaining 15 did not provide complete information and were, thus, discarded.

Table 3.3: Study Communities and number of respondents

District	**Communities**	**Irrigators**		**Non-irrigators**	**Total respondents**
		Men	**Women**		
Tempane	Burankuan, Kugsabla, Kugzua, Banatinga, Gagbire,	34	21	10	65
Bawku West	Soogo, Goo, Teshie, Yarigu, Kobore	54	11	10	75
Talensi	Pwalugu, Pusunamoo, Yinduri, Baare, Winkogo, Santeng	48	12	10	70
Kassena-Nankana Municipal	Doba-Gingamnai,Kulogo, Kuwania, Tampola,	42	8	10	60
Builsa North Municipal	Bubolzugu, Kori, Yisopsa	14	6	10	30
Total		**192(64%)**	**58(19.3%)**	**50(16.7%)**	**300**

Source: Field Survey (2022)

The study conducted 20 FGDs with 171 discussants, interviewed 33 KIs, 250 irrigation practitioners, and 50 non-irrigation practitioners. Although the total population of irrigation practitioners in the UER is formally documented, the adequacy of the quantitative sample was assessed using established regression-based sample size principles. The Cobb-Douglas production function included 17 predictor variables (e.g., land size, input cost, cost of water, among others). Using Green's (1991) rule of thumb for multiple regression:

$$N \geq 50+8m$$

Where m=17 predictors:

$$N \geq 50+8(17)$$

$$N \geq 50+136$$

$$N \geq 50+8m$$

$$N \geq 186$$

The minimum required sample size is therefore 186 observations. The sample size of 250 irrigation practitioners exceeds this threshold by 64 observations, indicating adequate statistical power for reliable estimation of model parameters. Additionally, the study satisfies the widely accepted guidelines of having at least 10-15 observations per predictor variable in multiple regression analysis. With 17 predictors this would require between 170-255 observations. The sample of 250 irrigation practitioners is withing this recommended range.

3.3 Research Design

Research design refers to creating a framework, plan or strategy for a research project (Leavy, 2017). The study employed a descriptive exploratory sequential mixed-methods design to explore the sustainability of FLI under climate change in the Upper East Region (UER) of Ghana. In this design, qualitative data were collected and analysed first to gain in-depth insights into farmers' experiences with farmer-led irrigation under changing climatic conditions. Mixed methods research design integrates quantitative and qualitative data and draws inferences from the integration to provide insights beyond what can be learnt from using one method (Creswell, 2015; Leavy, 2017)). This method is generally appropriate for research that seeks to describe, explain, or evaluate a phenomenon. Combining qualitative and quantitative data for this study helped us delve into intricate interactions between irrigation systems climate change and sustainability measures. It also allows us to capture detailed insights from FLI practitioners and community members while providing measurable data to support our findings. Qualitative data comprised of key informant interviews (KIIs) and focus group discussions (FGDs) while quantitative data comprised of individual interviews with FLI practitioners. Data was collected from twenty-four 24 simple randomly selected communities from the region. Qualitative data was collected from ten (10) out of the 24 selected communities, while the quantitative data was collected from all the twenty-four (24) communities.

3.4 Data Gathering Procedure

Both primary and secondary data were utilized in this study. Primary data is data collected specifically for the goal of a study, whereas secondary data is data collected for a different reason or study and used in a new study (Neuman, 2011). Primary data was collected through interviews and observations. Secondary data on irrigating communities was obtained from the Departments of Agriculture at selected Metropolitan, Municipal, and District Assemblies (MMDAs) in the UER. The combination of these data sources provided a comprehensive understanding of the research problem.

Mixed methods were used for this study. It involved the use of FGDs, KIIs, semi-structured interviews, field observations, and georeferencing of study sites. This was done using a FGDs guide, KIIs guide, and semi-structured questionnaire. The FGDs and KIIs guides were used to collect qualitative data from ten (10) simple randomly selected communities (two per district from the 24 communities), while the semi-structured questionnaire was used to collect quantitative data in all the selected communities. Pre-testing of the interview guides and questionnaire was done in the Talensi District and questions that were difficult for research assistants and researcher were referred to staff of Ghana Institute of Linguistics, Literacy and Bible Translation (GILBT) for translation into Gurune and Kusaal the dominant languages in the selected communities. Equipment used in the process included a tape recorder and field notebook, and a timer. In Addition, Computer-Assisted Personal Interviewing (CAPI) devices were used for individual interviews, and the Kobo Collect tool was employed to manage data for the CAPI devices. Semi-structured interviews help in providing valuable unexpected information, making them ideal for household interviews and focus group discussions (Adams, 2015). Audio recording of interviews can help reduce potential loss of detail from interview scripts written directly after the interview according to (Rutakumwa et al., 2020).

Key Informant Interviews (KIIs) offer insider insights into complex issues, facilitate community access, and provide deep knowledge grounded in trust-based relationships with researchers (Lokot, 2021). Community leaders and farmer-led irrigation practitioners were also interviewed to solicit their views of FLI in trend in their respective communities as in picture below. Key stakeholders such as personnel of the Departments of Agriculture (DoA) at the MMDAs and Ghana Irrigation Development Authority (GIDA) were interviewed to solicit information on measures taken to ensure sustainable use of resources by farmer-led irrigation practitioners, and on how they help farmers in their irrigation activities.

Plate 3.1 :Interview with community leader at river site in Bawku West District
Source: Field Survey (2022)

For objective one (1) which sought identify FLI systems and their trend of development in the UER, over the past 30 years, focus group discussions were held with community leaders and farmer-led irrigation practitioners to solicit information on the development of farmer-led irrigation through generations. Two focus group discussions were held in each of the 10 communities with groups of men and women separately see sample. pictures below. Each group comprised between six (6) to twelve (12) members.

PLATE 3.2:FGD SESSION TALENSI-MEN

PLATE 3.3:FGD SESSION TALENSI-WOMEN

PLATE 3.4:FGD SESSION, BAWKU WEST-MEN

PLATE 3.5:FGD SESSION, TEMPANE-MEN

Focus group discussion session in study communities
Source: Field Survey (2022)

A Global Positioning System (GPS) was also used to accurately geo-reference locations where FLI is practiced within the study districts. The GPS is a crucial component of precision agriculture, aiming to enhance resource use efficiency, productivity, quality, profitability, and sustainability in agricultural production (Pradhan et al., 2020). By capturing latitude and longitude coordinates, we created a map highlighting key FLI sites across the region, providing valuable insights into their spatial distribution. This precise location information will enable stakeholders to offer targeted support and promote sustainable resource use, particularly given the unregulated nature of these systems.

Objective 2 of the study sought to evaluate the various FLI systems with respect to their productivity and upscaling potential. The productivity aspect was evaluated based on yield in kg/acre of onions and pepper. The more standard measure of yield, kg/ha was not used, due to the fact that the land sizes cultivated under FLI are mostly small with many cultivating between 0.1 and 2 acres. Onions and pepper were chosen because they were cultivated in all the selected districts under all the irrigation systems identified. Data on yield of these crops and other factors that influenced their production such as cost of water used for the 2021/2022 irrigation season were collected through interviews (held with 250 FLI practitioners from the five purposively selected districts) and converted to per unit area (acre) of land.

Upscaling potential of FLI systems was evaluated based on the views of practitioners about the ability of more people within and outside the community to participate in irrigation using the systems they practiced based on resource availability in the community. Their views were based on factors such as cost associated with FLI systems, infrastructure required, availability and access to water and to land.

In-depth and key informant interviews, as well as focus group discussions, were held with farmers, and irrigation input and equipment suppliers in various communities practicing FLI to obtain data for objectives four (4) and six (6). These objectives sought to identify and analyse challenges and constraints of FLI systems along the irrigation value chain, and to examine the adaptation strategies used by FLI practitioners to combat climate change, respectively.

For objective five (5) which sought to assess the environmental, social and economic sustainability potentials of the FLI systems.

- Environmental sustainability was measured based on ecosystems services and environmental integrity (based on water availability). For the ecosystems services, information on measures taken by farmers to ensure that future generations benefit from the irrigation sites, ecosystem services lost and gained because of irrigation activities and the effects of irrigation systems on the environment were obtained from farmers. Our data collection process focused on understanding the environmental impact of various farmer-led irrigation (FLI) systems. We combined quantitative and qualitative techniques to interact with FLI practitioners across different sites to obtain information on Ecosystem services lost (e.g., species diversity, grazing land), water quality and quantity, health issues (e.g., bilharzia) and explored nuances, reasons behind observed changes, and community experiences.
- Social sustainability of farmer-led irrigation systems focused on equity, inclusion, gender dynamics and food security. Through individual interviews and FGDs with men and women directly involved in FLI, we explored their perspectives on FLI practices, decision-making, and gender roles. Specifically, we examined women's contributions to household irrigation decisions and their agency within the system, as well as men's views on gender dynamics and their roles in irrigation. In-depth interviews and focus group discussions allowed participants to share experiences related to irrigation, power dynamics, resource access, and decision-making

processes. Questions from the Women's Empowerment in Agriculture Index (WEAI), developed by the International Food Policy Research Institute (IFPRI), were incorporated into the semi-structured interview questions. The Household Dietary Diversity Scores (HDDS) indicator can be used as a proxy for the access dimension of food insecurity and is one of the indicators frequently used to assess how interventions designed to increase household income have affected food consumption because household dietary diversity generally increases, as income increases (Swindale & Bilinsky, 2006). The source of data for the HDDS is based on a recall of food groups consumed by the household in the previous 24 hours, reported by the person primarily responsible for food preparation in the household (Swindale & Bilinsky, 2006). The HDDS was used to access how FLI systems affected food consumption in households. Women in the sampled irrigating and non-irrigating households were the respondents for this section.

- Economic sustainability of systems was measured based on economic viability using benefit cost analysis and household dietary diversity scores (HDDS) for food and nutrition security. Net income (NI), Benefit-Cost Ratio (BCR) and the Return on investment (RIO) were computed for the different types of FLI systems. The latter were added to provide a holistic view since the BCR assesses overall efficiency and the ROI highlights profitability of the systems.
    - The cost-benefit analysis technique is used to evaluate the financial viability of a project by comparing its costs with the benefits it will provide (Dedovic Nedeljka, 2022). In this study the economic viability of FLI systems were evaluated by comparing their cost of production and benefits derived at

harvest. It helps determine the most economically viable system to recommend for sustaining FLI. In addition to the benefit cost ratio, the return on investment (ROI) was calculated for each system.

3.4.1 Data validation

The study used several procedures to ensure the validity and reliability of data collected. FGDs and KIIs were conducted before the household survey to obtain contextual understanding of FLI practices and local perceptions of sustainability and climate change. Insights from this qualitative engagement informed the design of the semi-structured questionnaire used for the quantitative survey, this helped improve the relevance and clarity of the research instrument.

Questionnaire was pre-tested in one district with similar characteristics to the study areas but which was not included in the final sample. The pre-testing helped identify and revise question which were ambiguous and poorly understood. In addition, terms such sustainability, and climate change which had no direct equivalents in the local dialects (Gurune, Kusaal), were carefully translated into locally understandable expressions during data collection to enhance respondent’s comprehension and accuracy of responses.

Data reliability was further strengthened through training of enumerators, and the use of Computer-Assisted Personal Interviewing (CAPI) devices, which minimised data entry errors and allowed for consistency checks during fieldwork. Findings from FGDs, interviews, and household surveys were compared to ensure that similar information was obtained from different sources. This process improved the accuracy and trustworthiness of study results.

3.5 Data Analysis

Data analysis refers to the systematic management, examination, and interpretation of data to extract meaningful patterns and evidence (Bryman, 2012; Kotronoulas *et al*., 2023). Qualitative data analysis started with listening to audio recordings from FGDs and transcribing them based on the topics in the FGD interview guide. The quantitative data was collected using CAPI devices and Kobo Collect software. Data was downloaded in Excel format, processed and analysed with the help of the Statistical Package for Social Sciences (SPSS). The R software was used for decomposition analysis of productivity (harvest value) gap between men and women FLI practitioners for objective 3. This software was used to generate graphs charts, and frequency tables for descriptive statistics. Cross -tabulations were also conducted with SPSS to compare responses between male and female respondents.

For objective one (1) the captured coordinates of all sites of farmer-led irrigation systems within the sampled study areas, were plotted on the map of the study region using ArcMap 10.3 version. Data from focus group discussion (for generational trend analysis) were analysed using Classical content analysis. This was done by creating smaller chunks of data and coding them. These codes were placed into similar groupings and counted (Onwuegbuzie, 2009). According to Morgan (1997) in (Onwuegbuzie, 2009), there are three unique ways to use classical content analysis with focus group data: the analyst can (a) identify whether each participant used a given code, (b) assess whether each group used a given code, and (c) identify all instances of a given code. The latter (c) was used because it is suitable for identification of all occurrences of chosen codes, regardless of whether it is associated with individual participants or specific groups. This method helped in quantifying the importance or relevance of a particular theme within the dataset and highlighted overarching patterns and recurring ideas.

Data obtained for objectives two (2) were analysed using descriptive statistics such as frequencies and percentages as well as a production response function. Data on yield and other production parameters for onions and pepper were used for analysis for this section since they were crops cultivated under all the irrigation systems across the study sites. The raw values obtained from interviews were converted to per acre of land. The production response function was estimated using double log (Cobb-Douglas) functional form. Cobb-Douglas production functions have been found to be the most appropriate in explaining the relationships between production inputs and outputs (Jia *et al*., 2016) in agriculture. It has also been found to be appropriate for response relationships such as in this work (Dittoh, 1980). A stepwise regression analysis was used to select relevant input variables (e.g. cost of water provision) based on statistical significance (Zhu & Hua, 2020) to help estimate the coefficients (parameters) of the production response function. The estimated equation is used to explain the factors that cause significant response in crop yields under various irrigation systems. It is to be noted that not all the factors are production inputs. Three specific production response functions for different scenarios (onions and peppers under various irrigation methods) as outlined below were used to model the relationship between yields and the 17 identified factors as stated below.

1) Production response function for onions produced under Gravity and Manual irrigation (1 = gravity; 0 = manual). Pepper was not considered for Gravity and Manual because the number of observations obtained (for pepper gravity and manual) were too few for meaningful regression analysis.
2) Production response function for onions produced under Pump groundwater irrigation and Pump surface water irrigation. (1= Pump GW; 0 = Pump SW)
3) Production response function for pepper produced under Pump groundwater irrigation and Pump surface water irrigation. (1= Pump GW; 0 = Pump SW)

The general equation for the production response function is as shown below.

$Q = f(X_1 \ldots X_{17})$

Where:

Q = Quantity of onions/pepper harvested (in Kg)

X_1 = Type of irrigation (1 = Gravity, 0 = Manual/1= Pump GW, 0 = Pump SW)

X_2 = acreage of onions

X_3 = acreage of pepper (a competing crop)

X_4 = labour cost (per acre)

X_5 = input cost (per acre)

X_6 = cost of water (per acre)

X_7 = equipment and other costs (depreciated and per acre)

X_8 = gender (1= male; 0 = female)

X_9 = age (years)

X_{10} = irrigation experience (years)

X_{11} = educational level (years of formal education)

X_{12} = household size

X_{13} = major occupation (1 = irrigation; 0 = otherwise)

X_{14} = access to credit (1 = yes, 0 = no)

X_{15} = access to irrigation extension service (1 = yes; 0 = no)

X_{16} = access to training (1 = yes; 0 = no)

X_{17} = member of a farmer/cooperative group (1 = yes; 0 = no)

The Cobb-Douglas (or double log) functional form is stated as follows:

$$\begin{aligned} lnQ = c_0 + c_1X_1 + c_2\,lnX_2 + c_3lnX_3 + c_4lnX_4 + c_5lnX_5 + c_6lnX_6 + c_7lnX_7 \\ + c_8X_8 + c_9lnX_9 + c_{10}lnX_{10} + c_{11}lnX_{11} + c_{12}lnX_{12} + c_{13}X_{13} \\ + c_{14}X_{14} + c_{15}X_{15} + c_{16}X_{16} + c_{17}X_{17} + \varepsilon \end{aligned}$$

Objective three (3) sought to investigate whether and to what extent gender inequalities exist in the FLI vegetable production and quantifies mechanisms of inequalities that can be attributed to differences in the level of resource use and the returns generated from these resources between female and male FLI practitioners. A conventional production function was estimated using R software. Farm production inputs used by men and women in their irrigation activities were used in estimating the production function. The productivity gap between women and men FLI practitioners was estimated by adopting methods used in previous studies by researchers such as Oseni *et al*. (2015), Slavchevska (2015) and Singbo *et al*. (2021) where the monetary value across all crops cultivated by the FLI practitioner were aggregated. The production function to assess gender-specific differences in FLI production adopted from the approach of Singbo *et al.* (2021) is defined as:

$$Y_i = F(A_i, X_i, V_i), \tag{1}$$

Where Y_i is a productivity measure related to farmer i's irrigated plots, A_i is a vector of inputs such as land, labor, the type of irrigation system used, and chemical inputs. X_i is a vector of farmer i's individual and household characteristics, and finally, V_i is a vector of community characteristics. If women and men FLI practitioners would operate on identical plots, growing identical crops, then gender-specific productivity differences can be due to differences in input use. Another explanation relates to gender differences in the opportunity costs of time as women typically carry the burden of household chores and caregiving. Thus, it is expected that gender differences in FLI productivity may be explained by gender differences in the level and returns of the above-mentioned production factors.

The empirical strategy follows a three-step procedure. First, the FLI productivity gap between men and women was estimated using Ordinary Least Square (OLS) with community-level fixed effects. Second, Oaxaca-Blinder (OB) decomposition analysis was employed to quantify the contribution of various factors to the average FLI productivity gap. Finally, we complement the latter by Recentred Influence Function (RIF) decomposition analysis to assess how factor contributions change along the FLI productivity distribution.

OLS analysis: Using a cross-sectional data set of FLI practitioners in the 24 selected communities in the UER of Ghana, the community fixed effects was applied to investigate whether within the same community, women are as productive as men. The model is specified as follows:

$$ln\ (Y_{iv}) = \alpha + \beta G_i + \gamma X'_{iv} + \delta H'_{iv} + \theta F'_{iv} + \omega_v + \varepsilon_{iv}, \qquad (2)$$

Where Y_{iv} is the natural logarithm of FLI practitioner's i harvest value per hectare, living in community *v*. G_i is a binary indicator equal to one if FLI practitioner i is a woman, zero otherwise. The matrix X'_{iv} contains FLI practitioner i's individual characteristics such as age, education, marital status, being a migrant, major occupation, experience in irrigated farming, whether i is engaged in off-farm employment, has access to social networks, formal credit institutions, and extension services. Furthermore, the matrix H'_{iv} includes household characteristics such as household size and dependency ratio, while matrix F'_{iv} represents farm characteristics such as land size, share of irrigated land, irrigation technology in use, number of crop varieties grown, and agricultural input expenditures per ha of land spent on water, equipment, labor, and chemical inputs such as fertilizer, seeds and pesticides. Finally, ω_v reflects the community fixed effects and ε_{iv} is the error term, which is assumed to be independently and identically distributed as $N(0, \sigma^2)$.

Including and controlling for community fixed effects eliminates unobserved community-invariant characteristics that may be correlated with FLI practitioners' gender such as prevailing social-cultural norms. Of interest is the coefficient β, which assesses the gender gap in harvest value in FLI vegetable production between men and women. A negative β value means that men tend to have higher harvest values or gross margins in vegetable production than women. We follow a progressive approach, where we include additional sets of right-hand-side (RHS) variables to identify whether and to what extent a specific set of variables affect the conditional gender difference.

OB decomposition: To better understand the relative importance of factors that contribute to the gender gap in harvest value, we follow recent studies such as Kilic *et al.* (2015), Oseni (2015), and Singbo *et al.* (2021) and decompose the gap using the Oaxaca-Blinder decomposition method. To do so, we specify the expected harvest value per hectare (Y_g) for FLI practitioners with gender $g = (f, m)$ representing women and men respectively, as:

$$E[Y_g] = \alpha_g + E[X_g]'\beta_g, \tag{3}$$

where X encompasses the RHS variables mentioned in equation (2). The gender gap can then be calculated as follows:

$$Gap = E[Y_m] - E[Y_f] = (\alpha_m + E[X_m]'\beta_m) - (\alpha_f + E[X_f]'\beta_f). \tag{4}$$

Following Oaxaca (2007), the gender gap arises from two sources, namely differences in explanatory variables, i.e., the explained part, and the unexplained part. To obtain the "two-fold difference", we follow Jann (2008) and include non-discriminatory coefficients in the above equation, which can be obtained from estimating a pooled model that also includes the gender indicator g, which is:

$$E[Y_{iv}] = E[y] = \alpha + \beta g + E[X]'\gamma^*, \tag{5}$$

where γ^* is the vector of non-discriminatory coefficients and *g* allows for the possibility that women's and men's expected harvest value lay on a different curve (Jann, 2008). Following Fortin (2006), we can then obtain the "two-fold decomposition" by including equation 5 in the gap equation (4), which is:

$$Gap = \ Q + U, \tag{6}$$

where Q is referred to as the part of the gender gap that is explained by gender differences in the right-hand side (RHS) variables and U is referred to as the unexplained part and attributed to discrimination or differences in returns. Q and U can be calculated as follows:

$$Q = \{E[X_m]' - E[X_f]'\}\gamma^* \text{and} \tag{7}$$

$$U = (\alpha_m - \alpha) + \left[E\left(X_m\right)'(\gamma_m - \gamma^*)\right] + \left(\alpha - \alpha_f\right) + \left[E\left(X_f\ \right)'\left(\gamma^* - \gamma_f\right)\right]. \tag{8}$$

Finally, equation (8) is then divided into two parts: the discrimination in favor of men, i.e., the structural advantage (this quantifies the advantage of men), and the structural disadvantage (this quantifies the discrimination against women). In this study, discrimination could refer to the unequal treatment of women emanating from social norms or burden associated with household chores which influences access to and control of agricultural resources. This effect is assumed to be unidirectional in favour of men because women are less likely to have access to and control over these resources.

It is important to note, that the OB decomposition analysis does not yield estimates of causal mechanisms but helps to understand the relative contributions of gender differences in observable characteristics in terms of the composition effect, and gender differences in unobservable characteristics due to the structural effect (Fortin *et al.*

2011; Oaxaca 2007). In addition, the method relies on two key assumptions, which are overlapping support and conditional independence. The former ensures that no single value of an observable or unobservable variable can serve to identify membership in one of the two gender groups. The latter implies that the joint densities of observable and unobservable variables for the two genders should be similar up to a ratio of conditional probabilities (Fortin *et al*. 2011).

RIF decomposition*:* While the OB decomposition described above yields insights into the average productivity gap between female and male FLI practitioners, RIF decomposition allows us to investigate gender differences across the entire productivity distribution. As originally proposed by Firpo *et al*. (2009), RIF is a regression analysis framework that allows the analysis of unconditional partial effects on quantiles and can be defined as:

$$RIF(y; v) = v(F_y) + IF(y: v), \tag{9}$$

where $v(F_y)$ is the distributional statistic of interest, in our case quantiles of harvest value per hectare and $IF(y: v)$ is the influence function measuring the influence that an observed value of y has on the estimation of the distributional statistic v. The influence function is defined as:

$$IF(y: v) = \frac{\tau - 1\{y \leq v(F_y)\}}{f_y(v(F_y))}, \tag{10}$$

where τ is the τ^{th} quantile of $v(F_y), f_y(v(F_y))$ is the density of y's marginal distribution, and $1\{y \leq v(F_y)\}$ is an indicator function equal to one if the condition inside the bracket holds, zero otherwise (Rios-Avila 2020). Following Firpo *et al.*

(2009), the RIF estimates for each observed value of y was obtained by assuming a linear relationship between $RIF(y; v)$ and the RHS variables X as specified above. The OB-type decomposition was then implemented using the RIF estimates as dependent variables and to analyse what factors explain the gender differences along the entire harvest value distribution.

Data for objectives 4 and 6 which sought to identify the challenges and constraints of FLI systems, and the adaptation strategies of farmer-led irrigation practitioners in the UER to the effects of climate change respectively were analysed using descriptive statistics and results presented as tables and charts.

Data analyses for Objective 5, which sought to assess the environmental, social and economic sustainability potentials of the FLI systems, were conducted as follows.

i) Data analysis for environmental sustainability of FLI aimed to uncover patterns and trends related to FLI's environmental effects. For quantitative data we calculated percentages of respondents reporting specific impacts and comparisons were made across different FLI systems. Focus group discussions were analysed using content analysis to provide a deeper insight into environmental changes and implications.

ii) Qualitative and quantitative data on social sustainability were analysed using descriptive statistics and **c**ontent analysis for data from the FGDs and results presented in tables or charts. Results from the quantitative and qualitative interviews were integrated.

iii) For economic sustainability, benefit cost ratio (BCR) and return on investment (ROI) analyses were undertaken. The benefit cost ratio estimated here was undiscounted as data used was from a single cropping season (Dhakal *et al.*, 2015; R. Yeboah & Nkegbe, 2011). The formula for benefit cost ratio is therefore;

- Benefit cost ratio $(BCR) = \sum Bi/\sum Cj$ ……………………….(1)

Where Bi = revenue (benefits) for the season, and Cj = cost of production for the season. The ROI is commonly used to forecast the potential return on investing in a program or project (Patti & Jack, 2010) and is calculated as:

- Return on Investment (ROI) = (Net Program benefits) / Program cost) x 100.
- Return on investment (ROI)= $(\sum Bi - \sum Cj) / \sum Cj \times 100$ ………………….(2)

3.6 Research Ethics

To ensure the trustworthiness of this study, and safeguard the participants' well-being, the study adhered to ethical processes and institutional protocols of the University for Development Studies Ethical Review Board (UDS-IRB) prior to conducting field interviews with respondents. The following ethical criteria was therefore implemented:

➢ Before administering the questionnaires, community leaders were informed and permission obtained to interact with community members. Respondents were told that the research was for academic purposes as part of a PhD study, and that participation was voluntary with the option to withdraw any time if they felt uncomfortable.

- Prior to data collection, informed consent was obtained from participants and their anonymity was assured. They were also informed that results would be used only in line with the stated research objective
- Participants' rights to privacy were respected at all times. Permission was sought from respondents before recording or taking photographs of respondents and their farms.
- To avoid plagiarism, the researcher was meticulous about documentation, identifying the many sources and study methodology employed.

The researcher studied a course titled EMS 503: Ethical considerations in environment and resource management, which addressed key ethical issues related to research. This training provided the researcher with an understanding of ethical responsibilities such as fairness, respect for participants, and sustainability in research. Where necessary, guidance was sought from the designated supervisors to ensure adherence to ethical standards throughout the study.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Demographic Characteristics of FLI Practitioners

4.1.1 Age of respondents

As indicated in Table 4.1, FLI practitioners in the UER had an average age of 43 years. Though the women's age (43.81) was slightly higher than that of men (42.62), there was no significant difference in terms of age between men and women. This shows that practitioners are mostly middle-aged and in their active stage of life. An observation on the field with regards most of the women who cultivated their own plots was that they had grown up children, or support for irrigation and household activities such as cooking or caregiving.

4.1.2 Level of education of respondents

FLI practitioners had an average of 5 years of formal education which indicates a low level of formal education (Table 4.1). This however implies that most of them may be able to read and understand simple instructions on how to use farm inputs or equipment. The men appeared more educated than women even though there is no significant difference in terms of gender. The level of formal education attained by farmers positively influences farmers understanding and adoption of modern sustainable agricultural practices *(Natwadia et al.*, 2022; Saleh *et al.*, 2022).

4.1.3 Marital status of respondents

A significant majority (88%) of practitioners were married, with male dominance. Most of the non-married comprised of widows and male youth. Most of the widowed respondents were female which is not surprising because males tend to remarry after losing their spouses more than females do. Male dominance in FLI in this study aligns with the findings of Saleh *et al*., (2022) in their study in the Katsina state of Nigeria, which showed that most irrigation practitioners are married. Marital stability has implications for family support and labour contributions. During the focus group discussions farmers indicated that being married was very crucial for timely access to labour and especially for male headed households engaged in FLI. A male discussant at Burankuan in the Tempane District said this.

"To succeed in FLI, you need to start early. This is only possible if you have a supportive family, especially a wife, as the early start of irrigation coincides with the harvesting of crops from the rain-fed farms. My family, especially my wives, handle the harvesting, drying, and storage of the rain-fed crops while I nurse seeds, build the fence and prepare the land for the irrigated plot. After this, they come to help with activities such as transplanting, watering, weeding, cooking for labourers and are again responsible for harvesting and marketing the irrigated produce, especially when we cannot sell at the farm gate. If even you have money to hire people they cannot work as a family member and especially a wife would" (interview No.19, FGD 9th /12/2022)

Similarly, at Kulogo in the Kassena Nankana Municipal Assembly, a key informant farmer and traditional leader acknowledged the importance of being married as a farmer by saying that;

"…. Though I am the head of my household, my wife plays a key role in my decision to engage in dry season gardening, especially the type of crop to cultivate and size of farm. If I take some of these decisions alone, I will be found wanting when it comes to major activities like transplanting harvesting, selling of tomatoes and pepper and most importantly storage and processing where possible, when it is not sold" (Interview No. 8, KII,5th/01/2023).

4.1.4 Occupation of respondents

Though respondents in this study engaged in both rain fed and irrigated agriculture, 54% of them considered rain fed agriculture as their major occupation while 33% of them considered irrigated agriculture as their major occupation as shown in the Table 4.1. Major occupation here refers to the primary job or activity that a person engages in to earn a living. It is the main source of income and typically takes the most time and effort compared to other activities or jobs the person might have. Other occupations included livestock rearing and trading. Rainfed agriculture emerging as the dominant (54%) major occupation among FLI practitioners, is a confirmation that it is initiated by farmers for farmers in response to climate change and consumers demand for high value vegetables (Osewe *et al*., 2020). The engagement of these farmers in FLI reduces vulnerability to variations in climate particularly rainfall.

There was significant difference between men and women in terms of major occupation at 10% significance level. It was significantly more likely for men to practice irrigated agriculture as their major occupation than women. These men produced cash crops mainly intended for the market. In contrast, women predominantly participate in rainfed agriculture, emphasizing subsistence crops. Overall, farmer-led irrigation (FLI) is primarily linked to cash crop cultivation, reinforcing gender-based occupational divisions. This finding aligns with the findings of Tejada, (2018), in her study on women in farmer-led irrigation development in the "Infulene" Valley in Maputo Mozambique, which highlights the association of irrigated farming with men as the primary breadwinners.

4.1.5 Indigene status of respondents

With regards indigene status, majority of FLI practitioners were indigens. Indigenous FLI practitioners may have long-term stakes in the land and water resources and will be more likely to adopt sustainable irrigation practices to preserve resources for future use especially if these practices are affordable. Migrant farmers made a small fraction (4.0%) of the sample surveyed and were mostly males. The presence of migrant farmers, though a small fraction, suggests the diversity of the FLI practitioner community. Understanding the characteristics and needs of migrant farmers could be important for targeted support.

4.1.6 Household characteristics of respondents

In relation to household characteristics of FLI practitioners, households headed by men had a slightly lager household size (7.17) than that of women headed households (6.62). A relatively large household size may indicate increased labour availability for irrigation activities though more food and resource requirement may put pressure on income and productivity. The dependency ratio suggests that both men and women headed households in the UER face similar burdens of supporting dependents. Access to credit is low for both men and women practitioners. This can restrict investment in irrigation infrastructure, thereby affecting productivity. With regards engagement in off-farm income generating activities, majority of the respondents rely mainly on agriculture for their livelihoods with only 33% of them being engaged in off-farm income generating activities.

The results show significant gender-based differences are observed in social networks and access to extension services with men more likely to participate in some form of social network and have more access to extension than women. This highlights a major inequality in access to technical knowledge, training and support services, suggesting that women may be disadvantaged in adoption of innovations which could affect their productivity and income compared to men. This difference can be attributed to socio-cultural barriers and result in gender productivity gaps and reduced food productivity levels in general.

Table 4.1: Demographic characteristics of FLI practitioners

	Pooled		**Men**		**Women**		**Difference**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**in means**
Respondent characteristics							
Age (years)	42.90	9.83	42.62	10.22	43.81	8.43	-1.19
Education (years)	5.09	5.56	5.39	5.72	4.10	4.92	1.28
Married (binary)	0.88	0.33	0.91	0.29	0.79	0.41	0.11*
Migrant (binary)	0.04	0.19	0.07	0.16	0.03	0.26	0.04
Major occupation (binary)							
Rain-fed farmer	0.54	0.50	0.53	0.50	0.59	0.50	-0.06
Irrigated farmer	0.33	0.47	0.37	0.48	0.21	0.41	0.16*
Salaried worker	0.04	0.21	0.04	0.19	0.07	0.26	-0.03
Other	0.08	0.27	0.06	0.24	0.14	0.35	-0.08*
Experience in irrigation (yrs)	11.20	9.53	11.82	10.23	9.16	6.34	2.67
Household characteristics							
Household size	7.04	2.78	7.17	2.94	6.62	2.11	0.55
Dependency ratio	37.84	17.17	37.86	16.69	37.78	18.84	0.07
Off-farm income (binary)	0.33	0.47	0.34	0.47	0.31	0.47	0.03
Social network (binary)	0.61	0.49	0.62	0.49	0.57	0.50	0.05
Access to credit (binary)	0.30	0.46	0.30	0.46	0.31	0.47	-0.01
Access to extension (binary)	0.78	0.42	0.82	0.39	0.64	0.48	0.18**
Num. Observations	250		192		58		

Note: Differences in means between men and women are based on Wilcoxon rank-sum test and the Fisher's exact test. Alpha = 0.05. ***, **, * denote significance at the 1%,5% and 10% levels respectively.

Source: Field Survey (2022), own calculations.

4.2 Development Trend of FLI in the Upper East Region

4.2.1 Historical evolution of FLI

Farmer-led irrigation (FLI) in the Upper East Region has evolved considerably over time both in terms of participation and irrigation technology. Evidence from the focus group discussions (FGDs) and key informant interviews (KIIs) show that FLI was initially practiced by elderly men, but over the past three decades it has expanded to include f males, females and the youth. Majority of farmer-led irrigation practitioners are the male youth. Their active participation reflects their role in sustaining agriculture and the importance of irrigated agriculture in sustaining livelihoods.

In terms of systems practiced, FLI started with manual lifting of water in most communities, but this is gradually replaced by use of motor pumps especially at the streams, rivers and areas of dam sites initially not demarcated as irrigable areas. The use of boreholes (mechanized) is gradually being adopted over the past 6 years. Figure 4.1 shows irrigation systems practiced over time by respondents in the study area. Pump surface water (Pump SW) irrigation systems are dominant (45%) with more males, followed by the manual systems. Pump groundwater (Pump GW) irrigation system is the least practiced. While some of the farmers still continue to use the irrigation systems with which they started FLI, others have adopted new or modified systems over time.

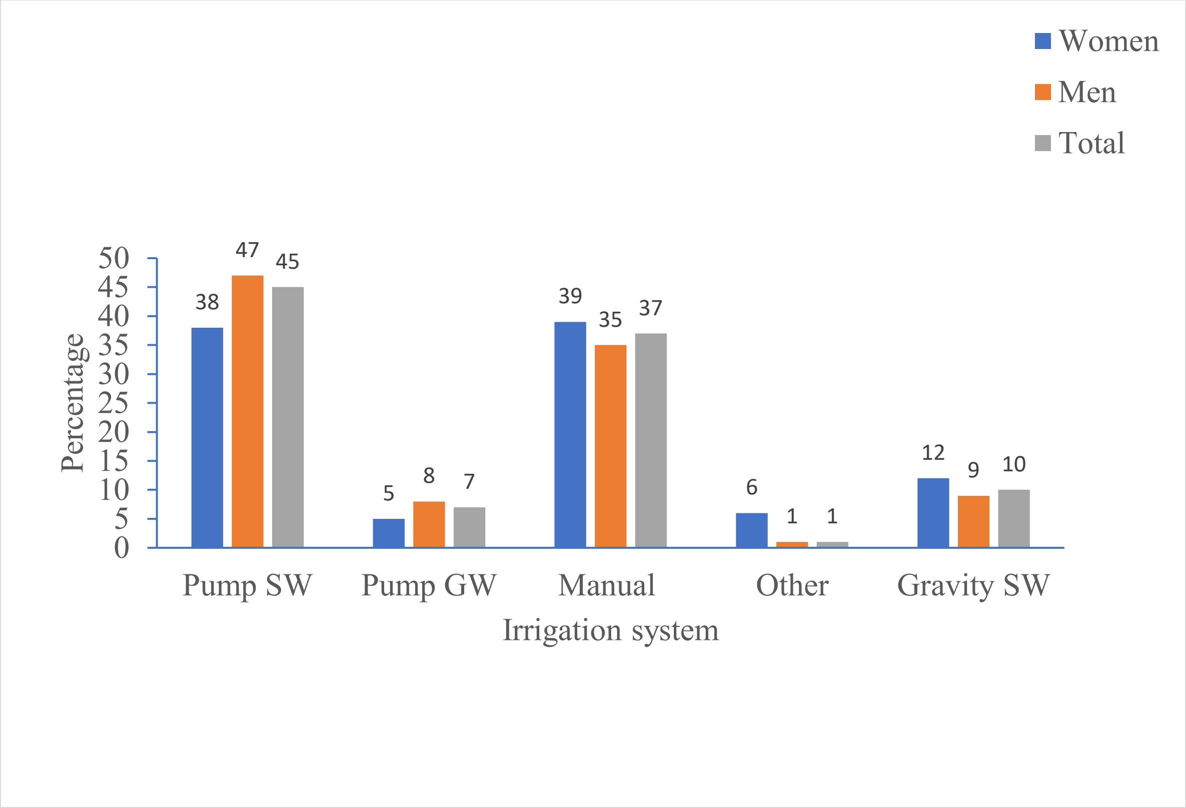


Figure 4.1: Irrigation systems ever practiced

Source: Field Survey (2022)

Figure 4.2 below shows farmer-led irrigation systems currently practiced by respondents in the study area, segmented by gender. Pump surface water (Pump SW) irrigation is the dominant system practiced, accounting for 58% of total usage. Men are the primary users of this system by a significant margin. Manual and Gravity systems follow, with 18% and 12% total usage respectively, with more women practicing them. Pump groundwater (Pump GW) and Supplementary systems are the least practiced systems. A comparison of Figures 4.1 and Figure 4.2 show that, while manual water lifting is decreasing, it remains common among women farming on small plots, and using water from manually dug wells.

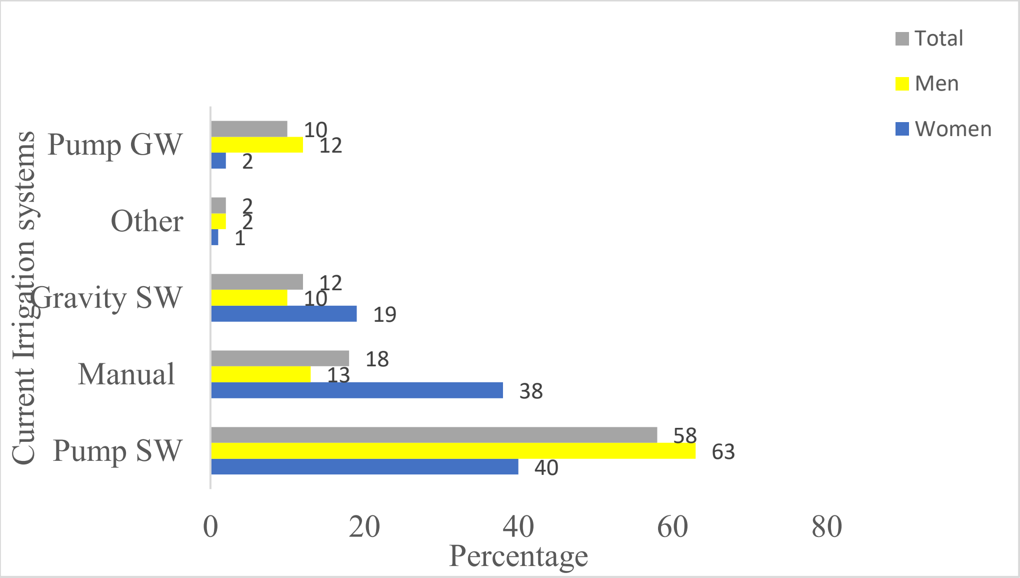


Figure 4.2: Current irrigation systems practiced

Source: Field Survey (2022)

Previous studies indicated that irrigation in northern Ghana is dominated by traditional methods (Dittoh *et al*., 2013), however the findings of this study show that there is a transition from manual water lifting to the use of motor pumps, which shows some technological advancements. Previously non-irrigable areas now benefit from tubewell (merchandised well/borehole) irrigation. Tube wells which used to be common in the Volta region are contributing to irrigation expansion in the UER (Namara *et al*., 2011). There is an observed gradual adoption of boreholes (mechanized wells/boreholes) powered electricity or solar pumps in the area which demonstrates a shift toward sustainable water and energy sources. This however requires connections to the electric grid, or access to a solar pump and its accessories. Connections to the electric grid are currently absent in many villages in Sub-Saharan Africa (De Fraiture & Giordano, 2014)

, and the solar pumps are currently very expensive for farmers. To overcome this challenge in communities in the study area, boreholes are innovatively fitted with small petrol or diesel pumps to lift water. While this improves water access, reliance on fossil fuels raises environmental sustainability concerns.

During the focus groups discussions, a few reasons were given for the continued use of females in manual irrigation by women. These include difficulty in transporting pumps to farms, challenges in and, and starting pumps and fitting hoses, And the cost of purchasing fuel regularly. The women have to depend on men to undertake those tasks. A of the male respondents from Soogo in the Bawku West district said that

> *".....most women cannot get money all the time for fuel. For us men sometimes we have to sell animals or borrow money for fuel to irrigate our crops" (interview No.184, with farmer, 16th/12/2022)*

Similar gender related constraints in irrigation technology adoption have been reported in other studies(Adebiyi *et al*., 2021; Quisumbing *et al*., 2021).While FLI was initiated and dominated by men, the increasing participation of women as plot managers suggest a gradual shift towards more gender inclusion in irrigated agriculture

These trends have important social and economic implications. The shift toward gender inclusive FLI, empowers women economically and socially and their active involvement contributes to household income and food security. The use of mechanized boreholes enhances overall community resilience and agricultural productivity by ensuring consistent water supply for agriculture and domestic use.

The overwhelming preference for Pump surface water (SW) irrigation systems, especially among men, could be attributed to its efficiency or accessibility. Though there are reports of efforts by organizations such as IWMI, Pump-tech, Action-Aid Ghana among others to support farmers with pumps in the region, there is a noticeable gender disparity in their use, which indicates a need for interventions to increase women's access or preference for this system. Interventions, however, should consider groundwater and provision of fences. In addition, interventions to empower women should focus on the marketing, storage and processing part of the irrigation value chain, which remain important constraints for many farmers.

4.2.2 Sources of water for FLI

Surface water comprising of water from dams/dugouts is currently the main source of water for FLI systems in the UER. Figure 4.3 below shows the distribution of water sources used by FLI practitioners in the study area. The results indicate that 41% of farmers rely on dams/dugouts while 36% obtain water from rivers/streams. Groundwater sources are used by a smaller proportion of farmers, with 15% accessing water from shallow wells and 9% using deep wells/boreholes

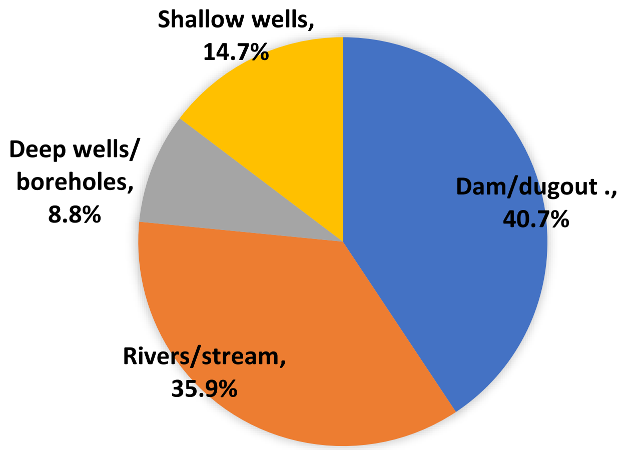


Figure 4.3: Sources of water for FLI
Source: Field Survey (2022)

The water is lifted mostly with small petrol/diesel/gas pumps and accessories, or manually with containers such as gourds, buckets, jerry cans or gallons usually perforated at the top (see figure 4.4 below). The engine capacity of pumps ranges from 3.5 to 10 HP (Namara *et al*, 2014). Petrol pumps were modified in some communities to use liquified petroleum gas (LPG) when prices of petrol and diesel were too high. Water from boreholes (popularly called mechanized boreholes), is mostly lifted with electric pumps and is either pumped directly to the farm or stored in an overhead tank for later use.

These findings indicate that although surface water is the dominant source of water for FLI, farmers are increasingly diversifying their water sources through groundwater development. This is important for improving reliability of irrigation water supply, particularly in the context of climate change/variability and seasonal water shortages.

A- Manually abstracting water from hand-dug well

B -Manually refilling hand-dug well

C - Petrol pump abstracting groundwater

D - Petrol pump abstracting groundwater

E - Petrol pump lifting surface water

F- Mechanized tubewell with drip kit

Plate 4.0.1: Sources and mechanism used to lift water for FLI in the UER.

Source: Field Survey (2022)

4.2.3 State of area under FLI

Changes in area irrigated under famer led irrigation provide an indicator of the overall growth or decline of irrigation activities in the region. Figure 4.5 presents farmers perceptions regarded trends in the area under FLI.

According to most (60%) of the respondents, the area under irrigation has been declining. Farmers attributed this decline to low prices of produce at harvest, limited water availability, high cost of inputs and fuel, and increasing incidence of pest and diseases for crops and in soils. Reports of declining irrigated areas may be associated with older irrigation sites that depend on surface water sources especially and dugouts. About 40% of practitioners, however, claim FLI has been increasing and the reasons given include the introduction of pump technology, and access to groundwater. Respondents reporting an increase in area under irrigation confirm findings of earlier studies that informal irrigation accounts for current expansion in irrigated areas (Namara *et al*., 2011; Osewe *et al*., 2020).

Results from the focus group discussions and field observations show that most of the areas reporting an increase in area irrigated are mostly able to access groundwater. This expansion may be attributed to increasing population, climate change, risk of food shortages and demand for more and better food/vegetables from the urban areas, and the implementation of the one village one dam policy of the current Government in northern Ghana among others. During the focus group discussions at Bubolzugu (district?), male discussants mentioned that most youth who used to migrate to city centres during the dry season no longer go because of FLI. A similar report was given by Laube et al., (2008) that migration was replaced by shallow groundwater irrigation in UER.

These findings show that although area irrigated at some traditional irrigation sites are declining due to economic and environmental challenges, the development of groundwater-based irrigation and improved technologies are contributing to the continued expansion and transformation of FLI systems in the region.

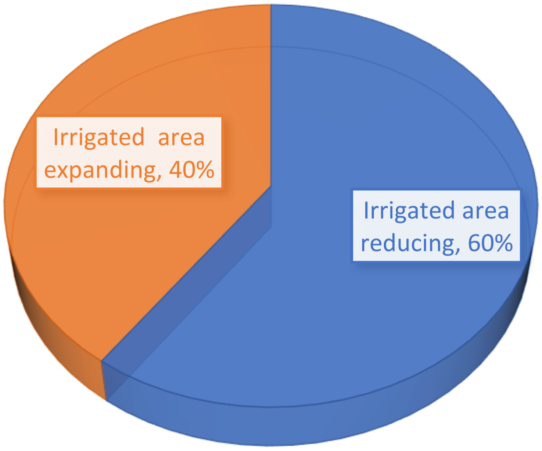


Figure 4.5: Farmers views on the state of area irrigated in the past 30 years

Source: Field Survey (2022)

4.3 FLI Farm Characteristics, Farming System, and Production Expenses and Returns

4.3.1 FLI farm characteristics

In relation to household farm characteristics as indicated in Table 4.2 below, there were significant differences in terms of use of household labour, and water lifting technology, at 10% significance level, while land size in hectares, and number of crop types cultivated were statistically significant at the 5% level. Women were more likely to use family labour than men. Men cultivated significantly larger land sizes than women. The mean area cultivated by FLI practitioners was 2.16 hectares. Irrigation technologies used were Gravity, Manual, Pump groundwater (GW), Pump surface water (SW) and a few into Supplementary irrigation. The later involves using water from rainfall to start cultivating a crop and supplementing with irrigation when the rainy season is over and vice versa.

Table 4.2: Farm characteristics

	Pooled		**Men**		**Women**		**Difference in means**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Farm characteristics							
Land size (ha)	2.16	1.17	2.25	1.16	1.84	1.18	0.41**
Share of irrigated land (%)	34.99	22.94	35.02	22.64	34.91	24.11	0.11
Family labour (binary)	0.70	0.46	0.66	0.47	0.83	0.38	-0.17**
Hired labour (binary)	0.57	0.50	0.58	0.50	0.53	0.50	0.04
Land Acquisition means(binary)							
Hired	0.29	0.45	0.27	0.45	0.34	0.48	-0.07
Inherited/family	0.59	0.49	0.61	0.49	0.52	0.50	0.09
Other source	0.12	0.33	0.11	0.32	0.14	0.35	-0.03
Irrigation system practiced (binary)							
Gravity	0.10	0.31	0.09	0.29	0.14	0.35	-0.04
Manual	0.18	0.38	0.13	0.34	0.34	0.48	-0.21***
Supplementary	0.02	0.13	0.02	0.12	0.02	0.13	0.00
Pump GW	0.10	0.31	0.12	0.33	0.03	0.18	0.09*
Pump SW	0.60	0.49	0.64	0.48	0.47	0.50	0.17*
Type of crops cultivated							
Tomato	0.19	0.39	0.22	0.42	0.09	0.28	0.14*
Pepper	0.32	0.47	0.36	0.48	0.17	0.38	0.19**
Okra	0.21	0.41	0.19	0.39	0.29	0.46	-0.11
Onions	0.55	0.50	0.57	0.50	0.47	0.50	0.11
Leafy vegetables	0.17	0.37	0.12	0.3	0.31	0.47	-0.19***
Cabbage	0.06	0.25	0.08	0.28	0.00	0.00	0.08*
Beans	0.05	0.22	0.06	0.23	0.03	0.18	0.02
Number of crops grown	1.56	0.80	1.62	0.84	1.36	0.64	0.26**
Num. Observations	250		192		58		

Note: Differences in means between men and women are based on Wilcoxon rank-sum test and the Fisher's exact test. Alpha = 0.05. ***, **, * denote significance at the 1%,5% and 10% levels respectively.

Source: Field Survey (2022), own calculations.

Men were more likely to practice pump irrigation whereas women practiced manual irrigation. Enhancing water availability for use during dry spells or combining the use of water from rainfall with irrigation we can improve the food security status of the many farmers dependent on rain fed agriculture in the region. Majority (59%) of the practitioners got land for irrigation from family members or inherited land. Men were slightly more likely to inherit irrigated land compared to women. Other sources of land include receiving it as a gift, and having land leased to you. This is attributed to the patrilineal system of inheritance.

Farmers during FGDs and KIIs at the Kassena Nankana Municipal Assembly, Builsa North, Bawku West and the Talensi Districts, reported of decline in tomato production in the region. This was associated with pest infestation (nematodes), and was also reported by Adongo et al., (2016) in their study on performance indicators of irrigation schemes in northern Ghana (surface water) though for formal schemes. The farmers complained about the lack of response from the Department of Agriculture. At Teshie, in Bawku-West District, for instance, a key informant said:

"*… We have complained to them many of the times they come here, even one time they came with the MP and took samples of the soil away but we never heard anything about it*"(interview No.13, KII, 17th/02/2022).

Similarly, a male discussant at Pwalugu, in the Talensi District, said;

"*….we used not have problems with nematodes here, but I think because of buying and transplanting seedlings nursed by farmers at the Vea irrigation scheme, we got our soils infested with it.*"(Interview No. 1, FGD, 14th /02/2022)

The main factors that influence the type of crop FLI practitioners cultivate in a season are, farmer's experience in the cultivating a particular crop and the market experience from the previous year, applicable to both men and women. Additionally, FGDs discussants at Pwalugu during the mentioned that a critical factor influencing the type of crop produced was the capital a farmer saved from the previous season. To buttress this point, one discussant said:

"…*When I am able to buy enough inputs for the irrigation season, I cultivate pepper or cabbage because these fetch a lot of profit but need a lot of farm inputs. I normally buy inputs that are subsidized for rainfed farming and keep them for use during the dry season when they are so expensive and sometimes not even available in the market when you need them*" (Interview No 1. FGD, 14th /02/2022).

There were no significant differences between male and female participation in the cultivation of onions, okro and beans. It was, however, significantly more likely to find males cultivating cabbage, pepper, and tomato, while women were more likely to cultivate leafy vegetables (Table 4.2). Most farmers cultivate more than one crop in a season on the same plot either in succession, or at the same time on different parts of the plot. During FGD discussions in the Talensi district, farmers who cannot afford costly farm inputs were said to cultivate leafy vegetables, okro and calabash (Gourds). An elderly male farmer at Pwalugu during the FGDs in relation to this said;

"… I cannot afford to buy farm inputs and petrol to lift water all the time, so I cultivate gourds here in place of onions. Previously I just needed to plant and weed but now I have to irrigate at least twice before they are harvested because the soils now dry early. It is my

kind neighbour who gives me his pump to use when I need to irrigate" (Interview with farmer on 03/09/2022).

Similarly, at Yarigu in the Bawku West District, A male FGD discussant said:

"*Because of high cost of fuel and farm inputs, women who have access to land here normally cultivate cowpea at the beginning of the irrigation season when the soil still has moisture so they don't incur a lot of cost to pump water. They sell the beans, the pods and the bean vines. The leafy vegetables that are locally consumed are also cultivated by them as these do not require costly chemical use and water,"* interview No.9 FGD, 16/02/2022)

4.3.2 FLI farming systems

Tables 4.3 and 4.4 illustrate the kinds of farming systems of farmer-led irrigators in the Upper East Region, in terms of crops cultivated as sole and those cultivated in mixtures by both men and women. The analysis of the decision by both men and women to cultivate particular crops reveals the importance each gender attaches to the different crops and also the importance attached to mixed cropping (intercropping). The reasons for those decisions should be important to decision makers and other stakeholders involved in farmer-led irrigation development. The two tables indicate that vegetable cultivation is the focus of farmer-led irrigation in the Upper East Region of Ghana. They are regarded as high value crops and thus farmer-led irrigation is clearly for commercial purposes despite the small sizes of the irrigated plots. Staple cereal crops are not irrigated at all in the area. Very few farmers, however, cultivate beans, a common grain legume but mainly for the leaves as a vegetable.

Onions, okra and pepper, either as sole crops or in mixtures are the crops cultivated most by men by Gravity, Manual and Groundwater Pumps as given in Table 4.3. Tomato production is also important in Surface water Pump irrigation. In the case of the women in the study area, leafy vegetables, okra, onions and pepper are most preferred and are also cultivated as sole crops or in mixtures (Table 4.4). According to both the men and women, the decision to cultivate a crop as sole or in mixtures is based on very many factors that cannot be easily enumerated. The main objective is, however, to reduce risks. There could be risks related to production, marketing, water availability, labour availability and several others. It is instructive that Table **4.4** shows that women undertake surface water pump irrigation.

Table 4.3: Men irrigated farming systems (crop/mixtures) by irrigation types

Crop/Crop mixtures			**Crop/ Crop mixtures**		
Gravity	**Freq.**	**% Freq.**	**Groundwater Pump**	**Freq.**	**% Freq.**
Onion	6	3.13	Pepper	10	5.21
Okra	4	2.08	Onion/pepper	5	2.60
Onion/pepper	3	1.56	Onions	3	1.56
LV/Okra	2	1.04	Pepper/LV/okra	1	0.52
Pepper	2	1.04	Pepper/LV	1	0.52
LV	1	0.52	Tomato/pepper	1	0.52
Cabbage/Okra/Garden eggs	1	0.52	Onions/tomato/ pepper	1	0.52
			Onions/tomato/ pepper/LV	1	0.52
			Onion/pepper/okra	1	0.52
Manual	**Freq.**	**% Freq.**	**Surface water Pump**	**Freq.**	**% Freq.**
Onions	14	7.29	Onion	31	16.15
Onion/ Okra	2	1.04	Pepper	13	6.77
Onion/ Pepper	2	1.04	Tomato	10	5.21
Tomato	1	0.52	Onion/pepper	7	3.65
Onion/ tomato	1	0.52	Tomato/pepper	4	2.08
Onion /LV	1	0.52	Onion/okra	3	1.56
Pepper/ Okra	1	0.52	Pepper/LV	2	1.04
Onion/pepper/LV	1	0.52	Pepper/okra	2	1.04
Tomato/LV	1	0.52	Onion/LV/okra	2	1.04
Tomato/ onion/LV	1	0.52	Onion/beans	2	1.04

			Tomato/LV	2	1.04
			Onion/tomato/cabbage	2	1.04
			Onion/pepper/okra	1	0.52
			Onion/LV/okra	1	0.52
			Onion/cabbage/LV	1	0.52
			Onion/calabash	1	0.52
			Cabbage/okra	1	0.52
			Pepper/green maize/beans	1	0.52
			Other crop mixtures	14	7.28

LV = leafy vegetables

Source: Field survey, 2022

Table 4.0: Women irrigated farming systems (crop/crop mixtures) by irrigation types

Crops/ crop mixtures			Crops/ crop mixtures		
Gravity	Freq.	% Freq.	Groundwater pump	Freq.	% Freq.
Leafy vegetables/ Okra	3	5.17	Pepper/ LV	1	1.72
Leafy vegetables	2	3.45	LV	1	1.72
Okra	2	3.45	onion/okra	1	1.72
Onions	1	1.72			
Manual			Surface water Pump		
Onion	9	15.52	Onions	9	15.52
Okra	4	6.90	Pepper	4	6.90
Leafy vegetables /Okra	3	5.17	Onion/pepper/beans	2	3.45

Onion/tomato	2	3.45	Onion/pepper	2	3.45
LV/Tomato	1	1.72	LV/Okra	2	3.45
LV	1	1.72	onion/ LV	2	3.45
Tomato	1	1.72	Okra	1	1.72
			Calabash	1	1.72
			Tomato	1	1.72
			Okra/garden egg	1	1.72
			Tomato/pepper	1	1.72

LV = leafy vegetables

Source: Field survey, 2022

4.3.3 Production expenses and harvest values

Table 4.5 shows costs and returns computations for men and women. It was possible to itemize the cost values but harvest values were used for the produce, which included different kinds of crops as they typically cultivate in mixtures as discussed above. Women’s expenditure per hectare on agricultural inputs such as water, equipment and labour are significantly lower than that of the men. The largest difference is in labour costs per hectare, with men spending significantly more (GHC 5,942.04) compared to women (GHC 3,443.18). This may be linked to the size of cultivated lands. It can also be deduced that the cost of water, equipment used (e.g. Pumps) and labour are key to successful FLI. The mean harvest value recorded for period was GHC 12,547.77/ha, with Men’s harvest value(GHC 14,105.72/ha) being significantly higher than that of women’s (GHC 7,391.26).

Table 4.5: Production Expenses and Harvest Value

	Pooled		**Men**		**Women**		**Difference in means**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Agricultural inputs							
Water (GHC'000/ha)	1.51	1.93	1.58	1.892	1.28	2.07	0.29**
Equipment (GHC'000/ha)	0.61	0.85	0.62	0.83	0.56	0.93	0.06 ***
Labor (GHC'000/ha)	5.36	6.56	5.94	6.87	3.44	5.01	2.50***
Inputs (GHC'000/ha)	3.39	2.75	3.32	2.73	3.62	2.79	-0.30
Other (GHC'000/ha)	2.52	3.45	2.69	3.72	1.95	2.31	0.74
Productivity measures							
Harvest value (GHC'000/ha)	12.55	12.31	14.11	12.81	7.39	8.77	6.71 ***
Num. Observations	**250**		**192**		**58**		

Note: Inputs is a monetary aggregate that includes expenditures related to fertilizer, seeds, and pesticides. Other includes expenditures such as transportation, and cost of fencing. Differences in means between Men and Women are based on Wilcoxon rank-sum test Alpha = 0.05. ***, **, * denote significance at the 1%,5% and 10% levels respectively.

Source: Field Survey (2022), own calculations

4.4 FLI Systems Productivity and Upscaling Potential.

4.4.1 Productivity of FLI systems

This section of the study investigated the relationship between irrigation systems and crop yield using onions and pepper. The systems are Gravity, Manual, Pump Groundwater (GW), and Pump Surface water (SW).

Figure 4.6 below illustrates substantial variation in onion yields(kg/ha) across four irrigation systems during the 2021/2022 cropping season. The Gravity surface water system produced the highest mean yield of 7008.3 kg/acre, while the Manual irrigation system recorded the lowest yield of 1625.03 kg/acre of onions. The Pump surface water system produced about 4815.96 kg/acre of onions, while the Pump groundwater system produced 2824.04 kg/acre of onions.

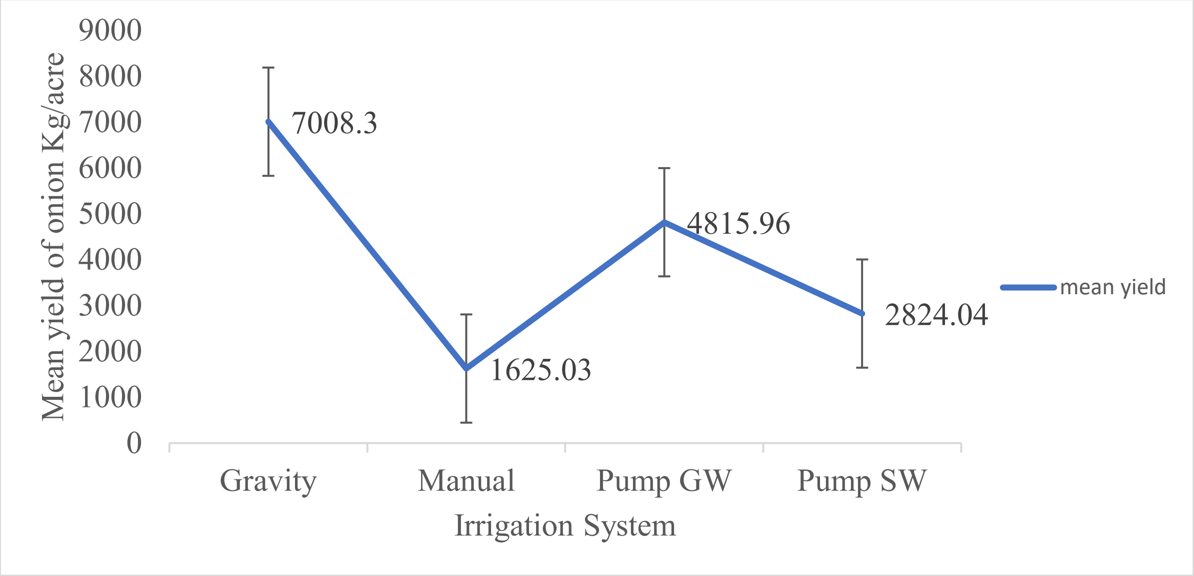


Figure 4.6: Mean Yield of Onion per Irrigation System
Source: Field Survey (2022)

Likewise Figure 4.7 below illustrates the mean yield of pepper (kg/acre) across the four different irrigation systems during the 2021/22 season. Similar to that of the onions, gravity irrigation system produced the highest average yield of 5301 kg of pepper, while the manual irrigation system recorded the least yield of 1241.17 kg during the 2021/22 season. The pump groundwater (Pump GW) and pump surface water (Pump SW) systems recorded mean yields of 4290.11 kg and 2833.80 kg respectively which were lower than that of the gravity but higher than yields from manual systems.

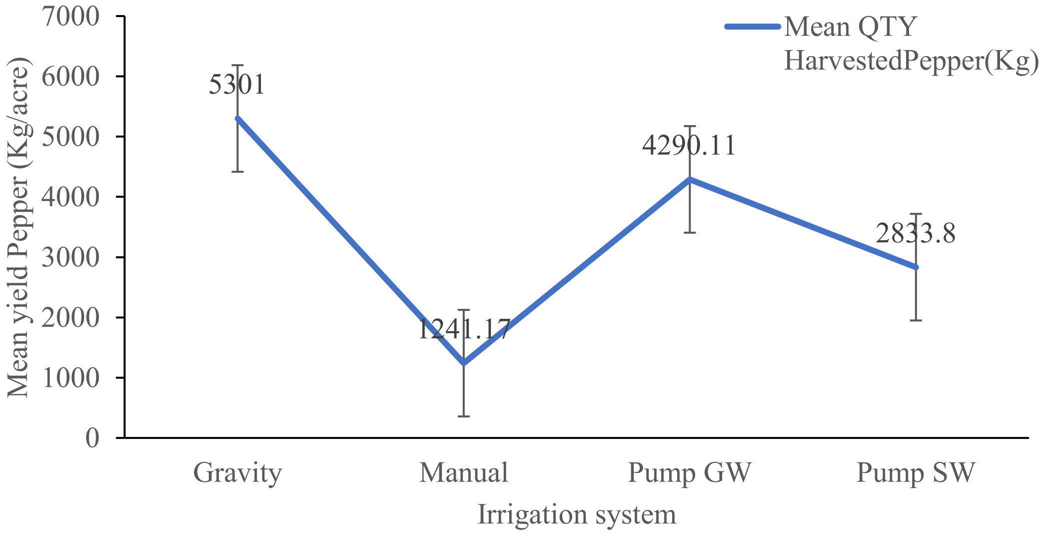


Figure 4.7: Mean yield of pepper per irrigation system

Source: Field Survey (2022)

The error bars in both figures above indicate variability in yields from farms withing the same irrigation systems with gravity irrigation systems showing the highest variability. Variation in yield is also noted across different irrigation systems, suggesting significant variability in mean yields across the different irrigation systems.

The results suggest that irrigation systems capable of delivering larger volumes of water, such as gravity systems, tend to produce higher yields for both onions and pepper. Larger variability observed under gravity irrigation indicates that outcomes depend strongly on farm-level management and environmental conditions. In contrast. Manual and pump-based systems although generally producing lower yields, show greater consistency probably because farmer are able to control water application more carefully.

The main difference between irrigation systems appears to be efficiency of water lifting and delivery, as well as the cost of energy, which determines the quantity of off water available to crops during the growing season.

These findings indicate that improving access to low cost-efficient water-lifting technologies could significantly enhance crop productivity under FLI systems. However, improving productivity will also require better management practices to reduce variability observed under higher-yield systems such as gravity irrigation.

4.4.2 Factors influencing onion and pepper yields under various combinations of irrigation systems

A Cobb-Douglas stepwise regression analysis was used to examine the factors influencing onion and pepper yields under different irrigation systems. The dependent variable was crop yield, while the independent variables included farm characteristics, production cost, and farmer socio-economic factors. (Tables 4.6 and 4.7).

For onions grown under Gravity and Manual irrigation systems in columns 3 and 4 of Table 4.7), the regression results indicate that the type of irrigation system practiced (X1) has a significant positive effect on onion yield ($p < 0.001$). The coefficient of 2.206, indicating that onion yields are 2.206 times higher under Gravity irrigation compared to Manual irrigation. The acreage of pepper (a competing crop) (X3) has a significant negative effect on onion yields ($p = 0.003$). The coefficient for the acreage of pepper variable is -1.471, indicating that onion yields decrease by 1.471 units for every unit increase in the acreage of pepper. Other variables that have a significant effect on onion yields include input cost per acre (p < 0.001), irrigation experience in years (p = 0.014), access to credit (p = 0.003), and access to irrigation extension service (p = 0.045)

For the regression results for onion yields under the Pump GW and Pump SW irrigation systems (columns 5 and 6), the type of irrigation system showed insignificance, implying that both Pump GW and Pump SW have similar effects on onion yields. However, input cost, cost of water, access to credit and access irrigation extension services significantly influence yields.

The last two columns (7 and 8) show the regression results for the yield of pepper grown under the Pump GW and Pump SW irrigation systems. The results also show that yield is significantly influenced by acreage of onions (the competing crop with a negative effect) and acreage of pepper with a positive influence, cost of water per acre and access to credit.

Table 4.6: Description of variables used in the model (Gravity-Manual; Pump GW and Pump SW irrigation systems)

		Onions				**Pepper**	
		Gravity-Manual		**PumpGW-Pump SW**		**PumpGW-Pump SW**	
Variable	**Variable Description**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Q	Quantity of onions/pepper harvested (in Kg) per acre	2,938.02	3,564.38	3,055.66	2,279.02	3,262.03	2,974.98
X1	Type of irrigation (1 = Gravity, 0 = Manual/1 = Pump GW, 0 = Pump SW)	0.24	0.43	0.12	0.32	0.29	0.46
X2	Acreage of onions	1.08	0.77	0.90	0.99	0.22	0.42
X3	Acreage of pepper (a competing crop)	0.06	0.18	0.23	0.37	0.96	0.66
X4	Labour cost (per acre) (GHC)	498.61	733.70	869.89	738.98	1,243.36	1,293.44
X5	Input cost (per acre) (GHC)	190.98	412.01	611.27	489.79	1,200.67	1,071.41
X6	Cost of water (per acre) (GHC)	1,526.34	1,442.49	1,446.39	1,109.49	1,489.89	1,313.49
X7	Equipment and other costs (depreciated per acre) (GHC)	490.73	518.62	1,057.94	910.20	1,132.41	1,335.30
X8	Gender (1= male; 0 = female)	0.68	0.47	0.83	0.37	0.85	0.36
X9	Age (years)	43.85	8.87	43.24	10.67	42.96	10.63
X10	Irrigation experience (years)	12.85	9.9	12.86	10.15	11.07	11.27
X11	Educational level (years of formal education)	4.65	6.34	4.55	5.25	6.18	5.9
X12	Household size	6.87	2.24	7.64	3.52	7.6	3.17
X13	Major occupation (1 = irrigation; 0 = otherwise)	0.05	0.22	0.45	0.50	0.29	0.46
X14	Access to credit (1 = yes, 0 = no)	0.32	0.47	0.23	0.42	0.34	0.48
X15	Access to irrigation extension service (1 = yes; 0 = no)	0.85	0.35	0.86	0.34	0.69	.46
X16	access to training (1 = yes; 0 = no)	0.75	0.43	0.82	0.38	0.61	0.49
X17	member of a farmer/cooperative group (1 = yes; 0 = no)	0.41	0.49	0.66	0.48	0.63	0.49

Source: Field Survey (2022)

Table 4.7: Factors influencing the yield of onions and pepper under various combinations of irrigation systems

Variable	Variable Description	**Gravity-Manual Onions**		**Pump GW-Pump SW Onions Cobb-Douglas**		**Pump GW-Pump SW** Pepper	
		Coeff	p-value	Coeff	p-value	Coeff	p-value
Constant	Constant	7.189	0.000	6.905	0.000	5.161	0.000
X1	Type of irrigation (1 = Gravity, 0 = Manual/1 = Pump GW, 0 = Pump SW)	2.206	0.000	0.305	0.106	-0.118	0.709
X2	acreage of onions	0.061	0.554	-0.035	0.635	-1.005	0.022
X3	acreage of pepper (a competing crop)	-1.471	0.003	0.119	0.467	2.601	0.012
X4	labour cost (per acre)	0.001	0.325	0.002	0.088	-0.001	0.194
X5	input cost (per acre)	0.001	0.000	0.003	0.092	0.001	0.274
X6	cost of water (per acre)	0.001	0.500	0.001	0.000	0.003	0.003
X7	equipment and other costs (depreciated and per acre)	0.001	0.430	0.001	0.987	0.001	0.119
X10	irrigation experience (years)	-0.021	0.014	0.005	0.445	0.011	0.133
X14	access to credit (1 = yes, 0 = no)	-1.471	0.003	0.010	0.042	1.473	0.000
X15	access to irrigation extension service (1 = yes; 0 = no)	0.675	0.045	0.921	0.009	0.921	0.009
X16	access to training (1 = yes; 0 = no)	-0.021	0.014	-0.722	0.063	-0.722	0.063
	R2	0.795		0.620		0.790	
	Adj R2	0.752		0.585		0.696	
	prob>F	0.000		0.000		0.000	

Source: Field Survey (2022)

In summary, the results from the regression analysis for yield of onions grown under Gravity and Manual irrigation methods show that the irrigation system practiced has a significant positive effect on onion yields, and suggests that gravity irrigation is a more effective system for growing onions compared to the manual irrigations systems.

The regression analysis indicates the critical role played by cost of water, experience of farmers, access to credit and access to inputs in influencing onion and pepper yields especially under the Pump GW and Pump SW irrigation systems. Farmers practicing the Pump GW and Pump SW irrigation systems who have access to credit are likely to have higher yields due to their ability to invest in the necessary inputs such as fertilizers, and water in addition to their experience in producing such crops. Addai & Kugbe, (2019) in their study about onion production in Northern Ghana reported that sufficient growth nutrients were very essential in determining the quality of seeds and productivity of onion. The cost of water also determines the amounts applied to these crops whose yield depends on amounts per irrigation session and duration of application in the season.

The finding that cost of water and access to credit influences the yield of pepper is a confirmation of the farmer in Pwalugu's saying that the factor that determines the type of crop a farmer will cultivate in a season is the capital he/she has for farm inputs (fuel and agrochemicals), and that he would cultivate pepper or cabbage if he has enough capital.

Overall, the findings suggest that improving productivity under farmer-led irrigation requires integrated support, including better access to credit, extension services and production inputs. Policies that strengthen these factors can significantly improve the effectiveness of irrigation technologies and increase crop yields.

4.4.3 Upscaling potential of FLI systems

Table 4.8 provides a summary of Farmer-Led Irrigation (FLI) practitioners' perspectives on upscaling potential of the irrigation systems they practice. The results show clear differences across irrigation systems, in relation to reliability of water sources, and the cost of expansion.

Gravity SW systems exhibit the lowest expansion potential, with 57.7% of practitioners indicating that these systems have limited upscaling potential. This is mainly because they obtain water from dams with fixed storage capacity and irrigable areas. Expansion of these systems would require the construction of more dams which is expensive and constrained by limited land availability In addition, water availability in these systems is rainfall dependent, making them vulnerable to climate change/variability. Field discussions also revealed operational challenges, including siltation and faulty outlets in dams at Pusunamoo and Bare in the Talensi District for instances, which reduces water availability.

In contrast Pump-based systems particularly groundwater irrigation, shows significantly higher potential for expansion. A large majority (92%) of Pump groundwater irrigators (Pump GW) said their system can be upscaled. This is largely due to the relative reliability and control of groundwater resources, which reduces production risks and encourages investment in inputs such as seeds and fertilizer. Similarly, 60% of manual irrigation practitioners indicated that their system has upscaling potential. This was attributed to lower cost and the indigenous nature of this system. All respondents practicing Supplementary irrigation indicated that it had potential for up scaling. This system, however, requires ownership of land.

Table 4.8: Up-scaling potential of FLI systems

Up-scaling Potential	**Irrigation systems**					**Total**
	Gravity	**Manual**	**Pump SW**	**Pump GW**	**Supplementary**	
	N=26	**N=45**	**N=149**	**N= 26**	**N=4**	**N=250**
No	57.7%	40.0%	44.3%	7.7%	0.0%	**40.4%**
Yes	42.3%	60.0%	55.7%	92.3%	100.0%	**59.6%**
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: Field Survey (2022)

Table 4.9 provides an explanation of the factors driving the expansion potential of FLI systems. Across systems, the availability of land and water emerges as the most important enabling condition. Practitioners of Pump GW irrigation systems, access to land and water, in addition to experience in using technology, supports expansion. Groundwater use reduces risk in investment for other inputs like seeds and fertilizer as they have full control of water (Villholth, 2013). However, even where water and land are available, high costs of pumps, fuel and infrastructure limit the extent to which farmers can scale up their operations as mentioned by Giordano et al., (2012). Ground water is available according to literature (Anayah *et al*., 2013; Barry *et al*., 2010; Namara, 2011b), however, there is a need to guard against overexploitation because of reports of drying up of shallow wells after a couple of months of water extraction for irrigation in the Upper East Region (ILSSI Project 2017). Additionally human activities such as irrigation return flows and fertilizer application affect the physicochemical characteristics of the groundwater (Obiri-Nyarko *et al*., 2022) and hence needs to be checked.

Table 4.9: Reasons given for up scaling potential of FLI systems

Reasons for up-scaling Potential	**Irrigation system**					**Total**
	Gravity	**Manual**	**Pump SW**	**Pump GW**	**Supplementary**	
Groundwater is abundant	0	0	0	2	0	2
It is less costly	0	10	0	0	0	10
Many have experience	0	0	5	8	0	13
There is land	6	5	31	8	4	54
There is land and groundwater	0	0	0	6	0	6
There is land and water	5	3	42	5	0	55
They are indigenous practices	0	9	0	0	0	9
Total	**11**	**27**	**78**	**29**	**4**	**149**

Source: Field Survey (2022)

Table 4.10 provides insights into the reasons given by FLI practitioners for believing there is no potential for up scaling or expanding their irrigation systems. For practitioners of pump surface water (Pump SW) irrigation systems, the most significant barrier is the high capital cost of pumps and accessories, as reported by 95% of respondents. Water scarcity is another major constraint for practitioners of “Manual" irrigation systems. In relation to the access to pumps and accessories, one of respondents of the survey questionnaire at Yinduri in the Talensi District said:

“…. *There is vast and fertile land along the river bank but the major challenge is the number of pipes you need to put together to move water. And the further you lift water the more of fuel consumed by the pumps*.” (Interview with farmer, 25th/09/2022)

These findings indicate that while pump-based systems offer greater expansion potential, their scalability is strongly influenced by access to affordable technology and reliable energy sources.

Table 4.10: Reasons for no potential for up scaling

Reasons for No up-scaling Potential	**Irrigation system**				**Total**
	Gravity	**Manual**	**Pump SW**	**Pump GW**	
Capital intensive	1	0	19	0	20
Insufficient land	0	4	6	0	10
Insufficient water	1	13	30	1	45
It is tedious	0	1	2	0	3
fixed dam capacity	13	0	0	0	13
Pump and its accessories	0	0	9	1	10
Total	**15**	**18**	**66**	**2**	**101**

Source: Field Survey (2022)

A key implication of these findings is that irrigation systems with greater control over water supply, particularly groundwater-based systems are more likely to support expansion and intensification. However, this also raises concerns about sustainability of groundwater use, including the risk of over-extraction and declining water tables. Therefore, while promoting pump-based irrigation can enhance productivity and resilience, it must be accompanied by appropriate water management policies and monitoring systems. Reducing the cost of irrigation equipment and improving access to pumps could significantly enhance the scalability of FLI systems.

4.5 Productivity Gap Analysis of Men and Women FLI Practitioners

Following the model for productivity gap analysis described in Chapter three, the results of the Ordinary Least Square (OLS), Oaxaca-Blinder (OB) decomposition and the Recentred Influence Function (RIF) decomposition analyses are presented below. Pump irrigation here is combination of pump groundwater and pump surface water irrigation systems. Combination was done to ease analysis.

4.5.1 OLS – Gender differences in FLI harvest value

Tables 4.11 to 4.12 shows the progressive approach used to investigate whether gender differences exist in FLI harvest value and how these differences change when other household and farmer characteristics are considered. The results show a substantial gender, with women's harvest values consistently lower than men's. this gap is largely explained by differences access to land, irrigation technology and extension services.

In the basic regression (Columns 1), which includes only gender as a predictor, Women's harvest value per hectare is on average 76.1% lower than that of men, a difference that is highly significant. This gap can be viewed as the unadjusted gender gap, which is explained in the subsequent analysis Controlling for community -level effects (Column2) slightly reduced the gap to 72.8%. When additional household and farm characteristics such as age, farm size and access to extension services are included (Column 3), the gap narrows further to 30.1%, though it still remains significantly visible between men and women. This shows that unequal access to resources explains much, but not all the gender productivity gap.

For comparison, Columns 4 and 5 show the results for women's and men's FLI harvest value separately. The separate regression results in Columns 4 and 5 show that there are gender-specific similarities and differences in correlations with RHS variables. In terms of similarities, land size and input use are statistically significant at the 5%-level and positively associated with both women's and men's productivity. Both coefficients are larger for women indicating higher returns. Specifically, the coefficient on land suggests that a 10% increase in land for a female FLI practitioner would be associated with an 8.05% increase in productivity, while men's productivity would increase by 3.4%. The positive association between land size and productivity observed in FLI production in northern Ghana contrasts with the negative relationship found in other studies in Nigeria and Mali (Oseni *et al*., 2015; Singbo *et al.*, 2021). Possible explanations could be related to differences in farming practices and the associated dominating market failure. Additionally, this study focuses on irrigated vegetable production, where specifically credit market constraints may limit the access to specific irrigation technology, while (Oseni *et al*., 2015) for example, looks at rain-fed production of staple crops such as cassava, yam or maize, where imperfect labour markets can make access to non-family labour difficult. Differences in farming practices and market failures, such as credit market constraints and imperfect labour markets, significantly impact gender-specific productivity in irrigated vegetable production.

In terms of gender-specific differences. Women benefit from access to extension services, alternative income sources, and larger household sizes. Men's productivity is positively associated with, having more experience in irrigation farming, growing more than one crop, having access to advanced irrigation systems, and irrigation related expenditures. This finding is in line with previous gender gap studies such as (Udry, 1996) in Burkina Faso, (Oseni *et al.,* 2015) in Nigeria, and (Singbo *et al.,* 2021) in Mali.

From field observations and key informant interviews, women often prioritize a main crop for sale while other crops are for home consumption and may rely on men's help to operate pumps. The use of motorized pumps requires sufficient water at the source. Overall, these findings highlight the percentage gender gap in FLI productivity and the importance of improving women's access to knowledge and resources.

Table 4.11: Gender differences in FLI harvest value (Ln) using OLS

Dependent variable:	**Harvest value (ln)**				
	Pooled			**Women**	**Men**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Female (binary)	-0.761***	-0.728***	-0.301*		
		(0.109)	(0.174)		
Age (years)			0.040	0.094	0.019
			(0.043)	(0.129)	(0.040)
Age squared (years)			-0.001	-0.001	-0.000
			(0.000)	(0.001)	(0.000)
Education (years)			-0.006	0.035	-0.002
			(0.011)	(0.037)	(0.013)
Married (binary)			-0.234	0.634	-0.117
			(0.180)	(0.873)	(0.244)
Migrant (binary)			0.054	0.084	0.156
			(0.266)	(0.769)	(0.328)
Major occupation (binary)	Baseline is irrigated farmer				
Other			0.165	1.405*	-0.044
			(0.195)	(0.680)	(0.285)
Rain-fed farmer			0.224	-0.379	0.330*
			(0.171)	(0.345)	(0.173)
Salaried worker			0.122	-0.567	0.136
			(0.276)	(0.461)	(0.339)
Experience in irrigation (years)			0.021***	-0.043	0.028***
			(0.006)	(0.028)	(0.005)
Household size			0.033	0.149*	0.019
			(0.022)	(0.080)	(0.023)
Dependency ratio			-0.002	0.003	-0.007
			(0.003)	(0.008)	(0.004)
Off-farm income (binary)			-0.099	-0.135	-0.077
			(0.148)	(0.488)	(0.154)
Social network (binary)			-0.014	-0.167	-0.085
			(0.158)	(0.345)	(0.170)
Access to credit (binary)			0.058	-0.066	0.168
			(0.141)	(0.369)	(0.161)

Note: Robust standard errors in parentheses. ***, **, * denote significance at the 1%,5% and 10% level respectively.

Source: Field survey 2022. own calculations

Table 4.12: Gender differences in FLI harvest value (Ln) using OLS continued

Dependent variable:	**Harvest value (ln)**				
	Pooled			**Women**	**Men**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Access to extension (binary)			0.286*	0.713**	0.316
			(0.156)	(0.260)	(0.239)
Land size (ln)			0.433***	0.805**	0.340**
			(0.089)	(0.323)	(0.139)
Share of irrigated land			0.002	0.007	0.003
			(0.003)	(0.008)	(0.003)
No. of crops grown			0.169	-0.444	0.206*
			(0.112)	(0.404)	(0.114)
Irrigation technology (binary) Baseline is gravity					
Manual			-0.561	1.105	-0.444
			(0.346)	(0.982)	(0.557)
Other			0.504	0.427	1.298***
			(0.523)	(1.488)	(0.450)
Pump			-0.092	0.907	-0.110
			(0.293)	(0.804)	(0.363)
Cost of Water (ln)			0.064	0.042	0.111**
			(0.042)	(0.085)	(0.048)
Cost of Equipment (ln)			0.046	-0.125	0.038
			(0.027)	(0.128)	(0.048)
Cost of Labour (ln)			-0.021	0.045	-0.028
			(0.038)	(0.115)	(0.040)
Cost of Inputs (ln)			0.229***	0.383**	0.287***
			(0.069)	(0.143)	(0.082)
Constant	7.233***	7.202***	4.330***	-0.979	4.578***
	(0.160)	(0.087)	(0.830)	(4.307)	(1.056)
Controls:	No	No	Yes	Yes	Yes
Community FEs:	No	Yes	Yes	Yes	Yes
Observations	250	250	250	58	192
R^2	0.102	0.201	0.572	0.806	0.576

Note: Community fixed effects included in model but not reported. Robust standard errors in parentheses. ***, **, * denote significance at the 1%, 5% and 10% level respectively. Inputs is a monetary aggregate that includes expenditures related to fertilizer, seeds, and pesticides.

Source: Field Survey 2022, own calculations.

4.5.2 OB – Decomposition of the gender gap in FLI harvest value

Table 4.13 presents the Oaxaca -Blinder (OB) decomposition of gender gap in FLI harvest value. This method splits the average difference into two components: the part explained by differences in observable characteristics (endowments), and the part due to differences in returns to these characteristics (structural disadvantage), which can reflect discrimination. This decomposition links the average differences in harvest value shown in Table 4.5 and the pooled regression coefficients in Tables 4.11 - 4.12 (Column 3) and provides a better understanding of the factors that condition the gender gap.

The results shows that 58.39% of the gap is due to differences in observed characteristics FLI practitioners, such as land size, crop types grown, access to irrigation technology, and extension services. The remaining 41.61% is due to unobserved characteristics that can be attributed to discrimination against women FLI practitioners. This indicates that resource endowments are the main drivers of the productivity gap, though social and institutional barriers also play a role. Both shares are statistically significant at the 1% level.

The disaggregated decomposition in Panel C of Table 4.14, shows the variables that contribute to the endowment effect. Note that a positive coefficient is indicative of increasing the gender gap, while a negative coefficient reduces the gap. Among the observed factors, land size is the largest contributor, consistently favouring men's productivity. Men tend to cultivate larger plots, grow more crop types, have greater access to extension services and irrigation equipment. These differences in resource endowments explain a substantial part of the productivity gap between men and women. In contrast, factors such as household size, marital status, off farm income and the use of manual irrigation tend to reduce the gap when women have access to them. This suggest that improving women's access to productive resources could help narrow the gender difference in harvest value.

The decomposition also shows differences in returns to these factors. For example, being married, having a larger household labour force, and access to extension services or off-farm income appear to improve women's productivity more than men's. In contrast, factors such as experience in irrigation farming, number of crop types grown, and expenditures on equipment are more strongly associated with men's productivity. These difference show that while unequal access to resources explain much of the gap, difference in how these resources translate into productivity also contribute to the observed disparities. This implies that policy and interventions focusing on improving women's access to land, technology and extension support could be effective in closing the gender gap.

The results suggests that the average gender gap in FLI productivity of 76.1% could be reduced, if constraints in access to land, irrigation technology, and extension services are removed. Furthermore, the finding that female FLI practitioners can earn higher returns from being married and household size than men is indicative of the persistent social discrimination against divorced or widowed women and the important role of available labour force in the household. Married women in most instances have access to their husbands' farmlands for production unlike widows or those divorced.

Table 4.13: OB decomposition of FLI harvest value per ha (ln)

Panel A: Mean gender gap in FLI	**Harvest value (ln)**					
Mean men	7.233***	(0.066)				
Mean women	6.473***	(0.120)				
Difference	0.761***	(0.135)				
Panel B: Aggregate decomposition	**Endowment effect**		**Male structural advantage**		**Female structural disadvantage**	
	Coeff	Robust SE	Coeff	Robust SE	Coeff	Robust SE
Total	0.444***	(0.141)	0		0.317***	(0.107)
Share of gender gap	58.39%		0%		41.66%	
Panel C: Detailed decomposition	Coeff	Robust SE	Coeff	Robust SE	Coeff	Robust SE
Age (years)	-0.058	0.083	-0.845	0.939	-1.700	2.907
Age squared (years)	0.048	0.099	0.260	0.474	0.149	1.285
Education (years)	-0.009	0.014	0.024	0.038	-0.121*	0.064
Married (binary)	-0.028	0.028	0.123	0.176	-0.752**	0.297
Major occupation (binary)						
Rain-fed farming	-0.004	0.009	0.102**	0.046	0.408***	0.113
Irrigated farming	-0.029	0.026	0.032	0.038	0.002	0.038
Salaried worker	-0.004	0.007	-0.004	0.009	0.038	0.025
Other	0.001	0.007	-0.010	0.012	-0.174**	0.084
Observations			250			

Continued

Note: Community fixed effects included in model but not reported. ***, **, * denote significance at the 1%,5% and 10% level respectively. Inputs is a monetary aggregate that includes expenditures related to fertilizer, seeds, and pesticides.

Source: Field Survey (2022), own calculations.

Table 4.14: OB decomposition of FLI harvest value per ha (ln) continued

Panel C: Detailed decomposition	Coeff	Robust SE	Coeff	Robust SE	Coeff	Robust SE
Migrant (binary)	-0.001	0.012	0.009	0.009	0.004	0.028
Experience in irrigation (years)	0.060*	0.036	0.090	0.058	0.566***	0.141
Household size	0.018	0.016	-0.090	0.074	-0.755**	0.326
Dependency ratio	0.000	0.007	-0.166*	0.088	-0.209	0.164
Off-farm income (binary)	-0.003	0.011	0.005	0.036	0.021	0.074
Social network (binary)	0.000	0.007	-0.032	0.040	0.077	0.127
Access to credit (binary)	-0.001	0.004	0.029	0.025	0.036	0.063
Access to extension (binary)	0.048	0.035	0.027	0.152	-0.294***	0.105
Land size (ln)	0.120**	0.054	-0.114*	0.068	-0.161*	0.089
Share of irrigated land	0.000	0.007	0.046	0.060	-0.128	0.130
Number of crops grown	0.047	0.031	0.048	0.062	0.848***	0.279
Irrigation technology (binary)						
Pump	0.010	0.029	-0.139	0.110	-0.101	0.092
Manual	0.096*	0.058	-0.013	0.024	-0.305**	0.120
Gravity	-0.004	0.011	-0.023	0.017	0.096	0.070
Other	0.000	0.007	0.008	0.010	0.007	0.010
Cost of Water (ln)	0.047	0.049	0.156	0.214	-0.032	0.189
Cost of Equipment (ln)	0.052	0.035	-0.018	0.127	0.480***	0.174
Cost of Labour (ln)	-0.016	0.032	-0.088	0.179	-0.284	0.324
Cost of Inputs (ln)	0.001	0.057	0.330	0.326	-0.858	0.549
Observations				**250**		

Note: Community fixed effects included in model but not reported. ***, **, * denote significance at the 1%,5% and 10% level respectively. Inputs is a monetary aggregate that includes expenditures related to fertilizer, seeds, and pesticides.

Source: Field Survey (2022), own calculations.

4.5.3 RIF – Decomposition of the gender gap in FLI harvest value

While the OB decomposition above examined the mean gender gap, the Recentered Influence Function (RIF) decomposition investigates how the gender productivity gap varies across the entire distribution of FLI harvest values. Figure 4.8 plots the productivity gap, showing the contribution of the endowment effect (differences in resources) and the female structural disadvantage (differences in returns) across percentiles including the respective 95% confidence intervals.

The results show that the gap is largest at mid-percentiles (60th and 70th), where it exceeds 100%. The gap decreases at the two higher productivity levels, and falls below 25% at the 90th percentile. The endowment effect (ED) is relatively small and statistically insignificant at the lowest productivity levels, but increases to 0.62 and 0.68 at the middle of the distribution, between the 40th and 80th percentiles. At the highest productivity percentile, the contribution of the endowment effect decreases to 0.41 but remains statistically significant. The female structural disadvantage in contrast is generally smaller than the endowment effect, and only statistically significant among the least productive farmers. This suggests that differences in access to productive resources are the main drivers of the gender productivity gap.

This study's finding that the endowment effect is larger than the female structural disadvantage for the most part of the productivity distribution is in contrast to other studies from Nigeria and Mali by Oseni *et al.,* (2015) and Singbo *et al.*, (2021) respectively.

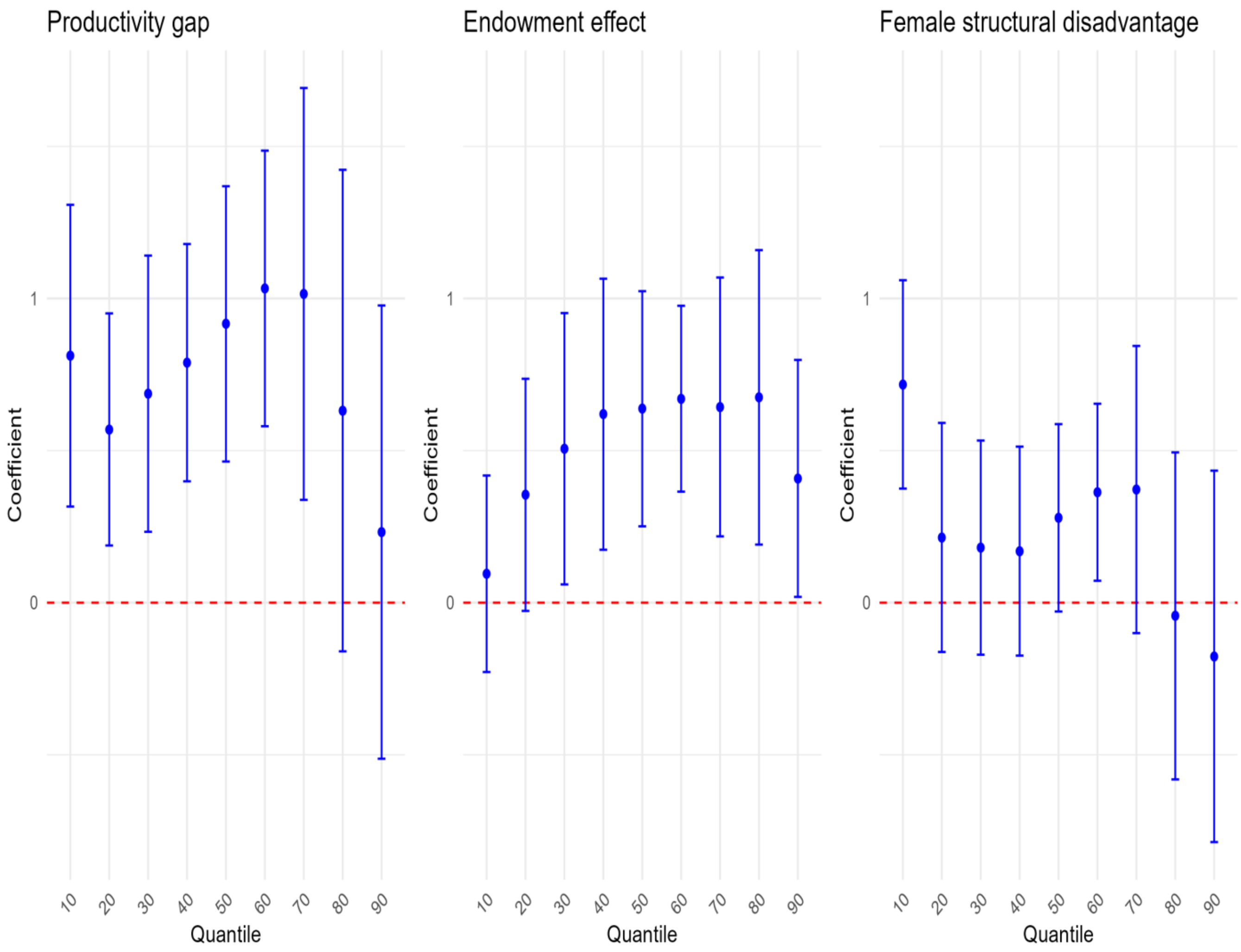


Figure 4.8: Farmer-led irrigation productivity gap between men and women, endowment effect and female structural disadvantage across productivity quantiles

Source: Field Survey (2022), own calculations.

Table A1 (see appendix) presents the detailed RIF decomposition results for only the 10th, 50th, and 90th percentiles, including the mean results from Tables 4.13 - 4.14 for ease of comparison. Similar to the findings in the mean decomposition in Table 4.14, land size per ha is the only factor that is positively contributing to the endowment effect and is statistically significant for all percentiles at or above the 50th. In other words, land size is the major factor that favours men's FLI productivity and drives the gender gap especially among the more productive FLI practitioners. Other observed factors, such as crop types, irrigation methods, and access to extension, also shape productivity differences. However, characteristics like household size, marital status and off-farm income can mitigate the gap, particularly for women with greater access to these resources. This is consistent with the OB decomposition results which identified land as a key contributor to the gender productivity gap.

Across the distribution, the female structural disadvantage shows patterns similar to the mean decomposition results. Women tend to gain more than men from factors such being married, household labour, access to extension, and off-farm income, while experience in irrigation, number of crops cultivated and irrigation expenditures tend to favour men. For more productive women, access to labour, education, finance and social networks helps reduce the gap, whereas for less productive women, these factors appear less effective and disadvantages persist.

Looking at the RIF decomposition results, the variables associated with higher returns for women in the mean decomposition, for example i.e., being married, engaged in other major occupations, household size, access to extension, land size, and using manual irrigation, also persist in the lower (10th and 20th) and in the higher (60th to 80th) percentiles. The exception is household size, which is only statistically significant at the 80th percentile. Education and dependency ratio which were not statistically significant in the mean decomposition, became important in the RIF decomposition. Women seem to be able to generate higher returns from education in the 40th to 60th percentile, and from the dependency ratio in the lower three percentiles.

In addition, variables that were associated with a lower return for women FLI practitioners in the mean composition such as number of crops grown, experience in irrigation, expenditures for equipment, and being mainly engaged in rain-fed farming, exhibit the same relationship across the entire productivity distribution. Hereby, both women that are in the lower productivity percentiles (10th to 30th) and women that are in the higher productive percentiles, specifically in the 80th, generate lower returns from rainfed farming and equipment expenditures. Lower returns from irrigation experience and number of varieties grown are more likely among women in the 40th to 80th percentiles and 20th to 80th percentiles, respectively. Finally, there are variables that switch sign across the productivity distribution. While returns from factors such off-farm income, social networks, and access to credit are low for women in the lower productivity percentiles, more productive women can generate higher returns from these factors. An exception from this pattern is the share of land allocated to irrigated farming, where women's returns are higher in the 80th percentile, and lower in the 90th.

In sum, the RIF decomposition confirms the mean decomposition results that access to resources such as land, irrigation technology and extension services are important factors shaping the FLI productivity gap between women and men. For more productive women, access to labour (household/hired), education, funding, as well as social networks seem to contribute to reduce the gender gap. However, these factors work in the opposite direction for less productive women. Factors such as being divorced or widowed, number of crops grown, experience in irrigation, expenditures for equipment, and being mainly engaged in rain-fed farming seem to work toward increasing the gender gap irrespective of women's productivity level.

4.6 Challenges and Constraints of FLI Systems along the Irrigation Value Chain

Farmer-led irrigation systems encounter a range of constraints along the irrigation value chain, from production to marketing. These constraints influence the productivity and long-term sustainability of FLI systems. Table 4.15 below presents the challenges reported by farmers, and shows mean responses and standard deviations for men and women. The "difference in means" column quantifies the gender-based variation in means.

The results generally show that production-related constraints are most severe, particularly the high cost of inputs and the incidence of pest and diseases. Marketing, transportation and storage challenges further affect the ability of farmers to sell their produce profitably. These findings help explain the sources of productivity differences observed earlier in this study, especially relating to limited access to credit, irrigation equipment and market infrastructure.

4.6.1 Production challenges

Production challenges reported by respondents mainly include high cost of inputs (91%), incidence of pest and diseases (85%), inadequate access to credit (53%), insufficient water (48%) and infertile soils (48%) as shown in Table 4.15. These results show that the main challenges affecting FLI farmers are related to production cost and access to resources.

Men and women face similar challenges in relation to the high cost of inputs and pests and diseases, with a marginal gender-based difference. Women however, face a significantly higher challenge regarding access to credit and sufficient water compared to men. Limited access to credit has been identified in other studies as a key constraint to practitioners of small-scale irrigation. Balasubramanya et al. (2023) for instance, cited credit as one among two well-known constraints to adopting smallholder irrigation technologies in Ethiopia. Some men during the interview indicated that they rely on money lenders, produce buyers, salaried relatives or commercial banks to fiancé their farming activities. Borrowing from money lenders was however described as risky due to high interest rates.

FGDs revealed that challenges of accessing water are closely linked to labour and energy cost. During the FGDs in Goo (Bawku West District) and Burankuan (Tempane District), women mentioned that digging wells is labour intensive, while pumping water requires fuel which increases production cost. Similarly male farmers in Doba (Kassena Nankana Municipal), also mentioned these challenges in addition to difficulty getting affordable and durable pumps.

These production challenges have implication for the sustainability of FLI systems. High input cost, limited credit access, and water constraints can reduce farmers' ability to maintain irrigation activities over time, which in turn affects productivity and viability of irrigated farming.

Table 4.15: Challenges encountered along the FLI value chain.

Challenge	**Pooled**		**Men**		**Women**		**Difference**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**in means**
Production related challenges (binary)							
High cost of inputs	0.91	0.29	0.92	0.28	0.88	0.33	0.04
Pest and diseases	0.85	0.36	0.85	0.36	0.84	0.37	0.01
Inadequate credit	0.53	0.50	0.57	0.50	0.40	0.49	0.17
Insufficient water	0.48	0.50	0.52	0.50	0.36	0.48	0.16
Infertile soil	0.48	0.50	0.46	0.50	0.55	0.50	-0.09
Other challenges	0.33	0.47	0.34	0.47	0.29	0.46	0.05
Marketing related challenges (binary)							
Bad or no Roads	0.60	0.49	0.58	0.49	0.67	0.47	-0.09
High cost of transport	0.85	0.36	0.85	0.35	0.84	0.37	0.01
No vehicles	0.18	0.38	0.16	0.37	0.22	0.42	-0.06
low sales prices	0.72	0.45	0.75	0.43	0.64	0.48	0.11
Number of observations	250		192		58		

Note: Differences in means between Men and Women are based on the Fisher's exact test. Alpha = 0.05.

Source: Field Survey (2022)

4.6.2 Marketing challenges

Marketing challenges for FLI practitioners were mainly related to high transportation cost, low sales prices and poor road infrastructure. Table 4.15, shows that 85% of respondents reported high transportation cost as a major marketing challenge, followed by low sales prices of produce at harvest (72%) and poor road networks (60%). The least challenge was the lack of vehicles. The study did not find any significant difference between men and women in relation to marketing challenges.

Both male and female FGD discussants in all the study communities said that the perishable nature of vegetables, made most of them sell their produce immediately after harvesting. This limits their ability to wait for better prices later. Tomato producers lamented seriously about the fact that Tomato traders preferred to buy from Burkina Faso due to the purported short shelf life of Ghanaian varieties, poor access roads and inconsistent local supply. They were hoping that the Government of Ghana would roll out policies to improve upon the situation. Some traders interacted with on this matter specifically cited the following as reasons for buying from outside the country; (1) Varieties cultivated in Ghana are highly perishable ("contain a lot of water") compared to that of the neighbouring countries. (2) Lack of roads linking farms (3) Unreliable supply as it is sometimes difficult to get a full truck load at a location thereby increasing their transportation cost.

Farmers during the FGDs also noted that producers themselves were not organized, which prevented them from negotiating better prices. For instance, during one of the FGDs session, a farmer said "farmers can never be organized to negotiate prices because they are scattered all over and their produce will get rotten if they decide to stick to one price". Many harvest more than the market can absorb at once, leading to low returns. Strengthening farmer groups or forming cooperatives could help improve market coordination, reduce losses, and enhance bargaining power. These marketing constraints are closely linked to productivity and sustainability, as limited market access and low prices may discourage farmers investing in irrigation infrastructure or improving production practices.

4.6.3 Sales point for FLI vegetables

Most farmers sell their produce at the farm gate followed by the District and Local market in descending order (Table 4.16). Produce sold through sales contracts were the least. Gender differences were observed in sales locations. Most of the farm gate sales were done by men, while women dominated the local market and roadside sales. This may be attributed to differences in produce volumes and storage capacity, as women typically cultivate smaller plots or locally consumed crops, sell in smaller quantities and are better at storage.

Table 4.16: Sales point for FLI vegetables

Sales point	Male n (%)	Female n (%)	Total responses n (%)	% of cases
Farm gate	127 (66.1)	33 (56.9)	160 (35.79)	64.0
District market	120 (62.5)	29 (50.0)	149 (33.33)	59.6
Local market	76 (39.6)	30 (51.7)	106 (23.71)	42.4
Road side sale	18 (9.4)	7 (12.1)	25 (5.59)	10.0
Produce sale contracts	6 (3.1)	1 (1.7)	7 (1.56)	2.8
Total	**192**	**58**	**447 (100)**	**178.8**

Source: Field Survey (2022)

The interviews highlighted that some farmers, especially men, wait to harvest only when a buyer is confirmed. This was especially for cabbage producers. At Pwalugu during the women's interview, a number of women acknowledged the fact that they sell at the roadside and also undertake farming hence they do not rush to sell their produce but rather store and sell in bits especially for produce like onions that can be stored for a relatively long time. One woman said;

"…The men usually want to sell all their produce at once so they can invest the money elsewhere or pay their depts and be free. Some of them also have contacts of buyer with whom they arrange to come and buy as soon as they harvest. It is only when some of these buyers come and do not get enough from them that other farmers also get to sell." (Interview No. 2 FGD, 14th/02/2022)

This finding is similar to the report of Namara *et al*. (2012) that the place of sale for about 78.4% of the vegetable farmers was the farm gate or in the nearest big town.

Some challenges related to relying on buyers/farmers for agreed prices were also noted during interviews. Traders in Bawku West and the Talensi Districts for instance indicated that farmers could not be relied upon to honour contracts if you prefinanced their production so they sell to you at harvest. Some would not want to sell to you at the agreed price when the market prices at the time of harvest is higher. They also sometimes report of no or very poor yields and your money will be lost. Farmers on the other hand said that some buyers tried to adjust prices at harvest or would not buy at all if they got produce of better quality from other farmers.

These sales patterns affect both stability and sustainability of FLI systems. Farmers with limited access to markets or storage sell immediately at lower prices, reducing returns and potentially discouraging investment in irrigation. Linking farmers to better markets, supporting storage infrastructure, and forming cooperative marketing groups could improve returns, reduce pos-harvest losses, and strengthen long-term sustainability.

4.6.4 Storage and processing challenges

Storage and processing constraints are important challenges for sustainability of FLI systems. In the study communities there were no designated storage or processing facilities for vegetables. This limits farmers' ability to preserve produce after harvest. During the FGDs at the Talensi District and the Builsa North Municipal Assembly, both the women and men's FGD discussants acknowledged the presence of a large storage facilities constructed under the ministry of Food and Agriculture's Northern rural Growth Programme (NRGP); however, these were only used for grains and farm inputs rather than vegetables. Farmers are often therefore compelled to sell their produce immediately after harvest or risk losing it due to spoilage. In some communities' farmers reported severe financial stress when large quantities of produce could not be sold after investing significant resources in production.

Table 4.17 shows that majority of respondents (52%, and 51%) strongly agreed that lack of storage and processing facilities respectively had impacts on the sustainability of FLI. A significant portion of respondents (39%) also agreed with the statement, with consensus among both Men and Women (40% and 39% respectively). With regards to training on how to handle produce at harvest, a few (23%) respondents "strongly" agreed that it was a challenge to sustainability of FLI.

The absence of adequate storage and processing facilities contributes to post-harvest losses and income instability, which discourages farmers from reinvesting in irrigation activities in subsequent seasons. Improving storage infrastructure and training farmers better post-harvest handling could enhance market opportunities and strengthen long-term sustainability of FLI systems.

Table 4.17: Extent of agreement to statements about storage and processing facilities and handling of produce

Extent of agreement	Storage facilities			Processing facilities			Handling Produce		
	F N=58 %	M N=192 %	Total N=250 %	F N=58 %	M N=192 %	Total N=250 %	F N=58 %	M N=192 %	Total N=250 %
Strongly agree	59	51	52	45	52	51	53	18	23
Agree	34	40	39	45	39	40	21	33	31
Uncertain	4	5	5	6	4	4	18	15	16
Disagree	2	3	3	3	5	4	8	31	27
Strongly disagree	2	1	1	1	1	1	0	3	3
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

*F-Women, M-Men, N-Number of respondents, % percentage

Source: Field Survey (2022)

During the FGDs in most communities, it was reported that a few farmers who were not able to sell their perishable produce try to process them for storage so as to sell later when fresh vegetables are out of season. The methods of processing as in Table 4.18 below are drying in the raw state, and parboiling before drying. Storage without processing is done for onions at home in well-ventilated rooms according to 38% of the respondents. Onions according respondents can be stored for a longer period but require some expertise to reduce the quantity that will get rotten. Women were more likely to dry unsold vegetables while men are more likely to store onions for some time before selling. Cutting and drying was done for tomatoes and okra, while parboiling before drying was done for pepper. The challenges associated with drying were changes to the taste and colour of tomatoes, where to dry especially for large quantities, in addition to the tedious and time-consuming nature of manually cutting. For okra, not all the varieties were good for drying. A tomato trader in the Bawku West District who traded in dry tomatoes and okra indicated that some consumers were skeptical about conditions under which the sun drying was done. She therefore felt the method impacted negatively on her sales. Cabbage, according to farmers and aggregators, can be kept for about one week after harvest before it starts to spoil, and are usually best left unharvested until farmers are sure of a buyer.

Table 4.18: Methods of storage and processing of vegetables in the UER

Method of storage/ processing	**Pooled**		**Men**		**Women**		**Difference in means**
	Mean	SD	Mean	SD	Mean	SD	
Dried only	0.22	0.42	0.18	0.38	0.36	0.48	-0.18**
Parboiled and dried	0.11	0.31	0.12	0.33	0.05	0.22	0.07
Stored in ventilated rooms	0.38	0.49	0.42	0.50	0.22	0.42	0.20**
Other	0.02	0.13	0.02	0.14	0.00	0.00	0.02
Number of observations	**250**		**192**		**58**		

Note: Differences in means between Men and Women are based on the Fisher's exact test. Alpha = 0.05. ** denote significance at the 5% level.

Source: Field Survey (2022)

4.6.5 Transportation challenges

Another important constraint of marketing and distribution of irrigated produce is transportation. Poor road infrastructure and limited access to appropriate transports services make it difficult for farmers to move produce from farms to markets efficiently.

The major means of transport for agricultural produce in most communities is the tricycle (50%) with head porting being the least (Table 4.19). According the FGDs tricycles are particularly effective in accessing farms where larger market trucks cannot reach, due to poor or non-existent road networks. Additionally, they acknowledged that farm plots are not arranged to accommodate roads for trucks. These further limit access for large vehicles. With regards ownership of vehicles used for transporting irrigated produce, respondents during the FGDs indicated that these were predominantly owned and operated by men, while women frequently hired their services to transport their goods. Donkey carts are also in use in some communities. A key informant in the Tempane district (a women's group leader) acknowledged that tricycles have significantly reduced the burden of head porting farm produce, a task traditionally performed by women. She said that;

"Women of today are very fortunate as these tricycles now carry us and our farm produce to and fro. Some are lucky to have these for carting other household needs that we had to head port in the past. The tricycles are also faster than the donkey carts we used to use. They are mostly owned and driven by young men, but I heard that in some villages some women own them as groups and operate them by themselves." (Interview No. 10, 14th /11/2023)

This finding suggests that while tricycles have improved access to transport services, transportation challenges still contribute to higher marketing cost and reduced profitability for FLI practitioners. The involvement of women in operating tricycles in some communities shows a potential opportunity for women's economic empowerment and improved market access. In terms of environmental impacts tricycles, being smaller may be more fuel-efficient than larger trucks, have a relatively lower environmental footprint. Improving rural road infrastructure and expanding access to affordable transport services could therefore enhance market participation and support the sustainability of FLI systems.

Table 4.19: Means of transport for farm produce

Means of Transport	**Women n(%) (n=58)**	**Men n(%) (n=192)**	**Grand Total n(%) N=250**
Tricycles	42 (72)	88 (46)	130 (52)
Bicycles or motorbikes	10 (18)	71 (37)	81 (32)
Head -portered	6 (10)	33 (17)	39 (16)
Total	**58 (100)**	**192 (100)**	**250 (100)**

Values are presented as frequency (n) and percentage (%)
Source: Field Survey (2022)

4.7 Sustainability Potential of FLI Systems.

4.7.1 Environmental sustainability potentials of FLI systems

Table 4.20 below shows the views of FLI practitioners about the ecosystem services lost at irrigation sites. The results show that FLI practices are linked with several perceived environmental trade-offs. The most frequently mentioned ecosystem services lost are grazing and forest land as reported by (80.7 %). This was followed by the loss of species diversity according to 54.7 % of respondents. In addition, 34.7% of respondents reported declines in water quality and quantity, indicating possible pressure on local water resources. Evidence from the focus group discussions support these perceptions, as farmers reported the migration or disappearance of some wildlife and plant species from their communities. The conversion of grazing and forest areas for irrigation also generates tensions between irrigating and non-irrigating community members due to reduced access to grazing land and water for livestock These findings align with previous studies that highlight environmental concerns associated with irrigation development. For example, Xie *et al.* ((2023) note that expanding FLI may increase localized environmental risks such as nutrient water pollution if not properly managed. Similarly, Akudugu *et al*. (2021) reported negative environmental consequences of irrigation activities, emphasizing the need for improved management to ensure sustainability.

Some health concerns associated with FLI were mentioned by 7.3% of respondents. These included water-related diseases such as Schistosomiasis due to the use of untreated water sources and the presence of standing water that encourages disease vectors. Due to lack of portable water some farmers drink from the streams or wells at FLI sites. Other services lost included loss of soil fertility, and top soil. Stress though mentioned by a few results in fatalities, and need to be taken into consideration.

These findings suggest that although FLI contributes to agricultural livelihoods, it may also generate environmental and health challenges that require attention to ensure long-term sustainability. Appropriate environmental management measures, such as improved water management and responsible agrochemical use can contribute to maintaining ecosystems services at irrigation sites.

Table 4.20: Ecosystem services lost at FLI sites

Ecosystem services lost	Male n (%)	Female n (%)	Total responses n (%)	% of Cases
Loss of grazing and forest land	170 (81.0)	60 (80.0)	230 (41.9)	80.7
Loss of species diversity	120 (57.1)	36 (48.0)	156 (28.4)	54.7
Reduction in water quality, and quantity	71 (33.8)	28 (37.3)	99 (18.0)	34.7
Increasing incidence of health issues	30 (14.3)	10 (13.3)	40 (7.3)	14.0
Other services lost	15 (7.1)	9 (12.0)	24 (4.4)	8.4

Note: Multiple responses were allowed. Percentages for male and female respondents are based on their respective group totals (Males- n=210, and females - n=75). Percentages in the "Total responses" column are calculated based on the total number of responses (n = 549), while "% of cases" represents the proportion of total respondents (N = 285) reporting each ecosystem service loss.

Source: Field Survey (2022)

Table 4.21 below presents the perspectives of FLI practitioners regarding the ecosystem services available at their irrigation sites. Majority (97.3%) of respondents mentioned that they have access to fresh vegetables which are valuable for both personal consumption and generating income. According to 76.7% of the respondents they had grass and crop residue from the irrigation site to feed their animals. This also contributes to food security and economic stability for livestock farmers as it enhances the availability of food resources for their animals, and hence contributing to their livelihoods. During the FGDs, male discussants at Yarigu were however of the view that the available grass and crop residue benefits landowners or irrigation practitioners' animals. One of them said:

"……This availability of grass and crop residue you talk about benefits mainly Irrigation practitioners and landowners because you are here and you tether your animal to feed on our crop residue or fringes of plot that has grass for them to feed. Crop residue like the bean vines and pods are sold to those who can buy"(interview No 9. FGD, 16th /02/2022).

About 18.400% of the respondents also indicated that irrigation sites provide water for domestic use. A smaller proportion (30.3%) of respondents mentioned the introduction of new crop varieties which may contribute to agricultural diversity, and adaptation to changing climatic conditions.

These findings show that irrigation sites provide several ecosystem services that support livelihoods, particularly through improved access to food, livestock feed and water resources. Access to fresh vegetables contributes to household nutrition and income generation. Crop residue and grass also provide additional feed for livestock production.

Comments from the FGDs however indicate that some of these benefits are not evenly distributed among community members. In particular, irrigation practitioners and land owners appear to benefit more from ecosystem services at irrigation sites than the non-irrigators.

These findings highlight the need to consider both benefits and the distribution of services in irrigation systems. Policies and interventions aimed at expanding FLI should consider ways to ensure equitable access to ecosystem services generated at irrigation sites.

Table 4.21: Ecosystem services available at FLI sites

Ecosystem services available	**Male n (%)**	**Female n (%)**	**Total responses (n)**	**% of responses**	**% of cases**
Fresh vegetables for income and Food	217 (97.3)	75 (97.4)	292	37.8	97.3
Fresh feed for animals	164 (73.5)	66 (85.7)	230	29.8	76.7
Availability of water for domestic use	105 (47.1)	37 (48.1)	142	18.4	47.3
Introduction of new crop varieties	67 (30.0)	24 (31.2)	91	11.8	30.3
Home for some wild birds and animals	9 (4.0)	2 (2.6)	11	1.4	3.7
Other Ecosystems services	5 (2.2)	2 (2.6)	7	0.9	2.3

Note: Male respondents n=223; Female respondents n=77; Total responses n= 773; Total respondents N= 300. Multiple responses were allowed.

Source: Field Survey (2022)

Table 4.22 below presents the perceptions of both FLI practitioners and non-irrigation practitioners regarding the environmental impacts of FLI in the study area. The results indicate varying environmental impacts associated with different FLI systems. The most frequently reported impacts are pollution of water bodies (71.4%), destruction of soil organisms (44.1%), and silting of water bodies (43.1%). Water pollution was largely attributed to improper use of agrochemicals, while silting was linked to soil erosion from constant ploughing of irrigated fields located near streams and rivers. Other environmental effects mentioned included depletion of soil fertility and structure, the spread of water borne diseases, and expansion of bare land.

These results show that irrigation may have several environmental implications if management practices are not adequate. Key issues to look out for are improper use of agrochemicals, siltation of water bodies and contributing to greenhouse gas emissions.

Table 4.22: Effects of FLI on Environment

Environmental effects	**Male n (%)**	**Female n (%)**	**Total responses n (%)**	**% of cases**
Pollution of water bodies	160 (72.4)	52 (68.4)	212 (35.7)	71.4
Destruction of soil organisms	98 (44.3)	33 (43.4)	131 (22.1)	44.1
Silting of water bodies	93 (42.1)	35 (46.1)	128 (21.6)	43.1
Emission of GHG	73 (33.0)	17 (22.4)	90 (15.2)	30.3
None	13 (5.9)	5 (6.6)	18 (3.0)	6.1
Other effects	10 (4.5)	5 (6.6)	15 (2.5)	5.1

Note: Male respondents n = 221; Female respondents n = 76; Total responses n= 594 ; Total respondents N= 297. Multiple responses were allowed

Source: Field Survey (2022)

The study further sought the views of irrigation practitioners on the environmental effects of the specific irrigation systems they practice. Details are shown in Appendix A2. It indicates that practitioners view pump systems as more significant contributors to water pollution, greenhouse gas emissions, and silting of water bodies compared to Gravity and

Manual irrigation systems. The Supplementary irrigation systems have a smaller sample size, but the data suggests they have the least negative impact according to the respondents.

4.7.2 Social sustainability potentials of FLI systems

Social sustainability, which is essential for creating inclusive, equitable, and resilient communities, was assessed by examining the extent of inclusivity and equity of the irrigation systems. This involved evaluating the roles and levels of community members, particularly men and women in various FLI systems, and their ability to cultivate their own plots, and possible interventions to enhance participation in FLI initiatives. Social sustainability also relates to the potential of FLI systems to promote food and nutrition security and food sovereignty.

Findings indicate that both men and women play important roles in irrigation production, although their level of involvement varies depending on the physical demands of specific task. Women are mainly engaged in activities such as weeding, watering crops, harvesting, planting, transplanting, and cooking for farm labourers as illustrated in Figure 4.9 below. About 52% of respondents acknowledged women's involvement in FLI decision-making within households. Men on the other hand, are more involved in roles requiring greater physical effort or financial responsibility, including land preparation, weeding, funding production activities, protecting crops, and decision-makers particularly in male-headed households. These role distributions reflect prevailing gender norms within the communities, Access to resources and control over productive assets. It also shows the complementary contributions of men and women to the functioning of FLI.

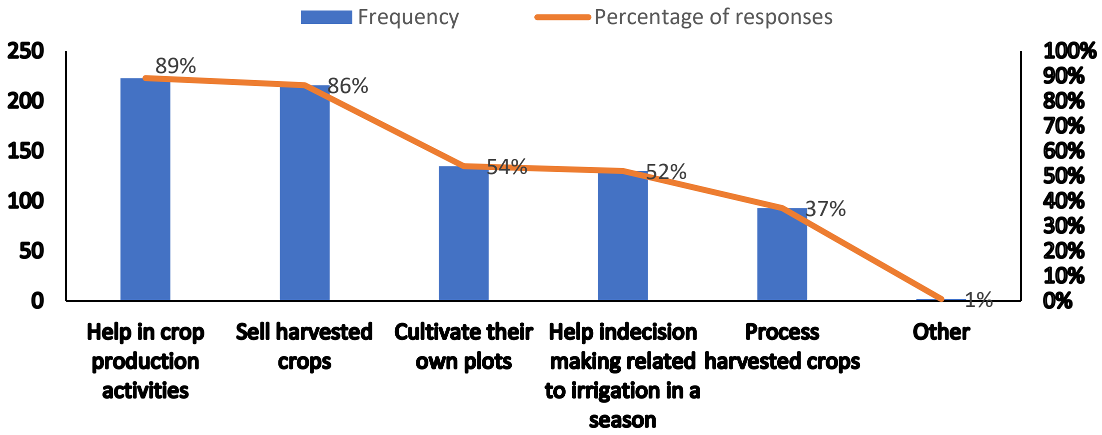


Figure 4.9: Roles of women at FLI sites

Source: Field Survey (2022)

FLI practitioners were asked during interviews about the extent to which women can practice the identified irrigation systems. As shown in Table 4.23, respondents perceived women as capable of practicing manual, gravity, pump (ground and surface water), and supplementary irrigation systems to varying degrees. However, Supplementary systems are perceived to be less inclusive of women. The KII and FGD interviews revealed that women participate more in manual irrigation systems, partly because these systems have lower production cost, and are easier to access compared to the other systems as also reported by Namara *et al.,* (2014).

Gravity irrigation systems also have relatively higher participation of women because communal or institutional rules often require that certain proportion of plots be allocated to women. In contrast, pump irrigation systems are male dominated. This is due to higher financial cost (buying pumps and accessories as well as fuel to power them), physical demands associated with operating pumps, and ability to travel to distant places to farm.

Respondents also noted that FLI systems based on tube wells and boreholes require land ownership. Although these systems could be advantageous for women as they are often located at or near the household, women are often disadvantaged due to limited land ownership. Unless women are able to lease land, their access to these systems remain constrained.

The results indicate that improving social sustainability withing FLI systems require interventions aimed at reducing gender barriers, related to access to land, irrigation technologies and credit. Enhancing inclusivity will be especially important for pump-based and supplementary systems, where women's participation is limited.

Table 4.23: FLI practitioners' views on extent women can practice FLI systems.

	Irrigation system					
Extent of practice	**Gravity N=26**	**Manual N=45**	**Pump GW N=25**	**Pump SW N=150**	**Supplementary N=4**	**Total N=250**
A high extent	10(38.46%)	23 (51.11%)	7 (28.00%)	34 (22.67%)	1 (25.00%)	75 (30.04%)
Medium extent	10(38.46%)	15 (33.33%)	9 (36.00%)	54 (36.00%)	0 (0.00%)	88 (35.20%)
Not at all	0 (0.00%)	0 (0.00%)	0 (0.00%)	7 (4.67%)	0 (0.00%)	7 (2.80%)
Small extent	6 (23.08%)	7 (15.56%)	9 (36.00%)	55 (36.67%)	3 (75.00%)	80 (32.00%)
Total	**26 (100%)**	**45 (100%)**	**25 (100%)**	**150 (100%)**	**4 (100%)**	**250 (100%)**

Source: Field Survey, (2022)

In terms of access to and control of resources (Table 4.24), men have a high extent of access to land for new irrigation technologies (groundwater, drip irrigation systems), primarily due to land ownership. Conversely, females' access varies from small to medium extents, as they often require approval from landowners or spouses before making structural changes to the land they cultivate.

Table 4.24: Extent of women and men’s access to land

Extent of access to land		**A high extent**	**Medium extent**	**Small extent**	**Not at all**	**Total**
Gender	Females	18 %	38%	42%	3%	100%
	Males	61%	18%	16%	4%	100%

Source: Field Survey, (2022)

Efforts to enhance women's participation in FLI, particularly under climate change conditions, are crucial. As shown in Table 4.25 below, the most reported interventions were targeted provision of credit and training on new irrigation technologies, which accounted for 28%, and 24.9% of the total responses respectively. While a higher percentage of women (30.2% of their responses) favoured targeted provision of credit, a higher proportion of men supported targeted training on new irrigation technologies to facilitate women’s inclusion in FLI. Facilitating access to water and suitable land was also considered important, accounting for 23.9% of the total responses.

The focus group discussions revealed that social support within communities may enhance women’s participation. In most communities, women who showed interest in irrigation were not discriminated against by land owners. In the Kassena Nankana Municipal and the Bawku West District where manual irrigation was prominent for instance, FLI practitioners supported each other. This support benefits especially women and poor/aged men, especially in activities such as provision of labour during well construction, provision of farm security, and sharing seedlings. In relation to this, A key informant during the interview at Goo, explained how communities support women's participation in FLI:

"…I am a community leader and most of the irrigable area happen to be within our farmlands. I am very happy to see women cultivate their own plots as it provides them money for their children's education and ingredients for soup at home, hence any woman who comes early to ask for land is given what is available. For those using water from the dam, the WUAs are obliged to give a certain percentage of land to women to cultivate. The only problem is that most of them cannot fund the cost of production coupled with their household roles, distance from home to the irrigation site and, the need for pumps" (interview No. 3, KII, (7/11/2022)

This finding aligns with that of Kwoyiga & Stefan, (2018) in their study in the Kassena Nankana Municipal, that irrigation practitioners are supportive of each other in the above irrigation activities in addition to conflict resolution.

Table 4.25: Interventions to facilitate the inclusion of women in irrigation.

Intervention	**Male n(%)**	**Female n(%)**	**Total n(%)**
Targeted provision of credit	164 (27.4)	52 (30.2)	216 (28.0)
Targeted training on new irrigation technologies	151(35.2)	41 (23.8)	192 (24.9)
Facilitating access to water and suitable land	144 (24.0)	40 (23.3)	184 (23.9)
Facilitating access to new irrigation technologies	133 (22.2)	39 (22.7)	172 (22.3)
Other	7 (1.2)	0 (0)	7 (0.91%)
Grand Total	**599(100%)**	**172(100%)**	**771(100%)**

Note: Male responses n = 599; Female responses n= 172; Total responses n= 771; Multiple responses were allowed.

Source: Field survey 2022

The Household Dietary Diversity Scores (HDDS) were used to determine the food security status of respondents. These findings underscore the importance of recognizing and addressing gender-specific challenges in promoting social sustainability and equity within farmer-led irrigation systems. The Table 4.26 below presents the household diversity scores for farmer-led irrigation (FLI) practitioners in the study area. They were utilized to gauge the food security status of FLI practitioners across various irrigation systems. The Kruskal Wallis test, which assesses the equality of population medians for different groups, revealed no statistically significant differences in HDDS among households practicing different irrigation systems. This suggests that, although irrigation systems differ in terms of technology and productivity, the overall contribution to household security appears to be broadly similar.

Table 4.26: Household dietary diversity scores for FLI practitioners

Statistic	Gravity	Manual	Pump	Supplementary	Total
	Irrigation System				
Mean	9.12	10.22	9.33	9	9.46
Std. Deviation	3.44	2.62	2.88	3.16	2.91
Std. Error of Skewness	0.46	0.35	0.18	1.01	0.15
N	26	45	175	4	250

Source: Field Survey (2022)

4.7.3 Economic sustainability potentials of FLI systems

The economic sustainability potential of the various FLI systems was assessed using cost-benefit analysis. The analysis covered Gravity, Manual, Pump (surface water and groundwater), and Supplementary irrigation systems. It considered production costs and revenues generated under each irrigation system. All values are reported in Ghana cedis (GHC), with standard deviations (±) indicating the variation in cost and returns as shown in Table 4.27 below.

The results show significant differences in both cost and benefits across the irrigation systems as indicated .by the p-values below 0.01. A benefit cost ratio of one or more indicate that production under the irrigation system is economically viable (Yeboah & Nkegbe, 2011).

Overall, practitioners using pump system incur the highest total production cost of GHC 6,603.52 (SD 6,765.59), which is significantly higher than the other systems. In contrast gravity irrigation systems recorded the lowest mean production cost of GHC 5,621.69 (SD

7,193.47), although this was not significantly different from the manual and supplementary systems. For specific activities, gravity irrigation practitioners incurred the lowest costs for land acquisition (GHC 90.00 ± 10.00) and water provision (GHC 100.80 ± 92.01), while the manual irrigation system recorded the lowest mean costs for land preparation (GHC 193.02 ± 253.28).

With regards to revenue, practitioners of supplementary irrigation systems recorded the highest mean revenue of GHC 16,246.97 (SD 14,448.51), While, the manual irrigation practitioners generated the lowest mean revenue of GHC 2,335.17 (SD 3,897.34). These differences are reflected in net income levels, where practitioners of pump systems recorded the highest net income of GHC 5,902.91 (SD 12,326.92), whereas practitioners of manual irrigation systems recorded a negative net income of GHC −143.33 (SD 1,472.85).

The undiscounted benefit-cost ratio (BCR) and return on investment (ROI) were also estimated to assess economic viability. All irrigation systems recorded BCR values greater than one, except the manual irrigation system, which had a BCR below one and a negative ROI, indicating that costs may outweigh benefits. Among the systems, supplementary irrigation recorded the highest BCR of 4.67 ± 7.83, suggesting that it generates the greatest economic returns relative to production costs.

Based on these results, the irrigation systems can be ranked in terms of economic viability as follows; Supplementary irrigation systems, Pump irrigation (surface and (Pump SW and Pump GW), Gravity irrigation and Manual irrigation. These findings are consistent with earlier studies. For example, Barry et al., (2010) reported that though farmers using pumps to abstract shallow ground water for irrigation obtained higher economic returns than those manually abstracting water (150 as against 550 USD). Similarly, Nangia et al., (2018) found that supplemental irrigation greatly enhanced crop (wheat) yields and farm income in Syria. They however cautioned that higher production per unit of land or water does not always translate to higher farm profits due to the complex interplay between various production inputs.

The results indicate that irrigation systems that require greater investment, such as pump groundwater systems, tend to generate higher economic returns. In contrast, manual irrigation systems, although less capital intensive, generates relatively low economic returns. This may imply that most FLI systems are economically viable, although the levels of profitability vary across systems. Improving farmers' access to efficient irrigation technologies and reducing production cost may further enhance the economic sustainability of farmer-led irrigation systems.

Table 4.27: Cost and Benefit Analysis of Farmer-Led irrigation systems
(All are in GHC, and standard deviations are in parentheses)

Production activity	Pooled	Gravity	Manual	Pump	Supplementary	P-values
Land acquisition	295.36 (246.98) ab	90.00 (10.00) bc	183.85 (125.06) bc	368.56 (274.22) a	133.33(57.74) bc	0.002
Land preparation	444.82 (444.49) a	400.77 (365.59) a	193.02(253.28) b	511.02 (473.07) a	607.50 (314.47) a	0.001
Water provision	922.67(1022.34) b	100.80 (92.01) d	385.18(501.50) c	1139.24(1069.85) a	312.50(17.68) cd	0.001
Input	1762.91(1765.89) ab	2210.00(2362.91) ab	906.29(698.67) b	1936.03(1806.94) a	963.00(696.57) ab	0.002
Equipment	446.30 (805.43) a	144.29(129.33) ab	161.36(232.95) b	531.47 (893.68) a	192.50(135.00) ab	0.001
Care taker	691.08(795.44) a	1200.00(1387.44) a	214.47(203.50) B	740.43(772.57) a	215.00(21.21) b	0.003
Weeding	397.43(376.57) a	310.00 (218.38) a	162.71 (146.61) b	460.48(408.78) a	500.00(336.65)a	0.001
Harvest	336.10(457.07) a	333.33(453.73) a	110.14(106.21) b	389.02(496.01) a	275.00(155.46)a	0.001
Transport	226.77(248.76) ab	167.50(178.04) bc	100.00(105.85) c	262.08 (269.86) a	135.00(44.35)abc	0.001
Other cost	273.03(702.73) a	665.00(1996.04) abc	61.47(50.86) bc	265.20(300.62) a	145.00(65.57)a	0.001
Total mean cost	5796.47(6865.70) b	5621.69(7193.47) b	2478.50(2424.49) b	6603.52(6765.59) a	3478.83(1844.69) abc	0.001
Mean revenue of crops	10507.45(17051.49) a	10314.11(12390.9) a	2335.168(3897.34) b	12506.44(19092.51) a	16246.97(14448.51) a	0.001
Net income	4710.98 (10185.79)	4692.42 (5197.43)	-143.33 (1472.85)	5902.91(12326.92)	12768.13(12603.81)	
Benefit cost ratio	1.81 (2.48)	1.83 (1.72)	0.94 (0.61)	1.89(2.82)	4.67 (7.83)	
Return on investment%	81.27(148.35)	83.46 (72.25)	-5.78 (60.75)	89.39(182.2)	367.02(683.24)	

a, b, c and d represent statistically significant differences between the FLI systems

Source: Field Survey (2022)

4.8 Adaptation Strategies of Farmer-Led Irrigation Practitioners to the Effects of Climate Change.

4.8.1 Effects of climate change

The results of the study indicate that FLI is affected by climate change through its effect on amount of water available and increasing atmospheric temperature. As shown in Table 4.28 the most significant effect is the increase in evapotranspiration which is mentioned by 60.3% of the respondents. This they attribute to the increase in temperature which leads to higher water loss from the soil and plants. The second most significant effect is the changes in biodiversity mentioned by 58.7% of the respondents. Other effects of climate change mentioned were scarcity of water, soil erosion, pest and diseases, and reduced crop yield. A female FLI practitioner at Goo practicing manual irrigation said this about water scarcity;

"*These days water is insufficient so I have to dig more wells and let them deepen them every three weeks so that I can get water till I harvest my tomato*" (interview No.12. FGD ,16th /02/2022).

Another female said;

"*…I used to let them deepen my wells twice after digging before the season ended but for the past two years, I have to do that four times per well. For the second digging my little boys dig for me but for the rest I have to hire grown up boys to dig for a fee*" (interview No.12. FGD ,16th /02/2022).

During the FGDs in the Bawku West and Talensi districts, discussants in relation to changes in rainfall pattern mentioned that unusual rainfall in the dry season and early onset between February-April destroys crops especially onion, and reduced crop yield. The reports of unusual rainfall in the dry season and consequent destruction of irrigated crops was also reported by irrigation farmers in Nigeria according to Adebiyi *et al*., (2021).

Table 4.28: Effects of climate change on FLI by gender in the UER

Climate change effects	**Male n (%)**	**Female n (%)**	**Total responses n (%)**	**% of Cases**
Increased evaporation	147 (31.2)	34 (25.8)	181 (30.0)	60.3
Biodiversity changes	131 (27.8)	45 (34.1)	176 (29.2)	58.7
Water scarcity	105 (22.3)	29 (22.0)	134 (22.2)	44.7
Erosion	87 (18.5)	22 (16.7)	109 (18.1)	36.3
None	1 (0.2)	2 (1.5)	3 (0.5)	1.00

Note: Male responses n = 471; Female responses n = 132; Total responses n= 603; Total respondents N= 300. Multiple responses were allowed.

Source: Field Survey (2022)

4.8.2 Adaptation strategies

Adaptation strategies adopted by FLI practitioners play a crucial role in enhancing resilience, improving livelihoods, and mitigating the impacts of climate change. The strategies mentioned by respondents as in Figure 4.10 below include soil and water conservation, use of improved seeds, reducing size of farm in dry years, scheduling irrigation among group members sharing a water point, and use of groundwater. To enhance water retention on farms, FLI practitioners used techniques such as mulching and leaving crop residue on farms. These practices help protect farmland, improve crop yields, and contribute to overall ecosystem health (Adimassu *et al*., 2017). The rationale for reducing farm sizes is to allow farmers to focus on intensive cultivation, efficient resource use, and better management, especially when water availability is limited. Collaboration and sharing water points through irrigation schedules among group members also promotes equitable water distribution and ensures optimal water use while minimizing conflicts.

Other strategies used to adapt to the effects of climate change mentioned were Planting/ maintaining tree cover/vegetation around water bodies, mixed cropping, mixed farming, diversification of crops, not irrigating at all, and practicing drip irrigation. These strategies were also mentioned during the focus group discussions. Planting or maintaining vegetation around water Bodies helps maintain natural buffers, preventing soil erosion, regulating water flow, and providing shade, as reported by Tambo, (2016). It also enhances ecosystem resilience and supports local biodiversity. During the focus groups discussions and key informant interviews, some communities such as Goo, had banned harvesting of wildlife in water bodies and fetching firewood at or near same as they believed this ensured water availability.

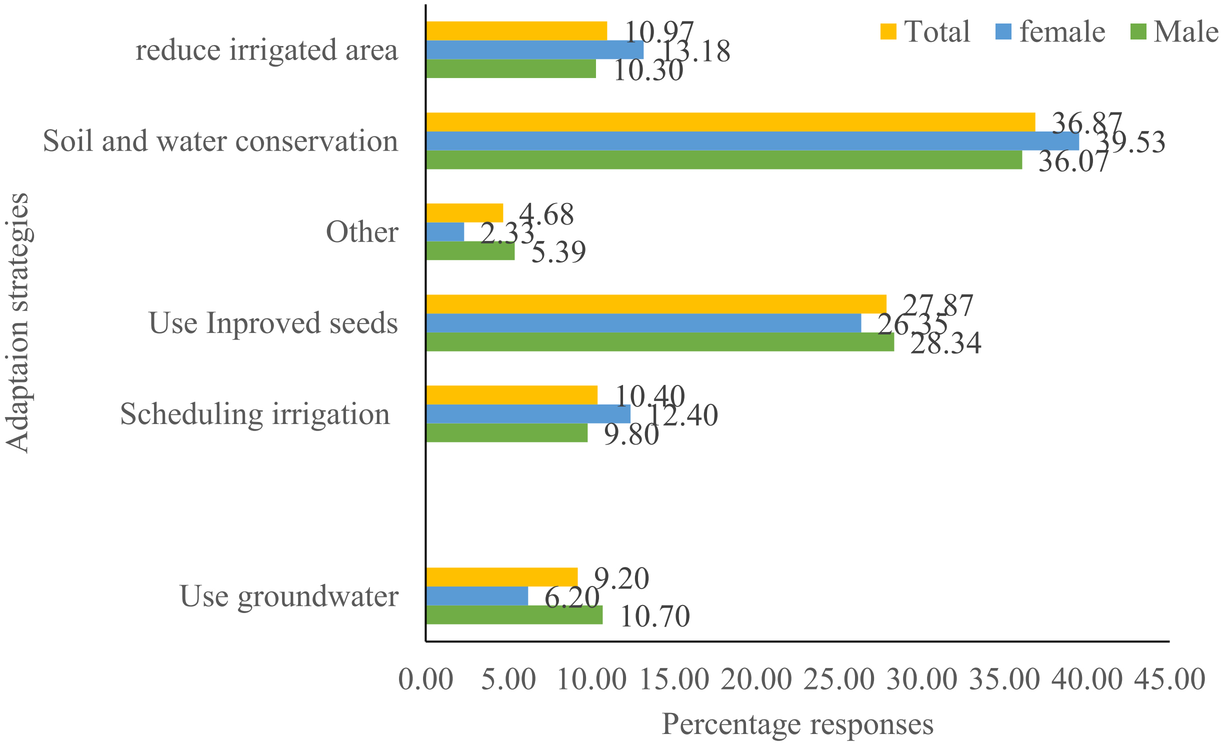


Figure 4.10: Climate change adaptation strategies

Source: Field Survey (2022)

Mixed farming was done by male practitioners who reared poultry, small ruminants, and cattle alongside irrigation as in Plate 4.2 below. During the FGDs at Goo and Teshie in the Bawku West District, the male discussants said that in years when sales were good, they invested profits in small ruminants especially goats which are later sold to buy cattle for fattening. Some of these animals were observed tethered at the irrigation sites. To illustrate this, a farmer at Teshie said:

"*….I bought this two goats from vegetable sales from the previous irrigation season. since I am at the site the whole day, I bring them here to tether at places where there is fresh grass or crop residue after harvest*" (interview No. 13 FGD, 17th /02/2022).

At the Talensi district, some male discussants said that they reared local fowls where at the irrigation sites as they slept over to cater for their crops. These fowls feed on the leaves and insects and are put in a fenced area when the crops are at a stage the fowls will be a nuisance. They are a source of extra income for them. One of them said;

"Bringing some of my fowls here protects them against disease outbreaks that kills a lot fowls in the community yearly, because they are isolated at the irrigation site".

A personal observation is that small to large ruminants are reared in the Bawku West District alongside irrigation at the sites while poultry (Guinea fowls and local fouls) are reared in the Talensi District. Mixed farming with livestock diversifies income sources, contributes to soil fertility (through manure from animals which benefits crop production. Mixed farming as an adaptation strategy aligns with the findings of Tambo, (2016) in the northeast Ghana though this study was about agriculture in general. This according to Gupta *et al*. (2012) can therefore help reduce poverty and malnutrition and strengthen environmental sustainability as it reduces erosion, increases crop yields and soil biological activity and nutrient recycling and intensifies land use. Under FLI, and at the study area this favoured men more as they spent almost all their time at the irrigation site to tend to their animals and crops.

A - Mixed farming at FLI sites- Pwalugu

B. Mixed farming at FLI sites – Santeng

Plate 4.2: Poultry rearing at FLI sites in the Talensi district

Source: Field Observation, (2022)

The Table 4.29 below shows the distribution of various climate-smart agricultural practices (CSAs) among male and female farmers in the study area. Some of these practices were mentioned earlier in the adaptation strategies. Fertilizer application was the most (90.8%) widely practiced CSA by both male and female FLI practitioners with a slightly higher percentage of men. This was mainly to improve nutrient levels of soils to enhance crop yields. The least practiced CSA was drip irrigation which was practiced by 0.8 % of the respondents. Other practices mentioned included early planting and supplementary irrigation (using part rainwater and irrigation to produce crops. The results indicate that most of the CSA practices were male dominated except mulching and agroforestry which were practiced by a slightly higher percentage of females.

Table 4.29: Climate Smart practices of FLI practitioners

Climate smart practices	Male n (%)	Female n (%)	Total responses n (%)	% of Cases
Fertilizer application	177 (92.2)	50 (86.2)	227 (25.0)	90.8
Use improved seeds	121 (63.0)	34 (58.6)	155 (17.1)	62.0
Mulching	105 (54.7)	35 (60.3)	140 (15.4)	56.0
Crop rotation	90 (46.9)	22 (37.9)	112 (12.3)	44.8
Crop diversification	75 (39.1)	22 (37.9)	97 (10.7)	38.8
Intercropping	74 (38.5)	16 (27.6)	90 (9.9)	36.0
Agroforestry	38 (19.8)	13 (22.4)	51 (5.6)	20.4
Use groundwater	19 (9.9)	2 (3.4)	21 (2.3)	8.4
Practice drip irrigation	1 (0.5)	1 (1.7)	2 (0.2)	0.8
Other	13 (6.8)	1 (1.7)	14 (1.5)	5.6

Note: Male respondents n = 192; Female respondents n = 58; Total responses n= 909; Total respondents N= 250. Multiple responses were accepted
Source: Field Survey (2022)

Respondents reported encountering some challenges while practicing climate smart agriculture. The three major challenges were high cost of fertilizer and improved seeds, and scarcity of mulching materials as in Table 4.30 below.

Table 4.30: Challenges of using climate smart practices.

Challenges	**Female n (%)**	**Male n (%)**	**Total responses n (%)**	**% of Cases**
High cost of fertilizer	56 (96.55)	170 (88.54)	226 (29.16)	90.4
High cost of improved seeds	45 (77.59)	162 (84.38)	207 (26.71)	82.8
Difficult on large plots	35 (60.34)	105 (54.69)	140 (18.06)	56.0
Scarcity of mulching material	15 (25.86)	91 (47.40)	106 (13.68)	42.4
Non ownership of land	24 (41.38)	35 (18.23)	59 (7.61)	23.6
Land Suits specific crops	4 (6.90)	16 (8.33)	20 (2.58)	8.0
Fake seeds	4 (6.90)	7 (3.65)	11 (1.42)	4.4
Other challenges	0 (0.00)	6 (3.13)	6 (0.77)	2.4

Note: Male respondents n = 192; Female respondents n = 58; Total responses n= 775; Total respondents N= 250. multiple responses were accepted

Source: Field Survey (2022)

4.8.3 Sustainable FLI practices

Table 4.31 below shows the measures taken by farmers to sustain farmer-led irrigation (FLI). The most commonly reported measure was the use of soil and water conservation practices (especially mulching) as reported by 80% of the respondents. This was followed by minimizing the use of inorganic fertilizers (70.8%) and not felling of trees when creating new areas for farming (68%). Other measures mentioned such as protecting vegetation and wildlife near water bodies, bringing children to help and learn on the farms when not in school and crop rotation were also mentioned during the FGDs as shown in Appendix A3.

In relation to protection of life at or near water bodies, respondents reported that hunting of wild life in the stream that provides irrigation water at Goo has been banned. Similarly, burning on the land, cutting of firewood or felling trees is not allowed along the Volta River at Pwalugu, Santeng and Yarigu. A male leader of a farmers group and FGD discussant explained the reason for the ban on hunting in the stream at Goo:

"*… In the past we used to hunt for animals such as crocodiles and fish in the stream but we have come to the realization that the presence of the water in stream is linked to their presence; hence it was banned in addition to cutting the trees for fuel wood.*" (Interview No. 15 FGD, 16th /02/2022)

Similarly, a female non-irrigating practitioner during an interview at Goo noted:

*"To fetch firewood in this area is now a problem for us, we cannot cut trees or even branches for firewood, we have to walk long distances to pick only dried twigs and branches of trees." (*Interview *No. 16 FGD, 16th /02/2022)*

These responses suggest that community members prioritize conservation-oriented practices in sustaining FLI, and recognise the importance pf protecting aquatic life and vegetation around water bodies as part of sustaining water availability for irrigation. Such perceptions reflect local ecological knowledge regarding the relationship between ecosystem health and water resources. Studies have similarly noted that excessive irrigation withdrawals can lead to hydrological deficits by reducing environmental flows, resulting in the degradation or loss of aquatic habitats (Borsato *et al*., 2020). Protecting vegetation and wildlife around irrigation water sources may therefore contribute to maintaining ecological balance and sustaining water resources for irrigation.

Table 4.31: Measures taken by farmers to sustain FLI

Sustainability measures	**Male n (%)**	**Female n (%)**	**Total responses n (%)**	**% of Cases**
Use soil and water conservation methods	153 (79.7)	47 (81.0)	200 (24.7)	80.0
Minimising use of inorganic fertilizer	134 (69.8)	43 (74.1)	177 (21.9)	70.8
Not felling trees when creating new farms	129 (67.2)	41 (70.7)	170 (21.0)	68.0
Bring children to help on farm	81 (42.2)	18 (31.0)	99 (12.2)	39.6
Protecting life around water bodies	66 (34.4)	21 (36.2)	87 (10.7)	34.8
Helping each other	61 (31.8)	16 (27.6)	77 (9.5)	30.8

Note: Male respondents n = 192; Female respondents n = 58; Total responses n= 810; Total respondents N= 250. Multiple responses were allowed

Source: Field Survey (2022)

The above measures are consistent with the principles of sustainable agriculture, which aim to promote the efficient use of natural resources, reduce environmental degradation, and improve the livelihoods of farmers. These measures also conform with the requirements for sustainable irrigation mentioned by Borsato *et al*., (2020). and reflect the importance of local knowledge and practices in promoting sustainable agriculture. The use of organic fertilizers and practicing crop rotation confirms findings of the study by Agula *et al*., (2019) that farmers in both private and state-managed irrigation schemes in northern Ghana use ecosystem-based practices to improve ecosystem health and promote sustainability. However, the effectiveness of these measures may depend on various factors such as the socio-economic conditions of farmers, the availability of resources, and the institutional support for FLI development.

4.8.4 Sustainable models of FLI

This study has identified the following key issues that need to be tackled for sustainability of farmer-led irrigation (FLI) systems in the Upper East Region of Ghana:

- Weak organization among FLI practitioners, which limits collective action, efficient water use, and knowledge sharing. Organisation FLI practitioners into viable groups and functional groups can enhance information sharing, efficient water management, strengthen social cohesion, and support environmentally sustainable practices.
- Limited economic viability of FLI enterprises. Developing well-designed business models for FLI practitioners can improve their access to finance, markets, and production resources. This can help to increase their income, reduce poverty, and promote sustainable development.
- Low adoption of agroecological practices. Promoting agroecological approaches can improve soil health, support climate change adaptation and mitigation, reduce dependence on external inputs, enhance inclusivity, and improve food safety and nutrition This includes the following aspects:
    - Environmental: Focus on climate change adaptation and mitigation strategies while enhancing soil health.

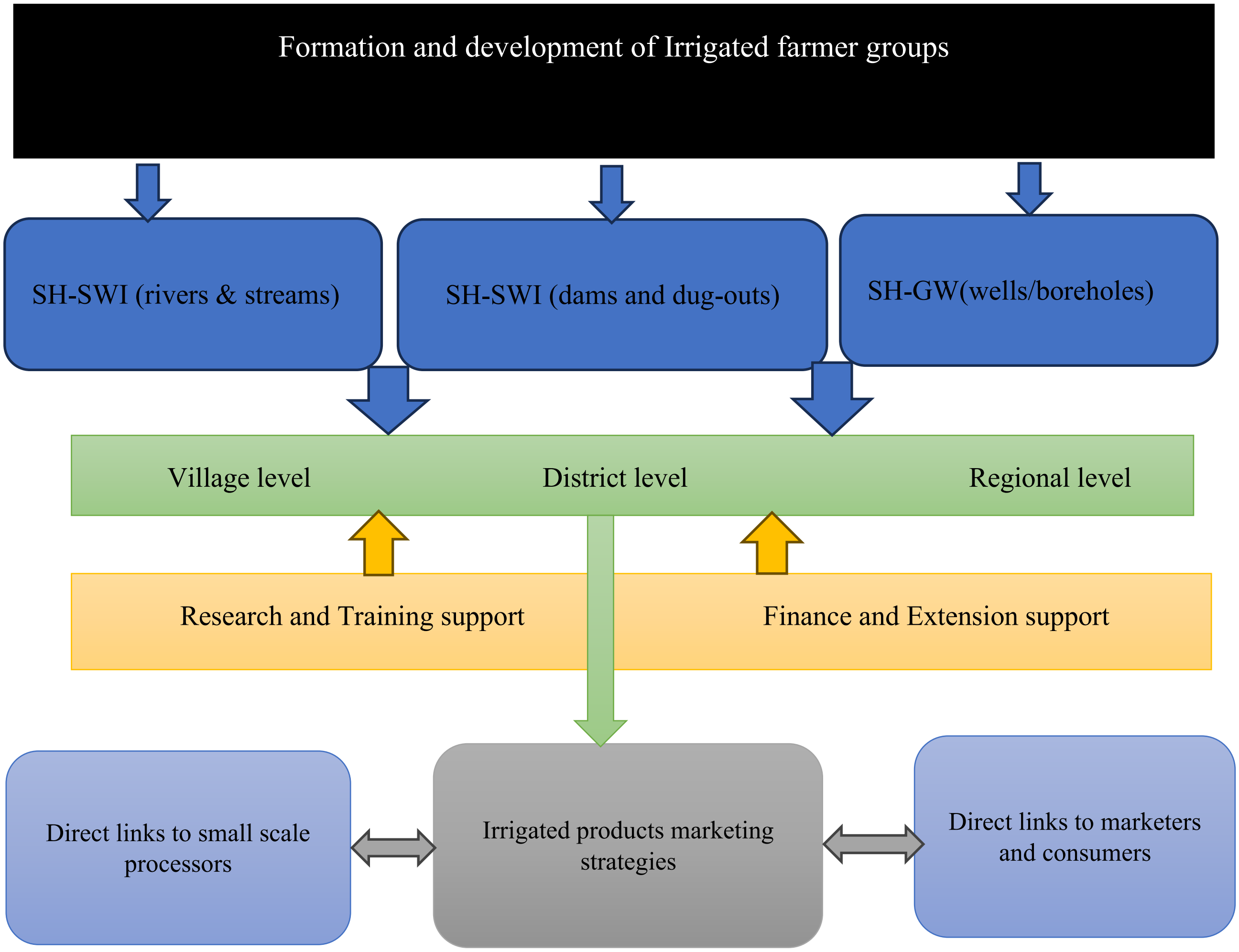
  - Social: Ensure equity with gender and inclusivity considerations at the forefront.
  - Economic: Promote the use of low-external inputs like locally produced seeds, compost, etc., to reduce costs.
  - Nutrition & Health: Prioritize nutrition-dense, safe, and quality products by avoiding the use of chemicals.
- Limited crop diversification into fruit production: Diversifying into fruit cultivation can increase income while improving dietary diversity and community nutrition.
- Inadequate marketing systems for FLI products. Developing appropriate marketing strategies for FLI products can expand market access and improve price competitiveness of irrigation produce. And hence can enhance economic sustainability.
- Unclear gender roles withing irrigation groups. Establishing clear and inclusive gender roles can promote equitable participation and strengthen social sustainability withing FLI systems.

From this study the most important FLI systems grouped in descending order of extent of practice in the UER are: 1) Pump surface water,58%, 2) Gravity surface water, 12%, 3) Manual,18% and 4) Pump groundwater,10%. Similarly, Dittoh (2020) in assessing development in Ghana, grouped these FLI systems into the following distribution:

- Smallholder surface water irrigation (SH-SWI) (rivers and streams) – 61.6% (pump surface water)

- SH-SWI (dams and dugouts) – 15.8% (gravity surface water)
- Smallholder groundwater water irrigation (SH-GWI) – 19.8 (manual irrigation, pump groundwater deep wells/ mechanized boreholes)
- Others – 2.8% (Flood recession supplemented 2%)

Organising FLI practitioners based on the first three categories above will help address some of the keys issues related to FLI for its long- term sustainability. The flowchart below summarizes the key issues identified in this study our research for sustaining FLI systems under climate change in the Upper East Region of Ghana: By addressing these key issues, we can move towards sustainability of FLI systems in the UER.



In all the three types of "irrigation groups", water lifting methods could be bucket/jerry cans, diesel/petrol pumps, solar pumps, gravity or appropriate combinations. Cooperative use of water lifting devices is to be encouraged. Drip irrigation is to be encouraged in SH-GW. Agroecological practices are critical for sustainability of FLI and hence should be incorporated).

Figure 4.11: Organisation of Farmer-led Irrigation practitioners and key sustainability issues

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

5.1.1 Introduction

This study assessed the sustainability of farmer-led irrigation (FLI) systems in the Upper East Region (UER) of Ghana under climate change. The research sought to understand the development trends of FLI systems, their productivity and scale expansion potential, gender-based productivity differences, challenges along the irrigation value chain, environmental, social, and economic sustainability potentials of FLI systems, and adaptation strategies adopted by farmers.

A descriptive mixed-methods research design which combined qualitative and quantitative (survey) methods was used. Five study districts were purposively sampled based on the dominance of FLI systems, and 24 communities randomly selected from them. Qualitative data were collected through 20 focus group discussions (FGDs) with 171 participants and 33 key informant interviews (KIIs) with extension agents, community leaders, and traders. Quantitative data were gathered from 250 FLI practitioners and 50 non-FLI practitioners using semi-structured questionnaires.

The qualitative data from the FGDs and KIIs were analysed by classical content analysis methods, while quantitative data was analysed with descriptive statistics, double-log production function modelling for crop yield responses, gender productivity gap analysis using Oaxaca-Blinder decomposition and recentred influence function decomposition, and spatial mapping of FLI sites within the region. Environmental and social sustainability were assessed based on farmer perceptions, while economic sustainability was quantified using benefit-cost ratios and returns on investment. ArcMap was used to map irrigation sites.

5.1.2 Key findings

5.1.3 Development trend of FLI systems in the Upper East Region

The trend of development of FLI systems in the Upper East Region of Ghana has been one of transformation, adaptation, and inclusivity. FLI systems have shifted form manual, labour -intensive methods towards mechanized groundwater-supported irrigation. Pump systems are increasingly common while gravity and manual systems remain important for inclusivity and low-cost irrigation. A few farmers on a very small scale are also incorporating animal rearing into FLI activities at the sites.

5.1.4 Productivity and scale expansion potential of FLI systems

In relation to productivity, in the 2021/2022 irrigation season, Pump and supplementary irrigation systems demonstrated the highest productivity and potential for expansion, while gravity systems face limitations due to communal water access and land related constraints. Manual irrigation systems present lower environmental pressure compared to mechanised systems; however, their economic sustainability remains limited without improvements in irrigation technology and labour efficiency.

5.1.5 Productivity differences between men and women FLI practitioners

Productivity differences (based on harvest values) between men and women are largely structural, due to unequal access to land, credit, labour, and irrigation technologies. Women who had equitable access achieved productivity comparable to men, underscoring the fact that closing resource gaps is key to maximizing system efficiency.

5.1.6 Challenges along the Irrigation Value Chain

The study found that across the irrigation value chain, farmers face high input cost, limited storage, transportation and marketing challenges, which constrain both economic sustainability and expansion prospects. Women experience additional barriers related to access to credit, water, and decision-making roles.

5.1.7 Sustainability potential

Environmental risks increase with mechanisation and motorized groundwater abstraction, Economic sustainability is highest in pump and supplementary systems, and social sustainability varies by irrigation type, with gravity systems fostering inclusivity while capital-intensive systems reinforce inequalities.

5.1.8 Adaptation to climate change Sustainability of FLI

The adaptation strategies are the same as those undertaken during the rainy season in the region, and are usually a combination of two or more strategies. The most common strategies include soil and water conservation practices, and diversification of water sources (groundwater abstraction) to ensure year-round irrigation. Farmers also adopt resource-management practices such as reduced reliance on inorganic fertilizers, tree planting, and protection of vegetation around water bodies to maintain ecosystem functions. Socially embedded strategies such as mutual assistance among farmers, and transfer of indigenous knowledge to younger generations, also play a critical role in strengthening the adaptive capacity of FLI systems. However, disparities in access to adaptation resources risk widening inequalities under climate stress.

To sum up, the findings demonstrate that FLI in Ghana is undergoing a transformation that is characterised by increasing mechanisation, persistent gender-based resource inequalities, and emerging environmental sustainability concerns. By integrating productivity analysis, decomposition analysis , sustainability assessment and climate adaptation strategies, the study provides new empirical evidence to show how these dimensions interact to shape the long-term sustainability of FLI systems.

5.2 Conclusion

This study demonstrated that farmer-led irrigation (FLI) is a critical driver of food security, livelihoods, and economic resilience in the Upper East Region of Ghana. Over the past three decades, FLI systems have evolved from predominantly labour-intensive, manual practices to more mechanized, and groundwater-dependent production systems, enabling expansion of dry-season cultivation and improving agricultural productivity. FLI systems have transitioned into climate-responsive production methods driven by farmer innovation, local investment, and adaptation needs.

A central conclusion emerging from this study is that FLI expansion is both a development opportunity and a sustainability challenge. While pump and supplementary irrigation systems offer strong economic returns and expansion potential, their rapid growth introduces environmental and resource governance concerns that require policy attention.

From an Environmental perspective, increasing dependence on motorised pumping presents long-term risks related to groundwater depletion, water quality deterioration, and greenhouse gas emissions. Balancing irrigation expansion with environmental stewardship is therefore essential for long-term resilience. Sustainable water management practices, efficient irrigation technologies, and alternative energy sources must be prioritized to support environmentally responsible agricultural intensification.

Economically, FLI systems demonstrate considerable potential, although manual irrigation systems remain financially unsustainable without technological upgrading. Market inefficiencies, high transportation costs, and limited storage infrastructure continue to undermine farmer profitability, indicating that irrigation sustainability depends equally on production and market systems. Without improved infrastructure and market linkages, the economic sustainability of FLI will remain uncertain.

The study further concludes that social sustainability is fundamental to the long-term viability of FLI systems. Irrigation development has enhanced rural livelihoods, employment opportunities, and household welfare, yet unequal access to productive resources continues to influence participation and productivity outcomes. Gender disparities remain a major constraint, as women’s lower productivity is primarily linked to limited access to land, credit, labour, irrigation technologies, and decision-making opportunities rather than differences in farming ability. Promoting equitable access to resources and strengthening farmer organisations and collective action mechanisms are therefore essential for inclusive and socially sustainable irrigation development.

Adaptation strategies such as soil and water conservation practices, groundwater utilisation, and diversification of water sources demonstrate farmers' resilience to climate variability. However, disparities in access to these adaptation options highlight the need for inclusive policies that support smallholder farmers in adopting climate-smart irrigation technologies.

Overall, the study establishes that farmer-led irrigation in the Upper East Region is not merely a coping mechanism but a transformative agricultural system shaped by farmer innovation, climate pressures, institutional conditions, and social relations. Sustainable future expansion will depend on coordinated investments in infrastructure, inclusive governance frameworks, technological innovation, and climate-responsive water management systems.

This study advances existing knowledge on farmer-led irrigation by providing integrated empirical evidence linking productivity performance, gender-differentiated outcomes, climate adaptation practices, and sustainability dimensions within a single analytical framework. Unlike earlier studies that examine farmer-led irrigation primarily from technological or livelihood perspectives, this research demonstrates that the sustainability of FLI systems in northern Ghana is simultaneously shaped by resource access inequalities, market structures, and evolving groundwater dependence.

5.3 Recommendations

To enhance the sustainability of farmer-led irrigation systems in the UER, the study recommends that the Government of Ghana, through the Ministry of Food and Agriculture (MoFA), in collaboration with non-governmental organizations and local communities, prioritise these interventions across short-term, medium-term and long-term implementation horizons.

Short-term Recommendations (1-3 years)

1. Infrastructure investment and technology support:
    - Facilitate the adoption of affordable, efficient irrigation technologies through subsidies, training and extension services.
    - Provide immediate technical support to improve the efficiency of existing pump and supplementary irrigation systems.
2. Implementation of gender-inclusive policies.
    - Ensure equitable access to affordable credit for the vulnerable especially women engaged in FLI.
    - Support targeted programs for female farmers to enhance productivity and close the gender productivity gap.
3. Market development and infrastructure
    - Encourage the formation and strengthening of farmer cooperatives or associations to enhance bargaining power and improve market access.
    - Organise FLI practitioners into viable groups based on water sources, districts, communities, and irrigation systems to improve production

planning and marketing strategies, including linkages with marketers and consumers

4. Addressing cultural barriers in FLI
    - Promote self-help groups, community dialogues, and awareness campaigns to strengthen gender-inclusive collaboration among farmers.
    - Actively engage local stakeholders and traditional leaders to foster cooperation and address socio-cultural barriers affecting participation in irrigation activities.

Medium -term recommendations (3-7 years)

5. Transition and upgrade pathways.
    - Provide support mechanisms (technical and financial) to transition farmers from manual irrigation methods to more productive and sustainable options.
    - Introduce energy-efficient and climate-smart irrigation systems to minimize ecological impacts.
6. Market development and rural infrastructure
    - Improve rural infrastructure such as roads and storage facilities to reduce post-harvest losses and transportation cost.
7. Climate-smart agriculture and adaptation support
    - Develop inclusive policies that enhance smallholder farmers access to resources needed for climate adaptation (e.g., farm input subsidies, water harvesting, diversified water sources).
    - Encourage the integration of agroecological practices into agricultural extension programmes.

8. Institutional and financial support
    - Expand access to affordable credit schemes and insurance services tailored to the needs of small-scale irrigation practitioners.
    - Strengthen institutional frameworks to provide consistent technical support, monitoring, and capacity building for FLI systems.

Long-term recommendations (7–15 years)

9. Strategic infrastructure investment
    - Prioritize strategic investment in irrigation infrastructure with high benefit cost ratios to ensure long-term sustainability and productivity gains.

10. Environmental sustainability and water governance
    - Promote sustainable water management practices, including regulated groundwater use, conservation agriculture, and pollution control,
    - Incentivize the use of renewable energy sources (eg solar pumps) to reduce greenhouse gas emissions.
11. Strengthen collaboration among renewable energy agencies, women's empowerment groups, farmer associations, community-based organizations, and government institutions to support sustainable irrigation development and environmental management.

5.4 Contributions of the Research

This study contributes to knowledge in the following ways:

- It gives an account and documentation of the development trends of farmer-led irrigation (FLI) systems in the Upper East Region (UER) over the past thirty years, providing a temporal perspective that is rarely documented in this regional context.
- By comparing benefit-cost rations and expansion potential, this study ranks irrigation types, highlighting pump and supplementary irrigation as most viable economically. This adds quantitative value to existing knowledge.
- Instead of stating the usual disparity, the research highlights cases of highly productive female practitioners, this provides evidence that productivity can be equal when access is levelled. This suggests a gender equity that is not just ethical, but economically strategic.
- The study distinguishes between systems with smaller ecological footprints (manual, gravity) vs. higher-impact systems (motor-pump) and ties this to their upscaling potential. This nuanced ecological assessment specific to irrigation typologies is missing in general sustainability discussions.
- The research underscores that lack of collective bargaining power among farmers is a key reason for low from gate prices, which is an institutional/organizational insight not always emphasized in irrigation sustainability studies.
- Unlike many studies that treat technical, social, and environmental aspects in isolation, this study delved into gender, economic viability, environmental risks, and market linkages to present a holistic sustainability assessment of FLI.

- This study also identified unique challenges of various FLI systems. Identifying these unique challenges is essential to improve sustainability and inclusivity of agricultural development. By understanding these challenges, interventions can be designed to meet the local context and needs of farmers.
- The study points to communal land and water management issues as unique barriers to gravity irrigation expansion, offering a context-specific insight that can inform localized policy.

5.5 Limitations of Study

Due to differences in geographical locations and challenges encountered during fieldwork, the findings of this study cannot be fully generalised. The linguistic diversity of the study area posed significant communication challenges in some communities, occasionally leading to misunderstandings or misinterpretations during data collection. This challenge was further compounded by the fact that concepts such as climate change and sustainability are not indigenous to the local linguistic context. Consequently, interpretations of these concepts varied across different languages and dialects.

In addition, the remote location of many FLI sites, combined with poor road networks, made access to the study sites difficult. This resulted in logistical constraints, increased travel time and higher fieldwork costs, and ultimately limited the frequency and scope of data collection.

Poor infrastructure, hindered the movement of researchers and enumerators to some communities, and hence affected the efficiency and effectiveness of the study.

Self-reported data from interviews can be subject to recall or social desirability biases, where respondents may provide answers, they think are expected rather than their true experiences.

Finally, limited funding and resources restricted the scope of the study, affecting the number of participants, the duration of the study, and the comprehensiveness of the data collected.

Addressing these limitations required careful planning, including the use of local translators to translate the questionnaire into some local languages to assist enumerators, flexible scheduling, and the use of mixed-method approaches to triangulate data. Collaboration with key informants, including unit committee members, leaders of farmer groups, and agricultural extension agents at various districts municipalities and metropolis, enhanced the reliability and validity of the research

5.6 Future Research

There is currently no data on the actual area irrigated under FLI in the UER over time. Despite reports indicating that FLI systems dominate the expansion of irrigated areas, the number of people employed and the amount of food produced under FLI and irrigation in general is a gap in data that remain data gaps to be addressed. Future research in these areas is therefore recommended.

In addition, future research should expand the geographic scope of analysis to enhance the generalizability of the findings and adopt longitudinal approaches to better capture the evolution of FLI systems over time. There is also need for more robust and geospatial techniques, as well as context-specific approaches that reflect local understanding of climate change and sustainability.

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APPENDIX

Table A1: RIF decomposition of FLI harvest value per ha (ln)

Panel A: Gender differential	**Mean**		**10th**	**20th**	**30th**	**40th**	**50th**	**60th**	**70th**	**80th**	**90th**	
Men	7.233***		6.042***	6.310***	6.664***	6.945***	7.280***	7.592***	7.874***	8.123***	8.389***	
	(0.066)		(0.118)	(0.134)	(0.134)	(0.148)	(0.154)	(0.156)	(0.169)	(0.115)	(0.096)	
Women	6.473***		5.230***	5.741***	5.977***	6.155***	6.363***	6.559***	6.859***	7.491***	8.158***	
	(0.120)		(0.217)	(0.201)	(0.241)	(0.209)	(0.227)	(0.215)	(0.319)	(0.404)	(0.392)	
Difference	0.761***		0.812***	0.569***	0.687***	0.789***	0.917***	1.033***	1.015***	0.631	0.232	
	(0.135)		(0.253)	(0.195)	(0.232)	(0.199)	(0.231)	(0.231)	(0.345)	(0.404)	(0.380)	
Panel B: Aggregate decomposition	**Endowment effect**				**Male structural advantage**				**Female structural disadvantage**			
	Mean	**10th**	**50th**	**90th**	**Mean**	**10th**	**50th**	**90th**	**Mean**	**10th**	**50th**	**90th**
Total	0.444***	0.095	0.638***	0.408**	0	-0.000	0.000	0.000	0.317***	0.717***	0.279*	-0.177
	(0.141)	(0.165)	(0.197)	(0.199)	(0.033)	(0.057)	(0.046)	(0.102)	(0.107)	(0.175)	(0.157)	(0.311)
Share of gender gap	58.34%	11.70%	69.57%	175.86%	0%	0%	0%	0%	41.66%	88.30%	30.43%	-76.29%
Panel C: Detailed decomposition	**Mean**	**10th**	**50th**	**90th**	**Mean**	**10th**	**50th**	**90th**	**Mean**	**10th**	**50th**	**90th**
Age (years)	-0.058	-0.092	-0.040	-0.101	-0.845	-0.028	-0.691	-3.309	-1.700	-3.450	-5.098	8.515
	(0.083)	(0.129)	(0.067)	(0.132)	(0.939)	(1.759)	(1.587)	(2.317)	(2.907)	(9.180)	(3.875)	(9.493)
Age squared (years)	0.048	0.065	0.035	0.072	0.260	-0.313	0.245	1.400	0.149	-0.253	0.821	-3.768
	(0.099)	(0.136)	(0.076)	(0.148)	(0.474)	(0.872)	(0.775)	(1.070)	(1.285)	(4.121)	(1.807)	(3.584)
Education (years)	-0.009	-0.012	0.011	-0.018	0.024	0.010	0.035	0.014	-0.121*	0.023	-0.582***	0.302
	(0.014)	(0.023)	(0.021)	(0.028)	(0.038)	(0.050)	(0.052)	(0.076)	(0.064)	(0.109)	(0.145)	(0.234)

Married (binary)	-0.028	-0.012	0.015	-0.082	0.123	0.020	-0.114	0.703	-0.752**	-2.922***	-0.766	0.915
	(0.028)	(0.033)	(0.031)	(0.083)	(0.176)	(0.217)	(0.281)	(0.439)	(0.297)	(1.013)	(0.643)	(1.416)
Migrant (binary)	-0.001	-0.018	-0.002	0.008	0.009	0.015	0.008	0.002	0.004	0.076	0.045	-0.108
	(0.012)	(0.030)	(0.020)	(0.019)	(0.009)	(0.016)	(0.011)	(0.012)	(0.028)	(0.084)	(0.049)	(0.097)
Major occupation (binary)												
Rain-fed farming	-0.004	-0.009	-0.006	0.011	0.102**	0.064	0.054	0.189	0.408***	1.196***	-0.170	0.356
	(0.009)	(0.021)	(0.014)	(0.024)	(0.046)	(0.095)	(0.078)	(0.127)	(0.113)	(0.336)	(0.158)	(0.318)
Irrigated farming	-0.029	-0.058	-0.068	-0.014	0.032	0.080	-0.018	0.130	0.002	0.206**	-0.055	-0.172
	(0.026)	(0.041)	(0.048)	(0.056)	(0.038)	(0.090)	(0.044)	(0.111)	(0.038)	(0.092)	(0.078)	(0.158)
Salaried worker	-0.004	0.012	-0.011	-0.007	-0.004	0.007	-0.006	-0.002	0.038	-0.005	0.042	0.149
	(0.007)	(0.018)	(0.016)	(0.020)	(0.009)	(0.009)	(0.011)	(0.024)	(0.025)	(0.041)	(0.042)	(0.097)
Other	0.001	-0.042	0.002	-0.004	-0.010	-0.034	0.007	-0.040	-0.174**	-0.409*	-0.008	-0.268
	(0.007)	(0.042)	(0.017)	(0.023)	(0.012)	(0.029)	(0.014)	(0.028)	(0.084)	(0.215)	(0.061)	(0.174)
Experience in irrigation	0.060*	0.024	0.099	-0.002	0.090	0.183*	0.036	0.075	0.566***	0.761	1.364***	1.185
	(0.036)	(0.029)	(0.061)	(0.023)	(0.058)	(0.098)	(0.086)	(0.080)	(0.141)	(0.510)	(0.320)	(0.969)
Household size	0.018	0.009	0.002	0.057	-0.090	0.039	-0.052	-0.148	-0.755**	-0.574	-0.365	-1.754
	(0.016)	(0.013)	(0.011)	(0.048)	(0.074)	(0.124)	(0.122)	(0.238)	(0.326)	(1.019)	(0.379)	(1.102)
Dependency ratio	-0.000	-0.000	-0.001	0.000	-0.166*	-0.074	-0.438**	-0.095	-0.209	-1.073**	0.063	0.799
	(0.007)	(0.009)	(0.023)	(0.016)	(0.088)	(0.205)	(0.171)	(0.157)	(0.164)	(0.421)	(0.223)	(0.591)
Off-farm income (binary)	-0.003	-0.003	-0.010	0.001	0.005	0.142	-0.035	-0.058	0.021	0.767***	-0.484**	-0.395
	(0.011)	(0.012)	(0.031)	(0.008)	(0.036)	(0.101)	(0.059)	(0.081)	(0.074)	(0.261)	(0.223)	(0.395)
Social network (binary)	-0.000	0.002	-0.010	0.001	-0.032	0.065	0.025	0.008	0.077	0.573*	0.194	-0.106

	(0.007)	(0.010)	(0.022)	(0.012)	(0.040)	(0.087)	(0.049)	(0.101)	(0.127)	(0.298)	(0.179)	(0.309)
Access to credit (binary)	-0.001	0.000	-0.003	-0.004	0.029	0.030	0.032	0.052	0.036	-0.141	0.365***	0.208
	(0.004)	(0.004)	(0.017)	(0.026)	(0.025)	(0.049)	(0.032)	(0.057)	(0.063)	(0.205)	(0.131)	(0.158)
Access to extension (binary)	0.048	0.044	0.040	0.057	0.027	-0.285*	0.235	-0.103	-0.294***	-0.544*	-0.412*	-0.883
	(0.035)	(0.034)	(0.048)	(0.084)	(0.152)	(0.155)	(0.193)	(0.383)	(0.105)	(0.296)	(0.245)	(0.673)
Land size (ln)	0.120**	0.099	0.140**	0.168*	-0.114*	-0.156	-0.127	-0.366**	-0.161*	-0.384*	-0.086	0.286
	(0.054)	(0.065)	(0.070)	(0.092)	(0.068)	(0.131)	(0.084)	(0.150)	(0.089)	(0.223)	(0.122)	(0.262)
Share of irrigated land	0.000	0.001	0.001	-0.000	0.046	0.044	0.076	0.064	-0.128	-0.283	-0.042	0.823**
	(0.007)	(0.018)	(0.018)	(0.008)	(0.060)	(0.120)	(0.080)	(0.126)	(0.130)	(0.377)	(0.237)	(0.419)
Number of crops grown	0.047	0.080	0.075*	0.060	0.048	-0.155	0.196*	-0.066	0.848***	1.114	1.469***	-1.032
	(0.031)	(0.051)	(0.044)	(0.042)	(0.062)	(0.138)	(0.109)	(0.101)	(0.279)	(0.834)	(0.512)	(1.491)
Irrigation technology (binary)												
Pump	0.010	-0.044	0.071	-0.059	-0.139	-0.293	0.081	-0.291***	-0.101	-0.114	-0.161	-0.353
	(0.029)	(0.048)	(0.050)	(0.053)	(0.110)	(0.200)	(0.155)	(0.100)	(0.092)	(0.308)	(0.104)	(0.273)
Manual	0.096*	0.098	0.147	0.034	-0.013	0.023	-0.015	-0.045	-0.305**	-0.516**	0.001	0.001
	(0.058)	(0.066)	(0.092)	(0.064)	(0.024)	(0.028)	(0.041)	(0.041)	(0.120)	(0.249)	(0.136)	(0.136)
Gravity	-0.004	-0.002	0.002	-0.016	-0.023	-0.004	-0.021	-0.036	0.096	0.238	0.123	-0.181
	(0.011)	(0.018)	(0.017)	(0.025)	(0.017)	(0.029)	(0.022)	(0.025)	(0.070)	(0.179)	(0.104)	(0.263)
Other	-0.000	-0.001	-0.001	-0.000	0.008	0.004	0.004	0.018	0.007	0.000	-0.010	0.035
	(0.007)	(0.013)	(0.011)	(0.000)	(0.010)	(0.008)	(0.006)	(0.018)	(0.010)	(0.021)	(0.015)	(0.046)

Water (ln)	0.047	0.089	0.093	-0.034	0.156	0.693**	-0.117	0.257	-0.032	0.377	0.048	-1.342***
	(0.049)	(0.092)	(0.091)	(0.053)	(0.214)	(0.322)	(0.338)	(0.386)	(0.189)	(0.544)	(0.320)	(0.494)
Equipment (ln)	0.052	-0.092	0.060	0.096	-0.018	0.080	-0.009	-0.248	0.480***	1.106***	-0.012	0.821*
	(0.035)	(0.078)	(0.056)	(0.085)	(0.127)	(0.242)	(0.189)	(0.238)	(0.174)	(0.429)	(0.210)	(0.482)
Labor (ln)	-0.016	0.014	-0.094	0.039	-0.088	-0.684*	0.045	-0.409	-0.284	-1.020	0.401	0.491
	(0.032)	(0.055)	(0.057)	(0.042)	(0.179)	(0.400)	(0.239)	(0.348)	(0.324)	(0.942)	(0.539)	(0.902)
Inputs (ln)	0.001	0.001	0.001	0.000	0.330	0.047	0.068	0.502	-0.858	-0.678	-1.891*	-3.106
	(0.057)	(0.073)	(0.044)	(0.007)	(0.326)	(0.812)	(0.505)	(0.519)	(0.549)	(1.597)	(1.063)	(2.587)
Observations	250											

Note: Community fixed effects included in model but not reported. ***, **, * denote $p < 0.01$, 0.05, and 0.1, respectively. Inputs is a monetary aggregate that includes expenditures related to fertilizer, seeds, and pesticides. Other includes expenditures such as transportation to the farm, and fencing.

Source: Field Survey (2022), own calculations.

Table A2: Environmental effects of FLI systems

Effect on environment		Irrigation system					Total
		Gravity	Manual	Supplementary	Pump GW	Pump SW	
Pollution of water bodies	Count	22	27	2	18	106	175
	% of Total	4.27%	5.24%	0.39%	3.50%	20.58%	33.98%
Silting Water Bodies	Count	16	22	3	12	70	123
	% of Total	3.11%	4.27%	0.58%	2.33%	13.59%	23.88%
Destruction of Soil organism	Count	14	21	2	18	60	115
	% of Total	2.72%	4.08%	0.39%	3.50%	11.65%	22.33%
Emission of greenhouse gasses	Count	7	0	1	7	69	84
	% of Total	1.36%	0.00%	0.19%	1.36%	13.40%	16.31%
None	Count	4	1	1	2	6	14
	% of Total	0.78%	0.19%	0.19%	0.39%	1.17%	3%
Other Effects	Count	1	0	0	0	3	4
	% of Total	0.19%	0.00%	0.00%	0.00%	0.58%	0.78%
Total	Count	64	71	9	57	314	515
	% of Total	12.43%	13.79%	1.75%	11.07%	60.97%	100.00%

Source: Field Survey (2022)

TableA3: Sustainability measures according to FGDs

Sustainability measures	**Percentage**
Maintenance of tree cover at sites and near water bodies	25
Crop rotation	14.3
Training children on farm	14.3
Fallowing of land	10.7
No burning on farms	10.7
Minimal use of inorganic chemicals	7.1
Use of organic fertilizer	7.1
Banning harvesting of wildlife in the water bodies or farms	3.6
Total	100

Source: Field Survey (2022)

QUESTIONNAIRE FOR A STUDY ON SUSTAINABILITY OF FARMER-LED IRRIGATION SYSTEMS UNDER CLIMATE CHANGE IN THE UPPER EAST REGION OF GHANA

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Thank you for your anticipated participation.

KEY INFORMANT INTERVIEW GUIDE (Organizational staff)

Name of Respondent: ……………………………………………………………………
District:…………………………………………………………………………………
Organization:……………………………………………………………………………
Date:…………………………………………………………………………………..
Section A: trend of Farmer-Led Irrigation (FLI)

1. In your view is the area(size of land) cultivated under FLI in the district increasing or reducing? Give reasons for
    a) Yes
    b) No.
    …………………………………………………………………………………………
    …………………………………………………………………………………………
    …………………………………………………………………………………………
2. what are the effects of FLI in the district (environmental, social and economic.)
    …………………………………………………………………………………………
    …………………………………………………………………………………………
    …………………………………………………………………………………………

3 What systems of irrigation (gravity, manual, pump-groundwater, pump-surface water, supplementary are practiced in this community? probe for the ff.

a) dominant system and reasons dominance,
b) systems that have been abandoned and reasons for them abandoning it
c) technologies used for abstraction and application of water to crops,

4. What measures have been implemented (by Government, NGOs, Community) in the district to enhance FLI activities (e.g. production skills, marketing, processing, storage, farm inputs, equipment etc)

a) Government
…………………………………………………………………………………………
………………………………………………………………………
…………………………………………………………………………………………
b) NGOs(Name)

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

c) Community

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

d) Your institution (name)

…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………………………………………………………………………

5.What is your institution doing to enhance sustainable use of scarce water resources in the district

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

6. What are the effects of climate changes on FLI in the district.

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

Thank you for your time.

QUESTIONNAIRE FOR A STUDY ON SUSTAINABILITY OF FARMER-LED IRRIGATION SYSTEMS UNDER CLIMATE CHANGE IN THE UPPER EAST REGION OF GHANA

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Thank you for your anticipated participation.

KEY INFORMANT INTERVIEW GUIDE (Community leaders)

Name of Respondent: ……………………………………………………………..
District:……………………………………………………………………………………
Organization:………………………………………………………………………
Date:……………………………………………………………………………….

Section A: trend of Farmer-Led Irrigation

1. How long has irrigation been practiced in this community? Prope for
   a) Average number years and how it started,

………………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………

   b) If is it expanding what is the reasons/causes of expansion;

………………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………

   c) If no probe for reasons/causes of non-expansion)

………………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………

2. Which category of persons are engaged in irrigation in this community? Probe for the ff
   a) How are resources (land water) allocated to men, women and youth's access to irrigation facilities.

………………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………

   b) What roles are played by men women and youth in the irrigation value chain.

………………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………

3. What systems of irrigation are practiced in this community? probe for the ff.

a) dominant system and reasons dominance

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

b) systems that have been abandoned and reasons for them abandoning it

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

c) technologies used for abstraction and application of water to crops,

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

d) measures to enhance the use of new climate smart and efficient water use technologies

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

e) measures by Government/NGOs/Community to help more people engage in irrigation in this community.

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

4.What are the major crops cultivated in the area? Probe for the ff

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

a) Factors that influence the type of crop cultivated by farmers,

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

5. Are there any traditional institutions/associations that manage water and land in this community/district? Probe for names, Yes/No

a) Name these institutions

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

b) What do they do

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

6. What can be done promote women and youth participation in irrigation in this community (Policies, economic incentives and institutional changes, etc)?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

Section B: Effects of climate change/variability on Irrigation

7. What changes have you noticed in the climate of this area over the past years? Probe for

a) Changes in climate over the past 10, 20 and 30 years

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

b) The effects of climate changes on irrigation such as effects on availability of water, prevalence of pest and diseases, erosion on plots by floods

c) Adaptation and mitigation measures adopted by farmers

Section C: Challenges and Constraints of Farmer led Irrigation

8. What challenges are encountered by farmer led irrigators in this community? Probe for the ff

a) Challenges such as access to marketing centers, transportation, farm inputs, irrigation equipment, market for produce, storage facilities, trainings, road network among others)

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

Section D: Sustainability

9. What are Impacts of irrigation in this community (probe for

a) Social impact of irrigation on community

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

b) Environmental Impact of FLI on ecosystems and ecosystem services

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

c) What are the economic impacts of irrigation on community

……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………
………

10. What measures are put in place to ensure sustainable intensification of irrigation? Probe for the ff

a) training on efficient use of water

……………………………………………………………………………………………
……………………………………………………………………………………………

b) appropriate use of agro-chemicals in terms of time of application, quantities applied disposal of containers,

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………

c) soil fertility conservation etc

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

d) Access to new irrigation technologies

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

Thank you four your time.

QUESTIONNAIRE FOR A STUDY ON SUSTAINABILITY OF FARMER-LED IRRIGATION SYSTEMS UNDER CLIMATE CHANGE IN THE UPPER EAST REGION OF GHANA

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Thank you for your anticipated participation.

CHECKLIST FOR EQUIPMENT AND INPUT DEALERS

Community/district………………………………. Enumerator's name:………………………..

Name of respondent……………………………… Phone number:……………………...

1. How long have you been in this business?...
2. What are the challenges of this business?
3. Do you receive any support from government/NGO for your business? If yes explain.
4. In what way do you support dry season farming activities in this community/district?
5. What does your business do to enhance access to irrigation equipment/inputs by farmers who cannot pay upfront.
6. Is there any special arrangement to enhance female dry season farmers to access to equipment/inputs?
    2. Yes
    3. No
7. If yes what is done?
8. Are you willing to supply equipment/inputs to farmers on credit?
    4. Yes
    5. No
9. If yes Please explain why
10. If no , explain why .
11. What is the maximum period for repayment for equipment/inputs given to farmers on credit ?
12. What are the sanctions for defaulting?
13. What services to you provide farmers beside selling your equipment/inputs to them?
14. How do you ensure efficient and safe use of farm input/equipment bought from you?
15. What is your organization doing to ensure that irrigation is sustained in this area?

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FOCUS GROUP DISCUSSIONS INTERVIEW GUIDE

Section A: trend of Farmer-Led Irrigation

1. How long has irrigation been practiced in this community? Probe for
   a) Average number years and how it started,
   b) if is it expanding probe for the reasons/causes of expansion;
   c) if no probe for reasons/causes of non-expansion)

2. Which category of persons are engaged in irrigation in this community? Probe for the ff
   a) those engaged in it in the past 10, 20 and 30 years and now,
   b) roles played by men women and youth in the irrigation value chain.
   c) women and youth's access to irrigation facilities,
   d) new irrigation and production technologies,
   e) available support services: mechanization, credit
3. What systems of irrigation are practiced in this community? probe for the ff.
   a) dominant system and reasons dominance,
   b) systems that have been abandoned and reasons for them abandoning it
   c) technologies used for abstraction and application of water to crops new technologies introduced and modifications made to new technologies
4. What are the major crops cultivated in the area? Probe for the ff
   a) Factors that influence the type of crop cultivated by farmers,
   b) Presence of any storage facilities
   c) Linkage with markets
5. What is done by the Government/NGOs, community to help more people engage in irrigation in this community,
6. What is done to enhance the use of new climate smart and efficient water use technologies
7. Are there any traditional institutions/associations that manage water and land in this community/district? Probe for names,
   a) Name these institutions and what they do

b) What Policies, economic incentives and institutional changes are needed to promote women and youth in irrigation in this community?

Section B: Effects of climate change/variability on Irrigation

8. What changes have you noticed in the climate of this area over the past years? Probe for

a) Changes in climate over the past 10, 20 and 30 years

b) The effects of climate changes on irrigation such as effects on availability of water, prevalence of pest and diseases, erosion on plots by floods,

c) Adaptation and mitigation measures adopted by farmers

Section C: Challenges and Constraints of Farmer led Irrigation

9. What challenges are encountered by farmer led irrigators in this community? Probe for the ff

a) Challenges such as access to marketing centres, transportation, farm inputs, irrigation equipment, market for produce, storage facilities, trainings, road network among others)

10. What are Impacts of irrigation on community (probe for environmental (ecosystems and ecosystem services), social and economic impacts of FLI in this community.

Environmental Impact of FLI

a) Soil parameters (soil fertility, soil erosion, sedimentation etc),

b) Hydrological aspects (water quality, drainage, water logging and effects on regional hydrology/flooding)

c) Ecological impacts (species diversity and aquatic weeds), and Landscape patterns (grazing and forest and grassland reduction).

d) Health issues

e) Availability of water for humans and animals

f) Availability of grasses for animals

Social impact of FLI on community

a) percentage of people in community with plots on irrigation sites,

b) Activities performed by various categories of people from the community with emphasis on women and the youth,

c) Abilities and opportunities for women and youth to engage in decision making.

Economic Impacts of FLI

11. What measures are put in place to ensure sustainable intensification of irrigation? Probe for the ff

a) training on efficient use of water,

b) appropriate use of agro-chemicals in terms of time of application, quantities applied disposal of containers,

c) soil fertility conservation etc

d) Access to new irrigation technologies

Thank you for your time.

QUESTIONNAIRE FOR A STUDY ON SUSTAINABILITY OF FARMER-LED IRRIGATION SYSTEMS UNDER CLIMATE CHANGE IN THE UPPER EAST REGION OF GHANA

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Thank you for your anticipated participation.

CHECKLIST FOR MARKETERS/TRADERS OF FLI VEGETABLES

Community/district…………………………Enumerator's name:………………………..
Name of respondent………………………………   Phone number:…………………

1. How long have you been in this business?..
2. What produce do you deal in?
3. Are you into contract farming arrangement with farmer led irrigation practitioners (individually/groups)?
    a) What are the terms of these contract?
    b) What are the challenges of the contract farming?
    c) How do you deal with these challenges?
    d) Where are these farmers located?
4. What challenges do you encounter in your business
5. What do you do to ensure that irrigation is sustained in this area
6. Do you receive any support from government/NGO for your business? If yes explain

QUESTIONNAIRE FOR A STUDY ON SUSTAINABILITY OF FARMER-LED IRRIGATION SYSTEMS UNDER CLIMATE CHANGE IN THE UPPER EAST REGION OF GHANA

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INDIVIDUAL QUESTIONNAIRE

Enumerator's name:……………………………………………………………………………

District.-------------- (Use codes below)	Community.--------	Date of interview	HH ID	Name of compound
District codes 1. Talensi 2. Bawku west 3. Kasena Nankana Municipal 4. Builsa south 5. Tempane	Bare Pwalugu Pusunamo Winkogo Yinduri Santeng Gbeogo Goo Teshie Yarigu Timonde Tampola Doba kologo Kugwania Bubolizugu Yisopsa Kadema-Apovia			

SECTION A: BACKGROUND INFORMATION OF RESPONDENT

1. Name of Respondent: …………………………………… Contact No:……………
2. Gender of respondent:
    1. Male ☐
    2. Female ☐
3. Age of respondent? ………. years
4. Marital status of respondent:
    1. Single ☐
    2. Married ☐
    3. Divorced ☐
    4. Separated ☐
    5. Widowed ☐
5. Residential status of respondent
    1. Migrant
    2. Native
6. Educational Level of respondent:
    1. No Formal Education ☐
    2. Primary☐
    3. Junior High ☐
    4. Senior High/Vocational/Tech ☐
    5. Tertiary ☐
7. Number of years of education of respondent………………..
8. Major and minor occupations of respondent

	Enter code	Codes:
8.1 Major Occupation (Use codes)		1. Rain-fed crop farming 2. Irrigated farming 3. Livestock rearing 4. Fishing 5. Produce marketing (rain-fed crops0 6. Produce marketing (irrigated crops) 7. Livestock marketing 8. Salaried worker 9. Trader 10. Artisan 11. Other (specify) …………………
8.2 Minor Occupation (Use codes)		

Age category of HH Members	Number males	Number of females
0 -14 years		
15 - 24 years		
25 - 60 years		
Above 60 years		

9. How many people live in your household?...

SECTION B: TREND OF FARMER-LED IRRIGATION

10. What is the total size of land owned by your household (land around the home, at irrigation sites and bush farms)? …………………………
11. What size of the land owned by your household is cultivated by the females in your household during this rainy season?...
12. What is the size of irrigated land owned by your household?..........................
13. What size of your household's irrigated land was cultivated by the females in your household during the last irrigation season?...
14. Do you or anyone in your household engage in farmer-led irrigation?
    1. Yes
    2. No - **skip to section G**
15. What role do women play in the irrigation, production and post-harvest activities of your household? **Multiple responses**
    1. Help in crop production activities (watering, sowing crops, etc)
    2. Sell harvested crops
    3. Process harvested crops
    4. Cultivate their own plots
    5. Help in decision making related to irrigation in a season
    6. Other (specify)…………………………………………………
16. What role do the youth (15-35 years) play in the irrigation, production, and post-harvest activities of your household? **Multiple responses**
    1. Help in crop production activities (watering, sowing crops, etc)
    2. Sell harvested crops
    3. Process harvest crops
    4. Cultivate their own plots
    5. Help in decision making related to irrigation in a season
    6. Other (specify)…………………………………………………
17. How long have you practiced irrigation? ………………………………… years
18. What is/are the source(s) of water for irrigation in this community? (multiple responses)
    1. Dam/dugout
    2. Rivers/stream
    3. Deep wells/ boreholes
    4. Shallow wells
    5. Other (specify)…………………………………
19. What technology is used to lift water in this community? (multiple responses)
    1. Manual (bucket and rope, treadle pump)
    2. Pump (petrol/diesel)
    3. Pump (electricity)
    4. Pump (Solar)
    5. Other (specify)………………………………………
20. How is water applied to irrigated crops in this community? (multiple responses)

1. Furrow system
2. Drip system
3. Flood/basin system
4. Sprinkler
5. Other (specify)……………………………………………

21. Which systems of irrigation have you ever practiced? **multiple responses**
    1. Small-scale pump irrigation systems (surface water - dams , dugouts, rivers and streams)
    2. Small-scale pump irrigation systems (ground water - deep wells and boreholes)
    3. Small scale bucket systems (ground water - shallow wells)
    4. Small scale bucket systems (surface water - dams, dugouts, rivers and streams)
    5. Small scale -urban and peri-urban irrigation (streams, storm water drains and shallow wells)
    6. Other (specify)…………………………………………………………
22. Which system of irrigation are you currently practicing?
    1. Small-scale pump irrigation systems (surface water - dams, dugouts, rivers and streams)
    2. Small-scale pump irrigation systems (ground water - deep wells and boreholes)
    3. Small scale bucket systems (ground water - shallow wells)
    4. Small scale bucket systems (surface water - dams, dugouts, rivers and streams)
    5. Small scale -Urban and peri-urban Irrigation (streams, storm water drains and shallow wells)
    6. Other (specify)…………………………………………………………
23. How long have you practiced your current system of irrigation?...
24. What challenges are associated with the current irrigation system you practice? **multiple responses**
    1. High cost of equipment
    2. High cost of fuel/electricity
    3. Need lot of strength to able to use it
    4. Must own land to be able to practice it
    5. Cannot cultivate large area of land
    6. Involves a lot of drudgery
    7. Other (specify)…………………………………………………………
25. How have you adapted to these challenges?
    1. Form groups to buy equipment and use
    2. Depend on friends and family for equipment
    3. Nothing can be done
    4. Relocate to our own land at home
    5. We involve our children
    6. Hire people to help us
    7. Other (specify)…………………………………………………………
26. What assistance have you/household members received from organizations (GOV/NGOs) for irrigation purposes?

1. A bore hole fitted with a pump
2. Rehabilitation of community dam
3. farm inputs (seeds, fertilizer, weedicides etc)
4. Access to credit
5. Training
6. Pump
7. Linked to buyers
8. Other specify…………………………………………………………………..

27. From which organization(s) did you receive the above assistance? Multiple responses
    1. MOFA(DAs)
    2. IWMI
    3. AKANDEM Farms
    4. ACDEP
    5. Other (specify)……………………………………………………………….
28. If assistance received was a training, what type of training was it?
    a. How to use water efficiently
    b. How to apply agrochemicals
    c. How to improve soil fertility
    d. Other (specify)………………………….

SECTION C: EVALUATION OF FLI SYSTEMS WITH RESPECT TO THEIR UPSCALING POTENTIAL.

29. To what extent can the irrigation system you currently practice be practiced by people in other communities.
    1. Not at all
    2. Small extent
    3. Medium extent
    4. A high extent

30. Give reasons for response to question above.

………………………………………………………………………………………………

…………………………………………………………………………………………

31. What factors will make it possible for the expansion of the system of irrigation you practice in this community?

………………………………………………………………………………………………

…………………………………………………………………………………………

32. Are there any existing/possible policy initiatives that can enhance upscaling potential of the FLI system you practice?
    1. Yes
    2. No
33. If yes please give examples of possible policy initiatives.

…………………………………………………………………………………………………
………………………………………………………………………………………………

SECTION D: ECONOMIC, ENVIRONMENTAL, SOCIAL AND SUSTAINABILITY POTENTIALS OF FLI SYSTEMS.

SECTION D1: ECONOMIC SUSTAINABILITY

Cost of production

34. Which crops do you cultivate on your irrigated plots? multiple responses
    1. Onions
    2. Tomatoes
    3. Pepper
    4. Cabbage
    5. Carrots
    6. Leafy vegetables (amaranthus, ayoyo etc)
    7. Green maize
    8. Rice
    9. Okro
    10. Garden eggs
    11. Beans (cowpea)
    12. Calabash
    13. Other (specify) ……………………………………….

How much did you spend (in GHC) during the last irrigation season on producing crops on your plot?

Crop	Cost of activities/items in GHC										
	land acquisition-	land preparation	provision of water, fuel,/electricity,manuaal power	Inputs (seeds, fertilizer,	Equipment(buying/renting repairs	Care Taking	Cost of weeding/ weedicides	Harvesting	Transportation (for production and marketing)	Other cost	Estimated total cost
Plot 1: Tomato											
Plot2: Pepper											
Plot 3: Carbage/											

Kenaf/jute											
Plot 4: Carrot/ green maize etc											
Kenaf/jute("Bito"											
Maize											
Rice											
Onions											

35. How much did you get from the sale of farm produce (in GHC) during the last irrigation season (2021-2022) from your plots?

Crop cultivated	Quantity harvested	Quantity sold	Quantity consumed (at home and given out as gifts)	Quantity of post harvest losses	Price per unit (of sold)	Amount obtained GHC
Tomato (crate)						
Pepper (bags)						
Carbage						
Carrot						
Kenaf and jute("Bito") (beds/bundles)						
Letus						
Maize (bags)						
Onions (bags/basins)						

SECTION D 2: ENVIRONMENTAL SUSTAINABILITY

36. What ecosystem services do you obtain from the area currently under irrigation?

1) Fresh grass to feed our animals
2) Fresh vegetables for income and home consumption
3) Introduction of exotic/new crop varieties
4) Availability of water in the dry season for humans/animals
5) Other (specify)……………………………………………………..

37. What ecosystems services have you lost/destroyed in your environment that can be attributed to irrigation? (Multiple responses accepted)

1. Soil fertility is depleted
2. Loss of species diversity and aquatic weeds
3. Loss of grazing and forest land
4. Water quality, and quantity reduced
5. Increasing incidence of health issues (eg bilharzia)

6. Other (specify)……………………………………………………..

38. What are the negative effects of your irrigation activities on the environment?
    1. Pollution of water bodies with agrochemicals
    2. Emission of greenhouse gases
    3. Siltation of water bodies
    4. Destruction of organisms in the soil
    5. Reduction of grazing/forest lands
    6. Other (specify)………………………………………..
39. What measures have you taken to minimize the negative effects of irrigation on the environment?
    1. Practice no burning on farmlands
    2. Use organic manure
    3. Use agrochemicals in moderation
    4. Protecting water bodies
    5. Don't clear vegetation when establishing new farms
    6. Other (specify)…………………………………………….
40. What measures are you taking to ensure that future generations can still benefit from irrigation in this area?
    1. Practice Organic farming
    2. Use soil and water conservation methods
    3. Don't fell trees when creating new farms
    4. Helping each other in any ways we can to participate in irrigation
    5. Plant grasses/trees at river banks to reduce rate of silting.
    6. Bring children to farm when they are not in school
    7. Other (specify)……………………………………………………………………..

41. In which way does the irrigation system you practice affect the environment?
    1. Pollution from use of fossil fuels
    2. Pollution from agro-chemicals (fertilizer, pesticides etc)
    3. Destruction of soil structure through digging of wells
    4. Destruction of soil chemical properties (salinity, pH etc)
    5. Other (specify) …………………………………………………………………….

SECTION D 3: SOCAIL SUSTAINABILITY

42. To what extent can your spouse contribute to decisions regarding irrigated agriculture in your household?
    1. Not at all
    2. Small extent
    3. Medium extent
    4. A high extent
43. To what extent can the youth in your HH contribute to decisions regarding irrigated agriculture in your household?
    1. Not at all

2. Small extent
3. Medium extent
4. A high extent

44. To what extent can women practice your current irrigation system?
    1. Not at all
    2. Small extent
    3. Medium extent
    4. A high extent

45. Give reasons for your response to the question above.

………………………………………………………………………………..

46. To what extent can the youth practice your current irrigation system?
    1. Not at all
    2. Small extent
    3. Medium extent
    4. A high extent
47. Give reason for your response to the question above.

    ……………………………………………………………………………………………

    …………………………………………………………………………………………….

48. To what extent can men practice your current irrigation system?
    1. Not at all
    2. Small extent
    3. Medium extent
    4. A high extent
49. Give reasons for response in above question.

…………………………………………………………………………….

50. To what extent do women have sufficient access to land needed to apply new irrigation practices/technologies?
    1. Not at all
    2. Small extent
    3. Medium extent
    4. A high extent
51. Please give reasons for your response above.

    ……………………………………………………………………………………………

    ……………………………………………………………………………………………

52. To what extent do the youth have sufficient access to land needed to apply new irrigation practices/technologies?
    1. Not at all
    2. Small extent
    3. Medium extent
    4. A high extent
53. Please give reasons for your response above.

……………………………………………………………………………………………
……………………………………………………………………………………………

54. To what extent do non-native irrigation practitioners have sufficient access to land needed to apply new irrigation practices/technologies?
    1. Not at all
    2. Small extent
    3. Medium extent
    4. A high extent

55. Please give reasons for your response above.
……………………………………………………………………………………………
……………………………………………………………………………………………
56. How frequently do you attend meetings or workshops related to irrigation?
57. How often do you collaborate with other farmers or irrigation practitioners in your area?
58. What interventions are needed to facilitate the inclusion of women and youth in irrigation related activities in this community?
    1. Targeted provision of credit
    2. Facilitating access to water and suitable land
    3. Training on new irrigation technologies
    4. Facilitation of access to new irrigation technologies
    5. Other (specify)………………………………………………………………

SECTION E: ADAPTATION STRATEGIES OF FARMER-LED IRRIGATION PRACTITIONERS TO THE EFFECTS OF CLIMATE CHANGE.

SECTION E1: Effects of climate change on Irrigation

59. What are your perceived environmental effects of climate change on irrigation? multiple responses
    1. Increased evaporation
    2. Erosion on irrigated land due to flooding during rainy season
    3. Scarcity of water for irrigation
    4. Changes in biodiversity
    5. Other (specify)………………………………………..
60. Was there a time you did not harvest anything because of insufficient water?
    1. Yes
    2. No-skip to 60
61. If yes how long ago was this?...................................

62. Was there a time you did not harvest anything because of pest and diseases?
    1. Yes
    2. No-skip to 62
63. If yes how many years ago was this?....................................

64. What are your perceived economic effects of climate change on irrigated agriculture? **Multiple responses**
    1. Increased production
    2. Reduced crop yield
    3. Reduced income from sale of produce
    4. Increased income from sale of produce
    5. Other (specify)……………………………………………………………………..

65. What are your perceived social effects of climate change on irrigation? **Multiple responses**
    1. Increased incidence of conflicts for access to water and suitable land
    2. Reduces the participation of women and youth in irrigation
    3. Increases participation in irrigation by women and Youth
    4. Increased out migration by women and youth
    5. Other (specify)……………………………………………
66. How does the use of water here for irrigation affect other people in this or other communities)?
    1. Their animals struggle to get water and feed
    2. They don't get easy access to water for other domestic uses
    3. They are not affected in any way
    4. It's a source of employment for them
    5. Other specify…………………………………………………

SECTION E2: ADAPTATION STRATEGIES TO THE EFFECTS OF CLIMATE CHANGE

67. How have you adapted to the effects of climate change on your irrigation activities?
    1. Practice soil and water conservation on irrigated plots (eg mulching, cover cropping)
    2. Use groundwater
    3. Formed water user associations to manage water use
    4. Decreased irrigated land area
    5. Practice Agroforestry (trees in farm)
    6. Do not undertake irrigation in dry years
    7. Other (specify)……………………………………………………………

68. Which of the following climate smart practices do you use on your irrigated plots? (mention practices) (multiple responses).
    1. Mulching
    2. Agroforestry,
    3. Fertilizer application
    4. Integrated Soil Fertility Management
    5. Crop diversification
    6. Intercropping
    7. Use of improved seeds (early maturing /high yielding seed varieties)
    8. Use groundwater

9. Crop rotation
10. Drip Irrigation
11. Other (specify)……………………………………………….

69. What challenges do you encounter in using the climate smart practices? **Multiple responses**
    1. Non-availability/scarcity of mulching material
    2. Difficult to apply mulch on large plots
    3. Non -ownership of land makes agroforestry difficult to practice
    4. High cost of fertilizer
    5. High cost of improved seeds
    6. Land is only suitable for specific crops
    7. Fake seeds
    8. Other (specify)……………………………………………….

SECTION F: CHALLENGES AND CONSTRAINTS OF FLI SYSTEMS ALONG THE IRRIGATION VALUE CHAIN.

SECTION F 1: PRODUCTION CHALLENGES

Resource Availability

70. What are the challenges of irrigation in this community?
    1. Insufficient water (water sources?
    2. Insufficient land for irrigation
    3. Infertile soils
    4. Bad market for produce
    5. Pest and diseases
    6. High cost of inputs
    7. Inadequate access to credit
    8. Inadequate labour availability /high cost of labour
    9. Other(specify)…………………………………..
71. What influences your choice of irrigated crop for cultivation in a season? (**multiple responses**)
    1. Soil type
    2. Experience in cultivation of crop
    3. Experience from previous year (market, yield)
    4. Availability of water
    5. Availability of labour
    6. Availability of suitable land
    7. Support for particular crops
    8. Other (specify)…………………………………………………………………
72. Do you have access to land for irrigation anytime you want it.?
    1. Yes ***skip to 72***
    2. No
73. If no explain why.

    ……………………………………………………………………………………………

………………………………………………………………………………………………
……………………………………………………………………………………………

74. What size of irrigated land (in *acres)* did you cultivate this year?......................................
75. What size of irrigated land (in acres) did you cultivate last year?......................................
76. What size of irrigated land (in acres) did you cultivate two (2) years ago ?.......................
77. What influences the size of land you cultivate during the dry season? (Multiple answers possible – Rank from most important to least important)
    1. Availability of funds
    2. Availability of land at irrigation site
    3. Availability of water
    4. Availability of market for produce
    5. Decision by landowner
    6. Other (specify)……………………………………………………………………

78. What influenced the size of land you cultivated during the last irrigation season? (Multiple answers possible – Rank from most important to least important)
    1. Availability of funds
    2. Availability of land at irrigation site
    3. Availability of water
    4. Availability of market for produce
    5. Decision by landowner
    6. Other (specify)……………………………………………………………………

79. What is your source of funding for irrigation?
    1. Personal savings
    2. Borrow from commercial bank,
    3. Borrow from VSLA,
    4. Borrow from money lenders
    5. From produce buyer
    6. From other private investor
    7. Other (specify) ………………………………

80. Is there an organization/individual that gives farmers credit (Cash/kind) for irrigation in this community?

    1. Yes
    2. No **skip to 82**
81. If yes what is name of the organization/individual that gives this support?
    1. ACDEP
    2. Akandem Farms
    3. CARE international
    4. Pump for life
    5. Other (specify)……………………………………………………

82. What are the requirements to be able to get this support?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………
83. Have you ever benefited from this support?
    1. Yes
    2. No
84. If no why?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
85. Which farm equipment do you have access to for irrigation? (eg tractor-plough, petrol/diesel/solar pump, treadle pump) for irrigation anytime you want to?
    1. Tractor
    2. Bullock plough
    3. Pump(petrol/diesel/treadle/solar)
    4. Watering can/bucket
    5. Other (specify)

SECTION F 2: MARKETING CHALLENGES

Marketing of produce

86. Where do you sell your harvested irrigated crop produce?
    1. On farm
    2. Local market
    3. District market
    4. Informal roadside sales
    5. Produce sale contracts, etc
    6. Other (specify)…………………………………………………..
87. Who are the buyers of your harvested irrigated crop? **Multiple responses**
    1. Community members
    2. People from neighboring communities
    3. People from neighboring districts
    4. People from neighboring regions
    5. Other (specify)……………………………………………………………….
88. What challenges do you encounter when selling your irrigated crops? Multiple responses possible – Rank)
    1. Oligolistic behaviour of buyers (they determine the prices to pay)
    2. Poor market prices at harvest
    3. No storage facilities
    4. No proper road network to cart produce to urban centers
    5. Inadequate access to transport
    6. Other (specify)…………………………………………………………

89. Are there any contract farming arrangements in this community for irrigated crops?

1. Yes
2. No **skip to 89**

90. If yes what are the terms of the contract?

……………………………………………………………………………………………

……………………………………………………………………………………………

91. What challenges are associated with contract farming under irrigation? **Multiple response**
    1. Defaulting by farmers due to higher prices in the market at time of harvest
    2. Delays in delivery of contract benefits to farmers
    3. Bad prices offered buy buyers
    4. Other (specify)……………………………………………………………………
92. Is there any trade or business association/group in this community/district?
    1. Yes
    2. No **Skip to 94**
93. Do you belong to any business association or group in this community?
    1. Yes
    2. No **Skip to 94**
94. If yes, what are the benefits of your membership to your irrigated farming activities?

……………………………………………………………………………………………

……………………………………………………………………………………………

95. What are the challenges of your membership to this association on your irrigated farming activities?

……………………………………………………………………………………………

……………………………………………………………………………………………

96. Do you have buyers whom you call to come and buy your produce from other towns/regions?
    1. Yes
    2. No **Skip to 96**
97. What challenges do you encounter with buyers from outside the town/region?

……………………………………………………………………………………………

……………………………………………………………………………………………

SECTION F 3: Storage and processing challenges

98. Are there any storage facilities for your irrigated farm produce in this community?
    1. Yes
    2. No
99. To what extent do you agree with the statement that lack of storage facilities for irrigated crops is a major challenge to the sustainability of FLI.
    1. Strongly agree (1)
    2. Agree (2)
    3. Uncertain (3)
    4. Disagree (4)
    5. Strongly disagree (5)
100. Are there any processing facilities for your irrigated farm produce in this community?
    1. Yes
    2. No

101. To what extent do you agree with the statement that lack of processing facilities for irrigated crops is major challenge to the sustainability FLI.

1. Strongly agree (1)
2. Agree (2)
3. Uncertain (3)
4. Disagree (4)
5. Strongly disagree (5)

102. To what extent do you agree with the statement that lack of training on how to handle irrigated crops is major challenge to the sustainability FLI.

1. Strongly agree (1)
2. Agree (2)
3. Uncertain (3)
4. Disagree (4)
5. Strongly disagree (5)

SECTION F 4: Transportation

103. How do you transport your irrigated produce to the sales point? Multiple responses

1. Head ported
2. Use bicycles/motor bikes
3. Use tricycles
4. Other (specify)……………………………………………………………………..

104. What challenges do you encounter when transporting your produce to sales points.

1. Bad road network
2. No access roads
3. No vehicles
4. High transport cost
5. Other (specify)……………………………………………………………………….

SECTION G: NON-IRRIGATING Household

105. Why are you not engaged in irrigation?

1. Lack of resources
2. Insufficient water
3. Lack of land
4. Other (specify)………

106. What ecosystem services do you obtain from the area currently under irrigation?

1) Fresh grass to feed our animals
2) Fresh vegetables for income and home consumption
3) Introduction of exotic/new crop varieties
4) Availability of water in the dry season for humans/animals
5) Other (specify)…………………………………………………..

107. What ecosystems services have you lost/destroyed in your environment that can be attributed to irrigation? (Multiple responses accepted)

1. Soil fertility is depleted
2. Loss of species diversity and aquatic weeds
3. Loss of grazing and forest land
4. Water quality, and quantity reduced
5. Increasing incidence of health issues (eg bilharzia)
6. Other (specify)…………………………………………………..

108. What are the negative effects of irrigation activities on the environment?

1. Pollution of water bodies with agrochemicals
2. Emission of greenhouse gases
3. Siltation of water bodies
4. Destruction of organisms in the soil
5. Reduction of grazing/forest lands
6. Other (specify)………………………………………..

109. How the use of water for irrigation in this community affect other people in this and Communities nearby?

1. Their animals struggle to get water and feed
2. They don't get easy access to water for other domestic uses
3. They are not affected in any way
4. Other (Specify)……………………………………………..

SECTION H: FOOD SECURITY STATUS OF HOUSEHOLDS

The QUESTIONS below should be answered by the person/female **in charge of meal preparation in the household** (HH) preferably a spouse of the interviewed HH head.

INSTRUCTIONS FOR ENUMERATOR: *Please let the respondent describe the foods (meals and snacks) that she and her HH members ate yesterday during the day and night, whether at home or outside. Starting with the first food eaten in the morning.*
Record all food and drinks mentioned by the respondent and probe for meals and snacks not mentioned. Consider foods eaten by any member of the household, ***AND EXCLUDE FOODS PURCHASED AND EATEN OUTSIDE OF THE HOME.*** *When the respondent's recall is complete, fill in the food groups based on the information recorded above. For any food groups not mentioned, ask the respondent if a food item from this group was consumed.*

Question number	**Food group**	**Examples**	**YES=1 NO=0**
110.	CEREALS	corn/maize, rice, wheat, sorghum, millet or any other grains or foods made from these (e.g. bread, noodles, porridge or other grain products)	
111. .	VITAMIN A RICH VEGETABLES AND TUBERS	pumpkin, carrots, squash, or sweet potatoes that are orange inside + other locally available vitamin-A rich vegetables (e.g. red sweet pepper)	
112.	WHITE TUBERS AND ROOTS	white potatoes, white yams, white cassava, or other foods made from roots	
113.	DARK GREEN LEAFY VEGETABLES	dark green/leafy vegetables, including wild ones + locally available vitamin-A rich leaves such as amaranth, cassava leaves, kale, spinach etc.	
114.	OTHER VEGETABLES	other vegetables (e.g. tomato, onion, eggplant) , including wild vegetables	
115.	VITAMIN A RICH FRUITS	ripe mangoes, ripe papaya, other locally available vitamin A-rich fruits	
116.	OTHER FRUITS	other fruits, including wild fruits	
117.	ORGAN MEAT (IRONRICH)	liver, kidney, heart or other organ meats or blood-based foods	
118.	FLESH MEATS	beef, pork, lamb, goat, rabbit, wild game, chicken, duck, or other birds	
119.	EGGS	chicken, duck, guinea hen or any other egg	
120.	FISH	fresh or dried fish or shellfish	
121.	LEGUMES, NUTS AND SEEDS	beans, groundnuts, lentils, nuts, seeds or foods made from these	
122.	MILK AND MILK PRODUCTS	milk, cheese, yogurt or other milk products	

123.	OILS AND FATS	oil, fats or butter added to food or used for cooking	
124.	RED PALM PRODUCTS	Red palm oil, palm nut or palm nut pulp sauce	
125.	SWEETS	sugar, honey, sweetened soda or sugary foods such as chocolates, candies, cookies and cakes	
126.	SPICES, BEVERAGES & CONDIMENTS	Spices (black pepper, salt), condiments (soy sauce, hot sauce), coffee, tea, alcoholic beverages OR local examples	
127. Did you or anyone in your household eat anything (meal or snack) OUTSIDE of the home yesterday?			

Thank you for your time

ouswin Mercy Abarike,

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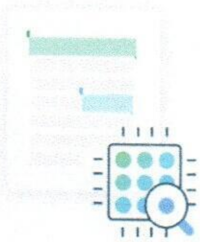

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ood of misinterpretation, no score or highlights are attributed and are indicated with an asterisk in the report (*%).

I writing percentage should not be the sole basis to determine whether misconduct has occurred. The reviewer/instructor
d use the percentage as a means to start a formative conversation with their student and/or use it to examine the submitted
nment in accordance with their school's policies.

does 'qualifying text' mean?

nodel only processes qualifying text in the form of long-form writing. Long-form writing means individual sentences contained in paragraphs that make up a
r piece of written work, such as an essay, a dissertation, or an article, etc. Qualifying text that has been determined to be likely AI-generated will be
ghted in cyan in the submission, and likely AI-generated and then likely AI-paraphrased will be highlighted purple.

ualifying text, such as bullet points, annotated bibliographies, etc., will not be processed and can create disparity between the submission highlights and the
ntage shown.

02/04/2026

*% detected as AI

AI detection includes the possibility of false positives. Although some text in this submission is likely AI generated, scores below the 20% threshold are not surfaced because they have a higher likelihood of false positives.

Caution: Review required.

It is essential to understand the limitations of AI detection before making decisions about a student's work. We encourage you to learn more about Turnitin's AI detection capabilities before using the tool.

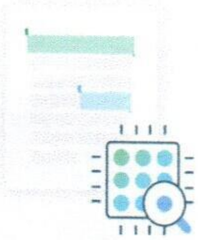
sclaimer

r AI writing assessment is designed to help educators identify text that might be prepared by a generative AI tool. Our AI writing assessment may not always be accurate (i.e., our AI models y produce either false positive results or false negative results), so it should not be used as the sole basis for adverse actions against a student. It takes further scrutiny and human dgment in conjunction with an organization's application of its specific academic policies to determine whether any academic misconduct has occurred.

requently Asked Questions

ow should I interpret Turnitin's AI writing percentage and false positives?

e percentage shown in the AI writing report is the amount of qualifying text within the submission that Turnitin's AI writing tection model determines was either likely AI-generated text from a large-language model or likely AI-generated text that was ely revised using an AI paraphrase tool or word spinner.



lse positives (incorrectly flagging human-written text as AI-generated) are a possibility in AI models.

detection scores under 20%, which we do not surface in new reports, have a higher likelihood of false positives. To reduce the elihood of misinterpretation, no score or highlights are attributed and are indicated with an asterisk in the report (*%).

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