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Local Knowledge and Innovations in Farmer-Driven Irrigation Systems in Northern Ghana

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ABSTRACT

Rainfall patterns in northern Ghana have shown a continuous contraction in the length of the rainy season over the years. Regional climate forecasts project that this trend will become even more pronounced, with climatic conditions expected to grow increasingly unpredictable and erratic. As a result, sustaining agriculture in semi-arid regions is becoming increasingly difficult without the development of irrigation systems. In addressing this challenge, most experts have focused on conventional irrigation technologies, often overlooking the role of local knowledge. This study therefore examines the range of local knowledge and innovations employed in Farmer-Driven Irrigation Systems (FDIS) for sustainable irrigation development. An exploratory sequential mixed-methods design was adopted. Qualitative data were collected through 11 key informant interviews and 5 focus group discussions, while quantitative data were obtained from a survey of 226 irrigators. The findings reveal that smallholder farmers integrate innovative local knowledge systems into FDIS at every stage of the agricultural production value chain. These innovations are diverse and include the application of ash or salt in furrows prior to transplanting to reduce pest and disease infestation, the construction of high-yielding wells, and the use of shallow wells with motorized pumps to improve access to irrigation water. Therefore, local knowledge as applied by irrigators represents a hybrid system that combines modern technologies with indigenous production practices in ways that are both affordable and sustainable for smallholder farmers. The study recommends the implementation of strategic policies that enhance farmers' sustainable access to water, inputs, and market opportunities, thereby strengthening their efforts to promote sustainable irrigation agriculture.

INTRODUCTION

In northern Ghana, the rainy season has shortened to approximately five months annually (June to October). Despite this limited period of rainfall, both floods and dry spells have become increasingly common, resulting in low agricultural yields (Atiah et al., 2021; Baffour-Ata *et al.,* 2021; Jarawura, 2014; Laube *et al.,* 2012). Under such conditions, irrigation development remains indispensable for ensuring food security and rural development by supporting year-round agricultural production (Adzraku, 2017; Adeniyi and Dinbabo, 2020). Recent statistics indicate a decline in crop productivity across West Africa, a trend projected to persist and exacerbate food insecurity, malnutrition, and rising food prices in the region (FAO, 2012; Sultan *et al.,* 2019; FAO, 2021). Expanding irrigation is therefore considered essential for extending productive farming periods and increasing food production. Achieving this will require substantial investment to at least double the current irrigated land area in

Sub-Saharan Africa (SSA) to maximize the benefits of irrigation farming (Dittoh *et al.,* 2013). However, Dittoh *et al.* (2013) report that the performance of conventional irrigation systems has been disappointing, contributing to persistent poverty and food insecurity in West Africa. Evidence increasingly suggests that smallholder, farmer-driven irrigation is more efficient and profitable than medium- and large-scale formal irrigation schemes developed by governments or civil society organizations (Dittoh *et al.,* 2013). Several studies further indicate that large-scale or formal irrigation projects often yield limited benefits relative to their high operational costs (Mendes *et al.,* 2014). These schemes typically involve substantial capital investments and intense competition for plots within irrigable areas, often marginalizing poor and less influential farmers (Awulachew *et al.,* 2005; Dinye and Ayitio, 2013). In contrast, small-scale irrigation initiatives that are led and managed by farmers themselves have demonstrated greater success (Laube *et al.,* 2012; Dittoh *et al.,* 2013). Dittoh et al. (2013) argued that such farmer-led irrigation systems (FLIS) are key to improving irrigated vegetable production in West Africa, as they require minimal capital and are thus more accessible to smallholders (Kamara et al., 2004; Awulachew *et al.,* 2005). These systems often employ simple technologies such as buckets attached to ropes or motorized pumps with hoses leading to enhanced food security, increased incomes, diversified crop production, and expanded employment opportunities (Laube *et al.,* 2008; Adzraku, 2017).

Historically, efforts to improve irrigation have focused predominantly on technological advancements and innovations (Adenle *et al.,* 2019; Gomollón-Bel, 2019), with limited attention to local knowledge-driven solutions. This neglect has contributed to unsatisfactory outcomes (OECD/FAO, 2016). Partnering and collaborating with indigenous communities is therefore crucial to promoting sustainable irrigation development. As Laube *et al.* (2012) note, traditional norms and values can enhance rather than hinder irrigation innovation. Increasing the productive application of local knowledge, encouraging innovation adoption, and promoting resource-conservation technologies are effective strategies for sustaining agricultural production, particularly in irrigation systems (Zhen and Routray, 2003; Birthal *et al.,* 2021). The most effective approach to achieving food security lies in integrating both traditional and modern agricultural technologies (Fiaz et al., 2018).

Research in Northern Ghana has largely focused on conventional irrigation systems (Achana, 2010; Agula *et al.,* 2018; Kabobah *et al.,* 2018; Baddianaah *et al.,* 2021). The few studies on farmer-led irrigation have examined its role as a climate adaptation strategy (Laube et al., 2012; Dittoh, 2020), its impact on smallholder incomes (Khatri-Chhetri et al., 2017), the relationship between irrigation suitability and farmers' socioeconomic status (Haile et al., 2022), and water management practices (Laube, 2012; Meinzen-Dick and Sharma, 2014). Other works explore farmers' resilience to environmental challenges (Laube *et al.,* 2013) and the efficiency of different irrigation technologies (Mdemu *et al.,* 2010). Collectively, these studies highlight the complex interactions among farmer-led irrigation systems, climate variability, agricultural practices, and livelihoods. Nonetheless, few have examined the role of local knowledge in fostering innovation among smallholder producers. This study therefore seeks to assess the contribution of local knowledge to innovation and the sustainability of farmer-driven irrigation systems (FDIS).

The concept of local knowledge encompasses a diverse set of skills, understandings, and practices deeply rooted in societies' histories and interactions with their natural environments (Fraser *et al.,* 2006; Woodward *et al.,* 2012; Ghorbani *et al.,* 2021). It is characterized by adaptability, context-specificity, and transmission through informal mechanisms (Derbile, 2010). Some scholars equate local knowledge with traditional or indigenous knowledge, while others adopt a broader perspective that includes both indigenous and externally derived potentially scientific knowledge at the local level (Arce and Fisher, 2003; McNamara and McNamara, 2011; Whyte, 2013). Given that no society exists in complete isolation from cultural exchange, most communities have integrated external knowledge and practices into their cultural repertoire. Thus, focusing exclusively on indigenous knowledge would be too narrow for this study. Rather, it is the fusion of indigenous and external knowledge, skills, and practices that drives local innovations in groundwater irrigation.

Local knowledge is intricately linked with customs, beliefs, and land-use practices, playing a crucial role in sustainable natural resource management and the preservation of traditional livelihoods (Pottier, 2003). It serves as a strategic resource for development by fostering innovation and enhancing adaptation to environmental changes such as climate variability (Van Huynh et al., 2020). In agriculture, smallholder farmers depend on local knowledge to optimize irrigation, reduce labor costs, increase productivity, and access markets (Kwoyiga and Stefan, 2018). Local institutions including taboos and customary regulations govern resource use to ensure sustainability and prevent depletion (Maragia, 2005; Chao and Hsu, 2011; Juanwen *et al.,* 2012; Ghorbani et al., 2021). In the context of climate change, leveraging local knowledge represents a vital strategy for building resilience and promoting sustainable adaptation (Angood *et al.,* 2002; Evers and Gerke, 2004).

The concept of innovation is multifaceted and lacks a universally accepted definition due to its broad scope. Rooted in Schumpeter's seminal work of the 1930s, innovation includes introducing new products or processes, opening new markets, sourcing new materials, or reorganizing production structures. Kogabayev and Maziliauskas (2017) define innovation as the economic impact of technological change, emphasizing new combinations of existing productive forces to solve problems. Caplow (1955) extends this view, suggesting that innovation involves not only the creation of new knowledge but also the diffusion of existing knowledge into productive activities. Twiss conceptualizes innovation as an integrative process linking science, technology, economics, and management from idea inception to commercialization. Van de Ven (1986) further argues that any idea perceived as new by those involved qualifies as an innovation, regardless of prior existence elsewhere. Goswami and Mathew (2005) emphasize innovation's value in generating profit and economic advancement through new ideas, improved practices, and continuous change.

In this study, innovation is defined as the generation of new ideas, improvement of existing practices, adoption and diffusion of successful approaches, and introduction of continuous enhancements. Innovation is particularly significant in agriculture, where irrigation inefficiencies have necessitated the adoption of farmer-led strategies promoted by institutions such as the World Bank (Dittoh, 2020). Local knowledge plays a pivotal role in informing, shaping, and reforming innovations within farmer-driven irrigation systems. Rooted in centuries of environmental interaction, yet enriched by externally acquired knowledge and skills, local knowledge provides farmers with the adaptive capacity to optimize irrigation, reduce costs, and enhance productivity (Fraser *et al.,* 2006; Woodward *et al.,* 2012; Kwoyiga and Stefan, 2018; Ghorbani *et al.,* 2021). Through locally grounded customs, beliefs, and land-use practices, farmers develop context-specific, innovative solutions that efficiently utilize available resources (Pottier, 2003). Moreover, local knowledge fosters sustainable water management, mitigates dependence on erratic rainfall, and enhances resilience against climate-induced challenges (Ghorbani *et al.,* 2021; Pienaah *et al.,* 2024). When integrated with scientific insights, it forms the foundation for sustainable, innovative, and resilient irrigation systems in West Africa.

MATERIALS AND METHODS

Study Area

The study was conducted in the Kassena Nankana West District of Ghana. The district is located approximately between latitude 10.97° North and longitude 01.10° West covering approximately 1,004 sq. km of total land area Generally, the relief of the district is low-lying and undulating with isolated hills rising up to 300 meters above sea level and mainly drained by the Sissili River, Atankwidi and Anayare Rivers and their tributaries (GSS, 2014). The district is within the Guinea Savannah with two pronounced seasons: dry and wet seasons. The dry season stretches between November and April and is warm, dusty and dry, and characterized by the absence of rainfall and winds carrying dust from the Sahara (harmattan) (GSS, 2014). The wet season ranges from May to October and is characterized by a lot of rains with a mean annual rainfall between 1,000 - 1,150 mm (Apuri et al., 2018).

A total population of 90,735 was recorded in the 2021 population and housing census for the district (GSS, 2022). It was reported that about 90.7 percent of all households in the district are engaged in agriculture and 98.2 percent of these agrarian households engage in crop farming (GSS, 2014). This study has been conducted in the Eastern part of the district in Mirigu and Sirigu communities (Figure 1) and along the Anayare and Pa-anga-Atankwidi basins where most of the farmer-driven irrigation in the district can be found (Laube *et al.,* 2012). Despite the impediments posed by limited surface water resources within the study area but an apparent abundance of groundwater, self-motivated farmers have developed local irrigation practices by integrating both external and indigenous knowledge since the 1950s and greatly expanded since the 2010s (Laube *et al.* 2012). In order to understand how different forms of knowledge have been integrated and in which ways the innovative local irrigation knowledge helps to improve irrigation, this study focused on the eastern part of the district.

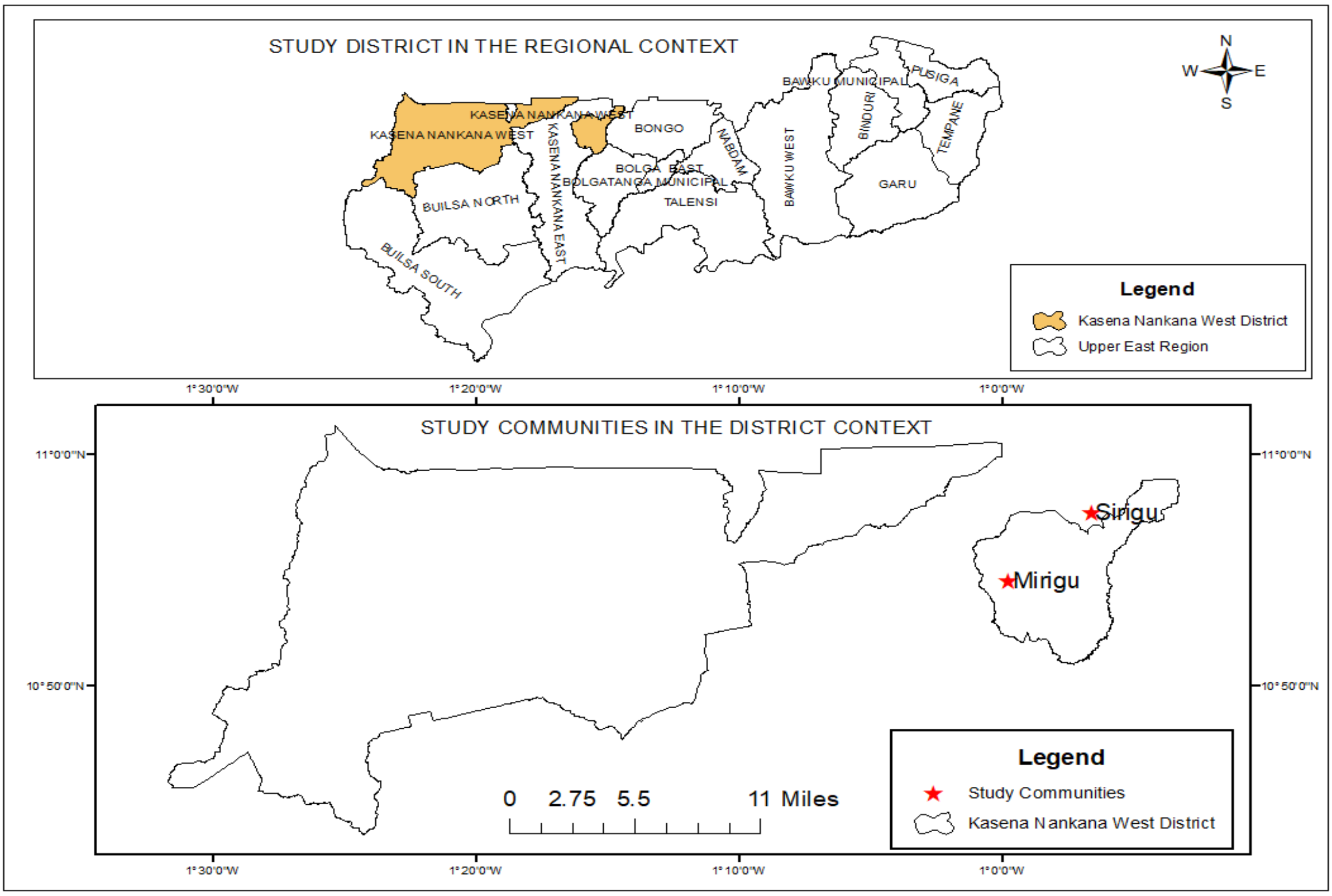

Figure 1. Map of the Study Area
Source: Authors' construct (2025)

Methodology

The study adopted an exploratory sequential mixed methods design. This approach was chosen to first collect qualitative data to gain a deeper understanding of local irrigators' innovations and how these contribute to enhancing irrigation practices. Subsequently, quantitative data were collected to examine the diffusion and prevalence of local innovations within farmer-driven irrigation systems (FDIS) (Johnson *et al.,* 2007; Bazeley, 2015). The development of the survey questionnaire was informed by insights obtained from the earlier qualitative phase specifically from interviews and focus group discussions (FGDs). The sample size for the quantitative survey was determined based on a reconnaissance survey, given the absence of reliable data on the population of smallholder irrigation farmers in the study area

(Dittoh *et al.,* 2013). Accordingly, three (3) methods of data collection were employed: key informant interviews (KIIs), focus group discussions (FGDs), and a quantitative survey.

Key Informant Interviews

Eight (8) experienced irrigators were purposively selected as key informants four (4) from each of two randomly chosen communities based on their experience and involvement in irrigation farming. Each had practiced farmer-driven irrigation for at least five years. In addition, three (3) agricultural extension officers (AEOs) from the Ministry of Agriculture, who were actively engaged in extension services and knowledge transfer within the study communities, were purposively selected as key informants. The interviews were conducted using a semi-structured guide and analyzed thematically. Thematic analysis involved systematically examining responses to identify recurring patterns and themes related to the role of local knowledge in facilitating innovation adoption within FDIS.

Focus Group Discussions (FGDs)

A purposive sampling approach was also employed to select between 10–12 irrigators representing different age groups for participation in the FGDs, with three (3) participants drawn from each of the selected communities. The FGDs aimed to provide a broader understanding of the spread and nature of innovations within FDIS. Three (3) groups were organized to represent the main irrigation methods (motorized pump and bucket) as well as gender representation within each community. However, due to the absence of female irrigators in Sirigu, it was not possible to conduct a women's FGD there. In total, five (5) FGDs were conducted using a semi-structured interview guide administered through face-to-face sessions. The data obtained were analyzed thematically and integrated with the findings from the KIIs to generate a comprehensive understanding of local innovation processes.

Quantitative Survey

The quantitative phase involved a structured survey administered to irrigators using a multi-stage sampling method. Stage 1: A cluster sampling approach was used to select two irrigation communities namely; Mirigu and Sirigu. Stage 2: A stratified sampling technique was employed to select irrigators representing different irrigation methods. In Mirigu, 85 bucket irrigators, 41 motorized pump irrigators, and 6 mechanized borehole irrigators were selected. In Sirigu, the sample included 32 bucket irrigators, 60 motorized pump irrigators, and 2 mechanized borehole irrigators. Stage 3: Finally, a systematic sampling procedure with a uniform interval of two (2) was used to select respondents for the survey. In total, 226 irrigators were interviewed through face-to-face questionnaire administration. To ensure convenience, efficiency, and data reliability, the Kobo Collect mobile data collection tool was utilized. The quantitative data were analyzed using SPSS, applying descriptive statistical techniques to summarize and interpret the data.

RESULTS AND DISCUSSION

Diversification in Vegetable Production for Minimizing Risks of Livelihood Failure

Major vegetables cultivated by farmers in FDIS include bell and chili peppers, tomatoes, onions, green pepper, okra, garden eggs, leafy vegetables such as 'alefu' (amaranth), 'bito' (roselle) and 'bengto' (bean leaves). It was found that more than 80 percent of irrigators cultivate pepper, tomatoes, and okra as shown in Figure 2. However, pepper remained the most dominant vegetable cultivated with about 92 percent of irrigators owning pepper farms. Therefore, for the purposes of this study, the researchers only focused on the cultivation of pepper in FDIS since it is the most dominant and largest crop cultivated as well as the critical role of local knowledge systems and innovations in its production process.

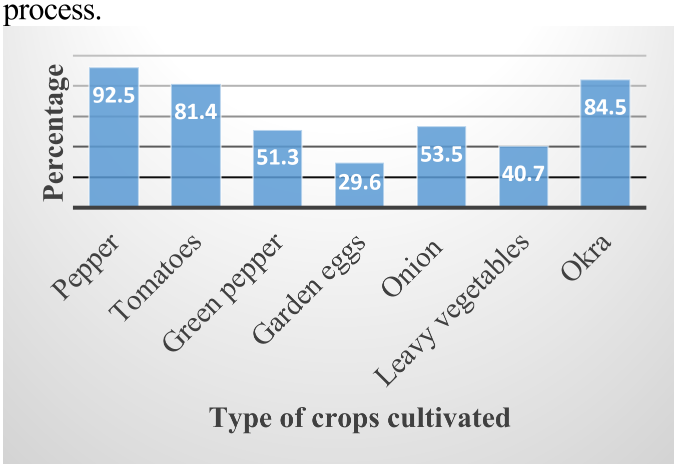

Figure 2. Types of crops cultivated in FDIS (N=226)
Source: Field survey (2025)

The findings indicate a prevalent practice among farmers wherein they exhibit a preference for either processing their own pepper seeds or acquiring them from fellow farmers or relatives, ensuring the authenticity of the pepper varieties selected for cultivation. The study identified three primary types of pepper varieties cultivated within the district, namely the 'local', 'rubber', and 'agric-rubber'. The 'local' variety is characterized by its leafy nature, tall growth, and bigger fruits when properly nurtured, requiring comparatively lesser water consumption compared to other varieties. Conversely, the 'rubber' variety exhibits a shorter stature, less foliage, yet boasts higher yields with shorter harvest period. The 'agric-rubber' variant, purportedly a hybrid of the 'local' and 'rubber' varieties, combines attributes from both parent strains. Notably, many farmers opt to cultivate a combination of two or all three varieties simultaneously. For instance, a farmer in Mirigu reported such a practice, indicating a pragmatic approach to pepper cultivation.

"*We cultivate a mixture of the different varieties. I cannot mention one farmer that I know who is cultivating only one variety. During seed selection, we are only interested in the fruits that look appealing and the plant also good. Besides, buyers do not reject any of them so why should we be bothered? Also, when you go to beg seed from a farmer, will you go enquiring what variety he has before begging? Clearly no!"* (FGD, Mirigu, April 2024).

Farmers assert that cultivating a combination of pepper varieties offers distinct advantages over mono-varietal cultivation, driven by three key considerations. Firstly, each variety possesses unique qualities that complement one another, serving as a safeguard against total crop failure in instances of water scarcity, among other challenges. Secondly, the diversity in varieties facilitates an extended harvest period, as different varieties mature at different times, thereby mitigating the risk of market failure associated with a single harvest peak. As such, cultivating a mix of varieties is deemed a prudent strategy, leveraging the strengths of each while mitigating their respective disadvantages. This approach underscores farmers' adaptive strategies to maximize yield potential and minimize risks inherent in agricultural production.

Land Preparation and Soil Management

The study highlighted two primary techniques in land preparation for irrigation, namely furrows and beds, which are largely influenced by the method of irrigation. These techniques typically involve the use of either hoes or bullock ploughs, with a predominant preference among irrigators for the hoe-based approach in furrow formation. However, in instances where larger farm sizes are involved such as in motorized pump or mechanized borehole irrigation methods, bullock ploughs are commonly employed due to their efficiency in handling such expansive areas. This choice is pragmatic, as utilizing hoes for land preparation on larger plots, as seen in bucket irrigation, would prove to be an arduous task. Furthermore, the study revealed that when bullock ploughs are utilized for furrow formation, significantly larger volumes of water are required for irrigation compared to the hoe-based method. This finding underscores the practical implications of the chosen land preparation method on water consumption, highlighting the need for tailored approaches based on the scale and context of irrigation practices. It was in the light of this a male young farmer responded, "…. *I make furrows by hand because ploughing with bullocks will widen the furrows and that is not suitable in areas like ours due to insufficient water* …." (KII Mirigu, 2024). This suggests that the manner in which farmland is prepared is contingent upon both the availability of water resources and the irrigation methods selected by farmers. Consequently, farmers exhibit a heightened awareness when selecting land preparation techniques, tailoring their choices to align with their intended irrigation methods. Moreover, in the motorized pump and mechanized borehole irrigation methods, furrows are considered incomplete unless waterways are established to facilitate efficient watering. These waterways consist of shallow channels constructed to interconnect each furrow within a line or column, typically positioned along the walkway as illustrated in Figure 3.

Figure 3. Picture showing a waterway created for easy watering in motorized pump irrigation
Source: Field Survey (2025).

Recognizing that disease and pest infestation pose significant challenges to farmer-led irrigation cultivation, particularly on previously cultivated lands, farmers have adopted the practice of applying table salt or ash in the furrows before transplantation. This preventive measure aims to mitigate the risk of pest and disease infection by moderating the exposure to pest and disease infection on crops, thereby enhancing crop health and yield potential. In a women FGD in Mirigu, a middle-aged farmers reported, "*In order to control diseases and insects, World Vision (*an NGO in the district) *taught us to sprinkle ashes in the prepared furrows before transplanting …*" (Women FGD, Mirigu, 2024). This practice effectively eradicates any existing diseases within the soil and eliminates insect/pest eggs present in the land. She added "*World Vision also taught us to add table salt to our fertilizer when applying to kill diseases and insects/pests attacking crops …*" (Women FGD, Mirigu, 2024). This integration of external knowledge into local practices signifies farmers' proactive adoption and adaptation of innovative techniques to enhance their irrigation cultivation.

Innovations in Water Management and Access for Irrigation

The study found that majority of irrigators procure their water from shallow wells situated along riverbanks or in riverbeds, particularly during the dry season when rivers cease to flow. However, in recent years, affluent farmers have begun to invest in drilling and installing mechanized boreholes on their properties at home for irrigation purposes. This emerging trend has been driven by the escalating water scarcity experienced by many farmers in recent times, prompting them to seek alternative water sources. Additionally, the study highlighted that the choice of methods of irrigation and watering techniques, is partially influenced by the scale of farming operations. In light of the foregoing, a 45 years old male participant asserted, *"I started with manual shallow well (bucket) irrigation, and moved to motorized pump when I needed to expand my farm, but now I have to switch to mechanized borehole due to the increasing water challenges at the river side ….*" (KII, Mirigu, 2024).

Due to increasing water crisis, many farmers have over time, developed strategies to manage the challenge. For instance, a 39 years old male participant reported as follows "…. *I wanted to cultivate two acres this year but for the water constraint. The water is not even adequate for the less-than one acre I cultivated so I have to abandon a section of the farm ….*" (KII, Mirigu, 2024). In a similar response, a FGD participant corroborated that *"…. we are forced to cultivate at a scale that the available water can serve. We also dig as many wells as possible to manage our gardens. I have for instance 3 dugouts in the riverbed but would have loved more but for space ….*" (FGD, Mirigu, 2024).

The scarcity of water has compelled many farmers to either reduce the size of their farms or abandon portions upon realizing that the available water supply is insufficient to irrigate the entire farm. Farmers contend that the land exhibits variability in water availability across its layers. Consequently, while one well may yield inadequate water, digging another a few meters away may yield abundant water due to differences in underground layers. This variance motivates farmers to dig multiple wells, as the likelihood of accessing sufficient water increases with the number of wells drilled. The absence of precise technologies for determining optimal water sources necessitates farmers to engage in trial and error, experimenting with different locations to identify suitable well sites. Consequently, upon identifying areas with ample underground water, farmers take measures to protect these wells for subsequent irrigation seasons by carefully refilling and maintaining them. However, this process is limited by the natural expansion of wells caused by erosion and soil movement. In an effort to prolong the lifespan of these wells, some farmers have begun constructing them using durable materials such as blocks or concrete, as depicted in Figure 4. This is evident in the extract from the response of a 42 years old male participant in a FGD,

"… I have suffered countless losses in irrigation farming and it can largely be attributed to water access. You plant with the hope that you will get water only to be disappointed midway and you have little to do about it. So, one time, World Vision advocated the idea of building our wells (an age-old practice that was built at homes to provide water for domestic use) to help maintain them. So, last year after digging a good water-yielding well, I decided to build it and it has actually been helpful to me" (FGD, Mirigu, 2024).

However, the dissemination of this new knowledge as now applied for irrigation farming remains constrained, as not all farmers are able to implement it. Some farmers do not cultivate on their own land and may encounter challenges obtaining permission from landowners to construct wells on their farms aside the financial requirement that come with the innovation. This reluctance stems from the fact that these plots are often cultivated by the landowners themselves during the rainy seasons, and the presence of wells may impede or pose hazards to farming activities during this period.

Figure 4. Constructed shallow well for motorized pump irrigation

Source: Field Survey (2025).

Moreover, certain motorized pump irrigators are now repurposing shallow wells in riverbanks (both constructed and unconstructed), traditionally associated with bucket irrigation (*Fig. 4 & 5*). This shift in usage is attributed to the escalating water scarcity in riverbeds caused by widespread sand mining activities. In a FGD, a 30 years old male farmer reported the following:

In February 2022, I could not get enough water from my three (3) riverbed dugouts. So, I just decided to put my machine in my junior brother's shallow well just to try and see, even though I have heard others do that, I have not seen it before. To my greatest surprise, it worked. Now, I solely depend on that well. That was the beginning of our break-through. Now, many of us here use the shallow wells and they have been of great help. These wells even appear to be more water-yielding than the dugouts in the riverbed .... (FGD, Mirigu, 2024).

This innovation, although recently discovered, is rapidly gaining popularity. In areas where the shallow wells are too deep, a stand is installed adjacent to the well to lower the pumping machine for ease of operation as could be seen in Figure 5.

Figure 5. Shallow well in riverbank for motorized pump irrigation

Source: Field Survey (2025).

Moreover, an increasing number of farmers are exercising selectivity in the choice of vegetables to cultivate. It is widely acknowledged among farmers that various crops demand specific levels of water and fertilization for optimal growth. Consequently, farmers who are aware of insufficient water availability in their fields opt to cultivate crops such as tomatoes, leafy vegetables, and okra. They asserted that these early maturing crops, including tomatoes, typically require only three months to reach maturity. As a result, by the onset of February, when water access is heightened, they would have already completed harvesting. Additionally, it was disclosed that this practice is predominantly adopted by female and older farmers. For instance, a 38 years old female participant reported as follows:

"*Due to the water challenges and considering that I am a woman, getting adequate water for a pepper farm would be very challenging because pepper requires more water than the other crops. Thus, I have rather cultivated more vegetables like bean leaves, 'alleefo', 'berise', 'bito', okra, tomatoes and water melons which require minimal water quantities to grow unlike pepper" ... (KII, Mirigu, 2024).*

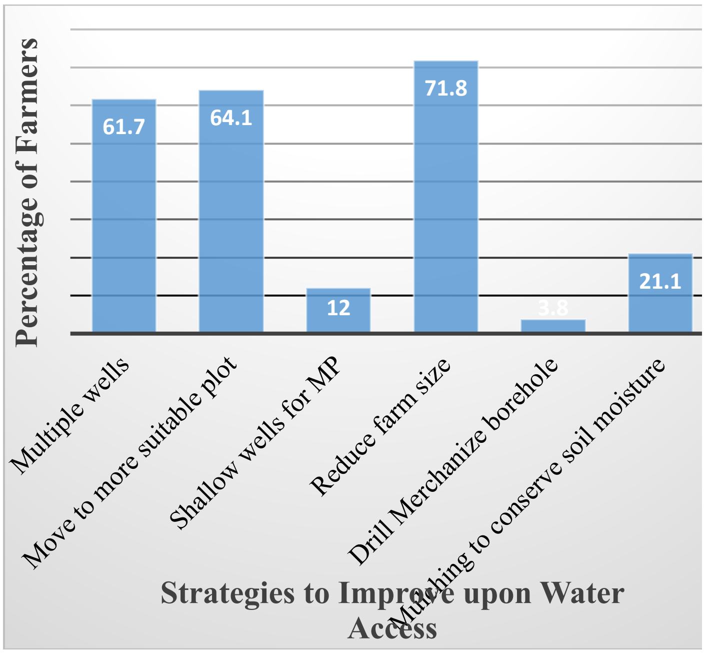

Figure 6. Strategies for improving Water Access in FDIS (N=226)
Source: Field Survey (2025).

The result from Figure 6 above provides a summary of the strategies employed by farmers to address their water-related challenges. A notable observation is that farmers often utilize a combination of two or more of these strategies concurrently. For instance, a farmer who opts to dig multiple wells may as well reduce their farm size due to water constraints, and may have relocated to their current farm location due to inadequate water availability in their previous farm, or may do so in the future. However, the adoption level of a particular strategy should not be equated with its perceived importance. Rather, several factors influence the adoption level, including available resources, familiarity with the strategies, and accessibility of the strategy. It was noted that farm sizes are primarily influenced by water availability and access to technology. Additionally, there is a notable trend of motorized pump irrigators increasingly turning to shallow wells in riverbanks, historically associated with bucket irrigation, as their primary water source (12 percent). Despite the practice being introduced to the district only within the past three years, it is rapidly becoming popular.

Methods of Pest and Disease Control

The study highlighted that the selection of pest and disease control measures is contingent upon the specific challenges encountered by farmers. Consequently, the agricultural inputs required are determined by the particular needs of the farm. Various agrochemicals for pest and disease control are available to address different agricultural issues. For example, farmers utilize 'Sulphur 80' to enhance crop growth, 'Co-optic' to maintain freshness, 'Milton' to combat caterpillars, 'Attack,' and several others. Recently, a new chemical known as 'E-master' has emerged, purportedly combining the attributes of many of the aforementioned agrochemicals. Consequently, it is perceived as the most effective pest and disease control agrochemical available to date. Despite the distinct functions of each agrochemical input, farmers often blend multiple chemicals for spraying to enhance efficacy and achieve optimal outcomes. Although farmers may lack formal technical expertise in the chemical combinations and potential reactions, their practical knowledge and experience accumulated over time have rendered them proficient in their application through shared knowledge and continuous experiential learning within their community. As reported by a 29 years old male participant in a FGD: *"…. Normally, you can mix 'Milton', 'Sulphur 80', and 'Attack' together for spraying so that you can achieve growth, flowers and killing of insects or pest all at the same time. Even the rate of efficacy is also improved when you mix them. So, rarely will you see a farmer applying only one of the above, except that it is 'E-master'" (FGD, Mirigu, 2024).*

It was also reported that whether or not a farmer makes good harvest largely depends on his or her own efforts, although the influence of faith cannot be entirely disregarded. For instance, a 45 years old male mechanized borehole irrigator reported:
"Now, if you want your crops to grow more flowers leading to great yield, there is a chemical you can apply to achieve that. Likewise, if you need the crops to be healthy and fresh, and free from pests or disease, there are chemicals for all that. There is even a chemical that can re-blossom old pepper plants to produce fresher and larger fruits again (KII, Mirigu, 2024)".

These strategies enable farmers to prolong their harvest duration while preserving the quality of their produce through the implementation of suitable measures. Consequently, it can be inferred that a significant impediment to both productivity and quality lies in the farmer's ability to procure the appropriate agrochemicals and apply them correctly.

Farmers have adopted a practice of regularly applying pest and disease control measures from the nesting stage to harvesting. The research indicated that managing pests and diseases becomes considerably more challenging once they have already infected crops. Furthermore, consistent spraying at two-week intervals was found to be effective in preventing the initial onset of diseases and pests on the farm. Conversely, failure to adhere to this preventive measure results in significantly higher costs for farmers when they need to manage infestations after they have occurred. In a FGD, a participant stated:

"… Spraying/chemical application starts after germination of the pepper through to transplanting and "harvesting. So, every week or two you need to spray till you have made your mind, you were vacating the farm. That is when the rainy season has set in or is about setting in. By doing this, 'giriba' (implying folded leaves and stunted growth) or sticky leaves or plant death would not occur in the place or their impact will be minimal …." (FGD, Mirigu, 2024).

The study also underscored that it is not advisable for prolonged cultivation on the same parcel of land due to the potential for pest and disease infestation, which can leave crops susceptible to damage. For example, a 56 years old male participant reported:

"… A land that has been cultivated for a maximum of three years must be allowed to fallow and recover from disease and pest infestation as further attempts to cultivate same may lead to low or no yield at all. Crops cultivated on old lands of this nature often die at flowering stage …." (KII, Sirigu, 2024).

This suggests that farmers must secure different plots to sustain their cultivation endeavors. Additionally, some farmers engage in crop rotation, albeit with a limited selection of crops since continuous planting of the same crop types can lead to nutrient depletion in the soil and an increase in bacterial concentration, thereby heightening the risk of pest and disease infestation. Consequently, crop rotation serves to disrupt the cycle of disease and pest infestation while allowing the soil to replenish its fertility. However, despite the potential benefits of crop rotation in extending the cultivation lifespan of a plot, it is feasible only for onions to be rotated with crops such as pepper, tomatoes, or other vegetables commonly cultivated in FDIS. This limitation arises from the predominance of crop species within the same group, rendering them indispensable and impeding the effectiveness of crop rotation as an innovation for addressing pest and disease challenges.

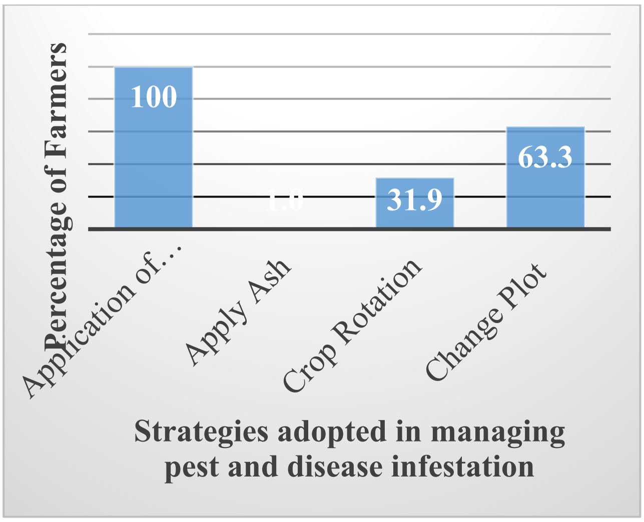

Figure 7. Strategies adopted for Pest and Disease Control (N=226)
Source: Field Survey (2025).

As revealed in the in-depth interviews, the survey results align with the discovery that no farmer relies solely on local remedies for pest and disease control in irrigation farming (Figure 8). Instead, the agricultural sector has undergone modernization with the integration of external inputs, albeit with varying application methods, showcasing the localization of knowledge. The adoption of crop rotation stands at a modest 31.9 percent, largely due to the limited options for suitable crops to rotate. Moreover, seasoned farmers face the dilemma of either switching plots or implementing crop rotation, as cultivating the same plot for more than three years is deemed unsustainable.

Methods of Soil Fertility Management

The research revealed a heightened demand for agrochemical inputs attributed to the region's low soil fertility and vulnerability to pest and disease infestation. This increased demand, combined with escalating manufacturing costs, has led to a surge in input prices. Confronted with this economic reality, farmers have resorted to innovative strategies to address their challenges. Among these strategies are the adoption of mixed-cropping practices, prudent financial management through smart saving techniques, and participation in susu borrowing, commonly known as village savings and loans associations (VSLAs), to pool resources for the purchase of inputs needed for agricultural production. For instance, a 30 years old male participant reported as follows,

"…. Evans, one needs to be smart in this business. It is not for nothing that I cultivated green pepper,

tomatoes, okra, leafy vegetables, garden eggs and pepper. The major crop we target to cultivate is the pepper but it takes too long to harvest and is very expensive to cultivate. However, okra, green pepper, tomatoes and leafy vegetables have much shorter maturity periods. So, cultivating these crops in a meaningful quantity when harvested and sold will help buy additional inputs to manage the pepper as well as sustain the household. If you don't do this then you may either steal or sell your entire household to help care for the garden" (KII, Mirigu, 2024).

Farmers engage in strategic mixed-cropping practices, considering the maturity periods of different crops to optimize their cultivation efforts. The question remains: If it was cheaper to cultivate other crops, why are farmers bent on cultivating pepper knowing well it is expensive to do so? However, farmers prioritize pepper cultivation due to its perceived profitability. They view pepper as a high-yielding crop that offers extended harvest periods and commands favourable market prices compared to other crops. Consequently, farmers are willing to allocate resources to pepper cultivation, recognizing it as a lucrative investment. Moreover, farmers face challenges in saving from their modest earnings due to competing financial obligations. To address this, they adopt a practice of purchasing inputs during the harvest period, ensuring readiness for the subsequent irrigation season. Additionally, farmers devise strategic approaches to navigate challenges in accessing credit, a persistent obstacle in agricultural operations, to avoid disruptions during cultivation.

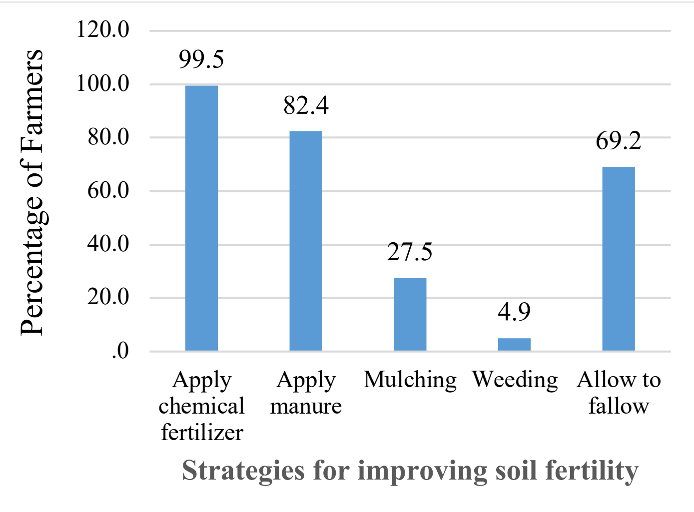

Figure 8. Strategies for Soil Fertility Management (226)
Source: Field Survey (2025).

In a detailed discussion, the study revealed that prolonged cultivation on a single piece of land heightens the risk of crop infestation by pests and diseases. In response, farmers have embraced innovative practices such as incorporating table salt or ash into furrows during land preparation prior to transplanting, aiming to moderate the exposure of crops to pest and disease infestations. This preventive measure is motivated by the understanding that continual cultivation provides a consistent food source for pests, leading to population surges and increased vulnerability of crops to infections (Mason, 2003). By applying ash or salt, farmers effectively disrupt the pest cycle, eliminating pests and their eggs from the soil and thereby creating favorable conditions for sustained production. This approach reflects the innovative process of 'generating new ideas, as advanced by Evans (1991), whereby conventional materials such as ash and salt are repurposed to address farmers' practical challenges. Consequently, the identification of novel applications for readily available resources underscores the adaptive capacity of farmers, contributing to agricultural resilience and productivity.

In line with the findings of Laube et al. (2012), Dittoh (2020), and Baddianaah et al. (2021), the study identified water scarcity as a significant and persistent challenge within the Farmer-Driven Irrigation Systems (FDIS). To address this issue, farmers have diversified their water sources, incorporating shallow wells located both along riverbanks and in riverbeds, along with the adoption of mechanized boreholes for irrigation purposes. Additionally, some farmers have innovatively repurposed shallow wells along riverbanks for motorized pump irrigation, a departure from their previous use solely for bucket irrigation. This shift is attributed to the depletion of groundwater caused by extensive sand mining activities, rendering riverbeds less reliable sources of water. Despite the potential benefits of this innovation, such as increased farm sizes and reduced labor requirements, its adoption remains limited to a few early adopters due to its recent introduction and unfamiliarity among farmers (Kaasinen, 2005).

Moreover, farmers are embracing innovations such as the construction of high-yielding shallow wells to enhance their access to water for irrigation, or the installation of mechanized boreholes for increased water availability. These initiatives exemplify both the generation of novel ideas, as proposed by Evans (1991), and the refinement of existing practices, as outlined by Goswami and Mathew (2005). While the construction of shallow wells is not new and has historically served to safeguard community water sources for domestic use, its application along riverbanks for irrigation marks a reimagining of traditional practices. Similarly, the construction of efficient water-yielding wells represents an innovation by enhancing the functionality and output of conventional shallow wells. However, the adoption of mechanized boreholes remains limited to a minority of farmers due to the substantial upfront investment required.

Conversely, innovative practices such as mulching has been embraced to prolong soil moisture retention, aligning with previous research by Baddianaah et al. (2021) and Naveen-Gupta et al. (2021), which identified mulching as an effective strategy for managing water scarcity by preserving soil moisture. Additionally, farmers prioritize the cultivation of less water demanding crops to mitigate the need for extensive irrigation. This deliberate crop selection reflects farmers' attentiveness to groundwater levels in their fields, often informed by their practical experience. They opt for less water-intensive or early-maturing crops, a strategy consistent with the findings of Wossen et al. (2014), who observed similar practices prevalent among farmers in farmer-driven irrigation systems. This trend is particularly notable among female farmers, as highlighted in the research by Obuobie and Danso (2013).

Despite the rising costs associated with inputs, they remain indispensable in contemporary irrigation production, corroborating the findings of Adzraku (2017) and Dittoh (2020) that the cost of inputs is one of the restraining factors facing agricultural production in West Africa. In response to these challenges, farmers have devised innovative financial strategies, such as smart mixed-cropping, where crops with varying maturity periods are cultivated strategically. This practice, while previously noted by Laube et al. (2012) and Dittoh et al. (2013), exhibits novelty in its strategic application and diverse purposes, diverging from conventional mixed-cropping approaches. The integration of early maturing crops to finance inputs for other crops represents a novel adaptation within mixed-cropping practices, aligning with the principles of generating new ideas emphasized by Evans (1991) and Goswami and Mathew (2005), which suggest that innovation can stem from reinterpreting existing practices rather than introducing entirely novel concepts.

CONCLUSION

Local knowledge as applied by smallholder farmers reflects a dynamic integration of innovations that combine new scientific and external technologies with indigenous knowledge systems rooted in culture and tradition. This fusion produces approaches that are both affordable and sustainable for smallholder farmers. The study revealed that farmers proactively adopt innovative practices to mitigate risks associated with continuous cultivation, including pest and disease infestations. For example, by incorporating locally available materials such as table salt and ash during land preparation, farmers disrupt pest life cycles while maintaining soil health.

To address persistent challenges of water scarcity, farmers employ diverse adaptive strategies such as sourcing water from multiple points and utilizing shallow wells for motorized pump irrigation demonstrating resilience, creativity, and effective resource management. Additionally, the study identified innovative financial management practices among farmers, including strategic savings and mixed cropping, which help alleviate input affordability constraints.

To reinforce and scale up these farmer-led efforts, the government should consider expanding the Planting for Food and Jobs (PFJ) programme to explicitly support irrigation-based cultivation. Ensuring the year-round availability of subsidized agricultural inputs such as fertilizers and improved seeds would enhance farmers’ access to essential resources in a timely manner, thereby improving productivity and the sustainability of irrigation farming systems.

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CONFLICT OF INTEREST

The authors have declared no conflict of interest regarding the publication of the paper.

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