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Small-Scale Irrigation Farming as a Climate-Smart Agriculture Practice; Its Adoption and Impact on Food Security for Ethiopian Smallholder Farmers: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

This review examines the adoption of small-scale irrigation farming as a climate-smart agriculture (CSA) practice and its influence on food security among smallholder farmers in Ethiopia. As climate change continues to threaten agricultural productivity in Sub-Saharan Africa, CSA practices offer

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potential solutions for enhancing resilience and food security. Small-scale irrigation, in particular, has gained attention as a promising strategy for Ethiopian smallholders. The study synthesizes existing literature to analyze the factors influencing the adoption of small-scale irrigation systems, the challenges faced in implementation, and the impacts on food security outcomes. Findings indicate that adoption is influenced by a complex interplay of socio-economic, demographic, and institutional factors. Access to credit, land tenure security, and farmers' education levels emerge as key determinants of adoption rates. Implementation challenges include limited technical knowledge, inadequate infrastructure, and water resource management issues. Despite these obstacles, evidence suggests that small-scale irrigation can significantly improve crop yields, income diversification, and overall household food security. Irrigated farms show higher productivity and greater resilience to climate variability compared to rain-fed agriculture. The review also highlights the gender dimensions of irrigation adoption, noting that women often face greater barriers to accessing and benefiting from these technologies. Policy implications point towards the need for targeted support to overcome adoption barriers, including improved extension services, credit facilities, and gender-sensitive interventions. Whereas small-scale irrigation demonstrates considerable potential as a CSA practice, its success depends on context-specific implementation and supportive policy environments. This review emphasizes the importance of holistic approaches that address both technical and socio-economic aspects of irrigation adoption to enhance food security for Ethiopian smallholder farmers in the face of climate change.

Keywords: Climate change; climate-smart agriculture; food security; frequent periods; small-scale irrigation.

1. INTRODUCTION

Climate change poses a significant risk to food security systems and represents one of the major challenges faced in the 21st century [1]. It is causing significant pressure on agricultural systems, particularly for small-scale farmers in sub-Saharan Africa, threatening their ability to produce enough food and maintain their livelihoods [2]. The increasing decline in agricultural production, coupled with the increased incidence and severity of famines, changes in climate, and dependence on rain-fed agriculture, is making it harder to access food and causing food shortages [3]. Smallholder farmers in sub-Saharan Africa heavily rely on farming methods that are affected by climate conditions and limited to certain seasons, often putting them at risk of falling into various levels of poverty [4]. These individuals, who have limited access to resources such as financial capital, arable land, and advanced technology, are commonly recognized as smallholder farmers. They are mostly located in rural areas where agricultural practices are the primary means of reducing poverty [5]. However, despite their contribution to rural economic development, most smallholder farmers, especially in Africa, face challenges such as poor yields, food insecurity, and rural poverty due to extreme climate events, climate variability, and change [6]. For agriculture to successfully address the issues of food security brought on by severe climate change, considerable changes must be made. Adopting improved land and water management practices, among other sustainable technologies, can assist smallholder farmers in sub-Saharan Africa to minimize poverty and improve food security [7]. The adoption of small-scale irrigation is one of the better water management strategies in agriculture. It is crucial to consider small-scale irrigation as a standard practice in smallholder agriculture that can enhance production, adapt farming techniques to cope with climate change, ensure household food security, and contribute to national development goals. Climate change poses a significant threat to Ethiopia's agricultural sector due to rising temperatures and unpredictable rainfall patterns; particularly affecting smallholder farmers' water needs for crops [8]. Alternative agricultural practices that can withstand climate change shocks and develop resilience in rural households are necessary [9]. According to Adane [3], climate change resilience has gained global attention in developed and least-developed nations, including Ethiopia. It is the capacity to effectively respond to and recover from unexpected events, reducing vulnerability and promoting development [10]. One of the technological approaches to resilience building recently gaining momentum is climate-smart agriculture (CSA) [11]. CSA is a framework that captures the concept of agricultural systems frequently developed and implemented to simultaneously improve food security. Climate-smart

interventions respond to the continuous challenges of climate change and may help smallholder farmers meet their needs such as enhanced yield, adaptation, and mitigation. The usefulness of these new techniques helps farmers decide on adopting climate-smart agriculture based on their local resources, context-specific factors, and agroecology [12].

Moreover, understanding climate-smart agricultural practices adoption decisions and their determinants helps identify production constraints for smallholder farmers, addressing low productivity at farm and household levels, and improving food security and income. This contributes to improving resilience and adaptability to achieve the Sustainable Development Goals (SDGs). The Ethiopian government is promoting the adoption of advanced agricultural technologies to combat droughts and meet the growing population's food needs. This includes strategic implementation using available local resources, such as small-scale irrigation, which is a crucial method that enhances food security and improves the lives of smallholder farmers through innovation and resilience [13,14]. The primary goal of agricultural transformation in Ethiopia is to enhance the food security of rural farmers through irrigation development [15].

Small-scale irrigation practices have been proven to enhance farmers' resilience to climate change and boost their income [13]. The adoption of these practices empowers farmers to mitigate the effects of climate change by maximizing productivity per unit of land and improving production volume [15]. Adopting small-scale irrigation technologies as part of climate-smart agriculture strategies allows for enhanced agricultural resilience, and improved water efficiency, and ultimately contributes to sustainable food production amidst changing climatic conditions, as well as reducing greenhouse gas emissions and promoting food security [16,17].

There are few reviews evaluating small-scale irrigation as a climate-smart agriculture practice and its impact on household income. To address this gap, this review aims to assess the adoption of small-scale irrigation farming as a climate-smart agriculture practice and its influence on the food security of smallholder farmers in Ethiopia. Specifically, it aims to review factors that influence smallholder farmers' decisions to adopt small-scale irrigation, as well as the impact of small-scale irrigation on smallholder farmers' household food security.

1.1 Types of Irrigation Systems in Ethiopia

1.1.1 Traditional small-scale irrigation systems in Ethiopia

Ethiopia has a rich history of traditional small-scale irrigation practices that have been developed and refined by generations of smallholder farmers. One of the most common traditional irrigation systems is the river/stream diversion canal, where farmers construct simple canals to divert water from nearby rivers and streams onto their farmlands. These gravity-fed canal systems are often labour-intensive to construct and maintain, but they provide a reliable source of irrigation water, especially during the dry seasons when rainfall is scarce.

Another traditional small-scale irrigation technique prevalent in Ethiopia is the spring-fed irrigation system. In areas with abundant groundwater resources, farmers have learned to harness the natural flow of springs to irrigate their crops. These spring-fed systems are typically low-cost and require minimal infrastructure, making them an attractive option for resource-constrained smallholders [18]. The water is often diverted through small canals or pipes to the farmland, providing a consistent supply of moisture for the crops.

Flood-based irrigation, where farmers utilize the natural flooding of rivers and streams to inundate their fields, is also a traditional small-scale irrigation practice in Ethiopia. This method is particularly common in areas with seasonal flooding patterns, as farmers time their planting and cultivation activities to coincide with the flood cycles. While this approach is highly dependent on the unpredictable nature of rainfall and river flows, it can be a cost-effective way for smallholders to supplement their rainfed agriculture.

1.1.2 Modern small-scale irrigation technologies in Ethiopia

In addition to the traditional irrigation systems, Ethiopia has also seen the adoption of various modern small-scale irrigation technologies in recent years. One of the most prominent of these is the use of motorized pumps, both diesel and

solar-powered, to extract groundwater for irrigation purposes. These pumps allow farmers to access deeper water sources and expand their irrigated areas, thereby increasing crop yields and diversifying their production.

Additionally, the modern small-scale irrigation technology gaining traction in Ethiopia is the treadle pump [19]. These manually operated pumps enable smallholders to lift water from shallow wells or surface water bodies, providing a low-cost and labor-efficient alternative to more expensive motorized pumps. Treadle pumps are particularly well-suited for small-scale, intensive vegetable production, as they allow farmers to precisely control the amount of water applied to their crops.

Furthermore, the adoption of pressurized irrigation systems, such as drip and sprinkler irrigation, is being promoted in Ethiopia as a means of improving water use efficiency and reducing labor requirements [16,17]. These technologies deliver water directly to the root zone of the plants, minimizing evaporation and ensuring more targeted application of the scarce water resources. While the initial investment in these systems can be a barrier for some smallholders, the long-term benefits in terms of increased productivity and reduced water usage make them an attractive option for those who can afford the upfront costs.

The choice of small-scale irrigation technology by Ethiopian smallholder farmers is influenced by a variety of factors, including water availability, topography, soil characteristics, and the financial resources of the household [20]. The diversity of both traditional and modern irrigation practices highlights the ingenuity and adaptability of smallholder farmers in Ethiopia as they strive to enhance their agricultural productivity and resilience in the face of changing climatic conditions.

2. LITERATURE REVIEW

2.1 Definition and Explanation of Relevant Concepts

2.1.1 Irrigation

Irrigation stands as a crucial tool for sustainable agricultural intensification, catalyzing enhanced farming practices. This technique plays a pivotal role in boosting agricultural output and efficiency among rural farmers [20]. At its core, irrigation involves the deliberate application of water to soil, complementing natural rainfall to maintain consistent soil moisture levels. This human-driven intervention in water resource management becomes particularly vital in regions where precipitation falls short of crop requirements [53]. The significance of irrigation extends beyond merely supplementing rainfall. It represents a strategic approach to agricultural water management, allowing farmers to exert greater control over one of the most critical inputs in crop production. By ensuring a stable water supply, irrigation mitigates the risks associated with erratic weather patterns and unpredictable rainfall, which are becoming increasingly common due to climate change. Moreover, irrigation systems enable farmers to expand their growing seasons, cultivate a wider variety of crops, and potentially achieve multiple harvests per year. This intensification of agriculture not only increases food production but also contributes to improved food security and economic stability in rural areas. The implementation of irrigation techniques varies widely, from traditional methods to advanced, water-efficient systems. Each approach aims to optimize water use while maximizing crop yields, reflecting the evolving nature of agricultural technology and the growing emphasis on sustainable resource management [21]. In essence, irrigation serves as a cornerstone of modern agriculture, bridging the gap between natural water availability and crop water demands. Its role in enhancing agricultural productivity, especially in water-scarce regions, underscores the importance of continued investment and innovation in irrigation technologies and practices.

2.2 Small Scale Irrigation

Small-scale irrigation refers to the application of water to small plots of land by individual farmers or community-based groups. These farmers and groups utilize their own design, decision-making, and cost-effective techniques that are customized to the specific land conditions. This approach allows them to produce a diverse range of crops, including both high-value horticultural crops and essential staple crops [22,23].

2.2.1 Adoption

Adoption refers to the process of taking up or accepting something new, such as an idea, technology, practice, or behavior, by a

community or individual household. This decision-making process involves carefully evaluating and choosing to use and implement innovative solutions, which may include the availability of a novel idea or practice within existing systems [24].

2.2.2 Climate-smart agriculture

Climate-smart agriculture (CSA) has emerged as a comprehensive approach to address the issue of food security and promote sustainable development, all while actively tackling the challenges posed by climate change [26]. This approach involves implementing strategies that optimize resource use, improve adaptation to climate variability, and mitigate environmental impacts. According to the World Bank [25], the smartness of a climate-smart technology is subjective, depending on the context and can differ significantly across various production systems and specific agro-ecological conditions and socio-economic contexts.

2.2.3 Food security

Food security: It is defined as a state of affairs in which anyone, at any time, has physical, social, and monetary access to sufficient, safe, and nutritious food that meets their nutritional needs and meal options for a healthy and active lifestyle [6].

2.3 Status of Small-Scale Irrigation Development in Ethiopia

Irrigation development, especially for smallholder farmers, is crucial for increasing production and productivity, achieving food self-sufficiency, and ensuring food security at both national and household levels, particularly in rural areas. With over 80% of Ethiopia's population residing in rural areas, the implementation of small-scale irrigation (SSI) practices is essential for the sustainable and robust development of the agricultural sector. Despite the importance of irrigation, there is a lack of precise understanding and documentation of Ethiopia's national irrigation potential. Most authors estimate the country's irrigation potential to be between 3.7 and 5.3 million hectares [27-30]. These estimates involve various mechanisms such as river and spring diversion, pumps, gravity, pressure, underground water, and water harvesting [31]. However, the Ethiopian Agricultural Transformation Agency suggests a much higher potential of 11 million hectares, with 48% of this potential being through groundwater resources [32].

According to the Ministry of Water Resources [33], irrigation expansion in Ethiopia is categorized by the size of the command area into three classifications: large-scale irrigation systems (>3,000 ha), medium-scale irrigation systems (200-3,000 ha), and small-scale irrigation systems (<200 ha). It has been observed that a substantial proportion, specifically 46%, of proposed irrigation advancements fall within the small-scale irrigation classification.

Irrigation practices significantly boost agricultural production to meet increasing food demands, primarily through increased yield in rural areas, arable land expansion, and higher cropping intensity. These practices contribute to poverty alleviation, food security, improved rural livelihoods, and national economic growth [33-35]. Recently, local governments have prioritized smallholder irrigation practices, enabling farmers to grow crops more frequently using traditional surface methods, leading to an increase in both the number of irrigators and the area irrigated. Recognizing the significance of small-scale irrigation in driving socioeconomic transformation, Ethiopia's irrigation strategy aims to enhance poverty reduction and food security by transforming the rain-fed agricultural system into a combined rain-fed and irrigation system. This strategy includes comprehensive value addition and postharvest technologies [36].

The Ethiopian government introduced a new approach within the Growth and Transformation Plan (GTP), mobilizing substantial public and donor support and resources to facilitate the impressive growth of small-scale irrigation. During the initial plan period of the two consecutive GTPs, small-scale irrigation expansion increased by 15.2% per year. The Second Growth and Transformation Plan aimed to expand small-scale irrigation by 1.75 million hectares, ensuring that 80% of smallholder farmers have at least one source of water for irrigation, enabling them to cultivate their lands and increase crop yields (MoA, 2016).

This approach is considered the most effective path to sustainable development in Ethiopia. The government is prioritizing the advancement of irrigation and supporting local farmers by promoting modern irrigation techniques and improving current practices. This includes evaluating small-scale irrigation and overcoming obstacles to adopting efficient technologies [37]. Additionally, developing medium and large-scale

irrigation systems is crucial. Despite considerable efforts by the government and stakeholders to enhance small-scale irrigation and rural water management, numerous challenges persist. These challenges include policy, institutional, technological, capacity, infrastructure, and market issues.

2.4 Role of Small-Scale Irrigation Rural Farming in Ethiopia

Small-scale irrigation (SSI) in rural areas is vital to Ethiopia's agricultural sector, enhancing productivity, alleviating poverty, and bolstering climate resilience [38-40]. A study by Ibsa et al. [41] using propensity score matching techniques in the Kersa district of the Oromia region found that SSI significantly improved crop yields. Farmers using SSI experienced a 30% increase in high-value crops such as vegetables and cash crops compared to those relying on rainfall.

Irrigation enables smallholders to adopt more diversified cropping patterns, producing higher market-value products. This diversification leads to a 25% income boost for households engaged in irrigation, significantly contributing to poverty reduction efforts [42]. Through transforming smallholder agriculture from subsistence-oriented to high-value marketed crops, SSI is also promoted as an adaptation strategy to recurrent droughts caused by climate variability and change. Additionally, implementing SSI practices can reduce crop losses by 40% during droughts, safeguarding agricultural productivity and minimizing the impacts of changing weather patterns [43]. SSI contributes to food security for rural households by reducing dependence on rain-fed agriculture and increasing the availability of nutritious food items [44]. The study found that 74% of households were food secure, with SSI users being more secure than non-users. Thus, SSI serves as a coping mechanism to improve household food security.

Water from SSI is a critical resource for various productive and livelihood activities, playing a crucial role in reducing poverty and food insecurity [45]. Integrating SSI into rural farming practices, particularly for smallholder farmers, holds immense potential for promoting agricultural sustainability, poverty alleviation, and inclusive economic growth [46]. SSI improves national food security by creating and maintaining soil conditions optimal for crop yields despite inadequate rainfall (Fig. 1) [47]. From a farmer's perspective, adaptive SSI significantly contributes to increasing crop yields and mitigating the risks of crop failure due to climate change.

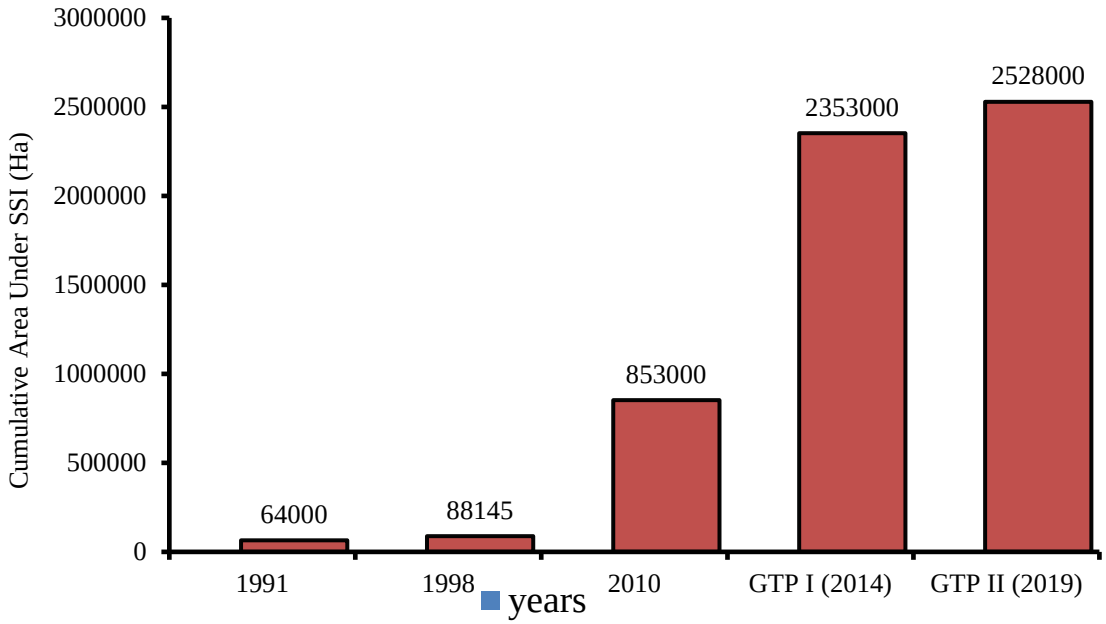

Fig. 1. Total small-scale irrigation area developed in the past 30 years (excluding traditional small-scale irrigation schemes)

2.5 Implementation of Small-Scale Irrigation as an Adaptation Strategy

Implementing small-scale irrigation (SSI) practices significantly enhances farm productivity and the livelihoods of rural households, offering a long-term solution to rising food demand, food security, and smallholder farmers' livelihoods. It also helps farmers adapt to climate change and increases their adaptive capacity [47,48]. Smallholder farmers across various regions can better adapt to climate-related risks through SSI. This proactive approach is essential for mitigating the negative impacts of climate change on agricultural production. By adopting these practices, local farmers can effectively maintain food security amidst the challenges posed by climate change [49].

SSI, when integrated with climate-smart agriculture (CSA) practices, becomes an invaluable strategy for promoting a climate-resilient approach to agriculture [50]. Effective water management through SSI can help farmers conserve water and make their crops more resilient to fluctuating weather conditions, particularly during mid-season dry spells, as irrigation acts as insurance against drought [50]. SSI farming supports the three pillars of CSA: sustainably increasing agricultural productivity and incomes (food security), adapting and building resilience (adaptation), and reducing greenhouse gas emissions (mitigation), while ensuring the sustainable use of water resources [51]. It is a crucial adaptation option for enhancing agricultural productivity in rural areas [52].

Participation in SSI has been associated with increased daily calorie intake, crop production, consumption, and revenue generation, leading to better food security compared to non-adoption [53,54]. In an economy heavily reliant on agriculture, SSI farming is promoted as a climate-smart agriculture approach to boost productivity and expand sustainable livelihood opportunities, mitigating the effects of climate change on food production (Fig. 2). The previous study findings underscore the importance of adopting irrigation farming as a key component of CSA. By implementing SSI techniques, farmers can better adapt to and mitigate the challenges posed by climate change, ultimately promoting long-term resilience and sustainability in agriculture [54].

Other studies demonstrates that small-scale irrigation interventions can significantly boost crop production, household income, and food security in Northern Ethiopia. The results, derived from propensity score matching, indicate that irrigation users have a lower poverty rate (20%) compared to non-users (30%). Small-scale irrigation is essential for maintaining stable agricultural production and increasing productivity, minimizing the negative effects of unpredictable or insufficient rainfall. This approach enhances yields and cropping intensity and serves as an effective adaptation strategy [55,56].

2.6 Importance of Small-Scale Irrigation to Food Security of Rural Households in Ethiopia

Fluctuations in temperature and rainfall across Sub-Saharan Africa significantly impact productivity and food security [57]. In recent years, Ethiopia has faced a substantial rise in food insecurity due to droughts, floods, and other natural and human-made disasters [58]. These challenges have exacerbated already insufficient food production, leading to increased starvation, poverty, and declining quality of life and health [59]. Additionally, rapid population growth has further strained food availability [60]. This situation has compelled both government entities and local communities to implement robust measures to address the challenges posed by changing climate conditions. Irrigation is recognized as an unparalleled approach with immense potential to overcome the diverse challenges in Ethiopia's agricultural sector. Implementing small-scale irrigation practices enhances food security for rural smallholder farmers by improving food availability, accessibility, utilization, and stability, ensuring long-term food sustenance.

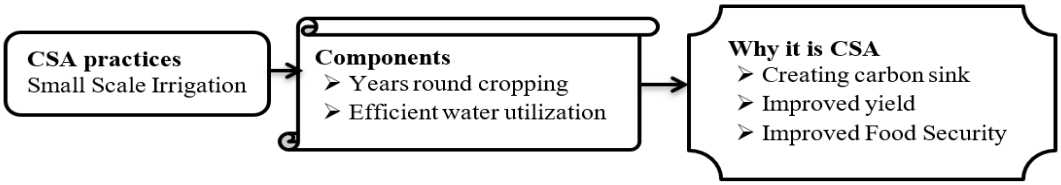

Fig. 2. CSA components, CSA practices (FAO, 2016)

Irrigation systems enable the regulated and effective use of water in farming, leading to increased crop yields and improved food production. Irrigation is crucial for productive and livelihood activities, playing a positive role in poverty alleviation. It contributes to food security by reducing crop failure risk and generating higher, year-round farm and non-farm incomes [61,62]. The FAO [30] found that irrigated areas have twice the productivity per hectare compared to rain-fed areas, with significantly higher household income and consumption levels, often showing a 50% gap.

Empirical studies indicate that developing irrigation and improving agricultural water management can greatly boost productivity and reduce climatic risks. To secure long-term food security in Ethiopia, it's vital to enhance the irrigation sector and address the challenges faced by smallholder farmers in rural regions. Irrigation plays a significant role in improving food security through various direct and indirect pathways, as shown in Fig. 3 [63,64].

Food Availability: This refers to the physical presence of sufficient, high-quality food in a given area, sourced from domestic production and internal market purchases [65,66]. This is supported by other studies that found irrigation practices significantly enhance crop productivity by extending growing seasons and enabling multiple crop cycles [67]. Small-scale irrigation contributes to food availability by providing consistent water access, reducing crop failure risks due to inadequate rainfall, and ensuring continuous crop productivity. For instance, irrigation increased onion yields by 46.7 t/ha, even with water shortages at some growth stages [68]. Additionally, small-scale irrigation extends growing seasons and intensifies crop production, improving food availability year-round.

Food Access: This refers to the ability of individuals and households to obtain sufficient, safe, and nutritious food that meets their dietary needs, both physically and economically. Irrigation enhances food accessibility by ensuring a reliable water supply, improving agricultural productivity, and supporting high-value and nutritious crops. These crops provide financial resources through the sale of surplus produce, enabling households to purchase additional food items and improve dietary variety. In Northern Wollo, Ethiopia, found that 32.1% of irrigation users reported increased crop production frequency, improving food accessibility. Irrigation also boosts household incomes and stabilizes the food market, reducing reliance on market purchases and lowering food prices, thus promoting better food access [69].

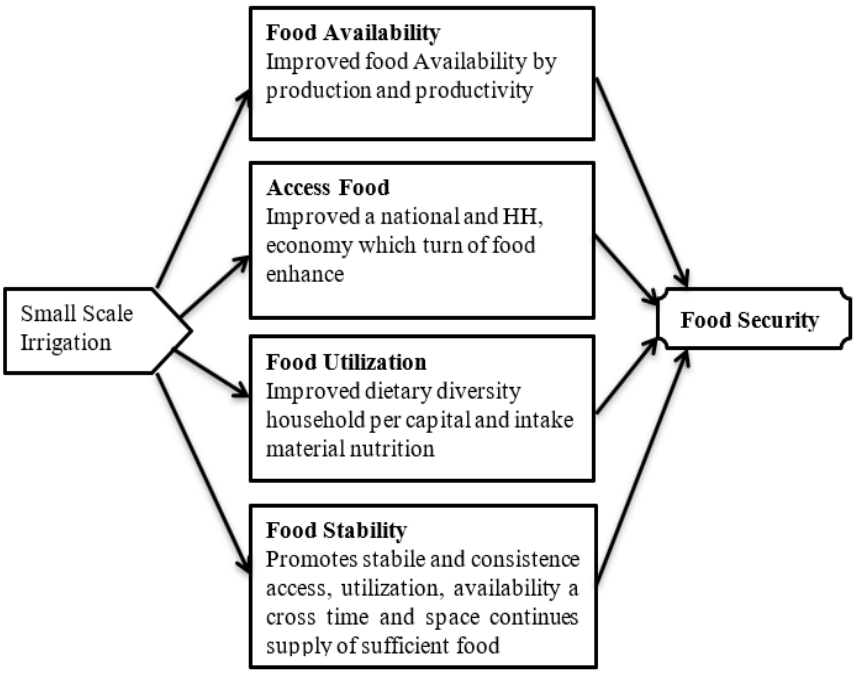

Fig. 3. Contribution of small-scale irrigation to the different dimensions of food security

Food Utilization: This refers to the likelihood of individuals or households consuming nutritious and diverse food groups, leading to a healthy lifestyle. Proper food utilization involves sufficient energy and nutrient intake due to food accessibility and availability. A study in Ethiopia revealed that irrigation systems increased daily per capita food consumption; for example, in Oromia, small-scale irrigation farmers consumed an additional 643.76 Kcal per day compared to non-irrigators [1,4,70]. Irrigation promotes dietary diversity, especially for women and children, by enabling households to cultivate various vegetables, fruits, and cash crops [10,34, 56]. Irrigated crops also have higher nutrient content and quality, supporting better food utilization and health outcomes. Surplus crops can be processed into value-added products while retaining nutritional value and supporting livestock feed cultivation for high-quality animal products.

Food Stability: This refers to the consistent availability of a sufficient food supply throughout the year without deficiencies [5,6,8,71]. To achieve stable food security, a population must always have access to adequate food. Stable food security depends on the consistent presence of elements contributing to food availability, accessibility, and utilization. Irrigation significantly enhances household food security and stability by improving agricultural resilience and reducing vulnerability to food shortages. For example, a study in Sibu-sire district, found 27% of small-scale irrigation users faced food insecurity compared to 56% of non-users, resulting in a 73% food security rate for irrigation users. Irrigation initiatives also empower smallholder farmers [34,35,72], particularly women, and enable diversified cropping patterns, contributing to long-term food sovereignty and stability within communities. Overall, small-scale irrigation is crucial for achieving food security, as it bolsters agricultural resilience, optimizes water usage, conserves natural resources, and promotes economic development. Continued support and expansion of small-scale irrigation initiatives are imperative to ensure a stable and secure food supply for present and future generations.

2.7 Impact of Small-Scale Irrigation on Food Security of Smallholder Farmers

The implementation of irrigation systems can have a significant impact on ensuring food security through multiple channels. According to the study [2,4,5,6,9,73] analysis, the implementation of irrigation systems can contribute to food security in two main ways:

2.7.1 Increased food availability

Firstly, the accessibility of irrigation water can lead to a substantial enhancement in both the quantity and diversity of homegrown food. This can boost a household's financial stability by generating additional income from the sale of irrigated products, which can then be used to purchase more food items, thereby improving food accessibility and availability.

2.7.2 Positive perceptions and impacts

Several empirical studies, have reported that small-scale irrigation (SSI) has a significant positive impact on enhancing the food security of households. This shows that SSI is crucial in ensuring food self-sufficiency within households and enhancing household food consumption by diversifying and increasing the frequency of production over time [73]. Furthermore, FAO found that people who use irrigation methods in their farming practices are better able to be food secure compared to those who do not. This study revealed that SSI has a significant impact on increasing crop yields, improving crop quality, and ensuring a more reliable and consistent food supply for smallholder farmers.

2.7.3 Adoption of irrigation and food security

The adoption of irrigation serves as a method for smallholder farmers to engage in cultivating multiple crops throughout the year, lessening reliance on erratic rainfall patterns and minimizing the threat of crop loss. This ultimately leads to enhanced crop yields and advances in food security irrespective of the season [74]. Furthermore, it acts as a means to cultivate various crops for family consumption, generate income through sales, and acquire additional food items for consumption, all of which contribute to the overall food security. In conclusion, the implementation of irrigation systems can have a significant and multifaceted impact on ensuring food security for smallholder farmer households. The accessibility of irrigation water can lead to increased food availability, improved financial stability, and positive perceptions and impacts on household food security.

2.8 Impact of Small-Scale Irrigation Use on Crop Production

Irrigation is being considered as a way to increase agricultural production and productivity in order to satisfy the rising food demand in Ethiopia [1]. Moreover, due to climate change impacts such as shifting precipitation patterns and increased water scarcity in terms of space and time, small-scale irrigation development, especially for small household farmers, is the best approach. Small-scale irrigation farming has been suggested as a climate-smart agricultural approach to decrease the impacts of climate change and variability, enhancing production, promote various livelihood opportunities, and ultimately ensure food security.

2.8.1 Increased profits and crop yields for smallholder farmers

Irrigation has the potential to increase profits for smallholder farmers because it allows them to increase crop yields and productivity, reducing the risk of experiencing crop failures [75,76]. According to a study conducted in Kobo town, participants in small-scale irrigation, primarily for households' own production, achieved a crop yield of 1266 kg, while non-participants achieved 820.5 kg.

2.8.2 Diversification of crops and enhanced food security

Small-scale irrigation is a critical technique that enables households to grow crops more than once a year and supports the cultivation of a wide variety of crops, including those that require specific water conditions or are not suitable for rain-fed agriculture [76]. This diversification of crops can enhance food security by reducing dependence on a single crop and increasing the availability of different types of nutritious and essential food items.

2.8.3 Positive impact on agricultural production and food availability

Different studies have found that small-scale irrigation has a positive impact on agricultural production. Irrigation plays a crucial role in enhancing food availability by promoting multiple harvests within a single year in a single plot. According to a study conducted, a significant proportion of irrigation users (32.1%) in northern Wollo reported that their crop production frequency increased due to irrigation [77]. Another study in the Adamitulu Jido Komoblcha area revealed that irrigation users produced more crops and higher production than non-users in major crops like onion, tomato [78,79], pepper, cabbage, maize, wheat, and bean across all matching estimators of the propensity score matching model. For example, the results showed that irrigated farming led to an annual tomato yield of 1831.56 kg, a significant increase compared to non-irrigated farming. This indicates that the average crop yield per hectare from small-scale irrigated land increases more than rainfed farming. Farmers in Haramaya district of eastern Ethiopia are reported to produce over two times a year using irrigation, resulting in their food self-sufficiency [80].

In general, irrigation has been shown to have a positive impact on crop production, reducing climate risks and improving crop production, which in turn reduces reliance on rainfall for agricultural production [15,43,81]. The adoption of small-scale irrigation farming has the potential to significantly contribute to increasing agricultural production and ensuring food security in Ethiopia.

2.9 Impact of Irrigation Adoption on Food Security and Consumption Patterns

Adoption of irrigation practices has resulted in a significant increase in crop production, making it a valuable tool for enhancing food security [82]. This increase in agricultural output has not only allowed for a greater variety of food items to be cultivated but has also facilitated the cultivation of crops that are more nutritionally dense and calorically rich. This, in turn, has had a profound impact on consumption patterns as individuals now have access to a wider array of food options and can make more informed choices in terms of their dietary preferences and nutritional needs [83-85].

2.9.1 Increased consumption and calorie intake

Irrigation was shown to increase the daily per capita intake of households in different parts of Ethiopia. According to a study by Yilma et al [91] on the impact of small-scale irrigation (SSI) on household consumption in central Ethiopia's Adamitulu Jido Komoblcha district, the nearest neighbor and caliper matching algorithms showed that irrigation users consume 498.68 kg more onion annually than non-user households. This demonstrates that irrigation increases the

consumption of these crop harvests, filling the food gap they had before irrigation use. Furthermore, the participants also engage in the sale of excess harvests to generate revenue for their sustenance, which allows them to buy supplementary food items such as dark green leafy vegetables, yellow or orange fruits, and eggs [91].

2.9.2 Improved Nutritional Status and Well-being

According to a study in Kobo town by Goitom [37], the mean food consumption score for irrigation users was 44.89, while for non-users it was 41.21. Irrigation practices promote the nutritional status and well-being of households, as they directly contribute to an increase in their calorie intake through the provision of a diverse and available food supply. A study by Yilma et al. [91] in the Oromia region revealed that small-scale irrigation farmers consume 643.76 Kcal more daily calories than those relying solely on rainfed agriculture. In the Arsi zone, only 26.25% of the households of irrigation users consume fewer than 1500 kcal daily, whereas for non-irrigation users households, the intake is 49.2% below 1500 kcal daily [89,90].

The adoption of small-scale irrigation has a positive and significant impact on annual production and enables individuals to access food by improving their purchasing power and increasing their calorie intake in smallholder farmers' households. The increased availability of diverse and nutritious crops, coupled with improved consumption patterns and calorie intake, highlights the crucial role of irrigation in enhancing food security and promoting the well-being of households in Ethiopia.

2.10 The Impact of Small-Scale Irrigation on Income and Food Security

Small-scale irrigation is a crucial income source for smallholders, as it is often utilized to grow marketable and highly profitable cash crops like vegetables and fruits [16,19,37]. Adopting small-scale irrigation farming as a climate-smart agriculture practice helps households produce more crops for additional income generation through the sale of surpluses. Small-scale irrigation allows farmers to produce off-seasonally by supplementing their crops with water during mid-season dry spells or shortages [45]. The author pointed out that small-scale irrigation development positively impacts rural households' income through both direct and indirect effects.

2.10.1 Increased income for irrigation users

Several studies have found that irrigation users have higher incomes compared to non-users. Demsew and Ermias [13] discovered that the average yearly income of irrigation users was ETB 44,739.94, whereas their non-irrigation income amounted to ETB 30,773.77. The findings indicated a substantial increase in the total income of households as a result of their involvement in SSI schemes. The Agerie [5] study found that households with irrigation access in North Gonder zone, Ethiopia, had an average annual income of 56,166.59 ETB, compared to 26,102.44 ETB without access. Yilma et al. [37] reported that households with access to irrigation had a mean annual income of ETB 102213.79 as a result of the propensity square matching model.

2.10.2 Improved food security, asset ownership, and income

The positive impact of irrigation on income shows that irrigation access has a positive impact on total farm income and asset holding of the smallholder farmers' households. In general, SSI farming contributes to improved food security, asset ownership, and income in rural households through increased agricultural production by diversification and intensification of crops [46,89]. Small-scale irrigation is a crucial tool for enhancing the income and food security of smallholder farmers in Ethiopia. By allowing farmers to grow profitable cash crops, produce off-seasonally, and sell surpluses, irrigation has a direct and positive impact on household income. This increased income, in turn, leads to improved food security, asset ownership, and overall well-being of rural households.

2.11 Factors Influencing the Adoption of Small-Scale Irrigation

To improve small-scale irrigation to increase the ability of small household farmers to adapt to climate variability and change, it's crucial to consider socioeconomic and institutional factors that influence farmers' decisions to adopt small-scale irrigation as a climate-smart agriculture practice [88]. The evidence from different studies indicates that various socio-economic and institutional factors influence household decisions to adopt small-scale irrigation farming practices.

2.11.1 Facilitating institutional infrastructure and awareness

Improving the awareness of people regarding irrigation adoption can be enhanced through the involvement of local institutions and the development of rural infrastructure services [86]. Furthermore, the creation of a facilitative institutional infrastructure can optimize the productive participation of rural people in small-scale irrigation.

2.11.2 Socioeconomic factors influencing adoption

The authors show that adoption of small-scale irrigation farming is significantly influenced by factors such as off-farm employment, access to irrigation equipment, reliable water sources, and awareness of water harvesting practices as well as improved seed varieties. According to Elias and Yitbarek [19], off-farm employment, access to irrigation equipment, access to reliable water sources, access to credit, access to agricultural extension service, and awareness of water conservation practices positively influence the adoption of small-scale irrigation in the Offa District, Southern Ethiopia. On the other hand, farmers' age, distance to market, and formal employment negatively influence the adoption of SSI (Gizachew and Birhan, 2022).

2.11.3 Household characteristics and adoption

Other studies have found statistically significant differences in farmland size, livestock, and education between irrigation users and non-users, but no significant difference in household size, age, and gender [24,25,87]. According to a study by Eshetu and Cho [23] in the Arsi Zone, Oromia Region, the education of the household head, cultivated land, oxen number, and livestock holding were significant and influenced positively household food security through their role on food production and income generation, thereby influencing SSI adoption. Ibsa et al. [40] found that household head age, dependency ratio, and farmland distance from irrigation water sources had a significant negative impact on households' decisions to adopt small-scale irrigation practices in the Kersa District, Eastern Oromia, Ethiopia.

In conclusion, the adoption of small-scale irrigation is influenced by a complex interplay of socioeconomic, institutional, and household-level factors. Addressing these factors through targeted interventions and the development of a supportive institutional environment can help to promote the widespread adoption of small-scale irrigation among smallholder farmers, ultimately enhancing their resilience to climate variability and change.

3. CONCLUSION AND RECOMMENDATIONS

The implementation of small-scale irrigation as a climate-smart agricultural strategy presents a promising avenue for enhancing food security among Ethiopia's smallholder farmers. This review underscores the positive outcomes of successful irrigation adoption, including increased crop yields, income diversification, and improved resilience to climate variability. However, the path to widespread implementation is fraught with challenges, such as limited access to financial resources, gaps in technical knowledge, and inadequate infrastructure. Gender disparities in access to and benefits from irrigation technologies further complicate the issue, highlighting the need for more inclusive approaches. To address these challenges and maximize the potential of small-scale irrigation, we propose a multi-faceted approach. This includes developing targeted policies to overcome adoption barriers, with emphasis on improving financial access, securing land rights, and enhancing agricultural education. Prioritizing investments in rural infrastructure, particularly water management systems and market access roads, is crucial for supporting irrigation expansion. Revitalizing and contextualizing agricultural extension services will equip farmers with the necessary skills to effectively implement and maintain irrigation systems. It's essential to integrate gender-inclusive strategies in all irrigation initiatives to ensure equitable opportunities and benefits for women farmers. Further research should focus on the long-term sustainability of small-scale irrigation systems, their environmental impacts, and resilience to future climate scenarios. Adopting a holistic perspective that considers the entire agricultural value chain will maximize the food security benefits of irrigation practices. By implementing these recommendations, Ethiopia can harness the full potential of small-scale irrigation as a climate-smart solution, significantly improving food security and resilience within its smallholder farming communities. This comprehensive approach will not only address immediate agricultural challenges but also contribute to

long-term sustainable development in the face of climate change. The success of these efforts hinges on collaborative action from policymakers, researchers, and agricultural practitioners, working in concert to forge a more resilient and food-secure future for Ethiopia's smallholder farmers. As climate change continues to pose threats to agricultural productivity, the adoption of such climate-smart practices becomes increasingly critical for ensuring food security and sustainable livelihoods in the region.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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