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**Review Article**

# Toward an Ideal Framework for Assessing Economic Viability of Micro-Irrigation Technologies: A Systematic Review

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**Abstract:** Micro irrigation technologies (MITs), such as drip and sprinkler systems, have been recognized as transformative solutions for enhancing agricultural productivity, optimizing water use, and promoting environmental sustainability. However, their adoption among smallholder farmers remains limited due to a complex interplay of economic, social, technical and environmental constraints. Traditional frameworks for assessing economic viability of these technologies often focus narrowly on financial metrics, neglecting critical factors such as water availability, market dynamics, and the technical and socioeconomic contexts. A systematic review of the literature from 2014 to 2024 was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Articles were sourced from major databases, including Scopus, Taylor and Francis, IEEE Xplore, and Web of Science, yielding a final dataset of 69 relevant studies from an initial pool of 719 articles. The analysis of selected studies highlights key trends, including a growing focus on economic and water management aspects and the role of institutional and policy support in MIT adoption. A novel framework is proposed that integrates dimensions such as water availability and management, market dynamics, socioeconomic factors, and environmental sustainability. This comprehensive approach addresses limitations in traditional financial metric-based evaluations, offering actionable insights to policymakers and stakeholders. The findings aim to advance the adoption of MITs by aligning technical and market strategies with the needs of smallholder farmers, contributing to global food security and environmental goals.

**Keywords**: Micro irrigation technologies, Economic viability model, Smallholder farmers, Conceptual framework, Systematic review.



## 1.0 INTRODUCTION

Micro irrigation technologies, which include advanced methods such as drip and sprinkler systems, have emerged as transformative tools in modern agriculture (Angold, 2023). These systems are designed to address pressing global challenges, including water scarcity, food insecurity, and climate change, while promoting sustainable agricultural practices (Absanto *et al*., 2025; Agbenyo *et al*., 2022; Ariom *et al*., 2022). By delivering water directly to plant roots in a controlled manner, micro irrigation systems reduce evaporation, minimize runoff, and optimize water use efficiency (Sarwar *et al*., 2023). This precise water delivery system ensures that crops receive only the amount of water they require, resulting in higher yields, reduced waste, and improved resource utilization (Ju *et al*., 2017; Wang *et al*., 2015). Despite these advantages, the adoption of micro irrigation technologies remains uneven and concentrated in high-income regions, and smallholder farmers in developing countries lag behind those who could benefit the most (Varshini & Jayanthi, 2022).

The critical role of micro irrigation technologies in addressing global water challenges cannot be overstated. Agriculture accounts for approximately 70% of global freshwater withdrawals, a staggering statistic that highlights the need for efficient irrigation practices (Hedden-Nicely & Kaiser, 2024a). The situation is even critical in regions already experiencing water scarcity, where population growth, urbanization, and climate change have intensified competition for limited water resources (Mume *et al*., 2023). By enabling farmers to use water more efficiently, micro irrigation technologies provide a pathway to mitigate these challenges while contributing to food security and environmental sustainability (Ghosh *et al*., 2020; Ho *et al*., 2022). However, realizing the full potential of these technologies requires overcoming significant barriers to adoption, particularly among smallholder farmers.

The transition from traditional communal irrigation schemes to individual farmer-managed systems equipped with micro irrigation technologies highlights a paradigm shift in global agriculture (de Bont & Veldwisch, 2020; Osewe *et al*., 2020; Patle *et al*., 2020; Suryavanshi *et al*., 2015). Traditional irrigation methods, which are historically crucial for ensuring water availability, are now being replaced by systems that emphasize water-use efficiency over water distribution efficiency (Mukherjee *et al*., 2023a; Vanghele C., 2019). This shift has been driven by mounting pressures of water scarcity, urbanization, and climate change, which demand more sustainable and individualized approaches to water management (Agbenyo *et al*., 2022).

Smallholder farmers, who constitute most agricultural producers in low- and middle-income countries, face many challenges in adopting micro irrigation technologies. High initial investment costs often deter farmers with limited financial resources, even when these systems promise long-term savings and productivity gains (Ferrarezi *et al*., 2020; Vilaça *et al*., 2017). Furthermore, the technical expertise required to operate and maintain these systems is often lacking in rural areas, creating a knowledge gap that undermines their effective use (Goyal *et al*., 2017; Panigrahi *et al*., 2022). Inadequate institutional support and limited access to credit further compound these challenges, leaving many farmers unable to afford or access micro irrigation systems. As a result, the adoption of these technologies remains suboptimal in regions that could benefit the most.

These issues are the contextual factors that influence the economic viability of micro irrigation technologies. Variables such as water availability, market conditions, crop types, and socioenvironmental dynamics play crucial roles in determining the success or failure of these systems (Helena Duenhas & Carlos Cury Saad, 2009a; Manning *et al*., 2018; Marques *et al*., 2023). Hence, the effectiveness of a drip irrigation system may vary significantly depending on the availability and quality of water, the types of crops being cultivated, and the market demand for those crops (Wang *et al*., 2016). These contextual factors are often overlooked in traditional frameworks for assessing economic viability, which tend to focus narrowly on financial metrics such as return on investment and operational costs (Escoto & Abundo, 2024; Salazar & Morales, 2023).

Existing assessment frameworks for micro irrigation technologies are limited in their scope and fail to provide a holistic understanding of their economic viability. While financial metrics such as cost savings and yield improvements are undoubtedly important, they do not capture the full range of factors that influence adoption and effectiveness (Mukherjee *et al*., 2023b). Keywords such as water management, socioeconomic realities, market dynamics, and environmental considerations are often excluded from these evaluations, resulting in incomplete analyses that fail to inform policy and practice effectively (Galioto *et al*., 2017; Nalley *et al*., 2015). Designed primarily for large-scale or communal irrigation schemes, these models are ill suited for evaluating individual farmer-managed systems, especially in water-scarce and resource-constrained regions (de Bont & Veldwisch, 2020). This mismatch limits their practical utility for smallholder farmers, who face unique challenges.

There is a noticeable gap in the literature regarding comprehensive frameworks that integrate financial, socioeconomic, environmental, and contextual dimensions to assess the economic viability of micro irrigation technologies. This research identifies a critical gap in literature; the lack of a comprehensive framework that integrates these multidimensional factors into the assessment of micro irrigation technologies. While previous studies have highlighted the benefits and challenges associated with these systems, few have systematically reviewed the literature to identify the key dimensions necessary for holistic evaluation (Fanadzo & Ncube, 2018; Guemouria *et al*., 2023a; Gupta *et al*., 2022; Sharma & Suhirid, 2018). The absence of such a framework limits the ability of policymakers, researchers, and practitioners to design effective interventions that address the barriers to the adoption of MITs.

This study addresses the identified gaps by proposing an integrated framework for assessing the economic viability of micro irrigation technologies tailored specifically to individual farmer-managed agriculture. By integrating various dimensions into a single framework, this study seeks to bridge the gap between theoretical evaluation and practical application to make several significant contributions to the field of agricultural water management. This includes providing a comprehensive synthesis of the literature, highlighting key trends and gaps in the research on the economic evaluation of micro irrigation technologies and then proposing a novel framework that integrates various dimensions, offering a more holistic approach to assessing economic viability. This approach aims to provide actionable insights into the suitability, effectiveness, and broader impacts of micro irrigation technologies. The findings will also inform policymakers and stakeholders in designing targeted interventions, such as subsidies, technical training programs, and institutional support mechanisms, to increase the adoption and improve the resilience and sustainability of smallholder farming systems.

## 2.0 MATERIALS AND METHODS

### 2.1 Systematic Review Design

The primary objective of this study was to review the existing economic viability models and recommend a comprehensive framework for evaluating the economic viability of micro irrigation technologies. By systematically reviewing the literature from 2014 to 2024 via the PRISMA guidelines (Goodwin *et al*., 2022), this research synthesizes evidence from studies to identify the key dimensions influencing the economic viability of MITs. This process included identification, screening, eligibility assessment, and inclusion of relevant studies to analyze the economic viability of micro irrigation systems, with a focus on water availability, market price, and demand. Below is a detailed explanation of each stage of the methodology.

### 2.2 Data Sources and Search Strategy

The first stage involved a comprehensive search across four prominent academic databases: Scopus, IEEE Xplore, Web of Science, and Taylor and Francis. These databases were selected because of their extensive coverage of multidisciplinary research, engineering, and irrigation technologies. The search strategy utilized a combination of keywords and Boolean operators, including terms such as 'economic viability of micro irrigation technologies', economic viability of drip and sprinkler systems' and 'economic viability of irrigation schemes'. A total of 719 records were identified, distributed as follows: 193 from Scopus, 181 from IEEE Xplore, 202 from Web of Science, and 143 from Taylor and Francis. The variation in the number of records reflects the coverage and focus of each database, with Web of Science yielding the highest number of studies due to its broad disciplinary scope and indexing of high-impact journals (Medrano *et al*., 2015).

### 2.3 Screening and Inclusion Criteria

The initial search yielded 719 articles. After removing duplicates and screening titles and abstracts, 412 articles were subjected to a full-text review. The screening phase commenced with the removal of duplicate records. This step reduced the total number of articles to 412 unique entries, eliminating 307 duplicates. Each unique record was then subjected to a preliminary screening on the basis of its title and abstract.

Articles were assessed for relevance to the study's objectives, which required them to address aspects of the economic viability of micro irrigation systems or related technologies. Articles were excluded if they did not meet specific inclusion criteria: they had to be written in English, be accessible as full-text open-access articles, and provide a clear focus on economic viability in micro irrigation or water management technologies. Following this screening process, 338 articles were excluded. These exclusions included 87 articles that were not written in English, 62 articles that were not accessible in open access, and 163 articles that did not address the study's core themes and 26 that were not articles but were thesis and conference papers. The inclusion phase included 74 studies that were incorporated into the qualitative synthesis. These studies were chosen for their robust methodologies, original contributions, and direct relevance to the study's aims. Sixty-nine studies provided the necessary qualitative data for analysis, and they were included in the qualitative synthesis.

The overall process adhered to the PRISMA guidelines, as illustrated in the PRISMA flow diagram in Figure 1. Each phase of identification, screening, eligibility, and inclusion was systematically executed to ensure the reliability and validity of the review (Delorme *et al*., 2017a; Senanayake *et al*., 2015). The final dataset provided a robust foundation for analyzing the economic viability of micro irrigation systems and contributed significantly to the development of the proposed conceptual framework.

### 2.4 Data extraction and analysis

Key information, including study objectives, methodologies, findings, and limitations, was extracted and categorized by year, thematic focus, and citation count. Thematic analysis was conducted to identify trends, recurring themes, and gaps in the literature (Delorme *et al*., 2017b).

### 2.5 PRISMA flow diagram

The systematic review process is summarized in a PRISMA flow diagram, highlighting the identification, screening, and inclusion phases. Among the 719 records identified, 650 were screened, and 69 articles were included in the final review, as shown in Figure 1.

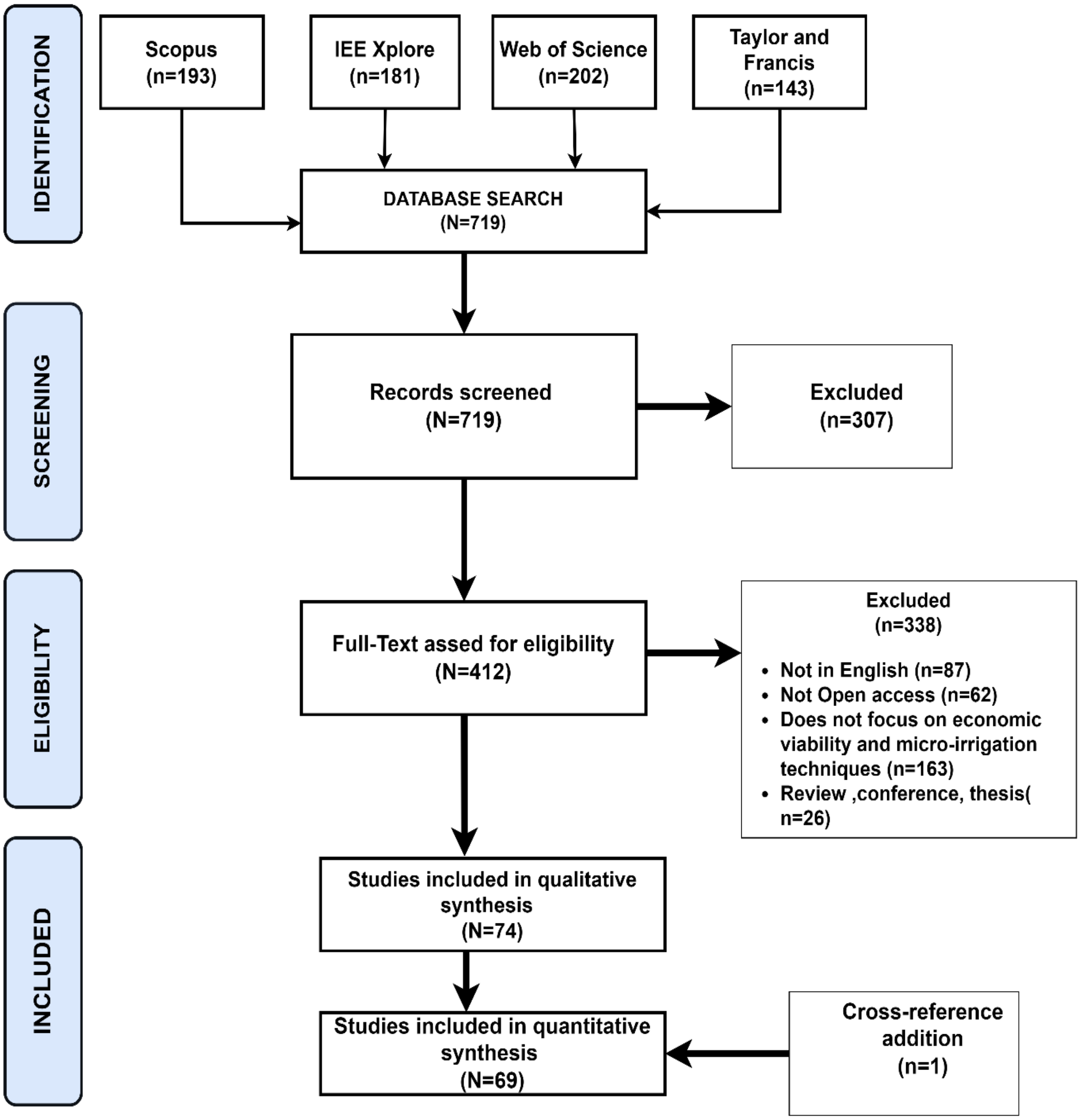


**Figure 1: PRISMA flow chart of the study**

## 3.0 RESULTS AND DISCUSSION

### 3.1 Insights from Literature: Trends and Themes

#### 3.1.1 Studies by Year:

Research on micro irrigation technologies has grown steadily over the past decade, with a notable surge occurring between 2019 and 2023, as shown in Figure 2. This increase corresponds to global policy emphasis on sustainable agricultural practices and water conservation. Key studies during this period explored technological advancements, economic feasibility, and adoption barriers for smallholder farmers (Ahmed, 2020; Alston *et al*., 2016; Elshurafa *et al*., 2022).

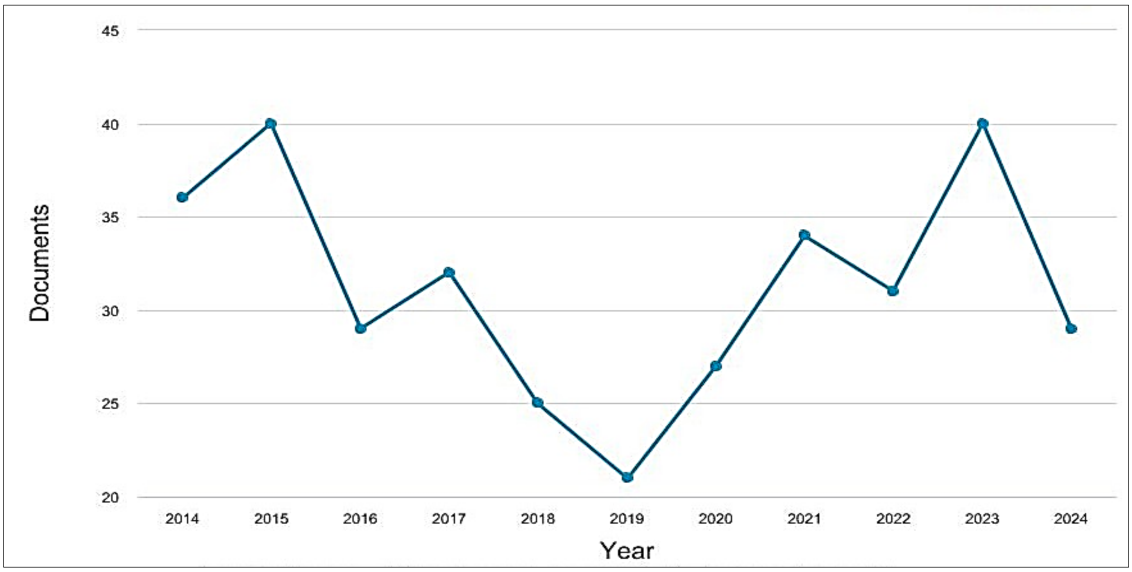


**Figure 2: Trends for micro irrigation studies by year**

### 3.1.2 Studies by Concept

Several thematic clusters emerged from the reviewed literature. A significant proportion focused on agricultural issues (33.8%) and environmental issues (24.4%), including adoption and food security, in line with climatic changes (Kabir *et al*., 2017; Pereau *et al*., 2019; Viol *et al*., 2015). Other studies have emphasized water management, explored the role of irrigation systems in optimizing water use and improving crop yields, which are linked with engineering (23%) (Bové *et al*., 2018; Rathoure *et al*., 2024; Satasiya *et al*., 2024; Solé-Torres *et al*., 2019). Social and environmental dimensions are less represented, highlighting the importance of farmer capacity-building and ecological sustainability (Hogan *et al*., 2014; Mandal *et al*., 2022; Trommsdorff *et al*., 2021).

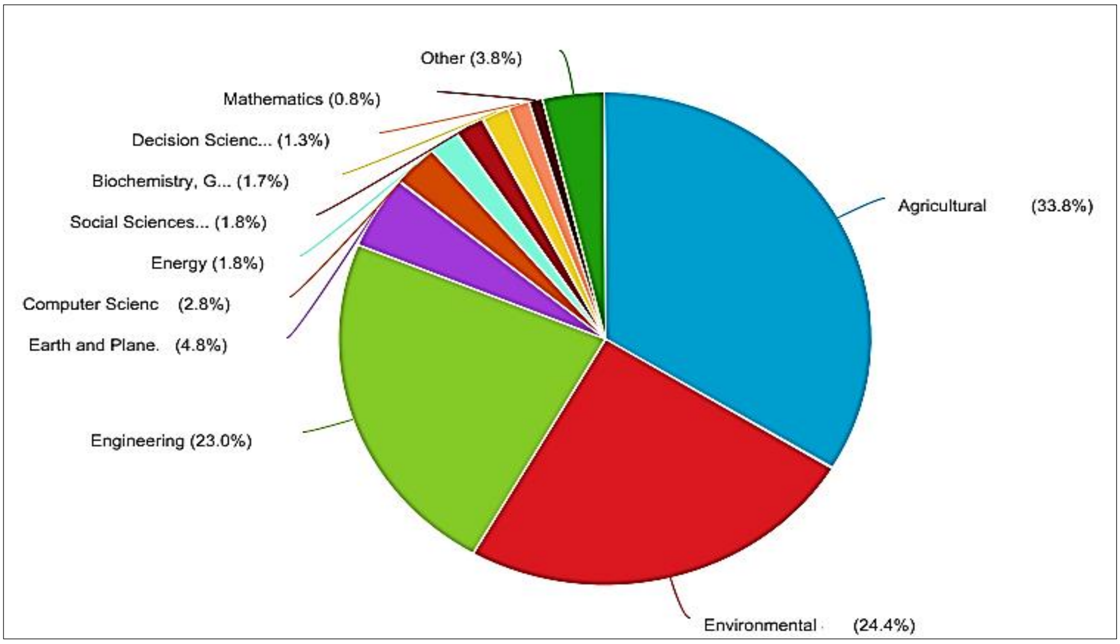


**Figure 3: Key concepts of studies**

### 3.1.3 Studies by Countries

The highly cited studies were from India and the United States, which are the leading countries that publish many irrigation technologies (Guemouria *et al*., 2023b; Jat *et al*., 2016a, 2016b; Narayanamoorthy, 2016, 2022; Sahoo & Panda, 2014; Smith *et al*., 2015; Summers *et al*., 2021). With respect to other countries, sub-Saharan countries such as Ethiopia, Kenya and Rwanda had the fewest publications on this topic (Hatungimana *et al*., 2023; Kikuchi *et al*., 2023).

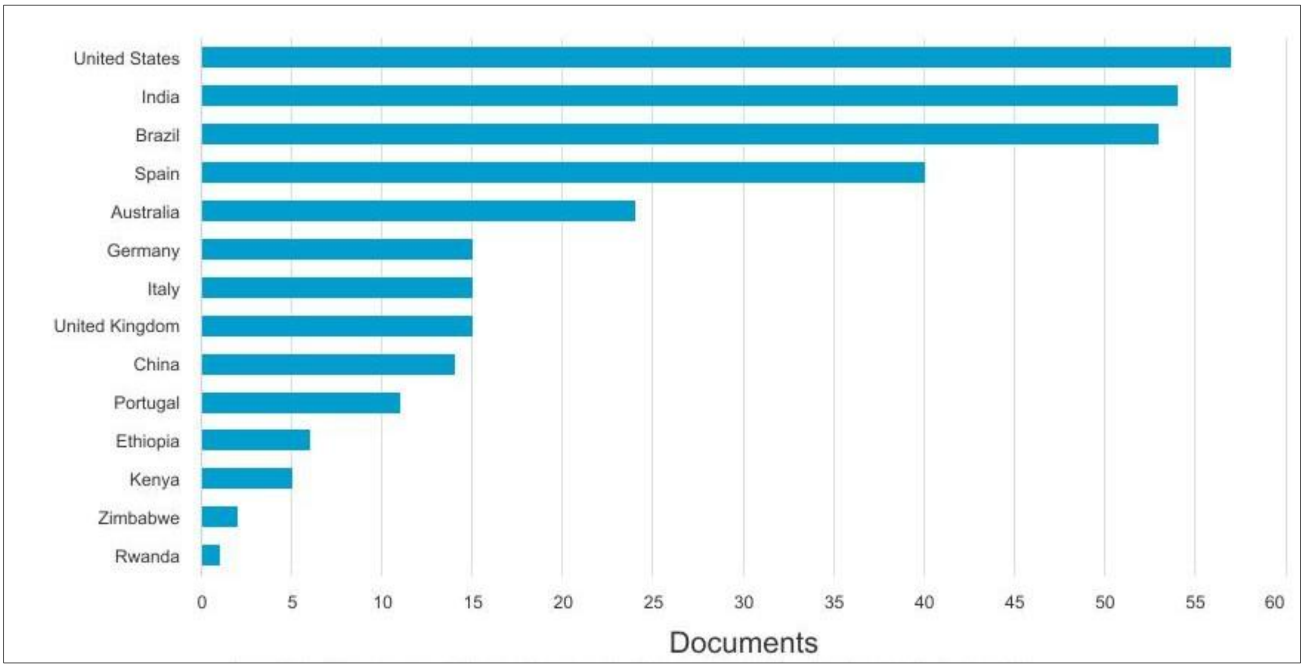


**Figure 4: Studies by Countries**

### 3.2 Weaknesses of Existing Economic Viability Models and the Need for a Comprehensive Framework

Economic viability models are crucial tools for assessing the practicality and sustainability of adopting micro irrigation technologies (MITs). However, existing frameworks exhibit several weaknesses that limit their utility, particularly for smallholder farmers in resource-constrained environments. These limitations underscore the pressing need for a more holistic and comprehensive model to guide decision-making and policy development.

#### 3.2.1 Weaknesses of Existing Models

**Overemphasis on Financial Metrics**

Most existing models narrowly focus on financial indicators such as cost–benefit ratios, return on investment (ROI), and net present value (NPV) (Gorain *et al*., 2020; Vanghele C., 2019). While these metrics provide valuable insights into economic feasibility, they overlook critical nonfinancial factors that significantly influence adoption and long-term success. For example, these models often fail to account for variability in water availability, seasonal fluctuations in resource access, and market volatility, which can substantially impact the practical implementation of MITs (Ariom *et al*., 2022; Patle *et al*., 2020).

**Limited Consideration of Contextual Factors**

Current frameworks tend to adopt a one-size-fits-all approach, disregarding the unique socioeconomic, environmental, and cultural contexts in which smallholder farmers operate (Khalifa W *et al*., 2020; Li *et al*., 2016). Factors such as land tenure systems, gender roles, and regional crop preferences are seldom integrated into evaluations (Y. B. Belay & Melka, 2024; Dawit *et al*., 2020; Sherpa *et al*., 2021). As a result, these models lack relevance and applicability for farmers in diverse geographical and socioeconomic settings, particularly in low-income regions where constraints differ significantly from those in high-income contexts.

**Neglect of Water Management Dynamics**

Water availability and its management are central to the effectiveness of MITs. However, many models inadequately address the interplay between water resources, infrastructure, and distribution systems (A. Belay *et al*., 2022; Cremades *et al*., 2016). This gap diminishes the ability of these frameworks to predict the sustainability of MITs in areas with fluctuating or limited water supplies. Furthermore, the efficiency of water usage and its impact on operational costs and environmental sustainability are often excluded from assessments (Ariom *et al*., 2022; Bojago & Abrham, 2023).

**Underrepresentation of Environmental Impacts**

Environmental sustainability is a critical dimension of MIT adoption, yet it is frequently omitted from existing models (Birkenholtz, 2017; Nyang'au *et al*., 2021). Considerations such as soil health, biodiversity, and greenhouse gas emissions are rarely evaluated, despite their significant influence on long-term agricultural viability and ecosystem health (Arifah *et al*., 2022; Gwambene *et al*., 2023; Singh & Singh Malik, 2018).

**Insufficient Integration of Institutional and Policy Support**

Institutional and policy factors, such as access to financing, technical training, and supportive regulatory frameworks, play pivotal roles in adoption (Mattoussi *et al*., 2023; Rouzaneh *et al*., 2021). Many models fail to account for these elements, which can either enable or hinder the widespread adoption of MITs (DiGennaro & Kraybill, 2015; SAXENA *et al*., 2022; Singh & Dangi, 2022). The absence of institutional and policy dimensions limits the models' ability to provide actionable recommendations for stakeholders (Bahinipati & Viswanathan, 2018; Thapa *et al*., 2020).

### 3.2.2 The need for a holistic comprehensive model

Addressing the weaknesses outlined above requires the development of a holistic framework that integrates multiple dimensions influencing the economic viability of MITs. The model should include financial, socioeconomic, environmental, and technical factors to provide a complete assessment of viability, capturing the interdependence among these dimensions, such as how water management impacts cost efficiency and environmental outcomes (Agbenyo *et al*., 2022; Gorain *et al*., 2020; Patle *et al*., 2020; Vanghele C., 2019).

It should also tailor assessments to reflect the specific challenges and opportunities faced by smallholder farmers in different regions, considering local water availability, cultural practices, and institutional landscapes (Deresse & Zerihun, 2018; Khanal *et al*., 2018). Evaluating the long-term environmental impacts of MITs alongside economic benefits ensures alignment with global sustainability goals and resilient agricultural systems (Khalifa W *et al*., 2020; Li *et al*., 2016). The framework must also address the role of subsidies, credit facilities, training programs, and regulatory support in enhancing adoption rates, providing actionable insights for policymakers to create enabling environments (Assefa *et al*., 2022; Shen & Yi, 2015; Singh & Singh Malik, 2018; Xiuling *et al*., 2023). The use of dynamic modeling techniques would account for the variability and interconnectedness of factors influencing MIT adoption, simulating scenarios for different water availability levels, market conditions, and climatic changes (Akinyi *et al*., 2022; Bojago & Abrham, 2023). By addressing the shortcomings of existing frameworks and adopting a comprehensive approach, the proposed model offers robust and actionable insights, enabling stakeholders to design and implement interventions that are not only economically viable but also socially inclusive and environmentally sustainable to overcome adoption barriers and unlock the full potential of micro irrigation technologies for smallholder farmers worldwide.

## 3.3 Proposed Comprehensive Framework for Economic Viability

The proposed framework emphasizes water management as the cornerstone of economic viability while integrating other key dimensions, including market dynamics, socioeconomic contexts, and environmental sustainability (Bezerra *et al*., 2024; Buttinelli *et al*., 2024). This framework addresses critical gaps in existing models, particularly their limited focus on water availability and market conditions. It focuses on two interlinked pillars: market dynamics and water management.

Market price and demand are critical factors that determine the affordability and adoption of these technologies, with particular emphasis on the cost of equipment, operational expenses, and farmers' ability to access financing options (Zhang *et al*., 2023). In addition to market factors, the availability and efficient management of water resources are fundamental for evaluating the practical application of micro irrigation systems (Hedden-Nicely & Kaiser, 2024b; Mebrahtu & Tamiru, 2018). Water availability, both regionally and seasonally, directly impacts the feasibility of these technologies, while efficient water use ensures optimal distribution and minimizes waste (A. Belay *et al*., 2022; Chunyao Huang *et al*., 2020). Fore-side socioeconomic, environmental and institutional factors were identified as control factors for economic viability in the use of micro irrigation technologies (Daghagh Yazd *et al*., 2020; Kiruthika & Kumar, 2020).

A comprehensive conceptual framework for assessing economic viability should therefore integrate these dimensions, examining how market conditions, water availability, and efficiency interact to influence the sustainability and profitability of micro irrigation solutions (Akram *et al*., 2019; Gomes *et al*., 2018). This framework highlights not only the need for a balanced approach to economic and environmental considerations but also the importance of aligning market demand with water management strategies to ensure the successful adoption of micro irrigation technologies (Dey *et al*., 2024; Helena Duenhas & Carlos Cury Saad, 2009b; Montazar *et al*., 2017; Pugeaux *et al*., 2023), as shown in Figure 5.

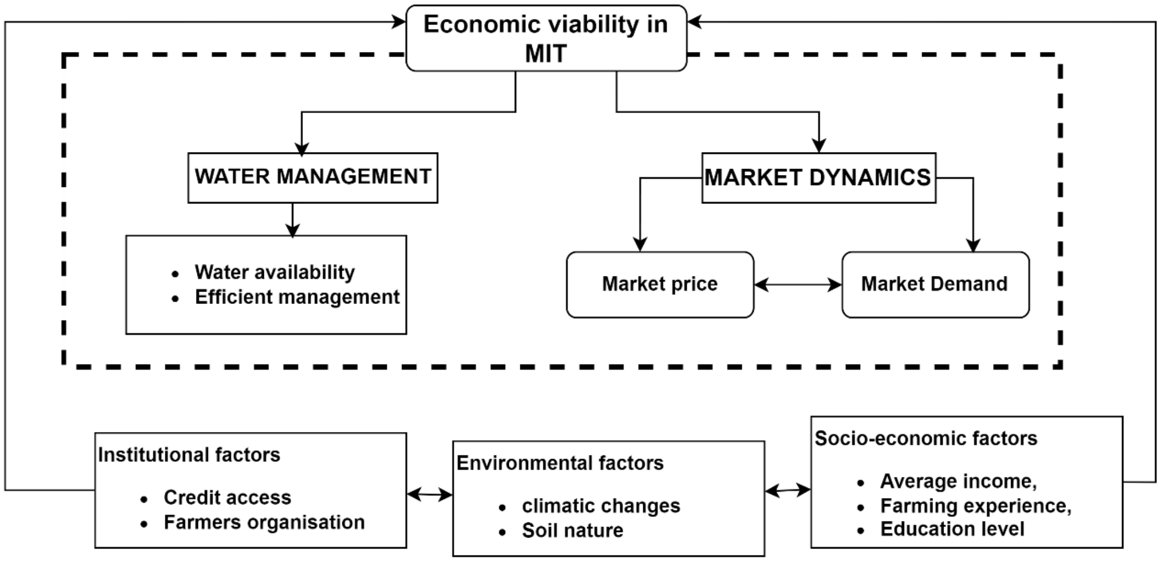


**Figure 5: Proposed economic viability model for MITs**

## 4. CONCLUSION

Micro irrigation technologies represent a vital solution to the dual challenges of water scarcity and agricultural productivity. However, their adoption is hindered by economic, social, and environmental constraints, particularly for smallholder farmers. By integrating water availability, market dynamics, socioeconomic contexts, and environmental sustainability, the proposed framework offers a holistic tool for assessing micro irrigation technologies. It addresses the unique challenges faced by smallholder farmers while aligning with global sustainability objectives. Future research should empirically validate this framework and explore the role of policy interventions and technological innovations in promoting adoption, as advancing the uptake of micro irrigation systems is essential for achieving sustainable and resilient agricultural systems in the face of increasing global challenges.

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