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Review

Exploring the smallholder irrigation equipment supply landscape in Zambia: a scoping review

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Abstract
Limited irrigation adoption hinders agricultural production for Zambia's smallholder farmers, despite its potential to mitigate the impact of erratic rainfall patterns. This scoping review investigates the irrigation equipment supply landscape in Zambia, focusing on its capacity to serve smallholders. Using the PRISMA framework, the review explores the range of available irrigation technologies, the technical knowledge of suppliers, and the challenges and opportunities surrounding equipment supply. The review identifies affordability of irrigation equipment, uneven distribution of technical support and spare parts, and limited access to credit and market opportunities as key challenges hindering smallholder farmers' irrigation adoption. However, opportunities exist through geographic targeting, collaboration with development initiatives and supermarkets, and improved access to financing. By addressing these challenges and capitalizing on opportunities, stakeholders can empower smallholder farmers to adopt irrigation technologies and achieve increased production.

Keywords Irrigation technology · Zambia · Smallholder farmers · Equipment suppliers · Technical capacity · Scoping review

1 Introduction

Zambia's agricultural sector plays a pivotal role in its economy, employing almost half of the population and contributing 3.4% to GDP [30]: [24]). However, erratic rainfall patterns and limited access to irrigation technologies constrain agricultural production and income potential, particularly for small-scale farmers [15, 21]. Recognizing this challenge, the Zambian government and the Millennium Challenge Corporation (MCC) have partnered on the Asset Financing Project, to increase investments in agricultural inputs including irrigation machinery through improved access to affordable finance..

While the potential of irrigation technologies, such as drip irrigation, to elevate yields by up to 50% while significantly reducing water use is well-documented [11, 31], their successful adoption and utilisation hinge on the technical knowledge and capacity of equipment suppliers [9, 10]. These suppliers act as critical intermediaries, advising farmers on appropriate technology choices, maintenance requirements, and effective irrigation management practices.

While research has explored the suitability of diverse irrigation technologies for various contexts [3, 14], a critical knowledge gap exists regarding the technical capacity of equipment suppliers specifically within the Zambian context.

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This gap presents a formidable barrier to maximizing the Asset Financing Project's impact and ensuring the effective dissemination and utilization of irrigation technologies amongst targeted beneficiaries.

Therefore**,** this scoping review aimed to address this gap by systematically mapping and synthesizing existing literature on two key areas (i) the major irrigation equipment suppliers and their locations: The review identified irrigation equipment suppliers operating in Zambia, including local and international companies. (ii) the challenges and opportunities in the irrigation equipment supply landscape: The review explored the opportunities and challenges facing the Zambia irrigation equipment supply landscape.

This scoping review will provide a comprehensive understanding of the irrigation equipment supply landscape in Zambia, highlighting strengths and weaknesses. The findings will inform interventions to improve access to appropriate irrigation technologies for smallholder farmers, ultimately contributing to enhanced agricultural production and food security.

2 Methods

This scoping review applied the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure transparency and rigor in the literature search and selection process [18, 23]. The PRISMA-P approach standardises literature search for replicability and involves (1) generating the search strategy, (2) detailing the inclusion and exclusion criteria, and (3) data extraction. The next sections describe the study area, search strategy employed by the review, evidence grading, and data synthesis methods.

2.1 Study area description

Zambia (Fig. 1), situated in Southern Africa, is a landlocked country renowned for its rich biodiversity, diverse ecosystems, and abundant water resources [25]. The country is traversed by several major river systems, most notably the Zambezi River, which forms Zambia's southern border and serves as a vital lifeline for both ecosystems and human activities. Other important catchments include the Kafue, Luangwa, Chambeshi, Luapula and Tanganyika.

Water resources play a pivotal role in Zambia's socio-economic development, supporting agriculture, industry, energy generation, and ecosystems. The country's hydrology is primarily influenced by seasonal rainfall patterns, with distinct wet and dry seasons prevailing across different regions. Numerous lakes, swamps and wetlands dot the landscape, with Lake Kariba, a man-made lake, offering vast potential for irrigation projects. However, the seasonal nature of rainfall, concentrated between November and March, presents a significant challenge. Rain-fed agriculture, the dominant practice, leaves farmers vulnerable to periods of drought, jeopardizing food security and agricultural productivity [6].

Despite the abundance of water resources, Zambia's irrigation sector remains underdeveloped, with less than 7% of irrigable land currently under irrigation. Moreover, less than 0.5% of the total agricultural land is equipped for irrigation. Several factors contribute to this underdevelopment. Public investment in communally managed irrigation schemes has been substantial, yet these projects often encounter significant challenges. These schemes frequently suffer from high costs and management issues, primarily due to a lack of ownership by local communities and the dysfunction of Water Users Associations (WUAs). The absence of effective local engagement and management leads to poor returns on these large investments. Furthermore, limited access to financing for irrigation infrastructure, coupled with inadequate infrastructure such as canals and pumping stations, restricts further expansion. Knowledge gaps among farmers regarding irrigation practices and a lack of technical expertise for system maintenance add to the challenges, further impeding the sector's growth [15].

2.2 Search strategy

A systematic search in electronic databases, including Web of Science, Scopus, ScienceDirect, and Google Scholar, was conducted using a comprehensive combination of keywords and terms. The initial search string was developed based on four key concepts:

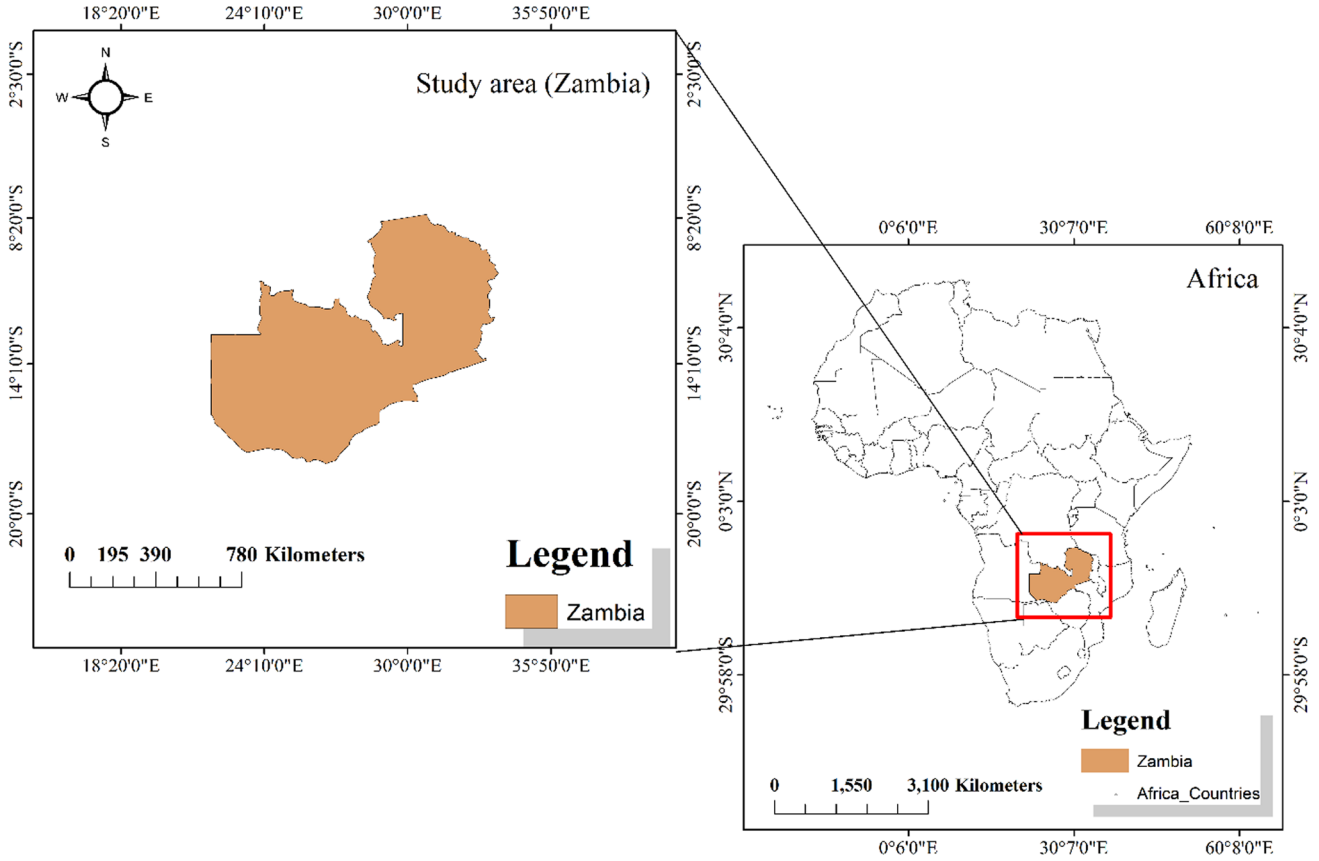

Fig. 1 Study country and its relative position in Africa. Source: Authors

- Irrigation technology: drip irrigation, sprinkler irrigation, furrow irrigation, small-scale irrigation, sustainable irrigation technologies.
- Equipment suppliers: irrigation equipment vendors, irrigation equipment distributors, irrigation system installation companies.
- Technical capacity: knowledge, skills, training, technical assistance, capacity building, Zambia.
- Opportunities and challenges in the irrigation equipment supply landscape.

The Boolean operators AND and OR were strategically combined to construct the search string. The initial search string was adapted for each database to account for differences in indexing and search functionalities. Table 1 shows the keywords and search strategy combination used.

2.3 Screening, selection process, and evidence grading of selected studies

After removing duplicates, titles and abstracts of identified studies were screened by two independent reviewers against the eligibility criteria. A third reviewer was on standby as an arbiter to resolve conflicts. Full-text articles of studies meeting the initial inclusion criteria were retrieved and assessed for final inclusion by both reviewers. The screening process facilitated the selection of relevant studies that matched the smallholder farming typologies.[1] process. The study applied the strength of evidence check (Table 2) by Koutsos et al. [13] to grade relevance of the included articles. The grading scale qualifies articles based on the substantiality of evidence provided. Other studies have applied the strength of evidence check [7].

[1] Zambia smallholder farm sizes can be broadly categorized based on factors such as farm size, access to resources, farming systems, and market orientation. For example, there are subsistence, emerging, and market oriented smallholder farmers across different agro-ecological regions Source. Profile of Zambia's smallholders: where and who are the potential beneficiaries of agricultural commercialization?.

Table 1 Keywords and search strategy combination

Keywords
Boolean search
(irrigation OR "drip irrigation" OR "solar irrigation") AND (supplier* OR dealer* OR vendor* OR "service provider*") AND Zambia AND (("drip irrigation" OR "micro-irrigation") AND ("pump*" OR "solar powered")) NOT "conference abstract" NOT ("opinion" OR "editorial")
Inclusion criteria
Studies were included if they met the following criteria:
Published in peer-reviewed journals, conference proceedings, or credible institutional reports
Published in English after 2014 (due to rapid advancements in irrigation technologies).Focused on irrigation technologies suitable for small-scale agriculture in Zambia
Addressed the technical knowledge, skills, or capacity of irrigation equipment suppliers in relation to advising farmers on irrigation technologies
Provided insights into potential knowledge gaps or challenges faced by equipment suppliers
Discussed the role of technical assistance programs in enhancing supplier capacity
Exclusion criteria
1. Abstracts, editorials, personal opinions and book reviews
2. Articles not in English

Table 2 Strength of evidence literature grading scale (adopted from [13])

Strength of evidence	Type of agricultural research	Study design	Study type	Evidence
Strong (I)	Applied research, adaptive/farm level research, strategic research, systematic reviews and meta-analyses	Experiments, field trials, systematic reviews	Experimental/ structured review	Substantiated
Moderate (II)	Case studies/reviews, modelling/ simulation	Case studies, narrative reviews, simulations	Observational	Partially substantiated
Low (III)	Opinion papers, conference papers, workshop papers	Qualitative research, opinion papers, reports of expert committees	Descriptive	Unsubstantial, qualitative analysis and opinions
Very Low (IV)	N/A	N/A	N/A	N/A

2.4 Data extraction

A standardized data extraction form was developed to collect relevant information from included studies, including author(s), year of publication, study location, study design, target audience, irrigation technologies discussed, reported knowledge and capacity of equipment suppliers, identified knowledge gaps and challenges, and details of any mentioned technical assistance programs. The extracted data was summarized narratively by thematic categories.

2.5 Synthesis and reporting

The extracted data was analyzed thematically following a method by Braun and Clarke [4] to provide a comprehensive overview of the current state of knowledge regarding the technical capacity of irrigation equipment suppliers in Zambia. The review identified the range of irrigation technologies suitable for different smallholder farm sizes and agro-ecological regions, analyzed existing knowledge gaps and challenges faced by equipment suppliers, and highlighted the value of targeted technical assistance programs in enhancing their capacity. The findings were reported in a narrative format, with key themes and insights clearly presented and supported by relevant evidence from the included studies.

3 Results

3.1 Literature search

The systematic search across electronic databases, including Google Scholar and ScienceDirect yielded a total of 200 records. After removing duplicates, 69 unique records remained for screening. Through the initial screening of titles and abstracts, 69 full-text articles were assessed for eligibility. Finally, 12 studies met the inclusion criteria and were included in the scoping review. Figure 1 shows the scoping review process based on the PRISMA diagram (Fig. 2).

The included studies encompassed a diverse range of literature types, including research articles (n = 2), reports (n = 9), and policy documents (n = 1). These studies provided insights into various aspects of the irrigation supply landscape in Zambia (see Table 3). The geographic focus of the literature was specifically on Zambia, reflecting the relevance of the findings to the local agricultural landscape. The publication years of the included studies spanned from 2012 to 2024, indicating a recent and up-to-date body of literature.

A thorough thematic analysis revealed three broad theme categories namely, (1) mechanisation (farm machinery and irrigation) as catalysts for agricultural production, (2) credit access and market integration, and (3) private–public partnerships (PPP) and donor involvement. Theme (1) and theme (2) underscore the importance of asset ownership for improved agricultural production, whereas theme (3) depicts the need for partnerships to facilitate asset ownership for improved agricultural production. Despite the well-researched areas such as institutional support and the role of PPP and donors for capacity building to mention a few, there exists knowledge gaps on providing unifying frameworks for scale appropriate irrigation hardware [22, 26]. Another research gap is on mapping the sustainability of groundwater use to support irrigated services across the country. We therefore opine that a responsible irrigation development and agricultural water management strategy should incorporate evidence based irrigation hardware sizing framework that is applicable across multiple scales coupled with groundwater mapping activities along the value chain.

3.2 Irrigation equipment suppliers identified in the study.

The scoping review identified various irrigation equipment companies operating within Zambia's agricultural landscape. Table 3 provides key details including company names, locations, contact information, types of irrigation technologies offered, and target customer segments. A trend analysis illustrating the evolution of smallholder irrigation is presented in Figure A1 (See Appendix Section). Despite a growing demand for irrigation at crop and field scales, there still exists a limited number of equipment suppliers across the country. Based on our understanding of the findings, we hypothesize the following: (Table 4).

Smallholder irrigation took centre stage in the early 2000's, with adoption significantly increasing from 2005 onward to date, currently registering an adoption rate of approximately 25%. According to Ngoma et al. [21], by 2010 an estimated 1% of the farmers adopted somewhat advanced irrigation technologies because small-scale irrigation equipment supply was limited to NGOs. Based on the trend analysis, irrigation and its low adoption was noted in the early 2000's and the issues of climate change took centre stage in the later stages of the 2010's. This suggests that the slow growth in irrigation supplier market was reactive to the growing needs of farmer needs to derisk their food systems from climate changes via irrigation.

Additionally, although issues relating to irrigation and water supply emerged concurrently, irrigation was more prevalent initially, dominated by traditional methods such as bucket irrigation systems [21], which inefficiently allocated water resources. The ease of access of the traditional methods of irrigation choked any demand and potential for advanced and water-efficient irrigation equipment offered by suppliers. Therefore, given the limited demand in their product(s) there lacked incentives to expand and possibly venture into the supplier market business.

A visual inspection of the locations of the irrigation companies showed that most of them were located in Lusaka. Figure 3 shows the locations of the irrigation companies.

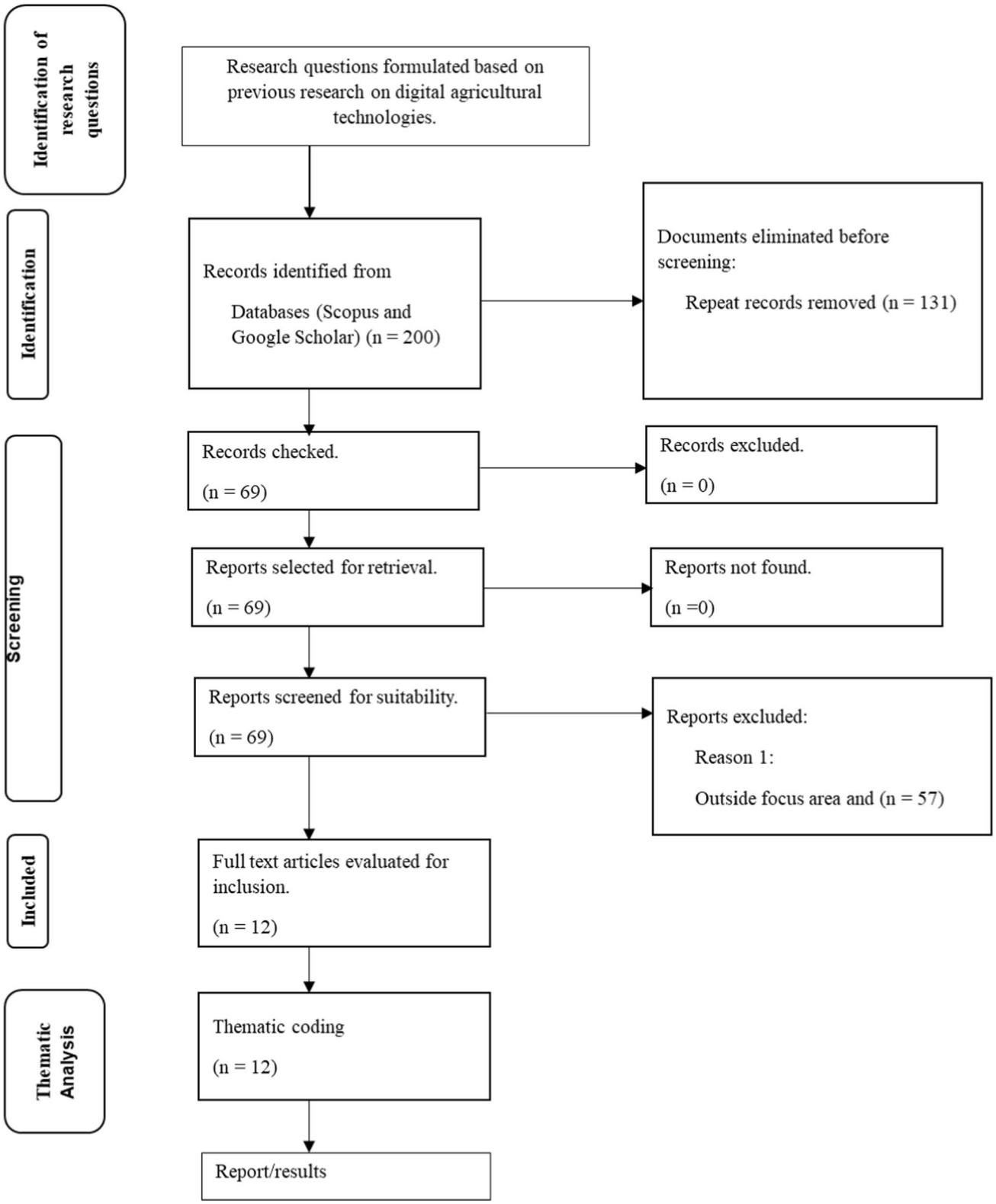

Fig. 2 The Scoping review process based on the PRISMA flow diagram showing a selection of studies and reasons for exclusion. Adapted from Moher et al., [19]

Table 3 Summary of studies included in this review and their key highlights/findings

No	Author(s)	Study title	Subject matter	Evidence	Strength of Evidence	Key study findings and Conclusions
Strength of Evidence: Strong (I)						
1	Veldwisch et al. [29]	Low-cost drip irrigation in Zambia, in: Drip Irrigation for Agriculture	Low cost drip kits	+ + +	I	Joint collaboration between NGOs and International Development Enterprises (iDE) for provisioning low cost drip kits
2	Senzanje & Dirwai [25]	Water and Agriculture in the Zambezi River Basin	Applying WEFE nexus approaches to assess irrigation development in the Zambezi River Basin	+ + +	I	WEFE nexus approach to characterize the current agriculture activities and future potential irrigation developments in the Zambezi River Basin
3	Teschemacher et al. [27]	What constrains agricultural productivity in Zambia?	Identifying policy challenges and shortcoming in Zambia's agric value chains	+ + +	I	Poor access to finance hinders mechanisation across multiple scales. A comprehensive policy reform and holistic approach can potentially overcome the challenges
4	Rosenberg et al. [24]	Zambia: Promotion of Mechanisation Ways out of poverty, vulnerability and food insecurity	Mechanisation -with particular reference to farm machinery-through leasing models as a driver to improved agricultural productivity	+ + +	I	Mechanisation coupled to flexible finance models is key to enhancing agricultural productivity. The leasing models should not only be limited to farm machinery such as tractors but to irrigation equipment too
5	Ngoma et al. [21]	Irrigation development for climate resilience in Zambia: the known knowns and known unknowns	Dissecting the socio-economic factors that influence irrigation uptake. The paper further evaluates the performance of existing irrigation schemes	+ + +	I	The study identified that access to water, finance /credit and secure land tenure positively influence irrigation uptake and adoption. The study promotes holistic policy formulation that improves credit access to farmers for improved resilience
6	Mikhail et al. [17]	Opportunities for Agricultural Water Management Interventions in the Mwembeshi Watershed in Zambia	Irrigation as AWM adaptation strategy in rainfed smallholder irrigation food production systems	+ + +	I	The study found that many smallholder farmers rely on rudimentary AWM practices such as bucket systems, manual wells signifying a technology gap. The conclusion was Multi-stakeholder collaborations to coordinate and enhance agric value chains (e.g. irrigation)
7	FAO [9]	Zambia: Irrigation market brief	Irrigation development and AWM as critical drivers for improving agricultural production across multiple scales	+ + +	I	The study recommended mechanisation through irrigation. The study also identified limited access to finance/credit as a major inhibitor to mechanisation. The study concluded that access to finance and promoting public–private partnerships as key to attracting targeted investments for smallholder irrigation mechanisation

Table 3 (continued)

No	Author(s)	Study title	Subject matter	Evidence	Strength of Evidence	Key study findings and Conclusions
Strength of Evidence: Strong (II)						
8	Danert et al. [6]	Achievements and Lessons Learned in the Implementation of Groundwater Regulation in Zambia	Groundwater management for sustainable development	+ +	II	The paper advocates for policy interventions (e.g. dewatering water permits) for sustainable groundwater management
9	Colenbrander & van Koppen [5]	Improving the Supply Chain of Motor Pumps to Expand Small-scale Private Irrigation in Zambia	Access to motorised pumps vital to expanding smallholder irrigation in Zambia	+ +	II	The study revealed that inconsistent fiscal policies that provide duty waivers to motor pumps, centralised supply chains, high cost of mechanised irrigation and limited access to finance/credit inhibit smallholder irrigation expansion. The study concluded that improving access to credit/finance, providing after-sale support, decentralising supply chains, and cohesive policies can potentially improve access to irrigation
10	Akayombokwa et al. [2]	Trends and Outlook: Agricultural Water Management in Southern Africa Country Report Zambia	AWM interventions such as irrigation are crucial for addressing food and nutrition insecurity	+ +	II	The study revealed that high cost of irrigation infrastructure, limited access to finance and inadequate market access hinder irrigation development in smallholder settings. The study concluded that low-cost irrigation technologies such a motorised pump and small-scale drip kits positively influences irrigation adoption. Additionally, the study concluded that improving after sale support and providing technical support to value chain players is key to expanding irrigation services to smallholder farmers
Strength of Evidence: Strong (III)						
11	African Agri-Business (2019)	Agritech Expo Zambia Edition	The report argues that mechanisation (irrigation and farm machinery) are essential to derisking food production systems in smallholder farm settings	+	III	The report identifies leasing models as championed by Stanbic Bank Zambia as a solution to improving access to mechanisation. The report advocates for public–private partnerships for catalysing irrigation expansion

Table 3 (continued)

No	Author(s)	Study title	Subject matter	Evidence	Strength of Evidence	Key study findings and Conclusions
12	Feed the Future (2016)	The Market for Small-Scale Drip Irrigation in East and Southern Africa Opportunities and challenges to commercialization	The report focuses on exploring the opportunities and challenges of commercializing small-scale drip irrigation systems in East and Southern Africa, including Zambia	+	III	The report evaluates the potential market for drip irrigation among smallholder farmers and assesses barriers to adoption, market segmentation, enabling environments, and the role of development initiatives In Zambia, adoption remains low due to financial constraints, lack of awareness, and challenges like uncertain land tenure and limited access to credit. The study emphasizes the need for targeted support to commercially viable smallholders in well-resourced regions, integration with input packages (e.g., seeds and fertilizers), and partnerships to provide financing options

Key: Substantiated (+ + +); partially substantiated (+ +); unsubstantiated (+) after Koutsos et al., [13]

Table 4 Irrigation service providers and leasing companies in Zambia: overview of locations, offered technologies, and target customer segments

Company name	Location	Website	Types of irrigation technologies offered	Target customer
Tritech	Lusaka	https://irritechsa.co.za/	Drip irrigation, sprinklers, pivots	Medium to large-scale farms
Agrico	Lusaka Mkushi	https://www.agrico.co.za/contact/	Centre-pivots Sprinklers Drip	Not specified
Melvel Investments	Lusaka	https://www.linkedin.com/company/melvel-investments/?originalSubdomain=zm	pumps, controls and electric motors	Not specified
Zamlist Irrigation Company	Lusaka	https://www.facebook.com/Irrigation2000?mibextid=ZbWKwL	Installation and design	Not specified
Ajay Industrial Corporation Zambia Limited	Lusaka	http://www.ajayindustrial.com/	Handpumps Solar equipment	Not specified
Acacia Works	Kitwe	Freedom Ave, Kitwe, Zambia	Design and installation of irrigation system Post-up sprinklers and sprayers Drip irrigation kits	Not specified
Irrigation House	Lusaka	https://irrigation-house.business.site/	Irrigation equipment	Not specified
Aqua Aura Limited	Lusaka	https://www.facebook.com/irrigation4ZimbabweZambia/	Drip kits, Centre pivots	Not specified
Irrigation zambia365	Lusaka	H7MH + 3GX, Freedom Way, Lusaka,		Not specified
SARO Agro Industrial	Lusaka	www.sarozambia.com	Drip, flood and overhead irrigation equipment	Commercial and emerging farmers
NDKAY Zambia	Lusaka	https://ndkayzambia.com/	Drip irrigation	Small-scale and emerging farmers

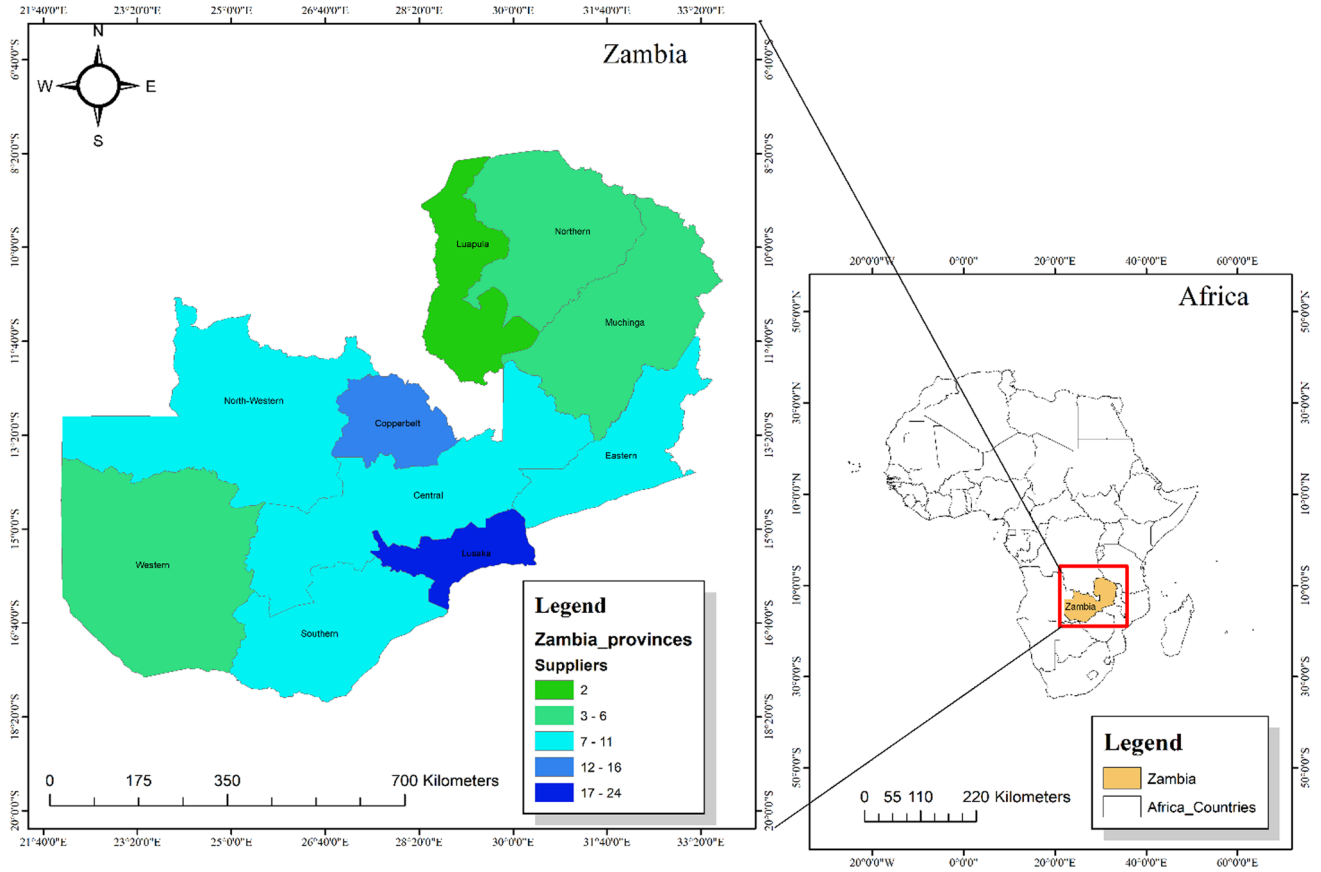

Fig. 3 Location of Irrigation equipment suppliers in Zambia and their relative distribution across the country. Source: Authors

3.3 Irrigation technologies and technical support

A thematic analysis of the included studies revealed several key themes related to the technical knowledge of irrigation equipment leasing companies and suppliers:

3.4 Irrigation technologies available

The results of the review showed that a range of irrigation technologies are provided by irrigation equipment suppliers in Zambia. These technologies range from drip irrigation, sprinkler systems to solar-powered pumps [5, 9, 10, 29]. For example, Zambia SIP mentioned flood irrigation using siphons as a specific irrigation technology being used at the Manyonyo scheme. Other technologies in use include treadle pumps and motor pumps [5, 17]. However, according to Ngoma et al. [21], the most prevalent irrigation technology used by smallholder farmers is manual bucket irrigation, with more than 80% of farmers using this method.

Mikhail et al. [17] explained that smallholder farmers and subsistence farmers generally used outdated irrigation technologies such as gravity, labour intensive treadle and watering cans, or small motor pumps to access surface or shallow ground water for irrigation.. Commercial farms, on the other hand, relied on high-technology systems such as boreholes and pumps to access deeper groundwater resources for crops like wheat and soybeans [9].

Different companies generally provide different irrigation equipment. For example, Agrico offers an internet-based control system for center pivots. This system allows for the control of the entire irrigation system, including pumps, valves, and reservoir water, on one interface. The system provides farmers with the ability to control their irrigation systems from anywhere using a smart device connected to the internet [1]. Other irrigation equipment suppliers

include Irritech which specialises in drip and centre pivot irrigation. Irritech states on its website that it is an irrigation solution provider able to design all types of irrigation systems.

Another key player in the irrigation supply sector is SARO Agro Industrial Ltd. SARO Agro Industrial, a Zambian company founded in 1987, offers a wide variety of products from tractors to generators and irrigation systems, and even manufacture some equipment themselves. Initially, SARO was focused on the import of agricultural equipment for small scale farmers but have since expanded their portfolio to cater for commercial and emerging farmers. On their website, SARO state that they have a dedicated team to service the parts needs of their customers and provide immediate technical assistance (www.sarozambia.com).

However, the review also showed that while a range of equipment is available, not all farmers can afford the equipment. For example, Rosenberg et al. [24] argued that drip irrigation equipment provided by SARO (an irrigation company) was currently too expensive for smallholder farms, and more affordable solutions such as mechanical pedal pumps or solar pumps should be promoted. To make irrigation equipment affordable, several organisations have promoted the use and development of low-cost irrigation technologies. Organizations, such as the NGO International Development Enterprises (iDE), have promoted low-cost irrigation technologies as a potential solution to rural hunger and poverty. The technologies developed include low-cost plastic tanks for collecting and storing rainwater, pressure and suction treadle pumps for lifting water, low-pressure sprinklers, and drip emitters for efficient water application [29]. iDE operates with a market-based approach, aiming to support farmers in becoming more entrepreneurial and increasing their crop productivity and income.

3.4.1 Technical assistance provided by irrigation equipment suppliers

The review showed several irrigation equipment suppliers that worked with the out-grower programs in Zambia. These suppliers include Irritech, MultiCrop, and Amiran [9]. While the Zambia Irrigation Market brief from FAO, [9] did not provide specific details about the technical knowledge possessed by these suppliers, it can be inferred that they have expertise in irrigation equipment and systems and likely know different types of irrigation methods, such as drip irrigation, sprinkler irrigation, and pivot irrigation. For example, the Irrigation Market brief mentions that the Kaleya Smallholders' Company works with three large irrigation equipment suppliers (Irritech, Multicrop Ltd Zambia, and Amiran). These companies are based in Lusaka, a two-hour drive from Kaleya. Farmers have reported that these companies have good maintenance, with same-day or next-day service.

However, Irrigation market also points out that this view is not universal as farmers further from Lusaka have difficulties getting assistance, and often have to bring ordinary sprinklers to Lusaka for adjustments and repairs. The availability of spare parts and repair services for irrigation equipment is crucial, as failure of the equipment and the difficulty of procuring spare parts can significantly delay agricultural activities. Rosenberg et al., [24], in their report, explained that while some spare parts could be ordered and paid for through mobile channels, challenges of who would install the spares professionally were being faced by remote farmers. Mikhail et al., [17] also reported that there was limited access to support and extension services for subsistence farmers located in remote areas.

3.5 Identified challenges and opportunities

From the wealth of literature on irrigation development in Zambia, several challenges and opportunities for improvement were identified.

3.5.1 Challenges

Firstly, the prohibitive costs of irrigation systems such as drip systems inhibit access for small-scale and emerging producers. Additionally, there is limited access to credit and lack of business skills among smallholder farmers [21]. Financial institutions are reluctant to lend to small-scale agricultural borrowers,. Ngoma et al. [21] specifically mention lack of finances and access to loans as critical issues hindering the full utilisation of water resources for irrigation in Zambia. Most financial institutions are reluctant to lend to small-scale farmers, primarily because these farmers are considered

high-risk based on asset-based models used by commercial banks. These models often require substantial collateral, which smallholder farmers typically lack, leading to prohibitively high borrowing costs [10]. Without access to credit, small-scale farmers are unable to afford the upfront costs of modern irrigation systems.

In instances where credit or finance is availed, the high interests as much as 30% of the principal rate, deter smallholder farmers to take up the solar irrigation packages availed by the supplier. Furthermore, the government, being a major client of these banks, influences lending practices, with commercial banks often prioritizing loans to the government over small-scale farmers. Additionally, farmers lack the necessary business skills to operate their farms as enterprises, further hindering their ability to invest in technologies such as drip irrigation.

Another significant challenge lies in the mindset of Zambian smallholder farmers. According Feed the Future [10], the typical Zambian smallholder farmer does not operate their farm as a business and relies on seasonal rainfall and staple crops for subsistence. However, shifting farmers to a farming-as-a-business mindset will require time, entrepreneurial skills training, and access to explicit output market opportunities for higher-value horticulture.

In addition, agricultural extension services for smallholders in Zambia are limited in scale and quality, similar to many countries in sub-Saharan Africa [10]. The majority of smallholder farmers have limited access to technical advice and training on drip irrigation. Extension services provided by the government and other organizations are understaffed and cannot cover all farmers comprehensively. Government extension services face capacity and resource constraints, and their focus is primarily on rainfed staple crop production and household nutrition initiatives rather than high-value irrigated agricultural production. According to Teschemacher et al. [27], the ratio of extension workers to farmers is considered insufficient, and there are communication hurdles due to technological and infrastructural factors.

Another obstacle is the limited market access for smallholder farmers in Zambia. While supermarkets like Shoprite are increasingly sourcing locally, smallholders find it challenging to meet year-round supply expectations. Drip irrigation could enable small-scale producers to increase their access to stable output markets, but there is a need for coordination and collaboration with supermarkets and other market actors.

Moreover, there is a lack of robust rural distribution networks for irrigation equipment in Zambia. Smallholder farmers often have to travel to major urban centres to purchase drip equipment, and rural sellers have limited technical capacity and capital to purchase inventory. strengthen service delivery in irrigated agriculture and encourage new private investment that increases area and productivity [2]. Building a strong rural distribution network is crucial for increasing the uptake of drip irrigation among smallholders. The government of Zambia (GoZ) has been aiming to improve that through the National Irrigation Policy Strategy of 2004 which seeks strengthen service delivery in irrigated agriculture and encourage new private investment that increases area and productivity [2].

Additionally, most irrigation equipment distributors in Zambia do not provide installation services or ongoing after-sales support to small-scale farmers [9]. This lack of support hinders the adoption and effective use of drip irrigation systems among smallholders. Customer support through regular servicing, troubleshooting, and repairs is critical to ensure the reliability and longevity of irrigation equipment, particularly in rural areas with limited access to technical support. While smallholder farmers received introductory training when they first received agricultural equipment from SARO, damage to equipment was still a significant problem [24]. Rosenberg et al. [24] then suggested that more training opportunities for smallholder farmers should be created to promote maintenance and light repairs of irrigation equipment, and farmers should be trained on the proper use and maintenance of the equipment.

3.5.2 Opportunities

In identifying potential areas suitable for irrigation investments, geographic targeting plays a crucial role. According to recommendations by Feed the Future [10], irrigation equipment suppliers should prioritize targeting smallholder horticulture production areas with higher than average rates of irrigation, such as Chibombo, Mukushi, Serenje and Chisamba. These areas not only have good access to water but also possess strong potential export markets, making them ideal for irrigation investments [10].

Collaboration with development initiatives presents another opportunity for the irrigation sector. Drip distributors can closely collaborate with initiatives such as the USAID-funded Mboga na Matunda project and the IFC 2030 Water Resources Group [10]. Another mechanization leasing programme AgLeaseCo [24] can be leveraged on to optimise agricultural productivity. These initiatives can provide valuable support for small-scale drip irrigation demonstrations,

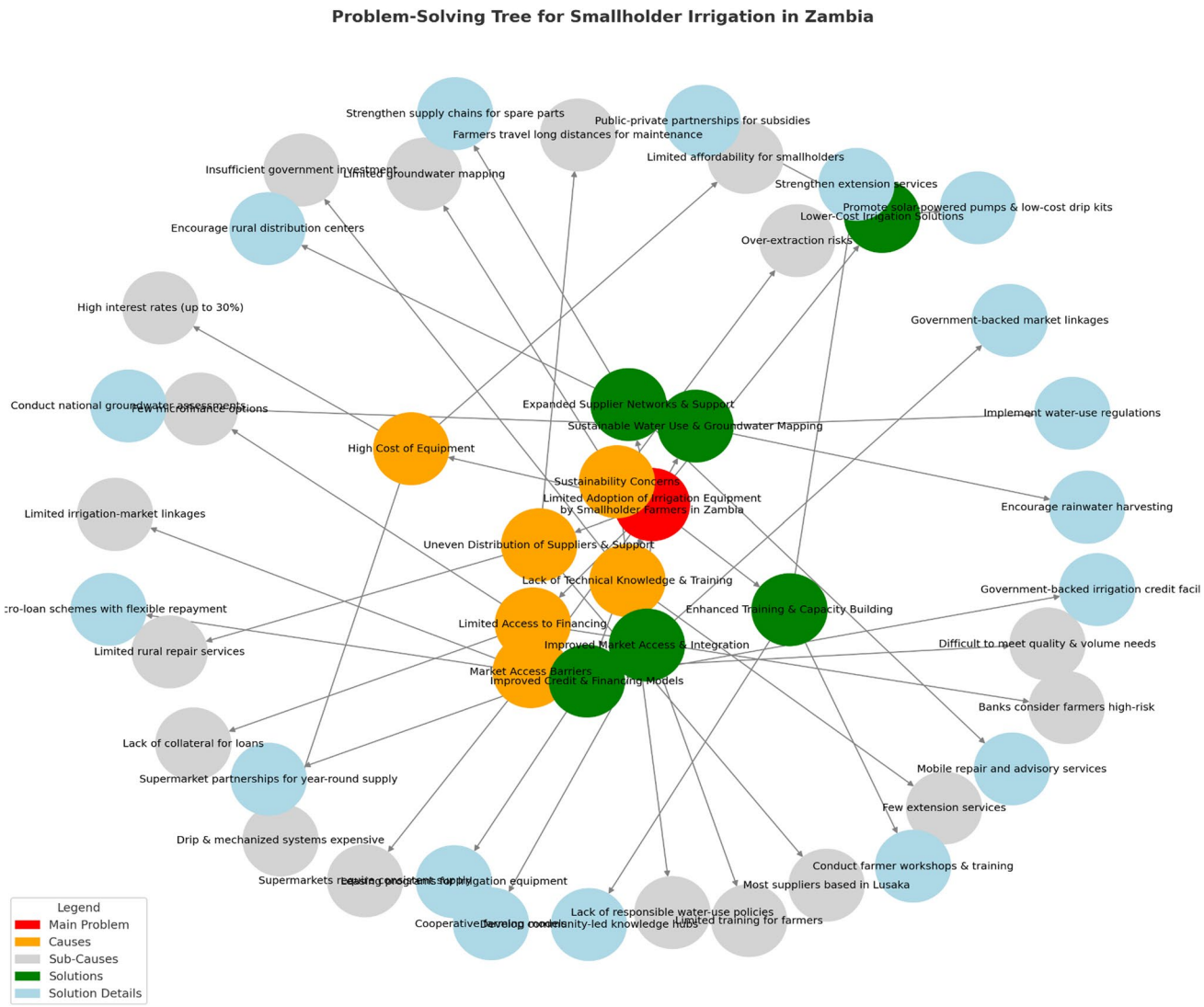

Fig. 4 Problem-solving tree based on the challenges, opportunities and potential solutions identified in the study

help expand rural distribution networks, and pilot equipment credit schemes with financial institutions. By leveraging the expertise and resources of these development initiatives, the irrigation sector can receive the necessary support to overcome some of its challenges and foster its growth.

Furthermore, collaboration with supermarkets holds great potential for small-scale producers in Zambia. Supermarkets like Shoprite are increasingly sourcing products locally, creating an opportunity for drip distributors to partner with them. By establishing partnerships with supermarkets, drip distributors can introduce drip irrigation to small-scale producers who have the capacity to meet year-round supply expectations. This collaboration not only provides a market opportunity for commercially oriented small-scale producers but also strengthens the link between irrigation and market access, enhancing the profitability of drip irrigation for farmers.

Figure 4 provides a problem-solving tree based on the challenges and opportunities identified by the scoping review.

The irrigation sector in Zambia presents several opportunities for growth and improvement. Geographic targeting can help identify suitable areas for irrigation investments with good access to water and strong export markets. Collaboration

with development initiatives that provide bundled services (i.e. farm machinery and irrigation services) for setting up demand driven demonstrations, supporting distribution networks that attract flexible credit schemes. Additionally, partnering with supermarkets creates market opportunities for small-scale producers. By capitalizing on these opportunities, the irrigation sector can overcome its challenges and contribute significantly to agricultural productivity, food security, and income generation for smallholder farmers in Zambia.

4 Discussion

Irrigation plays a vital role in enhancing agricultural production, particularly in regions prone to erratic rainfall patterns and water scarcity. In Zambia, as in many other developing countries, the adoption of irrigation technologies offers promising solutions to improve crop yields and livelihoods for smallholder farmers. However, a comprehensive understanding of the available irrigation technologies, associated challenges, and opportunities is essential for effective development interventions.

One of the key findings from the review of irrigation technologies in Zambia is the diverse range of options available to farmers. From traditional methods like treadle pumps to modern solutions such as solar-powered pumps and internet-based control systems, the array of technologies caters to the varying needs and contexts of farmers across the country. Despite this diversity, affordability remains a significant barrier for many smallholder farmers, underscoring the importance of promoting more accessible solutions. The affordability barrier is not unique to Zambia or southern Africa but has also been highlighted by studies conducted in East Africa [16, 20] and sub-Saharan Africa [8]

Moreover, the availability of technical assistance and support services is unevenly distributed across different regions of Zambia. This uneven distribution of the service providers/supplier (see Fig. 3) which inhibits access, consequently affects adoption of the irrigation technologies. While farmers near urban centers benefit from timely maintenance and repair services, those in remote areas face challenges accessing spare parts and expertise. Consequently, the lack of support can lead to disruptions in agricultural activities, highlighting the need for robust rural distribution networks and accessible repair services. In their study on communality in farmer managed irrigation systems in Spain, Ecuador, Cambodia and Mozambique, Hoogesteger et al., [12] emphasised that regular maintenance and easy access to technical assistance was crucial in sustaining irrigation systems.

The challenges of accessing credit and market opportunities further compound the adoption of irrigation technologies among smallholder farmers in Zambia. High borrowing costs and limited availability of credit hinder farmers' ability to invest in irrigation equipment, while the lack of business skills and market access inhibits the profitability of irrigation ventures. Evidence from Ethiopia also shows that the main constraints to smallholder farmers in adopting irrigation technologies are inadequate access to financing options and lack of technical know-how [28]. Consequently, many farmers continue to rely on rainfed agriculture, perpetuating the cycle of low productivity and poverty.

However, amidst these challenges lie opportunities for improvement and growth in the irrigation sector. Geographic targeting, for instance, can help identify areas with high potential for irrigation investments and export markets, guiding resource allocation and development strategies. Collaboration with development initiatives and supermarkets presents another avenue for enhancing support services and market access for smallholder farmers, thereby fostering the adoption of irrigation technologies and improving livelihoods.

5 Limitations

While this review provides a comprehensive overview of recent developments in Zambia's irrigation landscape, it is important to acknowledge its limitations. Potential biases in the selection and interpretation of studies may exist, and the exclusion of non-English language publications and grey literature might have slightly narrowed the scope.

However, by focusing on peer-reviewed studies and established sources, this review offers a robust synthesis of the most reliable and relevant information available. Despite these limitations, the review provides valuable insights that can inform future research and policy-making in the sector.

6 Future research directions

While the scoping review provides valuable insights into the technical knowledge landscape of irrigation equipment leasing in Zambia, several areas warrant further investigation. There are limited studies that analyse the demand and potential for the various irrigation technologies in Zambia. More information is needed on the size of the market, the technical knowledge possessed by irrigation equipment suppliers and importantly, the specific needs and preferences of smallholder farmers.

Future research should also focus on evaluating the effectiveness of capacity-building interventions, assessing the socio-economic impacts of irrigation technology adoption, and exploring innovative financing mechanisms to enhance access and affordability for smallholder farmers. In developing capacity-building interventions, it is critical to consider the gendered nature of farming in Southern Africa as this poses challenges for women in accessing and benefiting from low-cost irrigation technologies. Women often have less control over financial resources and face barriers in obtaining loans or making investments in their gardens. Additionally, longitudinal studies tracking the adoption trajectories and outcomes of irrigation technologies can provide valuable evidence for informing evidence-based policy and investment decisions.

7 Conclusion and recommendations

The development of irrigation in Zambia holds immense potential to transform agricultural production and alleviate poverty among smallholder farmers. By addressing the challenges of affordability, technical support, credit access, and market opportunities, stakeholders can unlock the full benefits of irrigation technologies and contribute to sustainable agricultural development. Moreover, leveraging opportunities for collaboration and strategic targeting can further accelerate progress towards achieving food security and economic prosperity in Zambia's agricultural sector.

High level support where government intervenes for sustainable irrigation development is an opportunity to improve and enhance the irrigation development value chain. For example, the value chain actors can leverage on the on-going Farmer Input Support Programme to target more clientele and potentially establish a revolving fund that improves access to credit. From a policy perspective, the state can prioritise polices that incentivise the use of locally produced and adapted irrigation technologies. Additionally, sector harmonisation i.e. improve collaboration between different government ministries can help improve access to credit for farmers. For example, a well-coordinated collaboration between government departments that issue title deeds and government accredited micro-financing institutions can help farmers access credit by using land ownership as collateral. The state can play a pivotal role in strengthening agricultural extension services providing training programmes on financial literacy, business skills development and irrigation management practices. Whilst the recommendations support irrigation development, a responsible agricultural water management approach is required to preserve groundwater sources to prevent over abstraction.

This scoping review offers valuable insights into the technical knowledge landscape of irrigation equipment leasing in Zambia and highlights opportunities for promoting inclusive agricultural development. By addressing gaps in technical capacity, enhancing maintenance practices, and improving market access, stakeholders can contribute to sustainable water management, enhanced agricultural productivity, and improved livelihoods for smallholder farmers. Moving forward, concerted efforts are needed to translate research findings into actionable policies, programs, and investments that advance the goals of inclusive growth and food security in Zambia.

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Declarations

Ethics approval and consent to participate Ethics declaration: not applicable.

Consent for publication Consent to Participate declaration: not applicable.

Competing interests The authors declare no competing interests.

Appendix

Appendix 1: Trend analysis for smallholder irrigation development in Zambia (Fig. 5).

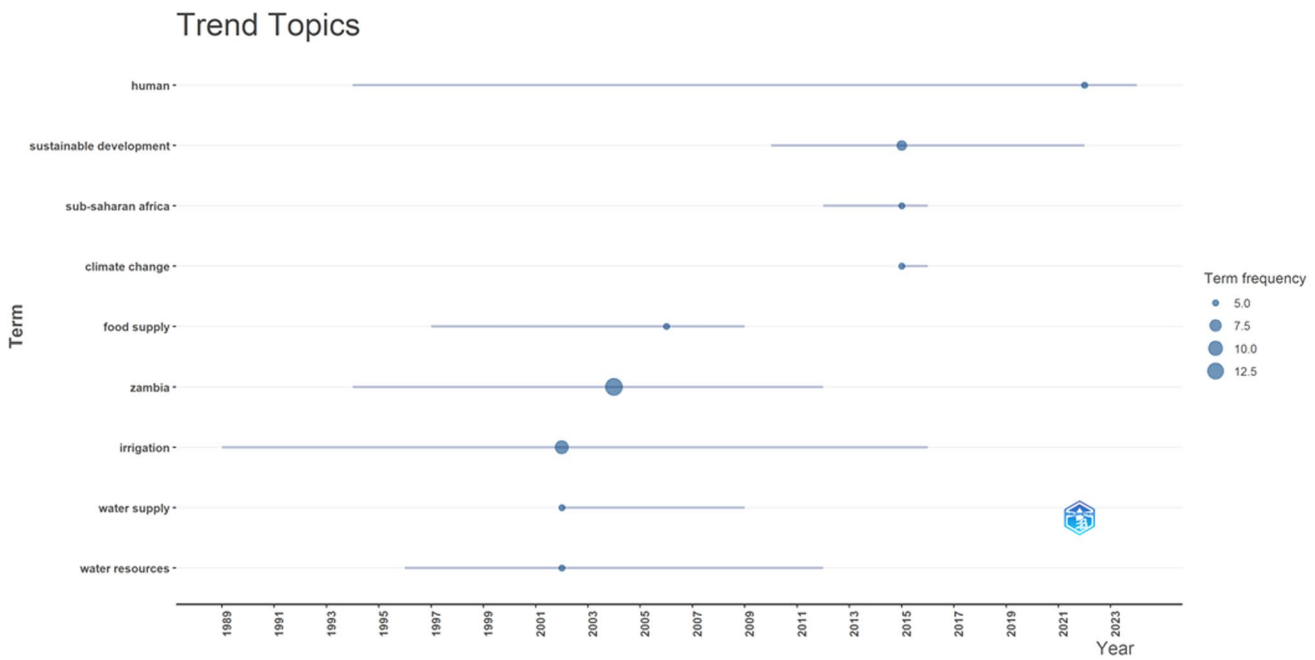

Fig. 5 Trend analysis for smallholder irrigation development in Zambia

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