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Review article

Constraints and opportunities for smallholder irrigation development in South Africa: a review

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ABSTRACT

Smallholder irrigation is critical in ensuring food security and reducing poverty, yet it has been typically neglected throughout Africa. This study draws on relevant policy, government documents and scholarly literature to investigate the biophysical and socioeconomic constraints and opportunities for smallholder irrigation development in South Africa. South Africa is one of the countries in Africa which is susceptible to climate change, and smallholder farmers are mostly affected by it. Using a coherent review method, the paper highlights restricted access to land, insufficient availability of irrigation water and infrastructure, drought impacts, and agronomic-related parameters as the biophysical constraints restricting smallholder irrigation development. Inadequate implementation of water policy and unfavourable financial systems, as well as technological limitations, worsened by a lack of knowledge and skills in irrigated farming, were some of the socio-economic factors influencing the development of smallholder irrigation. However, despite these limitations, there are opportunities for smallholder irrigation development if agrarian and land tenure reforms are considered, including water rights, innovative agricultural practices, technological advancements, institutional partnerships, and knowledge and skills development. These have implications for the development of smallholder irrigation in South Africa and Africa broadly.

1. Introduction

Smallholder farmers significantly contribute to addressing the increasing global demand for food, particularly in countries in Africa south of the Sahara (SSA), including South Africa [1]. Unfortunately, Africa faces significant food security challenges. The current food security challenges are exacerbated by climate change, shown by high drought intensity, land degradation, human population growth, and improper farming practices [2]. Smallholder farmers are disproportionately affected by the threat of food insecurity. Smallholder farmers practice farming for household consumption and markets [3]. Although farming is not the primary source of income for smallholders, it also contributes towards income for their families to complement off-farm economic activities [3]. Around the world, smallholder farmers are essential in contributing towards the global food supply [4]. However, due to climate change and other factors, it is now challenging to attain successful agricultural production to meet global food demand, especially by smallholder farmers. The risks associated with climate change are becoming noticeable worldwide [5]. The Intergovernmental Panel on Climate

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Change (IPCC) has also cautioned that climate change and variability will worsen the availability, accessibility and demand of agricultural water, especially in Africa [6]. The heavy dependence of countries in Africa on rain-fed agriculture exposes them to climate-related risks such as droughts and dry spells, which significantly affect the production of crops and livestock [5].

South Africa is the 30th driest country in the world, receiving 465 mm of average rainfall per year compared to the global average of 860 mm per year [7]. The country also receives the most significant rain in summer, and rainwater is the major input to the water resources [8]. Approximately 70 % of crop production in South Africa is under rain-fed farming. However, since sufficient rainfall is only received by 35 % of the country, it is difficult to practice dry land (rain-fed) crop farming [9]. Rainfall is also not reliable in most parts of the country, making irrigation a viable option for agricultural production [10]. Irrigation is an essential adaptation strategy for climate change for the majority of smallholder farmers who are more susceptible to the impacts of climate change in many developing countries [11]. In the context of this study, developing countries refer to countries that are continuously experiencing challenges such as poverty, inequality and unemployment. The capacity of irrigation farming to reduce poverty and improve food security has driven the government of South Africa to prioritise irrigation development [12]. However, irrigation systems developed in the smallholder farming sector are underperforming and failing to meet their intended purpose [12]. Additionally, irrigation constitutes the primary water consumption sector in South Africa, utilising about 62 % of available water resources, and it is also associated with water losses of around 30–40 % [13].

Considering the risks of drought, climate change, and inefficient use of irrigation water in South Africa, especially in smallholder farming systems, the development of sustainable and efficient irrigation systems for enhancing water use efficiency and agricultural production is necessary [13]. Due to climate change and variability threats, irrigation will also play an essential role in producing future food [14]. Smallholder irrigation schemes in South Africa contribute significantly to improved agricultural production, generating job opportunities, enhancing household food security, improving economic growth and reducing poverty, particularly in rural and marginalised areas where most of the schemes are situated [15,16]. However, despite the significant role played by smallholder irrigation farmers, the determinants of smallholder irrigation development in South Africa are poorly understood. This motivates this study to focus on smallholder irrigation development in South Africa.

Poor irrigation infrastructure development is persistently contributing to water access challenges for smallholder farmers in South Africa [17]. The challenges of water access are also continuously compounded by the adverse impact of climate change. This results in the reduction of agricultural production and ultimately affects the socio-economic status of smallholder farmers, resulting in poverty due to low income and negative impacts on livelihoods [18]. Since South Africa is a semi-arid country which is susceptible to the negative environmental impacts of climate change, such as frequent droughts and water scarcity, the development of sustainable and efficient smallholder irrigation as a measure for improving agricultural production is an urgent need [19]. Irrigation development is also an essential adaptation option that can be employed by smallholder farmers in the face of climate change. The National Development Plan (NDP) Vision 2030 has identified smallholder irrigation farming as a crucial approach that can significantly contribute to various socio-economic areas such as employment creation, income generation and food security [20], which in turn improve the livelihoods of smallholder farmers. Thus, the study sought to investigate the constraints and opportunities relating to smallholder irrigation development in South Africa. An assessment of biophysical and socioeconomic constraints was carried out, followed by exploring land-related opportunities, new approaches to farming, technology, markets and knowledge and skills. The rest of the paper is organised as follows: Section 2 describes the review methodology, Section 3 defines smallholder irrigation in South Africa, Section 4 presents the status of smallholder irrigation in South Africa, Section 5 describes the biophysical constraints affecting smallholder irrigation development, Section 6 describes the socio-economic challenges affecting smallholder irrigation development, Section 7 presents the opportunities for smallholder irrigation development and Section 8 provides the conclusions and recommendations of the study.

2. Review methodology

The literature used in this qualitative review was mainly searched from Google Scholar and Scopus electronic databases between March and July of 2023. The keywords used to search the literature included ' smallholder irrigation', 'smallholder schemes', 'irrigation technology', 'irrigation water management', 'irrigation development' and 'South Africa'. Documents from the governmental institutions in South Africa, including the Department of Agriculture, Forestry and Fisheries (DAFF), Water Research Commission (WRC) and Council for Scientific and Industrial Research (CSIR) were also searched and used. Initially, the literature utilised was sourced from the Scopus database, given its credibility in peer-reviewed research [21]. Also, the Scopus database is extensively used in academia, and it is less strict in journal selection compared to Web of Science [22]. The Google Scholar database was used to obtain literature unavailable in the Scopus database. Articles published in English were selected. This is mainly because English is the most widely used language in academia in South Africa, and it allows researchers to access a comprehensive body of knowledge on the topic under investigation. After database searching, the inclusion criteria, which comprise the relevance and scope of the study concerning the objectives, were applied to each publication. This was followed by a manual screening of the titles and abstracts to determine the potentially eligible articles relevant to the review. After the screening of titles and abstracts, articles were retrieved and downloaded. The screening of the full texts of downloaded articles was then conducted. The reference of each downloaded article was also checked to identify other potential articles relevant to the study. To improve the quality of selected and downloaded articles, duplicate articles were identified and removed. The articles included in the study addressed issues concerning the challenges of smallholder irrigation as well as opportunities for enhancing the development of smallholder irrigation in South Africa. Articles highlighting the status of smallholder irrigation in South Africa were also included. Since the study also used grey literature, the quality of grey literature acquired from government institutions was ensured by checking if they had been referenced in other articles in reliable databases such as

Scopus and Web of Science. Even though articles focusing on smallholder irrigation schemes in South Africa were included in this review, the study also included other articles that did not cover the context in South Africa, but with possible solutions or opportunities that can be used to promote smallholder irrigation development in South Africa. To identify the challenges of irrigation development on irrigation schemes for smallholder farmers in South Africa, studies that focused on other types of smallholder irrigation, including commercial irrigation farmers in South Africa, were excluded. Relevant downloaded articles were sorted and organised manually, evaluated, and then analysed by identifying the challenges in smallholder irrigation development and opportunities that can be used to improve the development of smallholder irrigation in South Africa. The papers included in the review concerning biophysical and socio-economic challenges, opportunities for smallholder irrigation development and the status of the smallholder irrigation sector in South Africa are listed in Table 2.1. Other papers relating to food security, climate change and rainfall status in South Africa, which form part of the introduction and methodology sections, are also listed in Table 2.1. The reliance on secondary data is usually associated with various limitations, such as biases due to inadequate access to the original primary data. In this study, the limitations of secondary data are acknowledged. To reduce the limitations, the secondary data sources were evaluated by analysing the methodology, including the credibility of the authors.

3. Defining smallholder irrigation

Smallholder irrigation is the controlled, organised, purposive and artificial supply of water to crops over limited areas by smallholder farmers [23]. According to Nakawuka et al. [5], smallholder irrigation comprises all irrigation activities practised by smallholder farmers who manage individual plots or are members of a community-managed irrigation scheme [5]. Smallholder irrigation can be categorised as either 'formal' or 'informal'. Formal smallholder irrigation refers to the private or public irrigation systems developed with universally accepted technical standards under a state institution. The characteristics and performance of formal smallholder irrigation are reported in national statistics. Informal smallholder irrigation refers to irrigation systems developed by farmers without complying with the state's formal requirements. Unlike formal smallholder irrigation, the characteristics of informal smallholder irrigation are not reported in national statistics [24].

Smallholder irrigation uses various ways of extracting, storing and controlling water, such as treadle pumps, motor pumps, river diversion, flood recession, flood water spreading, rainwater harvesting, porous jars, watering cans, small reservoirs and dams [25]. Lined and unlined canals and pipelines are also used to transport water from the sources to the plots. Some of the advantages of smallholder irrigation include easy and low maintenance costs, low investment costs, low management requirements and minor negative impacts on the environment [25]. Various factors restrict smallholder irrigation farmers from transitioning into commercial or large-scale irrigation. These include inadequate financial services, difficulties in water allocation and distribution, insufficient agricultural extension services and lack of managerial and entrepreneurial skills.

In South Africa, there are four groups of smallholder irrigation farmers. These are irrigation scheme farmers, independent irrigators, community gardeners or food-plot farmers and backyard or home-garden farmers. Irrigation scheme farmers are involved in agricultural activities on an irrigation scheme. Farmers within a specific irrigation scheme share a water source, infrastructure and, at times, equipment for irrigation with other community members who reside within the same scheme [26]. Many irrigation scheme farmers own land which is more than 5 ha. Irrigation scheme farmers usually live in the former homelands and other areas with restricted resources that enable successful irrigation farming. Independent irrigators are individual farmers who practice farming on a piece of land not part of an irrigation scheme. Independent irrigators often do not have title deeds for the land [26], but possess individual irrigation systems and pump irrigation water from the adjacent rivers. They can also extract irrigation water from their boreholes [27]. Community gardeners or food-plot farmers are involved in community garden projects. Their farming activities are mainly on very small plots, typically measuring about a hundred square metres [26]. Community gardeners usually share irrigation equipment and a common water source. Backyard or home-garden farmers undertake their agricultural activities on a small plot, which is similar to community gardeners, but they do not practice farming in a group. Additionally, backyard garden farmers conduct their farming practices within the confines of their homesteads. These farmers primarily source irrigation water from roof water tanks, greywater reuse or municipal domestic piping systems [27]. For this study, smallholder irrigation refers to farmers practising irrigation farming on an irrigation scheme.

4. The status of smallholder irrigation in South Africa

Approximately 3 % of the total irrigated area in South Africa is under smallholder irrigation schemes (SIS) [25]. However, the estimations of irrigated areas differ and have been reported to be outdated [28]. Based on the estimates that were conducted since 1990, the area under irrigation in South Africa varies between 1.21 and 1.58 million ha and the area that has been registered for irrigation use ranges between 1.44 and 1.68 million ha [28]. About 0.1 million has been allocated to smallholder irrigators, including farmers on irrigation schemes, independent irrigation farmers, and community and home gardeners. In 2004, there were approximately 287 SIS with about 31,000 plot holders. However, a significant portion of these schemes were underutilised or performed below potential. The largest number of SIS was in Limpopo Province, with a total of 101 operational schemes, followed by Eastern Cape (51). In 2008, about 1,675,822 ha of irrigated land was registered, of which 1,399,221 ha was irrigated annually. In 2010 only 47,667 ha of land was under 302 SIS [12]. Table 4.1 shows the operational and non-operational status of SIS by province and irrigation system in South Africa. The operational status of six schemes, five in the Eastern Cape and one in KwaZulu-Natal, was not known, bringing the total to 302. The smallholder farming sector in South Africa play an important role in ensuring food security, thus, the variation in the number of operational SIS among provinces has an implication on the livelihoods of farmers. More recently, the National Development

Table 2.1
List of reviewed literature.

No.	Authors	Title	Year	Challenges		Opportunities	Status and definition of smallholder irrigation	Other papers
				Biophysical	Socio-economic			
1	Mwadzingeni, L., Mugandani, R., & Mafongoya, P	Localized institutional actors and smallholder irrigation scheme performance in Limpopo province of South Africa	2020		X			
2	Tian, J., Bryksa, B. C., & Yada, R. Y	Feeding the world into the future–food and nutrition security: the role of food science and technology	2016					X
3	South African Department of Agriculture	Annual Report 2014/2015	2015					X
4	International Fund for Agricultural Development	Smallholders can feed the world.	2011					X
5	Nakawuka, P., Langan, S., Schmitter, P., & Barron, J	A review of trends, constraints, and opportunities of smallholder irrigation in East Africa	2018	X				
6	Intergovernmental Panel on Climate Change	Climate Change 2007: Impacts, Adaptation and Vulnerability.	2007					X
7	Pitman, W. V	Overview of water resource assessment in South Africa: Current state and future challenges	2011					X
8	Botai, C. M., Botai, J. O., & Adeola, A. M	Spatial distribution of temporal precipitation contrasts in South Africa	2018					X
9	Council for Scientific and Industrial Research	A CSIR perspective on water in South Africa	2010					X
10	Nephawe, N., Mwale, M., Zuwarimwe, J., & Tjale, M. M	The impact of water-related challenges on rural communities' food security initiatives	2021					X
11	Cai, X., Magidi, J., Nhamo, L., & van Koppen, B	Mapping irrigated areas in the Limpopo Province, South Africa	2017					X
12	Van Averbeke, W., Denison, J., & Mnkeni, P. N. S	Smallholder irrigation schemes in South Africa: A review of knowledge generated by the Water Research Commission	2011	X	X		X	
13	Fanadzo, M., & Ncube, B	Challenges and opportunities for revitalising smallholder irrigation schemes in South Africa	2018	X	X	X		
14	Woznicki, S.A., Nejadhashemi, A.P and Parsinejad, M	Climate change and irrigation demand: Uncertainty and adaptation	2015					X
15	Sinyolo, S., Mudhara, M., & Wale, E	Water security and rural household food security: Empirical evidence from the Mzinyathi district in South Africa	2014					X
16	Van Koppen, B., Nhamo, L., Cai, X., Gabriel, M. J., Sekgala, M., Shikwambana, S., … & Manyama, D	Smallholder irrigation schemes in the Limpopo Province, South Africa	2017	X				
17	Thabane, V.N., Agholor, I.A., Ludidi, N.N., Morepje, M.T., Mgwenya, L.I., Msweli, N.S. and Sithole, M.Z.	Irrigation Water and Security in South African Smallholder Farming: Assessing Strategies for Revitalisation. World	2025					X
18	Mwale, M., Sibuyi, W., Kativhu, S., Downsborough, L. and Zuwarimwe, J	Developing resilient small-scale farmers against water scarcity in rural-based crop production farms, South Africa	2021					X
19	Mkuna, E. and Wale, E	Smallholder farmers' choice of irrigation systems: Empirical evidence from Kwazulu-Natal, South Africa and its implications	2023					X

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Table 2.1 (*continued*)

No.	Authors	Title	Year	Challenges		Opportunities	Status and definition of smallholder irrigation	Other papers
				Biophysical	Socio-economic			
20	Mdoda, L., Obi, A., Ncoyini-Manciya, Z., Christian, M. and Mayekiso, A.,	Assessment of profit efficiency for spinach production under small-scale irrigated agriculture in the Eastern Cape Province, South Africa	2022					X
21	Pranckutė, R	Web of Science (WoS) and Scopus: The Titans of Bibliographic Information in Today's Academic World	2021					x
22	Fischer, T. B., & Onyango, V	Strategic environmental assessment-related research projects and journal articles: an overview of the past 20 years	2012					X
23	Tlou, T., Mosaka, D., Perret, S., Mullins, D., & Williams, C. J	Investigation of different farm tenure systems and support structures for establishing small-scale irrigation farmers in long-term viable conditions	2006	X			X	
24	Gutiérrez-Malaxechebarría, A. M	Informal irrigation in the Colombian Andes: Local practices, national agendas, and options for innovation	2013				X	
25	Maepa, M. A., Makombe, G., & Kanjere, M	Is the Revitalisation of Smallholder Irrigation Schemes (RESIS) programme in South Africa a viable option for smallholder irrigation development?	2014				X	
26	Du Plessis, F. J., W. Van Averbeke, and I. Van der Stoep	Micro irrigation for smallholders: guidelines for funders, planners, designers, and support staff in South Africa	2002				X	
27	Denison, J., Dube, S. V., Masiya, T. C., Moyo, T., Murata, C., Mpyana, J., … & Van Averbeke, W	Smallholder irrigation entrepreneurial development pathways and livelihoods in two districts in Limpopo Province	2016				X	
28	Van Niekerk, A., Jarmain, C., & Goudriaan, R	An earth observation approach towards mapping irrigated area and quantifying water use by irrigated crops in South Africa	2018				X	
29	South African Department of Agriculture	Annual Performance Plan	2017			X	X	
30	Fanadzo, M., Chiduza, C., & Mnkeni, P. N. S	Overview of smallholder irrigation schemes in South Africa: Relationship between farmer crop management practices and performance	2010	X			X	
31	Magidi, J., van Koppen, B., Nhamo, L., Mpandeli, S., Slotow, R., & Mabhaudhi, T	Informing equitable water and food policies through accurate spatial information on irrigated areas in smallholder farming systems	2021				X	
32	Manona, S., Denison, J., Van Averbeke, W., & Masiya, T	Proposed land tenure and land administration interventions to increase productivity on smallholder irrigation schemes in South Africa. Overcoming Inequality and Structural Poverty in South Africa: Towards Inclusive Growth and Development	2010	X				
33	Chipfupa, U., & Wale, E	Explaining smallholder aspirations to expand irrigation crop production in Makhathini	2018	X				

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Table 2.1 (*continued*)

No.	Authors	Title	Year	Challenges		Opportunities	Status and definition of smallholder irrigation	Other papers
				Biophysical	Socio-economic			
		and Ndumo-B, KwaZulu-Natal, South Africa						
34	Pariyar, B., Lovett, J. C., & Snell, C	Inequality of access in irrigation systems of the mid-hills of Nepal	2018	X				
35	Mnkeni, P. N. S., Chiduza, C., Modi, A. T., Stevens, J. B., Monde, N., Van der Stoep, I., & Dladla, R	Best management practices for smallholder farming on two irrigation schemes in the Eastern Cape and KwaZulu-Natal through participatory adaptive research	2010	X				
36	Cousins, B	Smallholder Irrigation Schemes, Agrarian Reform and 'Accumulation from Above and from Below' in South Africa	2013	X		X		
37	Madigele, P.K	Efficiency of common-pool resource institutions: focusing on water users associations in South Africa. Environment, Development and Sustainability, 20, pp.825-840.	2018	X				
38	Schalkwyk, H. D. V., Obi, A., Tilburg, A. V., & Fraser, G	Unlocking markets to smallholders: Lessons from South Africa	2011	X		X		
39	Agholor, A. I	Rural farmers participation in smallholder irrigation: Analytical stance of selected Shiloh scheme beneficiaries in Eastern Cape, South Africa	2016	X		X		
40	Food and Agriculture Organization	The State of the World's Land and Water Resources for Food and Agriculture	2021	X				
41	Calverley, C. M., & Walther, S. C	Drought, water management, and social equity: Analyzing Cape Town, South Africa's water crisis	2022	X				
42	Gomo, T., Senzanje, A., Mudhara, M., & Dhavu, K	Assessing the performance of smallholder irrigation and deriving best management practices in South Africa	2014	X	X			
43	Chikozho, C., Managa, R., & Dabata, T	Ensuring access to water for food production by emerging farmers in South Africa: What are the missing ingredients?	2020	X	X	X		
44	Denby, K	Institutional integration and local level water access in the Inkomati Water Management Area, South Africa	2014	X	X			
45	Rosa, L., Chiarelli, D. D., Rulli, M. C., Dell'Angelo, J., & D'Odorico, P	Global agricultural economic water scarcity	2020	X				
46	Hope, R. A., Gowing, J. W., & Jewitt, G. P. W	The contested future of irrigation in African rural livelihoods–analysis from a water scarce catchment in South Africa	2008	X				
47	Al-Weshah, R. A	Optimal use of irrigation water in the Jordan Valley: A case study	2000	X				
48	Dirwai, T. L., Senzanje, A., & Mudhara, M	Water governance impacts on water adequacy in smallholder irrigation schemes in KwaZulu-Natal province, South Africa	2019	X				
49	Gomo, T., Mudhara, M., & Senzanje, A	Farmers satisfaction with the performance of the Mooi River Irrigation Scheme, KwaZulu-Natal, South Africa	2014	X				

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Table 2.1 (*continued*)

No.	Authors	Title	Year	Challenges		Opportunities	Status and definition of smallholder irrigation	Other papers
				Biophysical	Socio-economic			
50	Phali, L., Mudhara, M., Ferrer, S., & Makombe, G	Evaluation of water-user performance in smallholder irrigation schemes in KwaZulu-Natal Province, South Africa: A stochastic meta-frontier analysis	2022	X	X			
51	Sharaunga, S., & Mudhara, M	Determinants of farmers' participation in collective maintenance of irrigation infrastructure in KwaZulu-Natal	2018	X				
52	Amoah, L. N. A., & Simatele, M. D	Food security and coping strategies of rural household livelihoods to climate change in the Eastern Cape of South Africa	2021	X				
53	Payus, C., Ann Huey, L., Adnan, F., Besse Rimba, A., Mohan, G., Kumar Chapagain, S., & Fukushi, K	Impact of extreme drought climate on water security in North Borneo: Case study of Sabah	2020	X				
54	Singh, V. P	Challenges in meeting water security and resilience	2017	X				
55	Mpandeli, S., Nesamvuni, E., & Maponya, P	Adapting to the impacts of drought by smallholder farmers in Sekhukhune District in Limpopo Province, South Africa	2015	X				
56	Gobler, C. J	Climate change and harmful algal blooms: insights and perspective	2020	X				
57	Ruwanza, S., Thondhlana, G., & Falayi, M	Research progress and conceptual insights on drought impacts and responses among smallholder farmers in South Africa: a review	2022	X				
58	Fanadzo, M	Revitalisation of smallholder irrigation schemes for poverty alleviation and household food security in South Africa: A review	2012	X				
59	Rambauli, M., Antwi, M. A., Tshikhudo, P. P., & Mudau, F. N	The Determinants of Smallholder Farmers on the Functionality of Plant Health Clinics in the Vhembe District, South Africa	2023	X				
60	Fanadzo, M., Chiduza, C., Mnkeni, P. N. S., Van der Stoep, L., & Steven, J	Crop production management practices as a cause for low water productivity at Zanyokwe Irrigation Scheme	2010	X				
61	Gashaw.T., Bantider, A., G/ Silassie, H	Land degradation in Ethiopia: Causes, impacts and rehabilitation techniques	2014	X				
62	Jayne, T. S., Chamberlin, J., & Headey, D. D	Land pressures, the evolution of farming systems, and development strategies in Africa: A synthesis	2014	X				
63	Matano, Ally-Said, Canisius K. Kanangire, Douglas N. Anyona, Paul O. Abuom, Frank B. Gelder, Gabriel O. Dida, Philip O. Owuor, and Ayub VO Ofulla	Effects of land use change on land degradation reflected by soil properties along Mara River, Kenya, and Tanzania	2015	X				
64	Manyevere, A., Muchaonyerwa, P., Mnkeni, P. N., & Dhau, I	Spatial variability of selected soil micronutrients under smallholder crop production in Zanyokwe, Eastern Cape, South Africa	2017	X				
65	Dlangalala, S. F., & Mudhara, M	Determinants of farmer awareness of water governance across gender dimensions in	2020		X	X		

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Table 2.1 (*continued*)

No.	Authors	Title	Year	Challenges		Opportunities	Status and definition of smallholder irrigation	Other papers
				Biophysical	Socio-economic			
		smallholder irrigation schemes in KwaZulu-Natal Province, South Africa						
66	Mugejo, K., Ncube, B., & Mutsvangwa, C	Infrastructure Performance and Irrigation Water Governance in Genadendal, Western Cape, South Africa	2022		X			
67	Mugejo, K., & Ncube, B	Determinants of water security in smallholder farming systems in South Africa: A review	2022		X			
68	Rawlins, J	Political economy of water reallocation in South Africa: Insights from the Western Cape water crisis	2019		X			
69	Hall, R., & Aliber, M	The case for re-strategising spending priorities to support small-scale farmers in South Africa	2010		X			
70	Sinyolo, S., Mudhara, M., & Wale, E	The impact of smallholder irrigation on household welfare: The case of the Tugela Ferry irrigation scheme in KwaZulu-Natal, South Africa	2014		X		X	
71	Burney, J. A., & Naylor, R. L	Smallholder irrigation as a poverty alleviation tool in sub-Saharan Africa	2012		X			
72	van Koppen, B., & Schreiner, B	Moving beyond integrated water resource management: developmental water management in South Africa	2014		X			
73	Kativhu, S., Mwale, M. M., & Zuwarimwe, J	Agricultural resilience under increasing water security threats: insights for smallholder farming in Limpopo Province, South Africa	2020		X	X		
74	Van Averbeke, W	Improving plot holder livelihood and scheme productivity on smallholder canal irrigation schemes in the Vhembe District of Limpopo Province	2013		X			
75	Muchara, B., Letty, B., Obi, A., Masika, P., Ortmann, G., Wale, E., & Mudhara, M	The role of capital assets and institutions in the success and failure of smallholder irrigation schemes in South Africa	2014		X			
76	Raidimi, E. N., & Kabiti, H. M	A review of the role of agricultural extension and training in achieving sustainable food security: A case of South Africa	2019		X			
77	Agholor, I. A	Comparison of two agricultural irrigation schemes in Eastern Cape, South Africa	2019		X			
78	Aliber, M., & Hall, R	Development of evidence-based policy around small-scale farming. Report commissioned by the Programme to Support Pro-Poor Policy Development, on behalf of the Presidency	2015			X		
79	Mutambara, S., Darkoh, M. B., & Atlhopheng, J. R	A comparative review of water management sustainability challenges in smallholder irrigation schemes in Africa and Asia	2016			X		
80	van Koppen, B., & Schreiner, B	Viewpoint–A hybrid approach to statutory water law to support smallholder farmer-led	2019			X		

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Table 2.1 (*continued*)

No.	Authors	Title	Year	Challenges		Opportunities	Status and definition of smallholder irrigation	Other papers
				Biophysical	Socio-economic			
		irrigation development FLID in Sub-Saharan Africa						
81	Bruns, B	Irrigation water rights: options for pro-poor reform	2007			X		
82	Sadiki, A., & Ncube, B	Challenges of accessing water for agricultural use in the Breede-Gouritz Catchment Management Agency, South Africa	2020			X		
83	Schreiner, B., & van Koppen, B	Hybrid water rights systems for pro-poor water governance in Africa	2020			X		
84	Jacobs, A. J., Van Tol, J. J., & Du Preez, C. C	Farmers perceptions of precision agriculture and the role of agricultural extension: a case study of crop farming in the Schweizer-Reneke region, South Africa	2018			X		
85	Onyango, C. M., Nyaga, J. M., Wetterlind, J., Söderström, M., & Piikki, K	Precision agriculture for resource use efficiency in smallholder farming systems in sub-Saharan Africa: A systematic review	2021			X		
86	Ncube, B., Mupangwa, W., & French, A	Precision agriculture and food security in Africa. Systems analysis approach for complex global challenges	2018			X		
87	McLennon, E., Dari, B., Jha, G., Sihi, D., & Kankarla, V	Regenerative agriculture and integrative permaculture for sustainable and technology-driven global food production and security	2021			X		
88	Lal, R	Regenerative agriculture for food and climate	2020			X		
89	Biazin, B., Sterk, G., Temesgen, M., Abdulkedir, A., & Stroosnijder, L	Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa–a review	2012			X		
90	Shrestha, J., Subedi, S., Timsina, K. P., Chaudhary, A., Kandel, M., & Tripathi, S	Conservation agriculture as an approach towards sustainable crop production: A review	2020			X		
91	Malobane, M. E., Nciizah, A. D., Wakindiki, I. I., & Mudau, F. N	Sustainable production of sweet sorghum for biofuel production through conservation agriculture in South Africa	2018			X		
92	Duru, M., Therond, O., & Fares, M. H	Designing agroecological transitions; A review	2015			X		
93	D'Annolfo, R., Gemmill-Herren, B., Amudavi, D., Shiraku, H. W., Piva, M., & Garibaldi, L. A	The effects of agroecological farming systems on smallholder livelihoods: A case study on push-pull system from Western Kenya	2021			X		
94	Wanger, T. C., DeClerck, F., Garibaldi, L. A., Ghazoul, J., Kleijn, D., Klein, A. M., … & Weisser, W	Integrating agroecological production in a robust post-2020 Global Biodiversity Framework	2020			X		
95	Wei, C	Agroecology, information and communications technology, and smallholders' food security in Sub-Saharan Africa	2020			X		
96	Zazu, C., & Manderson, A	Agroecology and climate change adaptation: farmers' experiences in the South African Lowveld	2021			X		
97	Odhiambo, K. O., Iro Ong'or, B. T., & Kanda, E. K	Optimization of rainwater harvesting system design for	2021			X		

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Table 2.1 (*continued*)

No.	Authors	Title	Year	Challenges		Opportunities	Status and definition of smallholder irrigation	Other papers
				Biophysical	Socio-economic			
		smallholder irrigation farmers in Kenya: a review						
98	Moswetsi, G., Fanadzo, M., & Ncube, B	Cropping systems and agronomic management practices in smallholder farms in South Africa: constraints, challenges, and opportunities	2017			X		
99	Nigussie, E., Olwal, T., Musumba, G., Tegegne, T., Lemma, A., & Mekuria, F	IoT-based irrigation management for smallholder farmers in rural Sub-Saharan Africa	2020			X		
100	Balana, B. B., & Zenebe, A	Assessment of economic feasibility and farmers' perceptions on wetting front detector (WFD) irrigation scheduling tool for dry season vegetable production in the Upper East Region of Ghana	2020			X		
101	Stevens, J. B., Van Heerden, P. S., Buys, F., & Laker, M. C	Training material for extension advisors in irrigation water management	2012			X		
102	Sharifnasab, H., Mahrokh, A., Dehghanisanij, H., Łazuka, E., Łagód, G., & Karami, H	Evaluating the Use of Intelligent Irrigation Systems Based on the IoT in Grain Corn Irrigation	2023			X		
103	Hlatshwayo, S. I., Ngidi, M., Ojo, T., Modi, A. T., Mabhaudhi, T., & Slotow, R	A typology of the level of market participation among smallholder farmers in South Africa: Limpopo and Mpumalanga Provinces	2021			X		
104	Bitzer, V., & Bijman, J	Old oranges in new boxes? Strategic partnerships between emerging farmers and agribusinesses in South Africa	2014			X		
105	Amede, T	Technical and institutional attributes constraining the performance of small-scale irrigation in Ethiopia	2015			X		
106	Thamaga-Chitja, J. M., & Morojele, P	The context of smallholder farming in South Africa: Towards a livelihood asset-building framework	2014			X		
107	van Koppen, B., Tapela, B. N., & Mapedza, E	Joint ventures in the Flag Boshielo Irrigation Scheme, South Africa: a history of smallholders, states, and business	2018			X		
108	Myeni, L., Moeletsi, M., Thavhana, M., Randela, M., & Mokoena, L	Barriers affecting sustainable agricultural productivity of smallholder farmers in the Eastern Free State of South Africa	2019			X		
109	Audinet, J. P., & Haralambous, S	Achieving the Millennium Development Goals: Rural investment and enabling policy	2005			X		
110	Baiyegunhi, L. J. S., Majokweni, Z. P., & Ferrer, S. R. D	Impact of outsourced agricultural extension program on smallholder farmers' net farm income in Msinga, KwaZulu-Natal, South Africa	2019			X		
111	Denison, J., & Manona, S	Principles, Approaches and Guidelines for the Participatory Revitalisation of Smallholder Irrigation Scheme. Volume 1 – a rough Guide for Irrigation Development Practitioners	2007			X		

(*continued on next page*)

Table 2.1 (*continued*)

No.	Authors	Title	Year	Challenges		Opportunities	Status and definition of smallholder irrigation	Other papers
				Biophysical	Socio-economic			
112	Sinyolo, S. A., Sinyolo, S., Mudhara, M., & Ndinda, C	Gender differences in water access and household welfare among smallholder irrigators in Msinga local municipality, South Africa	2018			X		
113	Chauke, P. K., Anim, F. D. K., Pfumayaramba, T. K., & Nekhavhambe, T. D	An assessment of factors affecting income generation from crop production under irrigation in the Limpopo Province of South Africa	2014			X		
114	Baloi, V. A	The impact of smallholder irrigation schemes on poverty reduction among rural households of Vhembe and Sekhukhune Districts in Limpopo Province, South Africa	2022			X		
115	Henning, J. I., Jammer, B. D., & Jordaan, H	Youth participation in agriculture, accounting for entrepreneurial dimensions	2022			X		

Table 4.1
Operational and non-operational status of SIS in South Africa by province and irrigation system [12].

Province	Number of operational schemes by an irrigation system				Number of non-operational schemes by an irrigation system				Total
	Gravity-fed surface	Pumped surface	Overhead	Micro	Gravity-fed surface	Pumped surface	Overhead	Micro	
Limpopo	49	9	30	13	12	5	41	11	**170**
Mpumalanga	3	0	4	0	1	0	11	0	**9**
North West	0	2	0	0	0	0	0	0	**2**
KwaZulu-Natal	5	0	30	0	0	0	0	0	**35**
Free State	0	1	0	0	1	0	0	0	**2**
Northern Cape	0	2	0	0	0	1	0	0	**3**
Eastern Cape	4	0	46	1	0	0	16	0	**67**
Western Cape	6	0	1	0	0	0	1	0	**8**
Total	67	14	111	14	14	6	59	11	**296**

Plan 2030 (NDP) indicated that out of the estimated 1.6 million ha under irrigation, about 50,000 ha are allocated to SIS [29]. A wide variety of field crops (wheat, maize, sugar bean, sugarcane, Irish potato and sweet potato) and vegetable crops (tomato, cabbage, beetroot, carrot, pumpkin, onion, spinach and butternut) are grown by SIS farmers in South Africa [30]. According to Magidi et al. [31], between 2019 and 2020, smallholder irrigation increased by over 19 %. More accurate datasets and recent statistics for SIS in South Africa are necessary. Remote sensing with high spatial resolution for quantifying and mapping irrigated areas provides an example of technology that can offer more accurate datasets for smallholder irrigation in South Africa.

5. Biophysical constraints to smallholder irrigation development

Various biophysical factors (Table 5.1) affect smallholder irrigation development in South Africa. Biophysical factors are described

Table 5.1
Biophysical factors affecting smallholder irrigation development.

Biophysical Factors	Constraints
Access to land	- Lack of land tenure security
Irrigation water and infrastructure	- Inadequate access to irrigation water - Inadequate access to irrigation infrastructure - Poor performance of irrigation infrastructure
Drought	- Depletion of water in sources - Reduction of water quality - Inadequate coping and adaptation strategies
Agronomy	- Inadequate crop protection - Poor crop management - Inappropriate nutrient management

as the natural and physical characteristics, as well as the biological activity within it, including climate conditions that affect the development of irrigation. These include land tenure, access to irrigation water and infrastructure, drought, and agronomic issues.

5.1. Access to land

In smallholder irrigation schemes in South Africa, there are various land tenure systems which determine the size of the land the farmers can access. These include traditional tenure, freehold, leasehold, quitrent and Trust tenure [32]. In the traditional tenure system, the arable land is normally acquired by the permanent residents in the village via the tribal chief or through the village headmen who represent the tribal chief. The Freehold tenure system is in relation to the individual's full ownership of land, whereas leasehold tenure is when individuals are allowed to utilise land for a particular period. In the quitrent tenure system, the land is technically owned by the state, with a legal right given to the holder in exchange for an annual payment of "qui rent", provided stipulated conditions are adhered to. Regarding the Trust tenure system, the land is generally in the hands of the trust. This means that the individuals are not the owners of the land, but the land is under the management of a legal entity on behalf of the beneficiaries. According to Chipfupa and Wale [33], farmers in smallholder irrigation schemes in South Africa are still experiencing insecurity concerning land access and ownership. Land tenure security issues need to be addressed to promote the growth of the smallholder irrigation sector. The absence of land tenure security makes it difficult for farmers to engage in land transactions aimed at increasing land sizes under irrigation [13]. Land tenure insecurity among smallholder farmers is worsened by the lack of a freehold land tenure system. Tlou et al. [23] highlighted land tenure as a major factor affecting irrigation farming. Land tenure security is also important in encouraging farmers to invest in various farming practices, and it also boosts farmers' confidence to engage in farming without fear that their land might be seized. According to Pariyar et al. [34], irrigation development in South Africa is biased against those individuals without possession of a freehold land tenure system. Some studies conducted in South Africa have identified land tenure insecurity as the major challenge contributing to the poor development of smallholder irrigation [12,30,35].

Issues relating to land tenure are linked to the historical legacy. During the apartheid era, inequalities regarding land access were apparent between Black smallholder farmers and White commercial farmers. The majority of the land was owned by the White minority, with only a small portion in the hands of a few Black populations residing in highly segregated areas [36]. After the apartheid period, land reform programmes were developed to correct past injustices. Regrettably, land ownership remained predominantly in the hands of the White minority population, who were wealthy and powerful [36]. The historically disadvantaged individuals, such as smallholder farmers, still experience challenges in accessing land. These challenges include a lack of possession of the freehold land tenure system. Madigele [37] also indicated that smallholder farmers in South Africa are usually excluded from owning land, as a result, they are excluded from water access for irrigation uses because land ownership is linked to water access. Consequently, the development of smallholder irrigation is restricted. In most smallholder irrigation schemes, the available land tenure system does not allow farmers to use their land as collateral to access loans from financial service providers such as banks [38]. This also hinders the development of smallholder irrigation because they usually lease land. The size of the land is another limiting factor for smallholder irrigation development. Smallholder farmers are usually in possession of small plots of land. In a study conducted in a smallholder irrigation scheme in the Eastern Cape province, Isaac [39]. highlighted that farm mechanisation was negatively affected by the small size of the land.

5.2. Access to irrigation water and infrastructure

Smallholder farmers usually have inadequate water access for productive use [40]. This is despite the critical role of water in contributing to the success of irrigation development. South Africa has a long history of inequality regarding water access. Access to productive water was divided along racial and class lines [41] before 1994. There is a huge disparity in water access in the smallholder farming sector in South Africa at present [42]. According to Chikozho et al. [43], ater access for many smallholder farmers in South Africa is not guaranteed, severely affecting the capacity of smallholder irrigation development. Governance and institutional arrangements are among the factors which contribute to inadequate water access for many smallholder farmers in South Africa [44]. The lack of institutional integration, inadequate communication concerning water access and non-alignment of mandates among institutions are the governance and institutional issues challenging water access for smallholder farmers. Without good and functional governance and institutional arrangements, it is difficult to manage water effectively and equitably to ensure equitable water access.

Insufficient water access can also result from economic water scarcity [5]. Economic water scarcity occurs when water is physically available, but inadequate infrastructure restricts the extraction and conveyance of water from its source to a place where it is needed [45]. Water infrastructure, therefore, plays an important role in promoting water access for smallholder irrigation development. Without adequate water infrastructure, farmers cannot fully maximise their formal water use rights. For instance, the underutilisation of available water by smallholder irrigation scheme farmers in the Limpopo Province was attributed to inadequate water infrastructure, ultimately resulting in a lack of water accessibility for smallholder farmers [16]. Compared to smallholder farmers, affluent commercial farmers most often have adequate infrastructure to access water from various sources [46].

The performance of water infrastructure is also crucial in enhancing water accessibility for irrigation development. Studies conducted in smallholder irrigation in South Africa have found a decline in the performance of irrigation water infrastructure due to insufficient operation and maintenance [42,47–51]. Lack of operation and maintenance of irrigation water infrastructure also reduces the efficiency of irrigation water delivery. As a result, this limits irrigation development by contributing to the underutilisation of water from sources [16]. Isaac [39] also pointed out that inefficient water use in many smallholder irrigation schemes in South Africa contributes to crop yield reduction.

5.3. Drought impacts

South Africa is a predominantly semi-arid country with scarce water resources. In many parts of the country, the occurrence of climate change-related disasters such as droughts is a common phenomenon [52]. Drought is when a prolonged rainfall deficiency leads to a water shortage for some activity or group. In agriculture, the deficiency is usually in crop production and a shortage of water for livestock. Compared to other climate change-related disasters, drought seriously affects water resources by depleting water in rivers, streams and reservoirs [53]. This ultimately results in water scarcity for irrigation development needed to enhance agricultural production for smallholder farmers. In South Africa, drought contributes to the reduction of the freshwater supply, which is already under strain [54]. Due to inadequate drought coping and adaptation strategies, smallholder farmers in South Africa have been affected by drought for several years. Unlike commercial farmers, most smallholder farmers in South Africa have inadequate resources to acquire water-saving irrigation technologies [55].

During drought periods, water-saving technologies, such as drip irrigation systems, are important in ensuring the effective utilisation of irrigation water. Water-saving technologies can play a vital role in promoting the sustainability of irrigation farming by effectively conserving water. In addition to reducing the physical availability of water, drought can also lead to a reduction in water quality. This decreases the usability of water for irrigation purposes and consequently affects the development of irrigation. The deterioration of water quality during drought periods is mainly due to reduced dissolved oxygen concentration and increased nutrients in suspension [56]. For instance, in KwaZulu-Natal, drought resulted in declining water quality for agriculture, significantly affecting smallholder irrigation farmers [57].

5.4. Agronomic-related challenges

Various agronomic-related challenges contribute to the failure of smallholder irrigation development in South Africa by reducing agricultural production [30]. These challenges include incorrect planting dates, incorrect planting density, inappropriate choice of cultivars, inadequate crop protection, poor crop management and inappropriate nutrient management [58]. However, pests, diseases and weeds are considered the major challenges experienced by smallholder farmers. This is because they significantly contribute to crop losses [30] and reduce agricultural production. In a study conducted in smallholder irrigation schemes in Limpopo province, several pest and disease management challenges severely affected smallholder farming. These challenges included the high cost of agrochemicals, lack of awareness concerning plant health, failure to identify pest-related issues and lack of appropriate pest identification tools [59]. When the costs of agrochemicals are high, it is very challenging for smallholder farmers to access the chemicals required to improve agricultural production. Rambauli et al. [59] further pointed out that smallholder farmers will continue to face pest-related challenges due to the absence of suitable pesticides and appropriate pest management practices.

The decline in soil quality also affects smallholder irrigation development. In South Africa, the soils in smallholder irrigation usually suffer from nutrient deficiencies essential for enhancing agricultural productivity [60]. This limits the development of smallholder irrigation by reducing agricultural production. Several factors contribute to the decline of soil fertility, including land degradation resulting from sub-optimal agricultural practices, soil erosion, lack of fertiliser application, inadequate soil and water conservation measures and deforestation [61–63]. Land degradation is further exacerbated by cultivation on wetlands and steep slopes, frequent ploughing, overgrazing, lack of crop rotation, overstocking of pasture land and reduced fallow cycles or non-existent fallow cycles [61–63]. The insufficient use of fertilisers also contributes to nutrient deficiencies in the soils in the smallholder farming sector in South Africa [64], and ultimately reduces agricultural production. In a study conducted in the Zanyokwe Irrigation Scheme in the Eastern Cape, Fanadzo et al. [60] found that farmers do not adhere to the recommended guidelines during fertiliser application. This resulted in the reduction of the levels of soil nutrients such as zinc, which ultimately affects crop productivity [64].

6. Socio-economic challenges in the development of smallholder irrigation

Various socio-economic challenges, including an unsupportive policy environment, financial system limitations, technological constraints, and knowledge and skills gaps, significantly impact smallholder irrigation development in South Africa (Table 6.1).

Table 6.1
Socio-economic factors affecting smallholder irrigation development.

Socio-economic factors	Challenges
Policy environment	- Inadequate implementation of policies - Farmers' unawareness of policies - Lack of coordination between institutions - Lack of coherent policies
Financial systems	- Lack of financial support - Inadequate access to credit
Technological constraints	- Inadequate access to modern irrigation technologies
Knowledge and skills	- Inadequate training to acquire knowledge and skills

6.1. Policy environment

The government of South Africa has developed and implemented various laws and policies. However, most of these policies focus on addressing and rectifying historical inequalities stemming from racial imbalances during the apartheid era. In South Africa, the National Water Act (NWA) of 1998 is a key piece of legislation that aims to improve water access for historically disadvantaged individuals, including smallholder farmers [44]. Regrettably, despite being a comprehensive policy, the NWA has been implemented slowly, and its intended objectives of ensuring equitable access to water have not been achieved [65]. The slow implementation of the NWA negatively affects agricultural development and the growth of many smallholder farmers.

Mugejo [66] also highlighted that sufficient NWA envisaged water allocation progress has not been achieved. Various challenges have contributed to the slow implementation of NWA. Some of the challenges include a lack of funding within the institutions supporting smallholder farmers [67] and inadequate coordination between various government institutions. Regulation, development, implementation, monitoring, administration and enforcement of the NWA remain centralised within the Department of Water and Sanitation (DWS) [68]. This also affects water availability for smallholder irrigation development. Despite the global recognition of the NWA as a progressive water policy, scholars have highlighted that it remains unfamiliar to many smallholder farmers [44]. If the institutions governing the use of agricultural resources, such as water, are not known and understood, their implementation is unlikely to be successful. Farmers' awareness of laws governing agricultural practices, such as NWA, is fundamental as it enables them to seek necessary support [50]. Additionally, ensuring the policy aligns with farmers' needs is a critical first step to fully realise the benefits of smallholder irrigation systems.

6.2. Financial systems

Even though funding plays a vital role in developing smallholder irrigation, the smallholder farming sector in South Africa has experienced inadequate financial support for several years [69]. This is despite various financial support programmes intended to promote smallholder irrigation development. The financial support delivered to smallholder farmers often falls short of fulfilling the objectives in policy statements.

Smallholder irrigation farmers are mostly associated with inadequate access to credit. Poor access to credit can restrict farmers from obtaining and purchasing essential agricultural production inputs, such as seeds and fertilisers. These inputs are vital for increasing production output and revenue [70]. This ultimately affects the development of smallholder irrigation.

Various factors limit smallholder farmers from accessing funding from credit providers. These factors include a lack of collateral and land ownership, high interest rates, distance from irrigation plots to financial institutions, apprehension regarding penalties in case of payment default, and inadequate information about credit providers [70]. In addition, smallholder farmers' occupation and use of land is usually through permission to occupy, and this cannot be utilised as collateral to access funding from banks [1].

6.3. Technological constraints

Numerous technologies can promote the development of smallholder irrigation. These technologies include tools used for extracting and distributing irrigation water, such as microjet/sprinkler systems, drip and buckets/watering cans, canals, reservoirs, wind pumps, solar pumps, motorised pumps, treadle pumps and rope and washer pumps [71]. Unfortunately, most of these technologies are not available to smallholder farmers.

Constraints such as inadequate access to extension services contribute to insufficient adoption of improved technologies. Extension services can help smallholder farmers access most irrigation technologies [1]. Technologies such as water-saving irrigation systems, including sprinkler and drip irrigation, are important in improving water use efficiency and water productivity.

The high cost of electric and diesel-powered irrigation pumps limits most smallholder farmers in South Africa from adopting technologies [72]. To reduce the high energy costs, smallholder farmers can also use other alternative and cost-effective renewable energy sources, such as off-grid wind-based and solar-based irrigation pumps [43]. However, it is very challenging for smallholder farmers to afford the initial costs that are associated with assembling renewable energy technologies [73]. In 2011, with support from the government of South Africa, about 52.2 % of the land in smallholder irrigation utilised overhead irrigation systems, while the remaining 48.8 % still relied on gravity-fed irrigation systems [73]. This shows the slow rate at which smallholder farmers were supported to transform to modern water-saving irrigation technologies.

Drip irrigation is considered a leading technology for high water use efficiency and improving agricultural production [73]. Unfortunately, its expansion is associated with high investment costs, which is a challenge even in well-developed countries [74]. Implementing water-saving technologies such as drip irrigation among smallholder farmers in South Africa is very difficult due to limited financial support [73].

6.4. Knowledge and skills

The failure of smallholder irrigation development is also linked to inadequate training for extension staff and smallholder farmers [13]. Adequate training to acquire essential knowledge related to irrigation is required to ensure the successful management and development of irrigation in the smallholder farming sector [42,75]. Smallholder farmers in South Africa usually lack irrigation management training [12,75]. According to Phali et al. [50], farmers need training to obtain the necessary knowledge and skills in various aspects, including agricultural production, irrigation scheduling, irrigation maintenance, financial management, pricing and

marketing, and training on proper planting techniques and timing is essential, and on the general good agricultural practices.

To efficiently and effectively disseminate training to farmers, some extension officers in South Africa are not capable of adapting to technological changes [76]. Extension services can also enable farmers to acquire new recommendations relating to market access and agricultural activities [70]. However, access to advice from extension officers is challenging for many smallholder farmers in South Africa [42]. Some of the extension officers are not specialists in issues relating to irrigation water management [42]. As a result, it is difficult for farmers to gain suitable skills to use irrigation water efficiently. Phali et al. [50] stated that when farmers receive agricultural training, it helps them better understand agricultural input combinations, which ultimately increases their yields and revenue.

The support services towards smallholder irrigation farmers in South Africa are inadequate, and this reduces the capacity of farmers to manage their irrigation plots and consequently leads to poor performance in irrigation development [70]. Acquiring knowledge and skills relating to economics, finance, and management is also very important in enhancing the economic viability of smallholder farming in South Africa [1]. Unfortunately, smallholder farmers have failed to acquire some of these necessary skills from extension officers [75]. This has ultimately led to a reduction in agricultural production. Insufficient knowledge among smallholder farmers, particularly in crop production, contributes to low yields. For instance, Agholor [77] indicated a lack of knowledge concerning farm management practices as the main factor contributing to low crop productivity at the Zanyokwe Irrigation Scheme in the Eastern Cape. Therefore, it is important to have real-time interactive platforms between farmers and extension officers (over the phone or radio) that allow farmers to get help from extension officers when needed. The partnership of farmers with universities and non-governmental organisations is crucial in disseminating knowledge and skills to improve agricultural production for smallholder irrigation farmers.

7. Opportunities for smallholder irrigation development

Despite the various constraints that affect the success of smallholder irrigation, there are many opportunities for improving the development of the smallholder irrigation sector in South Africa. These opportunities are linked to agrarian reform, land tenure, water rights, innovative farming approaches, technological advancements, partnerships, and knowledge and skills development.

7.1. Agrarian reform, land tenure and water rights systems

7.1.1. Agrarian reform and land tenure

The agrarian reform in South Africa aimed to support many smallholder farmers [36]. While there is capacity to expand the irrigated area, particularly on redistributed land, the agrarian reform has not effectively established the necessary conditions to foster the success of smallholder farming [78]. Conditions such as good soil quality, availability of inputs, labour, capital, appropriate mechanisation equipment, skills, and markets must be considered. These conditions will enhance the productive use of redistributed farming land for smallholder irrigation farmers. Additionally, to ensure meaningful and successful agricultural production by the beneficiaries of land reforms, smallholder farmers should receive support from responsible institutions in acquiring land title deeds. Institutions such as the Department of Agriculture, Land Reform and Rural Development (DALRRD) can offer such support to enable smallholder farmers to obtain land title deeds. Securing land rights is essential to promote long-term investment in irrigation systems for smallholder farmers [79]. Moreover, land ownership can play a role in granting access to irrigation water [65]. This is mainly because it is very challenging for a farmer to acquire a water use license without land ownership and title deeds. In addition, a water access guarantee, especially before or after land occupation, is necessary to enhance the success of land reform beneficiaries [43]. This will ultimately promote the development of smallholder irrigation.

7.1.2. Water rights or water permit systems

Smallholder farmers in South Africa have limited access to agricultural water due to various factors, including unclear water rights [13]. Unclear water rights contribute to the challenges of irrigation water management among smallholder farmers in South Africa. This also leads to low water use efficiency and eventually slow development in smallholder irrigation farming. Smallholder farmers in South Africa have encountered obstacles in obtaining water use rights and permits due to various factors, including inequalities relating to gender and race [80]. Access to water use rights and permits is necessary for motivating smallholder farmers to invest in technologies that can conserve and utilise water more productively [81]. Water rights and permits are also important in controlling and regulating water utilisation and ultimately help improve smallholder irrigation development. However, smallholder farmers are often unaware of the water use permit application process that assists farmers with permit applications [80]. The current licensing processes are lengthy and time-consuming for smallholder farmers [43]. Therefore, to enable the acquisition of water use rights and permits, it is crucial to provide training to smallholder farmers on the application processes [82]. Technical support for smallholder farmers from institutions such as the DALRRD and the DWS, as well as Catchment Management Agencies, can play a critical role in providing training for the application processes. However, sufficient technical staff is also needed to handle the water use permit application process [83]. Networking among farmers is also an important strategy that enables farmers to acquire knowledge about the application processes for water use licenses. It is important to strengthen the coordination between the institutions involved in the land and water reform programmes to improve water access for irrigation.

7.2. New approaches to farming

7.2.1. Precision agriculture

Unreliable rainfall and high costs of agricultural inputs are among the factors that adversely affect agricultural production [84].

Adopting farming practices such as precision agriculture is necessary to improve agricultural production and utilise the available resources optimally, especially in the smallholder farming sector [85]. Precision agriculture is a holistic and environmentally friendly farming practice whereby farmers can vary inputs and practices (spatially and temporally) using applicable technology and principles [84]. Precision agriculture technologies also play an important role in supporting the development of sustainable agriculture. However, in South Africa, such technologies are mainly used in large-scale commercial farms [85]. For example, FruitLook, a precision agriculture technology that farmers use, is assisting farmers to be climate-smart and use water efficiently in the Western Cape [86]. This implies that technologies such as FruitLook can provide opportunities for smallholder irrigation development in South Africa.

Precision agriculture offers numerous benefits, but its adoption in developing countries, including South Africa, is constrained by factors such as knowledge requirements and high costs [86]. Therefore, to promote the adoption of precision agriculture in smallholder farming in South Africa, the government should provide funding and training support to smallholder farmers in collaboration with other stakeholders from various institutions, such as universities and non-governmental organisations.

7.2.2. Regenerative and conservation agriculture

Soil quality is the primary foundation of regenerative and conservation agriculture. Regenerative agriculture utilises naturally occurring beneficial soil-plant interactions. This farming method minimises reliance on fewer external inputs and takes advantage of ecological agricultural practices [87]. Given that smallholder farmers are usually characterised by inadequate resources for farming, less reliance on external inputs provides a great opportunity for regenerative agriculture to be adopted by smallholder farmers. The regenerative approach also involves using various technical management practices to restore the land to a higher state after it has been used for crop production [87]. The main objective of adopting regenerative agriculture is to maintain the fertility of the soil by optimising the concentration of nutrients. Regenerative agriculture is valuable in strengthening the strategies for crop protection in agricultural fields by improving the soil's disease-resistance capability [88]. Furthermore, regenerative agriculture also encourages and emphasises the use of location-specific practices [87]. Since smallholder farmers in South Africa usually lack adequate and necessary resources to practice more intensive agriculture, regenerative agriculture will benefit the smallholder farming sector.

Conservation agriculture involves non-soil inversion agricultural practices such as zero and reduced tillage. These practices aim to increase the infiltration and productivity of soil and reduce water loss while conserving energy and labour [89]. No-till agriculture is vital in addressing issues related to soil fertility and erosion. It also plays a critical role in mitigating problems in soils with low water-holding capacity. Moreover, no-till agriculture promotes sustainable agricultural production. Conservation agriculture's other benefits include improving water and nutrient use efficiency [90]. These findings are supported by Ref. [91], who reported that conservation agriculture has enhanced sorghum production in South Africa, especially under semi-arid conditions. Therefore, smallholder irrigation farmers in South Africa can be enhanced by practising conservation agriculture.

7.2.3. Agroecology

Agroecological farming combines modern science and traditional local farming practices to allow the optimal management of biodiversity and nature's ecological functions. These practices reduce the dependency on external inputs and improve the performance of the farming system [92]. By reducing the dependence on external inputs, agroecological farming is an essential opportunity for smallholder farmers. Similar to regenerative and conservation agriculture, soil quality restoration is one of the common principles of agroecology. Agroecological farming practices have several benefits, including improved yields, enhanced food security, reduced greenhouse gas emissions and improved social cohesion [93]. Agroecology can also significantly contribute to reducing the utilisation of synthetic pesticides, which is a major cause of the loss of biodiversity [94]. In many countries in sub-Saharan Africa, including South Africa, agroecology is a promising farming concept for smallholder farmers [95]. A study conducted in South Africa indicated that the adoption of agroecology by smallholder farmers is influenced by many factors, including a decline in crop yields and soil fertility [96]. Agroecology can also serve as a crucial climate change adaptation strategy, particularly in smallholder farming systems where the adaptive capacity to climate change is generally low among most smallholder farmers. It is important for practitioners working with smallholder farmers to consider the integration of climate change adaptation and agroecological approaches when training farmers [96]. In South Africa, officials from the DALRRD, who usually work closely with smallholder farmers, should promote the adoption of agroecology.

7.2.4. Rainwater harvesting

Two methods are used for rainwater harvesting: in-situ and ex-situ rainwater harvesting (RWH). In-situ rainwater harvesting methods involve capturing and harvesting rainwater at the field level to increase the amount of water stored in the soil. Ex-situ involves the techniques used to capture rainwater outside the farm using natural or man-made reservoirs such as ponds and small earth dams [97]. In-situ RWH includes contour bunds, contour farming and using pits and strip catchment. The main purpose of RWH is to efficiently make use of rainwater that was supposed to get lost through evaporation or as runoff [98]. RWH can be used as a source of irrigation water for enhancing smallholder farm production and resilience to climate change [97]. South Africa is a water-scarce country. Therefore, RWH is essential in improving agricultural production in the smallholder irrigation sector.

7.3. Technological advancements

Sharing irrigation infrastructure and water among smallholder farmers usually results in conflict due to unfair management [99]. Implementing suitable irrigation water management system technology can improve the management and usage of water resources in smallholder irrigation. Efficient management of water supplies is essential for successful smallholder irrigation development, as it

significantly contributes to improved crop yields. Irrigation scheduling interventions, such as wetting front detectors (WFD), can be used to manage irrigation water efficiently. However, consistent and comprehensive farmer training regarding water requirements for crops and soil water characteristics is essential to determine the appropriate timing for irrigation. Therefore, the government should promote the adoption of such systems based on the demand [73]. Irrigation scheduling technologies such as WFD are low-risk and easy to use [100]. Thus, these technologies offer crucial opportunities for the development of smallholder irrigation.

In South Africa, furrow irrigation is one of the major irrigation systems mostly used by many smallholder farmers [101]. This is primarily because this method is easy and cost-effective; however, scheduling irrigation water is challenging, leading to significant water wastage [101]. The scheduling of irrigation is challenging in furrow irrigation mainly due to the uneven distribution of water across the field. This results in remarkable variations of moisture across the field and makes it very difficult for farmers to determine the exact amount of water to apply, including when to apply the water. Several smallholder farmers share irrigation infrastructure among themselves, and they grow various crops simultaneously. Therefore, appropriate irrigation scheduling mechanisms such as WFD are required in smallholder irrigation schemes to conserve water. The government should also support the development and adoption of the Internet of Things (IoT) as well as modern irrigation technology, such as drip irrigation systems that help to conserve water. IoT is a technology whereby the devices and objects that are connected to the internet are managed and controlled through the software on tablets and smartphones [102]. IoT technology's benefits in irrigation management include estimating irrigation water requirements and preventing crops from being stressed by accurately recording soil moisture and temperature. This reduces the wastage of water and ultimately promotes irrigation development. Even though IoT technology has the potential to promote smallholder irrigation development, support in terms of training to understand the technology and funding to acquire the technology is critical to enhance its adoption by smallholder farmers.

7.4. Markets and finance

7.4.1. Market access

Smallholder farmers in South Africa have experienced challenges in accessing markets for several years [38]. The reliability of market access is crucial in motivating smallholder farmers to attain reasonable levels of agricultural production [36]. There are two types of markets in South Africa, formal and informal markets. Formal marketing refers to the official movement of agricultural products through various chains. In contrast, informal marketing occurs when farmers sell or exchange their agricultural products directly with other farmers, local communities, or neighbours [103]. Smallholder farmers are facing challenges in accessing formal markets. Formal input markets ensure farmers receive the necessary inputs on time, allowing them to plant during the appropriate window. Output markets are an important pull factor, incentivising farmers to invest in irrigation and produce crops for food security and selling. To ensure access to the formal market, partnerships between smallholder farmers, agribusinesses and governments or NGOs are essential [104]. Partnerships also enhance the buyers' supply reliability and provide a guaranteed market to the farmers [13]. Partnerships are also crucial in facilitating the value chain and reducing farm losses, especially for smallholder farmers [105]. They also help in eliminating middlemen by enabling farmers to have direct access to the market. Accessing information concerning market prices for agricultural produce also plays a vital role in farmers' decision-making. Access to market information can also help farmers purchase agricultural inputs at the right time and reasonable cost [39]. Increasing global trade opportunities and intra-African trade, and implementing the South African Good Agricultural Practice (SA-GAP), provide opportunities to increase market access for smallholder farmers in South Africa [29]. Access to markets plays an important role towards investment in irrigation water infrastructure. This is because when farmers have reliable access to markets, it helps to earn the income required to invest in irrigation water infrastructure.

7.4.2. Access to finance and subsidies

Smallholder farmers in South Africa receive a low income from farming [106]. Many smallholder farmers do not have adequate capital or funds required to invest in irrigation infrastructure. Governmental and non-governmental support can significantly assist smallholder farmers. Providing subsidies on electricity tariffs can be particularly helpful in reducing challenges associated with high energy costs [43]. Subsidies also assist smallholder farmers in covering the high initial cost of assembling renewable energy technologies such as solar irrigation pumps [73]. Therefore, the government needs to provide suitable irrigation equipment for smallholder farmers rather than giving them financial grants [73]. Allocating adequate funds by government institutions is needed to invest in water-saving technologies and ensure the provision of sufficient extension services to train smallholder irrigation farmers on appropriate agronomic practices, including suitable operation and maintenance strategies of irrigation systems.

7.5. Knowledge and skills development

7.5.1. Training and extension services

Acquiring essential knowledge and skills through farmer training is very important in improving agricultural production [107]. However, many smallholder farmers in South Africa lack the necessary knowledge and skills required for improving agricultural production, such as appropriate water management practices, [43,108]. Capacity-building interventions through extension services are essential to enable smallholder farmers to gain suitable skills and knowledge [43]. Without extension services, it is challenging for suitable modern technologies to reach smallholder farmers [109]. Given the ever-changing nature of agricultural technologies, farmers need to stay informed and updated on how to effectively use current and suitable technologies [13]. Regrettably, due to factors such as outdated approaches used by extension officers that do not align with the needs of smallholder farmers, extension services in South

Africa have achieved limited success in increasing agricultural production and net farm income [110].

To disseminate the appropriate skills and knowledge, extension support services must fulfil the training requirements of smallholder farmers. Disseminating relevant knowledge and skills regarding irrigation water management can significantly enhance smallholder farmers' competence in making informed decisions regarding irrigation water conservation. Therefore, to successfully implement water-saving irrigation technologies, proper capacitation of extension staff is required [73]. The use of e-extension methods and interactive platforms to keep farmers engaged with extension and provide real-time support on issues arising in irrigation schemes will ensure timely action by the farmers and promote smallholder irrigation development. Training farmers in crop production is also essential in enhancing crop productivity [111]. Providing smallholder farmers with essential skills in irrigation scheduling, utilising suitable irrigation methods and determining crop water requirements is necessary to promote irrigation development. Farmers' community-based learning networks also allow them to share their knowledge regarding farming-related issues that can help to enhance irrigation development.

7.5.2. Role of women and youth

Youth and women are important human resources in the success of smallholder irrigation farming. Women are the majority in the smallholder farming sector in South Africa, including in smallholder irrigation schemes [112]. The government should provide necessary agricultural training programmes to the youth and women [113,114]. Empowering women to actively participate in farming, engage in the market and partake in decision-making processes [103], while also ensuring access to production resources is crucial. Participation in marketing activities can guide women in identifying suitable markets for their farm products, ultimately encouraging them to take a more active role in farming operations.

In many countries in Africa, including South Africa, young people generally lack interest in farming due to multiple factors, including negative perceptions surrounding agriculture, limited access to relevant information and a lack of access to credit [103]. To improve the productivity of smallholder farming, government support programmes that specifically aim to motivate and engage youth in agriculture are essential. [103]. Young people are often literate and can easily understand farming operations and management information, including understanding the latest farming technologies. Therefore, the involvement of youth in agriculture has the potential to improve smallholder agricultural production. However, to encourage youth participation in the agricultural sector, policy and development programmes should take into account the diverse nature of youth regarding their access to resources such as land and water [115]. Policies on climate-smart agriculture and programmes that motivate youth and women to actively engage in smallholder irrigation farming should be prioritised by policymakers and decision-makers.

8. Conclusions and recommendations

The review investigated the challenges and opportunities of smallholder irrigation development in South Africa. Various biophysical challenges identified were mainly related to land access, water access and agronomic practices. The study revealed inadequate land access among smallholder farmers, which also translates to a lack of water access. This is mainly because it is very challenging to access water without land access. The review revealed that water access challenges are also caused by drought impacts, insufficient irrigation water infrastructure and poor performance of irrigation water infrastructure. Regarding agronomic practices, pests, diseases, and weeds were the major challenges experienced by smallholder farmers. These were compounded by costly agrochemicals. The study also highlights several socio-economic constraints affecting the development of smallholder irrigation. Some of these socio-economic challenges include inadequate financial support and a lack of adequate knowledge and skills relating to farming. Sufficient financial support plays a critical role in enhancing the development of irrigation. Without adequate financial support, it is difficult for smallholder farmers to secure and access agricultural inputs and acquire modern water-saving irrigation technologies. Several opportunities for promoting the development of smallholder irrigation were revealed in the study. Some of these opportunities were related to land tenure systems, water rights, new approaches to farming, technological advancements, knowledge and skills, as well as access to markets and finance. The findings of the study are significant in improving the development of smallholder irrigation and enhancing food security for smallholder farmers in South Africa.

The study recommends the following opportunities that can promote the development of smallholder irrigation:

i. The coordination between institutions such as DALLRD and the DWS that are involved in the implementation of land and water reform programmes should be strengthened. This can be attained through the establishment of open communication channels and fostering a culture of collaboration by promoting teamwork as well as clearly defining the roles and responsibilities of the responsible institutions. As a result, this will help to improve the connection between land ownership and access to irrigation water for smallholder farmers.
ii. Government institutions such as the DALRRD and the DWS should allocate adequate funds for investment in water-saving technologies. Adequate funding is also critical to ensure sufficient human resources, particularly extension services. Extension officers can help to train farmers on appropriate agronomic practices such as pests, diseases and weeds management as well as suitable skills for the operation and maintenance of irrigation systems, including skills in irrigation scheduling, utilisation of suitable irrigation methods, determining crop water requirements, and irrigation equipment maintenance.
iii. Policies on climate-smart agriculture and programmes that motivate youth to actively engage in smallholder irrigation farming need to be prioritised by policymakers and government institutions.

In conclusion, it is important to consider the following issues in future studies:

i. Estimating non-productive water losses and developing water use efficiency practices for smallholder irrigation schemes in South Africa.
ii. Discussing issues relating to microfinance or cooperative models, including quantifying the magnitude of the funds that are supposed to be allocated to promote smallholder irrigation development in South Africa.
iii. Investigating the role of climate-smart agriculture, agroecology, and technological advancement in developing smallholder irrigation in South Africa, as well as understanding the adaptability of regenerative agriculture, conservation agriculture and rainwater harvesting in smallholder irrigation schemes
iv. Comparing insights with other neighbouring countries that are facing similar irrigation development challenges
v. Comparing the adoption of advanced technologies (such as IoT and drip irrigation) and more accessible approaches for smallholder farmers, such as rainwater harvesting and improved traditional irrigation practices
vi. Focusing on specific statistics, such as yield losses due to pests and recent drought-related data in South Africa
vii. Focusing on the effectiveness of irrigation technologies such as WFD, drip irrigation and IoT that have been implemented by smallholder farmers in similar contexts in Africa
viii. Focusing on the impact of youth and women's engagement in smallholder irrigation schemes on livelihoods and rural economies.

CRediT authorship contribution statement

Kudzai Mugejo: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Bongani Ncube:** Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition, Formal analysis, Conceptualization. **Evans Shoko:** Writing – review & editing, Validation, Supervision. **Walter Mupangwa:** Writing – review & editing, Validation, Methodology, Conceptualization.

Data availability statement

No data was used for the research described in the article.

Additional information

No additional information is available.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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