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Systematic Review

The Adoption and Impact of Climate-Smart Water Management Technologies in Smallholder Farming Systems of Sub-Saharan Africa: A Systematic Literature Review

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Abstract: Agriculture plays a significant role in global water consumption, accounting for approximately 70% of the world's freshwater usage. This makes this sector a critical factor in the depletion of water resources. Accordingly, this paper explores potential mitigatory impacts of climate-smart water management (CSWM) technologies in sub-Saharan Africa. About 70% of the population in sub-Saharan Africa is dependent on agriculture for sustaining their livelihoods. This is despite the low agricultural output in smallholder farming systems (SFS) due to water scarcity. This has spurred several attempts to promote the adoption of climate-smart agriculture (CSA) to raise agricultural outputs and improve smallholder farmers' livelihoods. However, there has not been a comprehensive analysis of data categorised by various aspects of climate-smart water management technologies. In this systematic literature review, climate-smart water management technologies in sub-Saharan Africa's agricultural sector were identified and analysed to determine strategies that could enhance their adoption and impact. To this end, academic articles reporting on the adoption of climate-smart water management technologies in databases were reviewed. Four significant literature databases were used. These were limited to Springer Link, ScienceDirect, MDPI, Wiley Online, and Google Scholar. The findings demonstrate that rainwater harvesting and micro-irrigation are the primary climate-smart water management technologies used by smallholder farmers. The literature review shows that adoption of CSWM practices is constrained by inadequate technological infrastructure, financial implications, unsuitable policies, and low user skills, particularly. It is therefore recommended that government agricultural departments and relevant advocates of CSA should incentivise and subsidise smallholder farmers to encourage CSWM technology adoption. This can be achieved through the implementation of suitable policies directed at technological infrastructure development, financial support for adoption, and technical skills training.

Keywords: climate-smart; smallholder farming systems; systematic literature review; technologies; water management

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1. Introduction

Global water scarcity is becoming increasingly difficult to address in both rain-fed and irrigated agriculture due to the impacts of climate change [1]. Climate change and variability manifesting as changes in rainfall and surface temperature pose a major threat to freshwater resources and food nutrition security [2,3]. Changes in climate and the associated negative impacts are primarily anticipated in developing countries. However, these impacts differ across regions, affecting yields and production in varying ways [2]. Some of the adverse risks of climate change include increases in droughts, heat waves, and heavy rainfall events, which negatively influence agricultural production [4]. Rosenzweig and Hillel [5] suggest that poor farmers in developing countries are the most vulnerable due to low levels of income, lack of capacity to seek alternate livelihoods, geographical exposure, and over-reliance on agriculture. Climate change and variability can play a significantly negative role in smallholder farming systems, especially those located in environments that are fragile and remote [2]. Integrated crop and livestock management and soil, water, and nutrient management technologies and practices have the potential to mitigate the impacts of climate change in southern Africa [6].

Climate-smart agriculture (CSA) is a new paradigm that aims to support food security and change agricultural systems [7,8]. There are several CSA practices and technologies that form part of the global CSA approach to be resilient in the face of climatic perturbations. There are several CSA practices and technologies designed to enhance soil fertility and health management. These include agroforestry, conservation farming, livelihood and crop diversification, the use of stress-tolerant crops and livestock, index insurance, and water management techniques [6,9,10]. Additionally, other studies highlight prominent technologies of intercropping, bio-fortified crop varieties, carbon farming, rotational grazing, efficient manure management, livestock diet improvement, livestock husbandry improvement, mulching, water harvesting, water re-use, and wetland planting [1,7,11–16]. These technologies and practices are probable solutions in water management and can improve the management of water resources in smallholder farming systems. Climate-smart water management technologies (CSWM) integrate innovative and traditional technologies, services, and practices such as those aforementioned [17]. Their adoption in smallholder farming systems can assist smallholder farmers to adapt to climate change.

There is limited information on the factors that impact (i.e., promote or hinder) the adoption of CSA practices and technologies and their interactions with smallholder farming systems [18]. Senyolo et al. [19] states that despite the potential of CSA technologies to address climate change impacts in smallholder farming systems in southern Africa, their adoption has remained low. According to Grainger-Jones [20], understanding the prospects for effective adoption of CSA technologies is essential, given that smallholder farmers in sub-Saharan Africa and Asia are highly exposed to climate change. Smallholder farmers in southern Africa are poorly resourced in terms of human capital and financial and physical assets, and usually occupy land that is minimally developed compared to commercial farmers [21]. The challenges they face related to water scarcity are mostly a result of climate change through extreme weather conditions and over exploitation of natural resources through agriculture, industry, and municipal services. According to Donnenfeld et al. [22], water in more than 60% of southern Africa's rivers is presently overexploited for irrigation, municipal drinking water, and industrial use. Continued overexploitation of water coupled with extreme weather events linked to climate change make smallholder farmers more vulnerable to droughts [22]. Therefore, the adoption of CSA technologies and practices, which include climate-smart water management, is recommended in smallholder farming systems. This review explores the adoption of CSWM technologies and their impact on productivity in smallholder farming systems in sub-Saharan Africa.

2. Materials and Methods

In this investigation, the following protocols suggested by Kitchenham and Charters [23] were used: identifying research questions; defining search strategy and performing a pilot search; defining study selection and exclusion criteria; defining the quality assessment criteria; defining the data extraction strategy and performing a pilot data extraction; and defining the data synthesis methods. This process of synthesis is referred to as a systematic literature review (SLR). The purpose of this SLR was to support the development of evidence-based guidelines for researchers [24]. The SLR synthesises literature on CSWM technologies to determine their adoption and impact in sub-Saharan Africa's smallholder farming systems. Additionally, the purpose of the review was to descriptively determine measures that can enhance the adoption of CSWM technologies in smallholder farming systems. This was achieved through the interpretation of patterns and trends on each subtopic. Furthermore, a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Table S1) and flow diagram (Figure S1) was completed and added as Supplementary Material. The rest of this section provides greater detail on the methodology used.

2.1. Research Questions

In this review, the interest was to examine empirical studies on the adoption and impact of CSWM technology in sub-Saharan Africa's agricultural sector. To fill the current knowledge, existing studies reporting on types of CSWM technologies implemented, the agricultural domains for which they were employed, and the impacts they had on farming systems [23,24] were examined. The following study questions were formulated for this purpose:

Question 1: What types of CSWM technologies are adopted in smallholder farming systems in sub-Saharan Africa?

Question 2: What are the potential impacts of CSWM technologies on smallholder farming systems in sub-Saharan Africa?

2.2. Search Strategy

The search strategy was established by defining the search scope, selecting the search method, and constructing the search string. The search scope includes the year of publication and the database in which the publication was found. The search was conducted in 2022; hence, the search was limited to academic papers published between 2012 and 2022. However, this scope was applied at the study selection criteria stage. To find the desired research publications, an automated literature search using a pre-defined search string was conducted in the following five databases: Springer Link, ScienceDirect, MDPI, Wiley Online, and Google Scholar. Keywords from the research questions and their synonyms were used to create the search string. A pilot search was then used to enhance the search string. The search terms that were returned are as follows: "climate change and variability impacts", "smallholder farming systems", "water management technologies", and "climate-smart agriculture." Academic papers that cited the primary terms were selected by the automated search, and additional articles that referenced those papers were also examined. The outcomes of the search process, after applying the search queries, are shown in Table 1.

Table 1. Literature search results overview.

Source	Retrieved	Included	Selected	Method
Google Scholar	648	312	22	Automatic
ScienceDirect	356	57	12	Automatic
Wiley Online	90	20	1	Automatic
MDPI	281	33	3	Automatic
Springer link	1	1	1	Automatic
Total	**1376**	**423**	**39**	

2.3. Selection and Exclusion Criteria

To reduce the number of publications while retaining relevant ones, specific details of the selection and exclusion criteria were provided. The selected papers were subjected to a series of selection and exclusion criteria to eliminate any papers that did not fit the study's goals [23]. Table 2 lists the exclusion standards applied in this investigation. The 423 papers that were found through the automatic search were subjected to this exclusion criteria. This was accomplished by first reading the paper's title and abstract and, if found relevant, reading the complete document [23]. After applying the exclusion criteria, 39 papers were retained for further evaluation.

Table 2. Exclusion criteria.

Exclusion Criteria No.	Criteria
EC1	Paper is published before 2012.
EC2	The paper is not in English.
EC3	There is no full text of the article online.
EC4	Paper has nothing to do with agriculture.
EC5	There is no discussion of water management in the abstract.
EC6	Duplicate content.

2.4. Data Extraction

Table 3 provides a list of primary studies that were selected for review. To accurately extract data from primary studies, a data extraction form (Table 4) was created. All the fields necessary for answering the research questions were selected during a pilot data extraction process. The process involves piloting search strategies, inclusion and exclusion criteria, and data extraction tables to minimise error in the large systematic review. The data extraction form encompassed 15 items, including authors, title, publication year, document type, and data repository. The necessary components included the chosen CSWM technology domain, the relevant agricultural context, the impacts of climate change and variability, and the adoption of CSWM technologies.

Table 3. List of primary studies selected for review (n = 39).

Authors	Title	Year
Abegunde et al. [25]	The dynamics of climate change adaptation in Sub-Saharan Africa: A review of climate-smart agriculture among small-scale farmers	2019
Altieri and Nicholls [2]	The adaptation and mitigation potential of traditional agriculture in a changing climate	2017
Anantha et al. [26]	Impact of best management practices on sustainable crop production and climate resilience in smallholder farming systems of South Asia	2021
Andrieu et al. [27]	Prioritizing investments for climate-smart agriculture: Lessons learned from Mali	2017
Aznar-Sánchez et al. [28]	An analysis of global research trends on greenhouse technology: Towards a sustainable agriculture	2020
Bafdal and Dwiratna [29]	Water harvesting system as an alternative appropriate technology to supply irrigation on red oval cherry tomato production	2018
Barros [30]	Impacts, Adaptation and Vulnerability: Part B: Regional Aspects; Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change	2014
Biazin et al. [31]	Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa–a review	2012
Chartzoulakis andBertaki [32]	Sustainable Water Management in Agriculture under Climate Change	2015
Connor and Mehta [33]	Modes of greenhouse water savings	2016
Cornelissen [34]	Wastewater re-use in agriculture: modelling contaminant transport and impact on soil structure’	2022
Corner-Dolloff et al. [17]	Climate-smart agriculture investment prioritization framework	2015

Table 3. *Cont.*

Authors	Title	Year
Donnenfeld et al. [22]	A delicate balance: Water scarcity in South Africa	2018
FAO [35]	The State of Food and Agriculture 2020: Overcoming water challenges in Agriculture	2020
FAO [36]	Climate-smart agriculture sourcebook	2013
Ghoulem et al. [15]	Greenhouse design and cooling technologies for sustainable food cultivation in hot climates: Review of current practice and future status	2019
Giller [37]	Can we define the term 'farming systems? A question of scale	2013
Goyal and Rao [3]	Impact of climate change on water resources in India	2018
Grant et al. [38]	Creating a Solar-Powered Drip Irrigation Optimal Performance model (SDrOP) to lower the cost of drip irrigation systems for smallholder farmers	2022
Knox et al. [39]	Climate change impacts on crop productivity in Africa and South Asia	2012
Kuivanen et al. [40]	Characterizing the diversity of smallholder farming systems and their constraints and opportunities for innovation: A case study from the Northern Region, Ghana	2016
Lipper and Zilberman [13]	A short history of the evolution of the climate-smart agriculture approach and its links to climate change and sustainable agriculture debates	2018
Lipper et al. [7]	Climate-smart agriculture for food security	2014
Makate et al. [6]	Synergistic impacts of agricultural credit and extension on adoption of climate-smart agricultural technologies in Southern Africa	2019
Murray et al. [41]	Smallholder farmers and climate smart agriculture: Technology and labor-productivity constraints amongst women smallholders in Malawi	2016
Mwongera et al. [42]	Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture technologies	2017
Nkonya et al. [8]	Climate Risk Management through Sustainable Land and Water Management in Sub-Saharan Africa	2018
Nyong and Martin [43]	Enhancing agricultural sustainability and productivity under changing climate conditions through improved agroforestry practices in smallholder farming systems in sub-Saharan Africa	2019
Patle et al. [1]	Climate-smart water technologies for sustainable agriculture: A review	2020
Rosa-Schleich et al. [44]	Ecological-economic trade-offs of diversified farming systems–a review	2019
Senyolo et al. [19]	How the characteristics of innovations impact their adoption: An exploration of climate-smart agricultural innovations in South Africa	2018
Shamshiri et al. [45]	Review of optimum temperature, humidity, and vapour pressure deficit for microclimate evaluation and control in greenhouse cultivation of tomato: a review	2018
Shekarchi and Shahnia [46]	A comprehensive review of solar-driven desalination technologies for off-grid greenhouses	2019

Table 3. *Cont.*

Authors	Title	Year
Sikka et al. [4]	Climate-smart land and water management for sustainable agriculture	2018
Teklewold et al. [18]	Does adoption of multiple climate-smart practices improve farmers' climate resilience? empirical evidence from the Nile basin of Ethiopia	2017
Thamaga-Chitja and Morojele [21]	The context of smallholder farming in South Africa: Towards a livelihood asset building framework	2014
Totin et al. [47]	Institutional perspectives of climate-smart agriculture: A systematic literature review	2018
Uphoff [48]	Improving international irrigation management with farmer participation: Getting the process right	2019
Zhuwakinyu [49]	A Review of South Africa's Water Sector, Creamer Media	2017

Table 4. Data extraction form.

Extracted Element	Content
General information	
ID	Unique identification of study
Authors	
Title	Full title of paper
Year	Year of publication
Source Title	Channel of publication
Document Type	Journal and Article
Repository	Google Scholar ScienceDirect Wiley Online MDPI
Considered water management domain	Climate-smart water management technologies
Country scope	Agricultural regions
Considered agricultural domain	Climate-smart agriculture and smallholder farming systems
Identified challenges Evaluation	Yes/No

2.5. Data Synthesis

The goal of data synthesis was to compile and display results from primary studies in a manner that would answer the two research questions presented above. This process involves a quantitative study based on the research objectives and the findings from the selected primary studies. Consequently, a descriptive synthesis of the extracted data was conducted [24,50]. The studies were examined individually and collectively. Studies that had the same or a similar meaning were compiled under one theme. For instance, the examination and categorisation of the basic concepts of CSWM technologies were grouped under similar themes.

3. Results and Discussion

3.1. Overview of Selected Studies

Academic papers published between 2012 and 2022 were included in the search. Figure 1 displays the distribution of the primary research by year. Journals in which the primary studies were published were also identified.

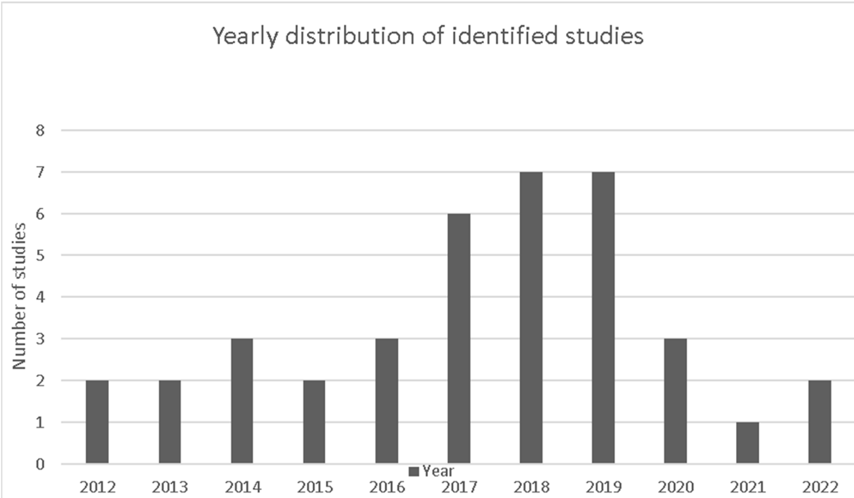

Figure 1. Distribution of primary research papers from 2012 to 2022.

While some journals covered a wide range of countries, others focused on regions. A context-specific publisher that solely seeks publication in emerging economies is the Food and Agriculture Organization of the United Nations. However, this publisher had the second highest number (2) of primary studies, together with "Springer Nature". "Agricultural Systems" had the highest number (3) of primary studies making it the most popular publication channel in this review (Table 5).

Table 5. Number of selected primary studies (n = 35) classified by publications.

No.	Publication Channel
1	African Journal of Agricultural Research
3	Agricultural Systems
1	Agriculture and Agricultural Science Procedia
1	Applied Energy
1	Biosystems Engineering
1	Climate
1	Climate Change Economics
1	Climatic Change
1	Ecological Economics
1	Engineering and Information Technology
1	Environmental Development
2	Food and Agriculture Organization of the United Nations (FAO)
1	Gender, Technology and Development
1	Institute for Security Studies
1	International Agrophysics
1	International Center for Tropical Agriculture (CIAT)
1	International Journal of Energy Research
1	International Journal of Environmental Research and Public Health
1	Irrigation and Drainage
1	Journal of Cleaner Production
1	Journal of Environmental Engineering
1	Journal of Human Ecology
1	Journal of Water and Climate Change
1	Nature Climate Change
1	Outlook on Agriculture
1	Physics and Chemistry of the Earth
1	Procedia Engineering
1	Routledge
1	Science
2	Springer Nature
1	Sustainability

3.2. CSWM Technologies and Their Role in Sub-Saharan African Agriculture

Table 6 lists the principal CSWM technologies that were mentioned in the original studies. Most of the research found that the most popular CSWM technology in the agricultural domain was rainwater harvesting. Most of the studies reviewed indicated that rainwater harvesting reduces the cost of water supply, meets irrigation demands, and helps mitigate water scarcity during droughts and dry seasons. The studies also revealed that 3–5% more land can be cultivated if run-off water is harvested for irrigating. Other studies [1,4,13,19,25–29,31–33,38,41,48] also emphasised the significance of micro-irrigation, which includes determining when and how much to irrigate, as an efficient and sustainable agricultural water management practice for smallholder farmers. Indeed, micro-irrigation seems to be the most popular water management practice in African smallholder farming systems. Reports indicate that micro-irrigation receives the most attention when it comes to water management [13,26–28,38] while little attention is devoted to irrigation methods, even though the two are interrelated [32]. Irrigation is essential because rainfall is often uneven both in timing and distribution [51]. However, smallholder farmers often lack the capital for advanced conservation and water management solutions, so they need more accessible and affordable options.

Table 6. Climate-smart water management technologies identified from primary studies.

Technologies	Studies
Rainwater harvesting	Patle et al. [1]; Altieri and Nicholls [2]; Sikka et al. [4]; Chartzoulakis and Bertaki [32]; Senyolo et al. [19]; Donnenfeld et al. [22]; Abegunde et al. [25]; Anantha et al. [26]; Aznar-Sánchez et al. [28]; Bafdal and Dwiratna [29]; Biazin et al. [31]
Micro-irrigation	Patle et al. [1]; Sikka et al. [4]; Lipper and Zilberman [13]; Senyolo et al. [19]; Abegunde et al. [25]; Anantha et al. [26]; Andrieu et al. [27]; Aznar-Sánchez et al. [28]; Bafdal and Dwiratna [29]; Biazin et al. [31]; Chartzoulakis and Bertaki [32]; Connor and Mehta [33]; Grant et al. [38]; Murray et al. [41]; Uphoff [48]
Greenhouse technology	Patle et al. [1]; Aznar-Sánchez et al. [28]; Bafdal and Dwiratna [29]; Connor and Mehta [33]; Ghoulem et al. [52]; Shamshiri et al. [45]; Shekarchi and Shahnia [46]
Wastewater re-use	Patle et al. [1]; Donnenfeld et al. [22]; Abegunde et al. [25]; Aznar-Sánchez et al. [28]; Chartzoulakis and Bertaki [32]; Cornelissen [34]

3.3. Impacts of CSWM Technologies in Sub-Saharan Smallholder Farming Systems

Smallholder farming systems in sub-Saharan Africa are thought to bear the brunt of rapid changes in climatic conditions [25,26,30,35,40,53], leading to increased food insecurity, higher vulnerability, and lack of sustainable development. It is, therefore, essential for smallholder farmers to adopt sustainable farming strategies such as CSWM technologies in mitigation [35,54]. Smallholder farming systems have characteristics that distinguish them from the other categories of farmers. For example, smallholder farmers work on small, fragmented plots of land but are crucial to food production, making them key players in the agricultural sector [37,40,53]. These farming systems are characterised by low levels of market participation, limited financial assets and access to land, and high levels of vulnerability [40]. The adoption of diversified CSWM technologies such as rainwater harvesting, micro-irrigation, wastewater re-use, and greenhouse technologies can provide benefits at farm level in smallholder farming systems. This will reduce the negative impacts of climate change, improve smallholder farmers' livelihoods, and increase sustainability [54]. In this section, the impacts of identified CSWM technologies are outlined.

3.3.1. Rainwater Harvesting

Rainwater harvesting encompasses all the approaches through which run-off and rainwater are effectively managed for different uses [9]. The term rainwater harvesting is defined as the control, management, and storage of rainwater for immediate or future use [54]. This water management method dates back to prehistoric times but remains an integral part of modern agricultural and domestic systems [54,55]. Rainwater harvesting is typically used in regions with insufficient rainfall for crop growth. It helps complement rainfall during water stress and supplement irrigation throughout the crop's growth [55]. The main aim of rainwater harvesting in CSWM is to collect water run-off from outlying farm areas not used for agricultural production for storage and make it available when and where water is scarce. The harvesting of rainwater may be conducted in several ways, including collecting water in tanks, ponds, dams, and storage tanks [1].

Engineering and agronomic measures are required to make use of harvested rainwater in smallholder farming systems. Agronomic methods including furrow irrigation, ridges, mulching, contour farming, trench plantation, deep tillage, and raised bed techniques enable efficient utilisation of harvested rainwater [1,25]. Engineering measures such as furrow systems, bench terraces, conservation ditches, contour trenches, graded bunds, and contour bunds are also important [6,9,10]. Rainwater harvesting from sloped roofs and gutters of polyhouses, as well as from roofs of urban and rural houses, is widely adopted and effective [1]. Rainwater harvesting ensures that demand for irrigation, in periods of water scarcity as a result of droughts and dry seasons, is met [29]. In arid areas where water limits the expansion of arable land, using harvested run-off water for irrigation could enable the cultivation of an additional 3–5% of land [56]. When rainwater harvesting is practiced in heavy rainfall areas, it also provides benefits such as reduced cost of water supply from municipal connections and irrigation schemes [29]. This is an adaptive strategy, with incredibly important structure for drought mitigation and increasing agricultural productivity [57].

3.3.2. Micro-Irrigation

Water demand often focuses primarily on irrigation timing and quantity, with less emphasis on the methods of irrigation itself, despite their interrelated nature [32]. Since rainfall is unevenly distributed in terms of both space and time, irrigation becomes crucial when rainfall is insufficient or irregular [51]. When considering irrigation, it is important to weigh the benefits and costs of what is both desired and achievable [48]. Given that crop irrigation accounts for about 70% of global water use, many governments promote advanced technologies to improve Irrigation Efficiency (IE) [58]. Enhancing IE benefits irrigators by conserving water for use in other sectors.

Micro-/localised irrigation is a practice that allows for the distribution of water to individual crops, through pipes laid on the surface or underneath the ground. Examples include drip irrigation and micro-sprinklers [11]. Drip irrigation is highly efficient, saving over 91% of water and providing uniform distribution, 90% of the time. It is also labour-efficient, reducing labour costs by up to 73%, decreasing weed growth by 70%, improving crop quality by 66%, and increasing yields by 76% [51]. There are several other technologies that vary in terms of pressure and localised irrigation such as micro-jets, LEPA and centre pivot, sprinkler irrigation, and trickle irrigation [1]. However, drip irrigation systems remain more effective and efficient than most other methods of surface irrigation when it comes to water efficiency, yields and water saving [1,48]. For instance, the reduction in the cost of solar-powered drip systems is one measure that could be used to enable more accessibility, increase smallholder farmers' income, and contribute to sustainability and food security [38]. However, smallholder farmers often lack the capital to invest in CSWM technologies such as these, making it difficult for them to adopt.

3.3.3. Greenhouse Technology

Greenhouse farming is a climate-smart agricultural management system with significant effectiveness and efficiency in combating climate change and intensifying food production [28]. Greenhouse technologies provide an alternative that is stable compared to traditional open-air cultivation practices since they allow year-round growth of crops while reducing water [33]. These technologies allow farmers to address the climate change-induced challenges of food insecurity and unsustainability in the agricultural sector [29]. New greenhouse methods and technologies are constantly being developed to reduce environmental impacts, meet market demands, and address specific crop limitations [59]. These technologies include the following: (i) hydroponics; (ii) new structures that have capabilities of enhancing production; (iii) vertical agroecosystems; (iv) control of the microclimate within the greenhouses; and (v) environmentally renewable energy within greenhouses [33,45,60,61]. Greenhouses typically feature simple technologies and construction, minimal controlling devices for managing environmental parameters, and a low level of mechanisation with increased automation [59]. This makes greenhouses less labour-intensive and more sustainable. It also allows them to be used together with diverse water-saving technologies, such as rainwater collection, seawater desalination, and water re-use, which are crucial in areas where water scarcity limits production [55,61].

3.3.4. Wastewater Re-Use

Climate change, population growth, and urbanisation have resulted in an increase in freshwater demand, placing freshwater resources under immense pressure [34]. This makes the use of alternative sources of water imperative. Treated wastewater may be used for agricultural irrigation, even though it does not necessarily meet the standards and requirements for drinking water [61]. The use of wastewater in irrigation systems can reduce pressure on freshwater resources [34]. The recycling and re-use of industrial effluent and municipal wastewater can minimise the pollution load and reduce freshwater use. Indeed, freshwater resources can be preserved by using stormwater and recycled municipal wastewater for irrigation. Wastewater, when treated, can be used for watering lawns, horticulture, and other landscaping purposes [1]. Implementation of water catchments for wastewater that can be re-used in smallholder farming can reduce the depletion of freshwater resources.

4. Conclusions and Recommendations

In this SLR, we have offered a thorough analysis of the most common CSWM technologies in sub-Saharan Africa's agriculture sector. The findings of this review will add to the limited body of literature on the state of CSWM technology adoption and impact in these farming systems. The review outlined critical impacts of CSWM technology adoption, which include agricultural production, sustainability, and improved smallholder farmer livelihoods. The primary studies' analysis showed that rainwater harvesting and micro-irrigation are some of the most adopted CSWM technologies in sub-Saharan Africa's agriculture sector. Smallholder farmers continue to employ traditional methods of water management in their agricultural systems. Thus, the study suggests empowering and educating smallholder farmers to improve their capacity to interact with emerging agricultural technologies. To encourage the adoption of CSWM technologies and other climate-smart agriculture technologies, suitable business and legislative environments must be created. Stakeholders in the agricultural value chain must demonstrate strong commitment and collaboration to effectively develop smallholder farming systems. The primary focus of the theoretical frameworks derived from the primary investigations is typically on evaluating the technical viability of the CSWM technologies that can influence adoption in smallholder farming systems. Exploring the benefits and drawbacks of adopting these technologies is a significant research topic, and the challenges associated with this exploration have already attracted academic attention. As a result, we suggest the use of a more comprehensive framework in the creation of CSWM technology initiatives. Available reports and non-scientific publications could be considered for this analysis. It is recommended that smallholder farmers should be incentivised for CSWM technology adoption through the provision of viable CSWM technologies to enhance sustainability and production. Subsidies should be provided for smallholder farmers who adopt and implement CSWM technologies in their farming systems by government institutions and other organisations advocating for green transformation. This can be achieved through effective local and provincial policies that focus on developing appropriate technological infrastructure, providing financial support for adoption, and offering technical skills training for smallholder farmers. This will result in more sustainable agricultural practices and the improvement of smallholder farming systems, thereby creating more conducive farming opportunities and environments for smallholder farmers to develop and ascend in the agricultural field.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w16192787/s1, Figure S1: PRISMA Flow Diagram; Table S1: PRIMA Checklist.

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