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Systematic Review

A Systematic Review and Meta-Analysis of Factors Influencing Water Use Behaviour and the Efficiency of Agricultural Production in South Africa

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Abstract: Water use behaviour and efficiency are essential topics regarding water scarcity. Water is a life-sustaining resource used for various activities within the three primary sectors: agricultural, industrial, and domestic. Increasing competition among these sectors could affect the availability and sustainability of water use. The higher demand for agricultural-related commodities emphasizes the efficient and productive use of water. Still, to achieve this, the behaviour of consumers regarding water use needs to be changed. This systematic review paper aims to highlight the factors affecting water use behaviour and efficiency for agricultural production in South Africa. It further aims to determine how agricultural producers change their behaviour to improve their water use efficiency. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria were used as a reporting framework and guidelines to identify the articles included in the review. The review only included articles focussing on agricultural water use behaviour and efficiency and articles written in English and excluded articles from web pages, blogs, magazines, etc. The databases used for the review were Google Scholar and Web of Science. The articles were reviewed by the five authors to avoid the risk of bias, along with the inclusion and exclusion criteria. The final review included 30 peer-reviewed articles. A word frequency table was developed using the NVivo 14 software to conduct a thematic analysis for the review. The main factors which played a role in the water use behaviour and efficiency of farmers were (i) climate and adaptation strategies, (ii) policy and water pricing, and (iii) agricultural production and management. Each category elaborated on how water use could be improved and the different measures adopted to incorporate sustainable farm water use. This could be a guideline for farmers, stakeholders, and policymakers to improve and enhance water use behaviour and efficiency in Sub-Saharan Africa, particularly South Africa. This could ultimately assist in efficiently using the water while enhancing sustainability within the agricultural sector and attaining Sustainable Development Goal (SDG) six, which is to increase water use efficiency. The limitation of this study was that it was only narrowed down to the geographical context of South Africa. This review was funded by the Water Research Commission (WRC) of South Africa (Project Number: C20222023-00798). This review was not registered.

Keywords: water scarcity; resources; water pricing; production and management; sustainability; adaptation strategies; policy

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1. Introduction

Water is a life-sustaining natural resource for all human activities. The activities include three primary sectors, namely agricultural, industrial, and domestic. Agriculture is the largest user of freshwater out of the three sectors, accounting for 70% of all water withdrawals [1]. The competition for water resources among the three sectors will directly affect its availability and use thereof. The competition for water will arise from the increasing rate of population growth, urbanization, and climate-related factors [2]. The competition for water resources will

have considerable social impacts on the growing water demand. Still, there will also be several environmental and economic implications with the decline in water availability [3]. Thus, policymakers need to promote the efficient and sustainable use of water resources, especially in the agricultural sector, as it consumes most freshwater resources.

The increase in demand for food due to the growing population will cause a rise in the need for water. More significant amounts of water will be needed for consumption and food production purposes, which could affect water use efficiency among producers. The water use behaviour of users is also crucial because it could affect how individuals extract water for their desired needs. Water use is increasing at double the population growth rate, with more areas reaching unsustainable limits [4]. For example, in southwest Iran, water resources are expected to diminish by approximately 20% by 2070, while climate change is projected to lead to a 19% to 35% increase in the number of people facing water stress [5]. The change in population is expected to increase the pressure on agricultural production due to higher demands for agricultural-related commodities and goods [6]. The water required to meet such needs could almost triple [4]. To meet these required needs for water resources, the efficient use and management of water resources will be crucial in the long run to ensure sustainable agricultural production.

Efficient water management for food production is becoming increasingly important due to several constraints like climate variability and climate change [7,8]. Climate change is putting tremendous pressure on water resources because it reduces the amount of water available for crop production, ultimately affecting crop yields [9–11]. Adverse climate conditions can affect agricultural yields over the next few decades. Thus, the efficient and sustainable use of water resources must be considered by all water users [12]. Water's sustainable use and management are vital when producing food, as groundwater provides 50% of all drinking water and 43% of all agricultural irrigation [1]. The agricultural sector, which is the primary food producer, must now constantly compete against the industrial and domestic sectors for available water resources. Water scarcity threatens the global agricultural industry but is even more prominent in South Africa. South Africa is a water-scarce country, and many challenges are faced in the current water systems that will cause water scarcity to remain a problem in the future [13]. The challenge for policymakers is ensuring enough water to meet demand amid water scarcity in many countries worldwide.

South Africa needs to improve the productivity of water use for food production in both rain-fed and irrigated conditions [14]. The productivity of water usage for agricultural-related activities must be enhanced to ensure enough water is left in rivers and lakes to sustain the ecosystems [15]. Water productivity can be defined in two categories, namely, physical water productivity and economic water productivity. Physical water productivity can be defined as the ratio of agricultural output to the amount of water consumed, and economical water productivity can be defined as the value derived per unit of water used [15].

The improvement of water efficiency and productivity could be a sustainable way to reduce the scarcity of water resources. Molden et al. [16] highlighted a few additional reasons to improve water productivity: first, to meet the rise in demand for food for a growing population: second, to respond to pressure to allocate water from the agricultural sector to the industrial and domestic sectors; and last, contributing to a reduction in poverty and enhancing economic growth. Using water resources more efficiently will improve food quality, enhance families' diets, and increase incomes. Increased water productivity can reduce the cost of the cultivation of crops and the cost of energy required for withdrawing water [15].

Given the limited availability of freshwater, it is imperative to prioritize efficient use and conservation practices in the agricultural sector [17,18]. The farmers within the agricultural sector are directly connected to water use, and their decision making regarding water conservation is critical for maintaining sustainable water levels [19]. Efficient water resource management can only be achieved if policymakers, researchers, and relevant stakeholders understand the water use behaviour of irrigators and the approaches they follow to conserve freshwater [18]. The efficiency of water used by farmers and their

understanding of water scarcity could improve the sustainable production of agricultural-related commodities and the overall economy of a country, primarily if farmers' decision making is understood better.

The water scarcity problem significantly threatens the amount of water available to the agricultural sector. There are multiple social, economic, and environmental effects due to the scarcity of water resources for all main sectors consuming water [20]. Agriculture is known to be the primary consumer of fresh water, and this trend will continue in the future as there will be a higher demand for food production due to the increasing population growth rates worldwide [15]. The decreasing amount and unreliability of rainfall, as well as limiting groundwater for irrigated agriculture, reinforces the need for efficient water use. Food demand grows as a result of population growth, necessitating more intense agricultural output. Water use efficiency within the agricultural sector will become more crucial with the higher demand for food and competition for available water resources.

The challenge will be to produce at the required rate to satisfy demand due to the changing climatic conditions. The competition for water resources could increase between the different sectors due to increasing scarcity caused by fluctuations in weather patterns [21]. The water demand can only be decreased if water is used more efficiently within each sector, but the excessive use in rural areas makes this task even more challenging [22]. Yun [22] further states that there is a direct relationship between farmers' water use behaviours and the shortage of water sources in rural areas. The pressure on available land and water will continue to grow, so water use efficiency will be crucial, given the limited water resources and the improvement in farmers' water use behaviour. There is a need to determine the factors that affect water use behaviour and the efficiency of water users and identify the adaptation and improvement strategies for water use within the agricultural sector.

Several approaches are used on a global scale to enhance water use behaviour and efficiency within agriculture. Farmers' conservational behaviour is a new approach to improved water management. Various behavioural theories are used as an approach to determine farmers' behaviour towards water conservation [23]. The promotion of groundwater-saving behaviour is a method used to achieve better groundwater management and adapt to climate change [24]. Improved water allocation and irrigation efficiency could lead to better water management. These approaches could be determined by irrigation techniques, environmental conditions, and water application schedules [25]. Irrigation efficiency could be achieved through methods like deficit irrigation and increased harvest index [26,27]. Water use behaviour and efficiency from a global perspective are essential for evaluating water use nationally.

There are a few common approaches for reviewing literature, such as systematic review and meta-analysis. Several studies have combined these two approaches to conduct their research. A systematic review is a detailed and structured approach to identifying and synthesizing relevant studies based on a research topic or question. The scope of a systematic literature review is to provide a qualitative summary of the findings of the identified studies. This might also include meta-analysis but does not necessarily involve statistical data representation. They ultimately provide an overall understanding of the research topic, the findings, and limitations of the included studies and identify possible gaps in existing knowledge. On the other hand, meta-analysis involves using statistical approaches to combine quantitative data from included studies to derive statistical outcomes. It often forms part of a systematic review but involves separate statistical analysis. The key differences between these two approaches can be summarized as the difference between the synthesis, the use of statistical analysis, and the output of the research topic.

The main aim of this study is to provide a comprehensive systematic review of the water use behaviour and efficiency of producers within the agricultural sector of South Africa by identifying the factors that affect water use behaviour and efficiency in the agricultural sector. Further, we aimed to determine what decisions farmers make regarding

their water use to withstand the factors that influence their water use. This aim was achieved by answering the following research questions:

(i) What are the factors influencing water use behaviour and efficiency among agricultural producers in South Africa?
(ii) How do these factors affect their decision making and the adaptation of production practices?

The following section will discuss the materials and methods used to conduct the review. It will elaborate on the literature search and selection criteria used to identify the articles included in the review.

2. Materials and Methods

2.1. Contextual Factors of South Africa

To better understand the factors affecting water use behaviour and efficiency in South Africa, it is necessary to look at several contextual factors. These contextual factors include population, climate, topography, plantation type, irrigation infrastructure, and water resources.

According to Stats SA [28], South Africa's population increased from 55 million in mid-2015 to approximately 60.6 million by mid-2022, representing a total growth of 10% over seven years. The annual growth rate for 2021–2022 is also estimated at 1.45%. The increase in population could impact the water use behaviour and efficiency of water users because of the increased demand for water resources.

Climate conditions can also affect water demand, with South Africa having an average temperature of 17.5 °C, fluctuating between the winter and summer seasons [29]. South Africa is a water-stressed nation, receiving about 40% less rainfall than the global average of 860 mm per year, placing it among the top 30 driest countries in the world [30].

The topography of South Africa varies from arid to semi-arid in the northwestern region, which is the drier part of the country. The areas along the eastern coast are more sub-humid, with 50% of the country classified as arid or semi-arid [29]. The topography covering the country's most significant part is a plateau, dropping from 2400 m in Lesotho (South Africa's neighbour country) to 600 m in the western part of South Africa.

Most of the 96.8 million hectares of agricultural land comprises permanent meadows and pastures (87%), and the cultivated area covers 12.9%. Further, 12.93% of the cultivated area is fully equipped for irrigation [31].

In the agricultural land of South Africa, irrigation infrastructure is present over 1.67 million hectares, with 23.05% being surface irrigation, 55.09% sprinkler irrigation, and 21.86% localized irrigation. The rest of the agricultural land comprises natural forests, plantation forestry, and woodlands. The natural vegetation varies across the region: the dry central and western parts of the plateau are covered with shrubs and desert grasses; the southwestern areas, with a Mediterranean climate, feature fynbos; and the eastern parts host grasslands, savannah, bushveld, and forests, depending on the altitude [31].

South Africa is characterized by high variability in rainfall, and water resources are under constant pressure. In South Africa, 98% of water resources are already allocated, meaning that opportunities to supplement water demand in the future will be limited. South Africa's water security is at risk due to a decline in water supply caused by climate change's adverse effects on yields, wetland and water resource degradation, and dam siltation. At the same time, water losses and demand are increasing due to population and economic growth, urbanization, and inefficient use, which emphasizes the efficient use of water resources [32]. This critically highlights the need to assess the factors affecting water use behaviour and efficiency in South Africa.

2.2. Literature Search Criteria

A literature search was conducted to identify peer-reviewed articles. The articles searched were in English only, and the Google Scholar and Web of Science databases were used. The search excluded articles from web pages, blogs, magazines, etc. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria were used

to assess the literature under review. The search was conducted from January to February 2024 within the geographical context of South Africa. There was no limit to the year of publication because the study was geographically restricted to South Africa alone. A literature search was conducted to identify the articles that assessed farmers' water use behaviour and water use efficiency in South Africa.

The phrases used for the search in Google Scholar were "water use behaviour", "agricultural production", and "South Africa" as well as "water use efficiency", "agricultural production" and "South Africa". The search for water use efficiency was limited to phrases within the title to refine the results. The phrase used to search in Web of Science included "water use behaviour of agricultural production in South Africa" as well as "water use efficiency of agricultural production in South Africa". The following section will discuss the selection criteria used to identify the included articles.

2.3. The Selection Criteria Used

Figure 1 illustrates a schematic layout for the inclusion and exclusion criteria process. The search phrase "water use behaviour", "agricultural production", and "South Africa" in Google Scholar yielded 69 records. The search phrases "water use efficiency", "agricultural production", and "South Africa" in Google Scholar yielded 62 records. This gave a total of 131 records identified from Google Scholar. The search phrases used in the Web of Science were "water use behaviour of agricultural production in South Africa" and "water use efficiency of agricultural production in South Africa", which delivered 68 and 91 records, respectively. This gave a total of 159 records identified from the Web of Science. The total number of records identified was 290 from both databases, after which 70 duplicate records were removed. All five reviewers were part of the screening process, with each reviewer working independently when screening the records. The titles and abstracts of the records were added manually to Excel. Each reviewer had to characterize each record as include, exclude, or maybe—articles characterized as maybe were reviewed by all the reviewers through face-to-face discussions. The remaining 220 records were then screened, with 60 articles left to be assessed for eligibility, with the other 160 being excluded due to the irrelevance of research and the unavailability of full text. From the 60 articles assessed for eligibility, 20 were removed for being previous systematic review articles, and ten were removed for not being relevant to the research questions identified. This procedure yielded the final 30 articles included in the study for the systematic review.

The data obtained from each article included the name of the authors, the year of publication, water use behaviour, and water use efficiency data, as well as the outcomes each study managed to highlight. The data for each article were collected in Excel, with the articles divided equally between all five reviewers. Each reviewer collected the data independently. Each reviewer categorized their reviewed articles into a section according to the characteristics of the article. The articles from each reviewer were grouped into separate sections based on the characteristics identified by each reviewer. The methods used to assess the risk of bias were for each of the five reviewers to work independently, excluding articles that were not written in English from the review, as well as studies that were not related to water use behaviour and efficiency. Each reviewer had to categorize the articles in the Excel spreadsheet into include, exclude, and maybe, after which the 30 articles were chosen for the review. Table A1 in Appendix A gives a detailed summary of the articles used for the systematic review. The summary of each article includes the author/s, objectives of the study, methods and data used, findings of their research, and remarks on the main discussion points for each study to categorize them in the correct section for the discussion point, as illustrated in Figure 1.

Furthermore, Figure 1 provides a detailed layout of each discussion point and how many articles in the review relate to each. This provides a breakdown of each section discussed in the article and the number of articles related to them individually. The 30 articles included in the systematic review are broken down into three sections, as shown in Figure 1. A total of 9 articles addressed climate and adaptation strategies [33–41],

10 articles addressed policy and water pricing [36,42–50], 12 articles discussed agricultural production and management [33,37,40,49,51–58], and 4 discussed sustainability [59–62]. The sum of the discussion points (agricultural production and management, policy and water pricing, climate and adaptation strategies, and sustainability) in Figure 1 will be 35 articles. Still, some articles were addressed in more than one section of the review. Thus, the final review only included 30 articles in total, as illustrated in Figure 1. The findings from the included articles in the review will be addressed in the following section, with the results discussed in the three sub-sections derived from Figure 1.

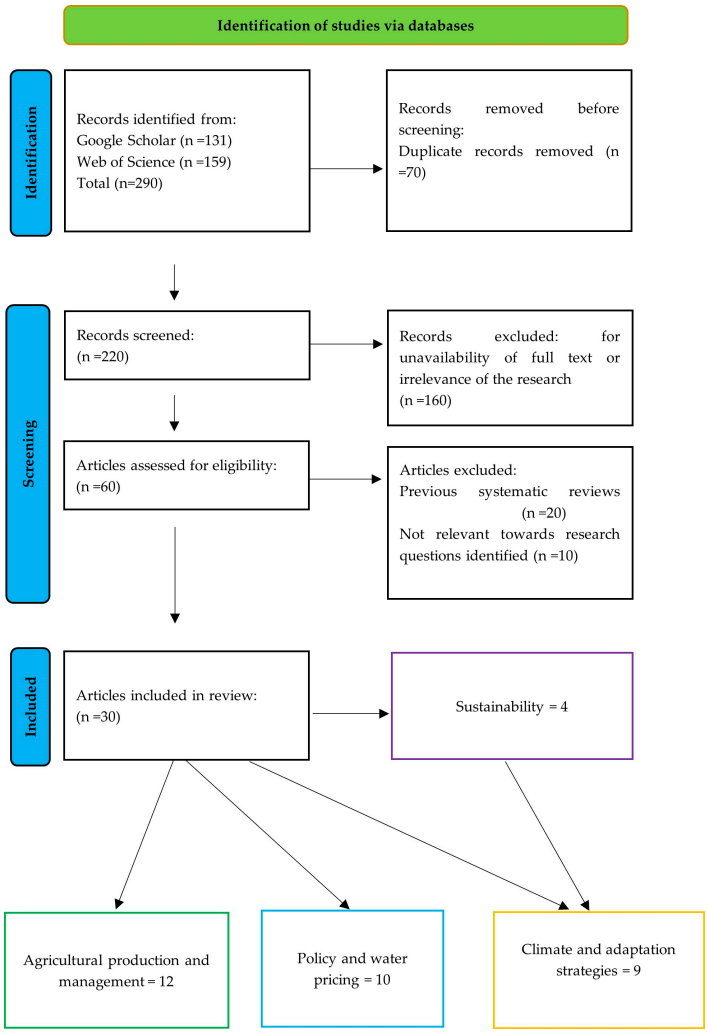


Figure 1. A schematic representation of the inclusion–exclusion criteria used and different discussion points identified in each article. Source: Author's adaptation from PRISMA [63].

3. Results

This section aimed to address the results that were obtained from each of the selected articles to review. This study evolved around two main sections, namely water use behaviour and water use efficiency, both of which apply to agricultural production in South Africa, given the country's status as a water-scarce country. It investigated the factors affecting farmers' water use behaviour and efficiency. It also looked at the decisions farmers could make to change or adapt their water use behaviour. Furthermore, it highlighted the predominant practices farmers could use to improve their water use efficiency within their agricultural production activities. These results are discussed in different sections below depending on the category most applicable to each selected article for this review, with the first section being climate and adaptation strategies.

3.1. Climate and Adaptation Strategies

The behaviour of water users is vital for agricultural production, and their decisions could significantly impact their water use; this leads to various response strategies and adaptation measures to withstand climate-related challenges. South Africa is known as a dry country where variable climate and climate extremes are often experienced [35]. An arid climate characterizes the country, and it receives only a fraction more than the global average rainfall [37]. The variable conditions that are experienced in the agricultural sector will undoubtedly have an effect on farmers' decision-making regarding their water use. The drought conditions that South Africa has gone through in recent times have emphasized stakeholders' involvement in changing their water use behaviour [36]. They found it economically more viable to decrease the number of hectares planted and instead apply maximum irrigation to obtain higher yields when water restrictions were in place. This could assist policymakers in considering introducing a policy that will ensure that farmers reduce their hectares and instead apply full-capacity irrigation on the smaller production areas because it will ultimately lead to increased yields.

There are several techniques to overcome challenges regarding droughts. In a study by Lankford et al. [40] in a semi-arid catchment of South Africa, they evaluated the resilience of irrigated agriculture regarding drought conditions. They found that water storage and conservation strategies enabled fruit growers in that region to counter the drought. The farmers stored water in dams to conserve water and build up water in reserves between drought periods. They also found that farmers could absorb a drought by saving water for some time. Still, the water withdrawal rate and depletion of water resources have become significantly challenging over extended periods.

The agricultural sector of South Africa is under significant pressure due to climate change; hence, the implementation of the desired adaptation strategies is essential for the agricultural sector in the future. Farmers are known to be the decision-makers regarding land use and strategies to combat climate change, which makes it necessary to understand their actions on their agricultural land [38]. A crucial component of agricultural production is farmers' adaptation policies and strategies for future success [39]. The trade of commodities could impact South Africa's economy, and it is essential to understand how climate variability could impact the productivity of the agricultural sector. A better understanding of climate's impact could improve the related sectors' adaptive capacity [34]. They elaborated that citrus production in tropical regions of South Africa is vulnerable to hot and dry climates and that these regions must implement different strategies for adapting to climate change. The country's agricultural systems are mainly developed under arid and semi-arid climate conditions, and the related agricultural practices must be adapted to these conditions [33]. Dalin and Conway [34] found that the regional food trade concerning water use is efficient but ineffective because water-productive exporters, like South Africa, depend on scarce water sources. They further stated that the shortage in food production could be reduced with the trade of water resources across continents. The trade of water resources across continents will only be successful if adequate structures are implemented, thus putting the onus on policymakers to carefully consider the specific trade agreements and the practical application thereof.

Vilakazi et al. [35] mentioned that communal farmers need help to obtain trustworthy information on the climate, which could affect their water use behaviour. Kom et al. [41] added that many indigenous farmers in South Africa depend on rain-fed agriculture. Still, reliable indigenous weather information is needed to help rural farmers make decisions. They further mentioned that indigenous knowledge helped rural farmers counter the effects of climate change and assisted them with adaptation measures.

Indigenous Knowledge Systems (IKS) can be used to conserve water and soil while managing the effects of climate change. Several factors affect farmers' abilities to adopt strategies to counter climate problems due to factors such as lack of knowledge, technology, and the lack of credit [35]. Indigenous farmers adopt several strategies to battle climate problems, like conserving water through building dams, rainwater harvesting, crop rotation,

and drought-resistant crops, among others [35]. Furthermore, they found that farmers in communal areas who applied manure were 0.17 times more likely to engage in soil and water conservation than those utilizing artificial fertilizers. This implies that indigenous knowledge can be used to manage climatic extremes and preserve soil and water resources. Policymakers must encourage communal farmers to introduce such methods on their farms because it could improve soil and water use. Du Preez and van Huyssteen [37] also emphasized that national institutions must take action to manage and rectify soil and water degradation. They stated that water quality is affected by pollution, salinization, and sedimentation, which must be corrected to ensure the sustainability of water resources.

Kom et al. [41] also showed that farmers used similar techniques as mentioned above, along with adjusting planting calendars, shifting from long-season crops to short-season crops, and using local irrigation strategies. Indigenous farmers could employ the use of IKS for weather prediction strategies as a reference to adapt. Still, they often need more knowledge to interpret meteorological data accordingly [41]. In both these studies, using IKS has helped farmers withstand the pressures of climate-related challenges and make the necessary adaptations to ensure future production.

The adaptive behaviour of farmers could be influenced by previous experiences with extreme climatic events [38]. There are also external barriers to adaptation, like institutional and biophysical factors. Their study focused on the drought affected by the Western Cape province of South Africa and found that farmers experienced a long-term change in the regional climate, especially rainfall and temperature. Farmers implement several adaptive strategies towards climatological changes, with current strategies being predominantly technological, which address the direct effects of climate even though the effects are not only at a farm level. Adopting soil and crop management, water harvesting techniques, and planting drought-resistant crops are some of the adaptation strategies used by farmers facing climate constraints [33,38,39]. Policymakers must be actively involved in training and education programs for farmers to enable them to make informed decisions regarding adaptation strategies.

Farmers in Limpopo's citrus production have considered adapting fertilizers with higher nitrogen content, but this could be more costly. The only profitable change for these farmers was to change their fertilizer content as an adaptive measure, with water harvesting and the planting of drought-resistant crops needing to be more significant to use as an adaptive measure. The prices of fertilizer and water were the main factors affecting profit efficiency [39]. Bennie and Hensley [33] added that one of the most effective measures to utilize precipitation is to limit water loss from the soil and maximize the gains. They found that 50–75% of annual rainfall is lost due to evapotranspiration from the soil's surface, which results in relatively low precipitation efficiency. They further mentioned that the risk involved with crop production could decrease when good soil water is stored before planting. The following section will elaborate on policy and water pricing, examining the various factors affecting water use behaviour and efficiency.

3.2. Policy and Water Pricing

The management of water resources and restrictions is crucial for sustainability and future availability. The agricultural sector of South Africa is the largest water user of all industries; hence, it experiences much pressure to increase water use efficiency and decrease consumption [46]. There must be efficient and effective policies to ensure this scarce resource is utilized accordingly. Still, the practical implications of such policies must be realistic to achieve at the farm level, which stakeholders must keep in mind. Several measures could be implemented to ensure water is used efficiently, but the government often influences water use behaviour through policy instruments [48]. The behaviour of water users could be changed by policy interventions [36]. The government suggests that this could be achieved through methods to educate farmers to have sufficient knowledge of previous, current, and future fluctuations in water levels and climate conditions to reduce the effects of such natural occurrences. The implementation of water policies can be

used to manage equity, efficiency, and sustainability in water use [49]. The South African government implemented a comprehensive reform process for the water sector in the 1990s to ensure a water management system that promotes equitable distribution [47]. Such policies must constantly be revised to ensure they are accurate and realistically achievable in an ever-changing agricultural industry.

Citrus farmers need to be aware of the possible changes in policy because they need to manage and regulate their irrigation water and scheduling instruments [48]. One study found that assessments conducted in various citrus orchards spanning different climatic regions in South Africa revealed that citrus water consumption, when soil water availability is not a limiting factor, is influenced by atmospheric requirements and internal impediments to water flow within the plant. These internal resistances curtail the citrus tree's capacity to transpire water, particularly under hot and arid conditions. The desired objectives of water policy interventions will only be achieved if the behaviour of farmers is changed [36]. Various factors could affect farmers' decisions, like the price of crops, water, and electricity. They proposed that the government and different role players should find a way to educate farmers and improve their understanding of water and climate-related risks. The policies introduced by the government and role players must be tailored to address water and climate risks in a manner that is practical and within the financial ability of farmers and policymakers.

Several policies have been implemented to improve water use efficiency, one of which is compulsory water licensing. A farmer's water rights could enhance the efficiency of water use, whereas the cost of water does not necessarily show improvements in farmers' water savings. Water pricing and membership in a water user association considerably influenced the quality of water use. The results from the Data Envelopment Analysis indicated that the average water use efficiency for irrigators was approximately 31%. They also propose that technical assistance and improving extension services could be a policy indicator for better water management [49]. Reinders [46] stated that guidelines should be developed to improve the water management of irrigators. Such guidelines can support water users and regulatory authorities in using them as strategies to improve water management. These guidelines can build capacity and enhance investment to reduce social and environmental costs, which could support adopting the water balance approach.

Inter-regional water allocations can yield higher benefits and the implementation of sustainable water supply policies. There could be benefits from water trade and policy measures, but they would only sometimes have the desired outcomes [47]. Their findings showed increased benefits from inter-regional water allocation. They found that reducing water supply levels to align with sustainable water policies showed that while water supply is reduced by almost 50%, the total gain from water use decreases by only 5% for inter-regional and 11% for intra-regional allocation regimes. Jordaan and Bahta [36] stated that a higher water cost did not drastically impact the yield of crop producers. Still, the main challenge for farmers was the availability of water rather than the policy interventions. Water pricing is generally used as a measure to enhance the efficiency of water use in agriculture. Still, this study found that farms do not reduce water use even if a water price is introduced. The cost of production is a factor that will increase with increased water pricing [43]. Small-scale irrigators play a fundamental role in rural development. Still, the increasing concerns regarding water scarcity have brought up water charges in these areas, which were previously fully subsidized [44]. The impact of a pricing policy on irrigation farmers and the effect it will have on their water use for agricultural production still needs to be clarified [45]. Policymakers must consider that each introduced policy will have a different effect on farmers and that new regulations could lead to both positive and negative reactions on a regional and national level.

The study conducted by Munro et al. [50] showed that South Africa could gain from water footprint analysis to assist water catchment management agencies in achieving better water use efficiency results. This could help the water catchment management agencies and other stakeholders with allocation decisions, reduction strategies, trade-

off risks between water users, etc., for better water use. Their study area of the Lower Sundays River Valley experiences infrastructural and institutional scarcity, with 14% of the population not having access to piped water. They also added that the different indicators explored in the study could assist policymakers in reviewing and adapting the current water user licensing system. Speelman et al. [44] mentioned that socio-economic factors like the land size of a farm, the ownership, the type of irrigation scheme, irrigation methods, and crop choice could substantially impact the sub-vector efficiency of water. The improvement in regulations regarding the water use efficiency of agricultural water users could assist the management agencies of various catchments across South Africa in alleviating water scarcity in their irrigation areas. They further mentioned that the strong correlation between water sub-vector efficiencies and overall technical efficiencies raised concerns about the viability of poor performers if a water price is introduced. However, the lower efficiency estimates indicate that substantial reductions in water use can be obtained with the current technology while maintaining the crucial role of smallholder irrigation in rural development. The role of smallholder irrigations can be supported, and their contribution to the regional economies is vital, which is another factor that key stakeholders must comply with when developing or adjusting water use policies.

The study by Speelman et al. [42] found that smallholder irrigators need help to attain optimal levels of technical efficiency regarding their water use. In the case where there is no cost for water use, they have a low level of incentive to use water efficiently. They propose that an integrated approach to water pricing may lead to more efficient water use, but the outcomes may be less desired in many cases. Their study used Data Envelopment Analysis (DEA) to obtain farm-level technical efficiency indicators and sub-vector efficiencies for farmers' water use. The results found that for the constant returns to scale specifications, the technical inefficiency was 49%, and for the variable returns to scale specifications, it was 16%. The results of Speelman et al. [45] showed that farmers in South Africa are relatively responsive to minimal changes in water prices and that water pricing encourages irrigators to use water resources efficiently. They also found that introducing water charges could negatively affect the profitability of farms because smallholder farmers are mainly poorer, and even a slight increase in current costs may have a significant economic impact on them and even lead to them not producing in the future. Extension officers and policymakers could increase water use efficiency in their areas by using this information to their advantage when making decisions. The last discussion point will address agricultural production and management, which is reviewed in the next section.

3.3. Agricultural Production and Management

The threat of water scarcity in South Africa is a significant challenge to sustainable agricultural production [51]. The need for more water resources often forces producers within the agricultural sector to explore alternative production methods and crops to deal with the limited water available for producing their desired commodities. Drastic changes in rainfall patterns are seen in semi-arid regions across the globe, which forces producers of agricultural commodities to develop intensive cultivation methods. This has led to the increased use of spineless cactuses for fodder production and biomass in semi-arid climates, where irrigation is not necessarily used [58].

Water use efficiency is affected by various factors like the variety, climate conditions during drought periods, irrigation management, and the amount of fertilizer applied. Alternative crops like sweet sorghum are recognized as potential biofuel crops for ethanol production because they are tolerant to drought and well-adapted to different growing conditions [53]. Previous studies have proven that the water use efficiency of sweet sorghum was sensitive to plant density. Still, it has a high water use efficiency under varying climate conditions, which could make it suitable as an alternative feedstock for biofuel production. The production of maize by smallholder producers also often depends on rainfall, which could be negatively affected by drought conditions [54]. One study

showed that maize cultivated in rotation with two-year pigeon pea fallow periods exhibited greater dry matter yield (11.661 kg ha^{-1}) and water use efficiency (WUE) at 20.78 kg mm^{-1} compared to maize grown continuously, which yielded 5314 kg ha^{-1} and had a WUE of 9.48 kg mm^{-1}. They mentioned that given the current challenges of water scarcity and increased drought occurrences due to climate change, rotating maize with pigeon peas is recommended for smallholder farmers in South Africa. This approach offers higher WUE, ensuring improved food security in the region.

Identifying alternative crops and production techniques is essential for eradicating water scarcity and policy-related challenges. According to Adetoro et al. [55], their study aimed to examine how water scarcity can be encountered by reducing the water footprint of sugarcane production under different soil mulching and irrigation systems. The blue water footprint of subsurface drip-irrigated sugarcane was 8–10 m^3/ton lower compared to central pivot-irrigated sugarcane, primarily due to its superior application efficiency. Additionally, the economic productivity of blue water for subsurface drip-irrigated sugarcane surpassed that of central pivot-irrigated sugarcane crops. Policymakers can encourage farmers to introduce the use of drip-irrigated systems on their farms because it will improve their water footprint. They found that the economic water productivity of blue water usage for crops grown with a thick mulch cover was slightly higher (5%) than those grown with a light mulch cover under subsurface drip irrigation. These findings showed that the water use efficiency of sugarcane can be improved by implementing more productive irrigation systems. Owusu-Sekyere et al. [51] highlighted that in South Africa, one ton of milk containing 4% fat and 3.3% protein necessitates 1352 m^3 of water. Notably, the water utilized in producing feed for lactating cows constitutes a significant portion, accounting for 86.35% of the total water footprint of milk. Moreover, the water footprint associated with the feed ration for lactating cows is approximately 85% higher than that of non-lactating cows.

Olivier and Singels [56] added that practices such as a crop residue layer, adjusted row spacing, and improved irrigation scheduling could improve water use efficiency. They also aimed to identify if the use of such practices could improve the water use efficiency of sugarcane producers. They also found that using a crop residue layer could enhance water use, but this could only be achieved when accurate irrigation scheduling is applied on the farm level. The outcomes indicated that the most significant reduction in water usage was observed in plants, with decreases of 26% in crop water use and 32% in irrigation demand. However, substantial water savings of approximately 15% were also noted in ratoon crops. Bennie and Hensley [33] mentioned that reducing runoff and evaporation and increasing soil water storage by mulch practices could improve precipitation use efficiency. Their study found that lengthening the fallow period before planting resulted in a more significant accumulation of pre-plant stored water in the soil, consequently lowering the susceptibility of crops to drought damage during wet seasons, with measurements reaching up to 20% of the annual precipitation with above-average rainfall.

The constant pressure on water resources in South Africa drives water users to higher water use efficiency through technology development. With the boom in knowledge and use of technology, it must be utilized productively and efficiently to withstand water scarcity, especially in areas where the agricultural and urban industries compete for this limited resource [52,57]. Roux et al. [52] indicated that technological tools like remote sensing could be used to generate information to help with agricultural production. The research study by De Witt et al. [57] showed that farmers do not often have the time to evaluate data from new technologies and these should instead be integrated to supplement existing technologies. The latest technology can only assist with decision-making and must be very useful for the farmer to adopt it. The personal relationship between the provider and farmer must be reasonable; otherwise, the product use will not be successful in the long run. Some new technologies are time-consuming, and farmers would rather stay with current systems. These results showed that technology had a high usage level (83%) but only used one type—soil water measurement. The majority of farmers employing water-use efficiency technology, at approximately 78%, opt for the services of the same probe provider.

This preference is primarily attributed to the perceived accuracy and ease of use of the probes, along with the personalized after-sales service offered. Despite 86% of farmers being aware of FruitLook, only one farmer utilizes it for irrigation purposes. The factors affecting the low adoption rate of technologies must be investigated to enable policymakers to make informed decisions when advising agricultural producers and introducing new regulations.

The water use efficiency of sugarcane producers could be improved if there is a better management and understanding of the factors affecting farmers' water use [56]. The management and control of water resources must be regulated in the long term by water users and stakeholders to enable irrigators to survive climate challenges. Some management and control techniques include technological changes, institutional changes, and improved absorptive and adaptive resilience [40].

Soil and water resource management are essential to sustainable food production, but physical, chemical, and biological degradation poses a threat. There is an urgent need to address the issue of water use efficiency management in agriculture and forestry in South Africa because these sectors are the largest consumers of water resources. The management of these problems needs to be performed at the ground level by the farmers and the broader national industry to ensure that the soil and water resources are maintained even further than they are at present [37]. The management of soil and water resources must be addressed and promoted by introducing sustainable policies targeting the problems farmers face.

Water reform and management could be improved if certain policy factors are adequately addressed. These factors include water pricing, licensing, and membership in a water user association. Still, regional- and national-level management must be sufficient to reach the desired outcomes. If a farmer has a water license, it could promote more efficient water use and management in some instances, but only sometimes, because some farmers would pay the costs incurred for the higher quantity of water used [49]. The following section will discuss the results generated from the word frequency analysis.

3.4. Word Frequency Analysis

A word frequency analysis was conducted using the NVivo software to conduct a thematic analysis of the 30 included articles. The analysis results can be observed in Table 1 for the water use behaviour studies (10 articles) and the studies focused on water use efficiency (20 articles). Specifically, the top 15 most frequently occurring words were reported for both the water use behaviour and water use efficiency studies. For the water use behaviour studies (10 articles), the word "water" is the most frequently occurring word, with a count of 1316 occurrences and a weighted percentage of 2.51%, indicating its central focus in these studies. In addition, the prominence of words such as "Climate" and "change" indicates significant highlights of the impacts of climate change on water use behaviours. This observation is further supported by the frequent occurrence of the word "adaption", which suggests that adaptive strategies are a significant area of interest in coping with climate change. Furthermore, frequently occurring words such as "farmers", "production", "crop", "soil", and "agricultural" highlight the study's emphasis on how farmers manage water use in the context of agricultural production.

In terms of the water use efficiency studies (20 articles) in Table 1, the term "water" appears most frequently, with a count of 3427 and a weighted percentage of 2.83%, which is in line with what has been observed for water use behaviour studies (10 articles). The word "irrigation" ranked second with 985 occurrences and a weighted percentage of 0.81%, highlighting that irrigation practices are a significant area of focus in the context of water use efficiency. The frequent use of the word "use" (796 occurrences, 0.66%) further supports the strong emphasis on irrigation practices and general water utilization across the 20 articles. The frequent mention of words such as "soil" (786 occurrences, 0.65%) and "crop" emphasizes the critical role that agronomic factors such as soil conditions and crop production play in water use efficiency. The concepts of "efficiency" (426 occurrences, 0.35%) and "management" (381 occurrences, 0.31%) are central to the water use efficiency

studies (20 articles), highlighting efforts to optimize water use and implement effective water management strategies.

Table 1. A word frequency analysis for the 30 articles in the systematic review.

Water Use Behaviour Studies (10 Articles)					Water Use Efficiency Studies (20 Articles)				
Word Ranking	**Word**	**Length**	**Count**	**Weighted Percentage**	**Word Ranking**	**Word**	**Length**	**Count**	**Weighted Percentage**
1	water	5	1316	2.51	1	water	5	3427	2.83
2	climate	7	592	1.13	2	irrigation	10	985	0.81
3	change	6	477	0.91	3	use	3	796	0.66
4	farmers	7	403	0.77	4	soil	4	786	0.65
5	south	5	336	0.64	5	south	5	679	0.56
6	production	10	314	0.60	6	Africa	6	667	0.55
7	Africa	6	307	0.59	7	crop	4	469	0.39
8	use	3	267	0.51	8	farmers	7	437	0.36
9	footprint	9	246	0.47	9	production	10	433	0.36
10	adaptation	10	236	0.45	10	efficiency	10	426	0.35
11	used	4	204	0.39	11	drought	7	397	0.33
12	soil	4	203	0.39	12	management	10	381	0.31
13	crop	4	187	0.36	13	efficiency	9	322	0.27
14	indigenous	10	173	0.33	14	yield	5	321	0.27
15	agricultural	12	162	0.31	15	data	4	320	0.26

Note: the weighted percentage in a word frequency query assigns a portion of the word's frequency to each group to ensure the overall total does not exceed 100%. Source: Authors' compilation.

This section extensively elaborates on the results found from the studies in each of the three identified sections. It further illustrated the word frequency analysis, a form of quantitative analysis conducted in the NVivo software. The following section will discuss the articles reviewed and address the critical issues identified within the study.

4. Discussion

A broad field of studies has attempted to analyse the factors that affect water use behaviour and efficiency within the agricultural sector, which exemplifies its importance in South Africa. The challenge is to satisfy irrigation demand for agricultural production as it competes with the industrial and domestic sectors for the available water sources [64]. The sustainable use of water in the agricultural industry will be vital for the future because there will be an increasing demand for this scarce resource, especially in South Africa.

The water use efficiency and behaviour of farmers in South Africa could be improved if their knowledge and ability to manage water resources are improved. The previous section elaborated on the different factors that could affect such farmers' water use behaviour and efficiency. Farmers have different views on climate and how they adapt to the challenges arising from variable climate conditions. Agricultural producers in South Africa can enhance their water use efficiency by adapting to climate change and other related challenges. Policymakers in South Africa must align farmers' challenges with the policies they ought to implement. This could create an opportunity for farmers in South Africa to adhere to these policies and withstand the factors that affect their water use behaviour and efficiency.

This article also discussed how various policies and water pricing strategies are used to enhance the more efficient use of water. South Africa's agricultural producers adapt and change how they manage the production of their commodities to ensure that they comply with policies and utilize water sustainability. Still, these producers cannot always meet such guidelines. Farmers in South Africa encounter numerous financial challenges at

the farm level, making it difficult to meet their basic needs, let alone cover the expenses associated with compliance with newly introduced policies. The financial and economic constraints that farmers in South Africa face reduce their ability to use water efficiently because they do not always have the required resources.

One of the targets of Sustainable Development Goal (SDG) six is to increase water use efficiency [65]. This aligns with the results that water resources should be utilized appropriately and efficiently to protect this scarce resource for future generations. All consumers in the agricultural sector of South Africa will be responsible for water use, which will enhance its sustainability. Farmers adapt their farming practices in various ways to withstand challenges from variable climate conditions. The costs of adapting their practices constantly challenge farmers in South Africa. Implementing adaptation strategies like new technologies is expensive, and without sufficient capital or assistance from the government, it is a huge problem. However, when it is possible to adapt their farming techniques, it could significantly improve their production capacity and ensure long-term profitability. Policymakers play a vital role by implementing strategies like changes in water use behaviour, water pricing, and others to ensure that water is used more efficiently, which will help achieve SDG six.

Multiple studies have been conducted to assess the sustainability of water use in South Africa. Water footprint assessments can gather crucial information for water users and stakeholders towards sustainable water management [50,51,60,62]. Scheepers and Jordaan [60] stated that water use behaviour must be interpreted within the context of water availability to gain more insight into the degree of environmental sustainability of water use. Changes in water use behaviour could have significant social, ecological, and economic implications for South Africa. Thus, this study emphasizes the degree of ecological sustainability with which water is used to guide policymakers and water managers correctly [51,60]. Ngxumeshe et al. [62] found that agriculture is the largest user of blue water for food production for crops and animal products. However, more research is needed to measure the water footprint of beef production in South Africa and make recommendations for sustainability measurements.

The introduction of alternative farming practices is becoming more prominent. Conservation agriculture has been proposed as a sustainable intensification and climate-smart solution, which could result in the higher productivity of agricultural production in South Africa [61]. Conservation agriculture could be an alternative, but many agrarian producers would not necessarily adopt it because it will not be sustainable for them in the long term. Farmers in South Africa must consider incorporating such techniques into their farming operations because they can promote the sustainable use of resources like water and soil. Chami and Moujabber [59] suggest four strategic goals that could assist in reaching sustainability. These strategies include the following:

(i) Conducting crop research aimed at discovering resistant breeds and varieties that are resilient and tolerant to drought and heat to counter climate challenges;
(ii) Increased focus on research in agricultural practices;
(iii) Enhancing water utilization efficiency in agriculture;
(iv) Incorporating all of these strategic objectives into a sustainable research framework.

Introducing these strategies could further enhance sustainable water use in South Africa. Research on crops that could be tolerant of drought and heat can enable agricultural producers in South Africa to adapt to climate challenges. New research on enhancing farming practices and water utilization can assist policymakers and farmers in introducing innovative practices at lower costs. Introducing these strategies will lead to several positive outcomes in South Africa's agricultural industry. Farmers must be educated on the efficient use of water resources by being assisted with the necessary information and resources to adapt to challenges like climate, finances, credit, policies, and government regulations. Sufficient education, assistance, and support to farmers who face these challenges will positively affect their water use behaviour and efficiency, which could ensure that water resources in South Africa are maintainable for future generations.

From a global perspective, several policies have been proposed and implemented in relation to water use. Implementing the correct policies will ensure that water is consumed responsibly while assisting stakeholders and policymakers with managing water resources. Gruère and Le Boëdec [66] found that it is necessary to implement four challenging water policies:

(i) Charging for water use in agriculture;
(ii) Removing subsidies that negatively impact water resources;
(iii) Regulating groundwater use;
(iv) Addressing nonpoint source pollution.

Ahmed et al. [25] stated that water resources for agriculture are limited because of socioeconomic demands and climate change and that the implementation of the following strategies could assist with sustainable water management in agriculture:

(i) Changes in irrigation application;
(ii) Soil and plant practices;
(iii) Water price;
(iv) Farmer participation in water management.

The policies and strategies implemented for water management could have several socio-economic impacts and implications on policies, which must be considered. Speelman et al. [43] noted that water pricing is regularly seen as a method to improve water use efficiency, as also highlighted above [30,66]. However, they stated that water saving could be limited and have several negative economic and social implications. Moreover, they stated that there is a pressing requirement for methods that enable policymakers to predict the impacts of introducing or increasing the price of water. Talanow et al. [38] identified that climate change adaptation is primarily technological and does not explicitly highlight the socio-economic impacts of climate change and the effect that it could have on commercial farmers in South Africa.

Combining scientific knowledge with IKS is essential to maintain agricultural production, particularly for communal farmers who rely on agriculture for survival. There is a necessity to encourage using traditional methods to deal with climate change, especially in cases where modern techniques are too costly or challenging to adopt [35]. The cost of acquiring new techniques and methods to deal with climate change could pose significant socio-economic challenges in communal areas. The farm profit of smaller and poorer farmers is reduced with the introductions of water pricing, which have substantial economic effects on such farmers [45]. Water pricing is only sometimes effective because commercial farmers can effortlessly cover the associated expenses for higher quantities of water used [49]. In contrast, smallholder farmers can only sometimes cover those costs, reducing their capacity to be profitable and generate sufficient income to look after their families.

Several factors addressed throughout this review, such as climate extremes, irrigation technology, land degradation, rainwater harvesting, and government support, are some of the most substantial drivers of agricultural water management in South Africa [67]. All of these factors mentioned have significant social and economic implications for agricultural producers, and they must be carefully considered when evaluating the water use behaviour and efficiency of critical stakeholders within the agricultural sector.

The global policies and strategies mentioned also align with some of the results found in this study from a South African perspective. The strategy and policies listed above could assist as a guideline for farmers, stakeholders, and policymakers to improve and enhance water use behaviour and efficiency in South Africa, which could ultimately help in reducing water scarcity while improving sustainability. The Section 5 of this review will be rounded off with a conclusion.

5. Conclusions

This study aimed to provide a comprehensive systematic review of the water use behaviour and efficiency of producers within the agricultural sector of South Africa. There

needs to be more studies about agricultural producers' water use behaviour and efficiency, especially when looking at both aspects. In doing this, the study identified the factors that affect the water use behaviour and efficiency of agricultural producers in South Africa. Several factors were identified, such as climate conditions, water policy, water pricing, water management, and farming practices. Each factor played a unique role in farmers' decision-making and how they use water to produce commodities on their farms.

The study further highlighted agricultural producers' techniques and practices to adapt to climatic challenges and enhance their water use efficiency. It found that some producers planted drought-resistant crops, changed their fertilizer application, and implemented crop rotation. Further, water pricing and policies are commonly introduced to enhance the efficiency of irrigators' water use. Lastly, it found that producers adopt alternative management techniques to increase their water use efficiency.

This study identified several factors that affect farmers' water use behaviour and efficiency. This could assist stakeholders, management boards, policymakers, and farmers with their decision-making regarding water use. This could be achieved by developing various measurements and action plans to use the identified factors as a guideline for designing strategic policies. These strategies and policies will enable stakeholders to educate, guide, and support agricultural producers to encounter the challenges faced on the farm level successfully. It also mentioned several adaptation strategies and management techniques that farmers use, which could assist other farmers in introducing similar systems on their farms. The limitation of this study was that it only analysed the water use behaviour and efficiency from a South African perspective. From a global perspective, there would be different factors that affect agricultural producers, and they would also have different adaptation strategies and techniques. Further studies could investigate the behaviour of global water use and the efficiency of agricultural production, and it might be worthwhile for future research to explore water use behaviour by aggregating countries with similar climates. The results we found can also be used to design and develop a specific methodological approach to explore similar and relevant topics in agricultural fields of study. This could assist water users in significantly improving their water use behaviour and efficiency, ultimately leading to the sustainable use of scarce water resources.

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Data Availability Statement: All the literatures and refined literature explained in this study available on reasonable request from corresponding author.

Conflicts of Interest: The authors declare that they have no competing interests.

Appendix A

Table A1. Summary of articles used for the systematic review.

Author/s	Objectives	Methods and Data	Findings	Remarks
Scheepers and Jordaan [60]	This research aimed to investigate the blue and green water footprint associated with lucerne cultivation for utilization as animal feed in the dairy sector while considering water scarcity in a designated lucerne production area.	The study used the Global Water Footprint Standard approach to calculate the blue and green water footprint indicators.	The findings indicate a volumetric water footprint indicator of 378 m^3/tonne for lucerne. Out of the combined blue and green water footprint, 55% constitutes the green water footprint, and 45% constitutes the blue water footprint. Consequently, despite being situated in a significant irrigation zone in South Africa, the primary portion of the overall water demand is fulfilled by efficient rainfall. Evaluating water usage sustainability revealed that the period coinciding with Lucerne's need for irrigation water aligns with a water scarcity index below 100%.	Environmental sustainability, arid, dry climate, water use
Vahrmeijer et al. [48]	The study aimed to model citrus water use and establish an understanding of the factors governing citrus water use.	The study used reference evapotranspiration, which was determined using the modified FAO Penman–Monteith equation, and they also used Sap Flow for further calculations.	Findings from assessments conducted in various citrus orchards across different climatic zones in South Africa revealed that when soil water supply is abundant, citrus water consumption is not exclusively determined by atmospheric requirements. It is also influenced by internal barriers to water flow within the plant, restricting the volume of water a citrus tree can release through transpiration on hot, dry days.	Policy
Speelman et al. [43]	This research presents a new methodology, employing data envelopment analysis, which enables the estimation of the impacts on agricultural production processes and water demand when implementing or increasing a water price.	This study uses a novel two-stage application of Data Envelopment Analysis (DEA) to simulate the effect of changes in water prices.	It has been discovered that most farmers still need to modify their water usage; despite this, production costs have risen considerably. Nevertheless, the results also demonstrated that further adjustments to the model are necessary to simulate farmers' behaviour realistically better.	Water pricing, cost of water
Talanow et al. [38]	To assess how farmers perceive climate change, what factors influence their risk perception and adaptive behaviour, and what adaptation strategies they apply.	MaxQDA version 18 software coding was used along with semi-structured interviews. The data was qualitative and collected through face-to-face interviews.	According to the study, farmers saw long-term climatic changes, including variations in rainfall and temperature rises. Farmers' adaptation behaviour was impacted by their intrinsic characteristics and prior climatic experience. They discovered that farmers used adaptable techniques on their farms but were planning less for the future than their current ones.	Climate
Kom et al. [41]	This study had two primary objectives: firstly, to evaluate the significance of indigenous knowledge in weather predictions relied upon by local farmers for adapting to climate variations, and secondly, to investigate farmers' perspectives concerning climate change in the Levubu and Nwanedi regions.	Indigenous knowledge indicators used by farmers for weather forecasting within their communities were collected through questionnaires, interviews, and focus group discussions.	The findings unveiled several indigenous indicators employed by local farmers for weather forecasting, including observations related to celestial bodies like stars and the moon, the presence of specific ant species, and the occurrence of mist-cover on mountains. An enhanced understanding of indigenous knowledge systems is crucial for developing appropriate adaptation strategies in response to climate change.	Adaptation strategies for climate, indigenous knowledge for adaption

Table A1. *Cont.*

Author/s	Objectives	Methods and Data	Findings	Remarks
Vilakazi et al. [35]	The study aimed to record the indigenous techniques employed by smallholder farmers in Bergville and Msinga, located in the KwaZulu Natal Province, for weather prediction, soil and water conservation, and managing extreme climate events.	Data were gathered through key informant interviews, focus group discussions, and questionnaires.	The results indicated that a more significant number of farmers in Msinga, compared to those in Bergville, observed reduced rainfall and increased temperatures as signs of climate variability ($p < 0.05$). Both Bergville and Msinga communal farmers utilized indigenous indicators such as wind and cloud patterns, animal and bird behaviour, moon phases, and the position of the sun for weather prediction. Additionally, communal farmers who employed manure were 0.17 times more likely to engage in soil and water conservation than those using artificial fertilizer ($p < 0.05$).	Indigenous observations, climate change, and variabilities
Findlater et al. [61]	This study used a nuanced and contextualized analysis of CA adoption by South Africa's commercial grain farmers to understand better the implications of the simplified methods commonly used to track it.	They used a national survey of South Africa's commercial grain farmers, contextualized by previous interviews, to investigate standard measures of adoption and their implications for CA's promotion, monitoring, and evaluation.	Their findings indicated that farmers are autonomously adopting Conservation Agriculture (CA). Still, there is considerable variation in its implementation, and their understanding of farming practices differs from that of local experts. While single proxies, binary adoption variables, and general farmer self-assessments suggest that between 40 and 80% of farmers have adopted CA, a comprehensive evaluation based on the three CA principles using UN-defined adoption thresholds reveals a much lower adoption rate of only 14%.	Adoption of conservation agriculture and related ways to climate
Ngxumeshe et al. [62]	This paper aims to discuss the diverse issues related to water utilization in beef production. It will also further explore the various methods for assessing the water footprint of a product.	The study used the Global Water Footprint Standard approach.	They found that no studies were conducted to evaluate the water footprint in the extensive beef production system. Therefore, with supporting scientific evidence, it is only possible to assert that beef production in South Africa is the primary contributor to the country's water scarcity issue. Additionally, extensive beef production also consumes green water, utilizing land unsuitable for any other form of production.	Behaviour related to social, economic, and environmental factors
Jordaan and Bahta [36]	This paper assessed the impact of policy intervention on irrigation agriculture.	The study used a modified IFPRI CGE, SWIP–E model, and SAM.	The findings revealed that implementing water restrictions made it more profitable to decrease the number of planted hectares and instead focus on thoroughly irrigating to achieve higher yields. Increasing irrigation water tariffs had only a minimal effect on yield. The primary challenge identified was water availability, with policy interventions playing a lesser role.	Drought, climate, and policy interventions
Owusu-Sekyere et al. [51]	The study assessed the water footprint of milk produced and processed in South Africa using the procedures outlined in the water footprint assessment manual.	The study used the Global Water Footprint Standard approach.	The findings indicate that 1352 m^3 of water is necessary to produce one tonne of milk with 4% fat and 3.3% protein in South Africa. Water used in the production of feed for lactating cows alone constitutes 86.35% of the total water footprint of milk. Interestingly, the water footprint of feed ration for lactating cows is approximately 85% higher than that of non-lactating cows. Moreover, the green water footprint accounts for over 86% of lactating cows' total water footprint of feed ration. Both green and blue water footprints significantly contribute to the overall water footprint of milk production in South Africa.	Management of rangeland and pastures improves water productivity.

Table A1. *Cont.*

Author/s	Objectives	Methods and Data	Findings	Remarks
Speelman et al. [44]	The study aimed to analyse the efficiency with which water is used in small-scale irrigation schemes in the North West Province in South Africa and studies its determinants.	Data Envelopment Analysis (DEA) techniques were used to compute farm-level technical efficiency measures and sub-vector efficiencies for water use. Tobit regression techniques were also used to examine the relationship between sub-vector efficiency for water and various farm or farmer characteristics.	The study demonstrated that significant technical inefficiencies exist among farmers under constant returns to scale (CRS) and variable returns to scale (VRS) specifications, amounting to 49% and 16%, respectively. Furthermore, the sub-vector efficiencies for water were found to be even lower. This suggests that by enhancing efficiency using existing technology, it would be feasible to redistribute a portion of irrigation water to fulfill other water needs without jeopardizing the importance of small-scale irrigation.	Water price and change in water use: WUE changes when pricing
Mengistu et al. [53]	This study aimed to assess the water use efficiency, defined as the utilizable yield per unit of water used, of drip-irrigated sweet sorghum (variety Sugargraze) under two distinct climatic conditions in South Africa.	Field trials were conducted in two successive seasons. Seasonal water use was estimated using eddy covariance and surface renewal methods. Fresh and dry aboveground biomass yield, stalk yield, and stalk Brix % were measured at the final harvest. Theoretical ethanol yield was calculated from fresh stalk yield and Brix %.	This study showed that the water use efficiency of sweet sorghum was sensitive to plant density. The water use efficiency values confirmed that sweet sorghum has high water use efficiency under different climatic conditions.	Adoption of alternative crops
Adetoso et al. [55]	The study examined how water scarcity can be alleviated by decreasing the water footprint of sugarcane production using different soil mulching and irrigation systems in South Africa. The study also quantifies the economic benefits of reducing blue water footprints.	The MyCanesim model and water footprint assessment methodologies were employed to estimate blue and green water footprints under the different systems in the Malelane region of South Africa.	The results indicate that blue water usage for sugarcane cultivated with a thick mulch cover was notably reduced compared to sugarcane grown with a light mulch cover. This disparity was more pronounced in center pivot-irrigated sugarcane than in subsurface drip-irrigated sugarcane. Interestingly, both the blue water footprint and the total water footprint (combining blue and green water) for crops grown with a thick mulch cover were only slightly lower than those for crops grown with a light mulch cover.	Changing soil and irrigation systems to increase WUE
De Witt et al. [57]	The study tried to investigate the reasons behind the use or non-use of irrigation technology for scheduling, and in particular, the uptake of a free, government-funded remote-sensing service called FruitLook for commercial farmers from the water-scarce Central Breede River Valley area in South Africa.	Three methods were considered for information gathering on technology adoption: self-completion questionnaires, face-to-face interviews, and workshops.	In-depth interviews uncovered a significant adoption rate of technology among farmers, reaching 83%, albeit predominantly limited to one type: soil water measurement. Within the subset of farmers utilizing water-use efficiency technology, 78% rely on the services of the same probe provider. This popularity stems from perceived accuracy, ease of use, and personalized after-sales service associated with the probe. Despite an 86% awareness level among farmers, only one farmer incorporates FruitLook for irrigation purposes.	Technology uptake to improve water use efficiency
Joseph et al. [39]	This study was conducted to evaluate the impact of adopting various climate change adaptation strategies on the production efficiency of citrus farmers in the Limpopo province of South Africa.	The stochastic frontier production function with Cobb Douglas production functional form was used along with a semi-structured questionnaire.	The likelihood ratio tests conducted for profit models indicated that farmers were deemed profit-efficient when considering the identified adaptation strategies. The inefficiency model revealed that, apart from changing fertilizer as an adaptation measure, implementing other adaptation strategies such as IPM, water harvesting, and planting drought-resistant varieties did not significantly alter the profit efficiency of farmers.	Climate change adoption

Table A1. *Cont.*

Author/s	Objectives	Methods and Data	Findings	Remarks
Chami et al. [59]	They suggest four primary strategic goals that research institutions can focus on and promote through good governance to achieve water sustainability in agriculture.	The NWRS2 has been briefly reviewed, and a practical framework has been developed.	This article serves as an urgent plea to all stakeholders and policymakers within government bodies and research institutions to expedite the implementation of the roadmap. They proposed this framework to help all stakeholders make decisions about sustainable water levels.	Climate and government implementation strategies
Speelman et al. [45]	They introduced an innovative two-stage methodology that estimates these effects at the farm level.	The first step in this study was determining the current technical and allocative efficiency levels of the farms in the sample using the non-parametric data envelopment analysis approach. Secondly, they simulated the impact of different water prices on the farm level.	The findings indicate that farmers in South Africa exhibit considerable responsiveness even to minor adjustments in water pricing. Given the existing low levels, this heightened response can be attributed to the substantial room for enhancing water use efficiency. Pricing mechanisms serve as a motivating factor for farmers to curtail water consumption. Additionally, a significant and adverse impact on farm profitability, a finding echoed by other studies, was also observed.	Water pricing policies
Roux et al. [52]	This study aimed to develop a new technology using satellite data to show spatial and temporal variations of crop water use, which could assist farmers with their farming practices.	FruitLook makes use of a processing framework that utilizes several algorithms (e.g., MeteoLook, SEBAL), satellite (DMC, VIIRS, MSG, Landsat 8, and Sentinel-2 images), and field data (weather).	The GrapeLook and FruitLook projects have demonstrated that an innovative tool such as remote sensing can project valuable information on crucial growth parameters. This information can potentially enhance agricultural production while concurrently diminishing water consumption.	Technology uptake to improve water use efficiency
Njiraini et al. [49]	The study assessed the effects of water policy on irrigation water use efficiency and quality in the Olifants basin of South Africa.	The study uses data envelopment analysis and regression techniques to ascertain the effects of water policy on water use efficiency and quality.	The analysis revealed that the average water use efficiency among irrigation water users was as low as 31 percent. Among the policy factors under scrutiny, compulsory licensing emerged as a significant influencer of water use efficiency. Conversely, water pricing, compulsory licensing, and membership in Water User Associations (WUAs) significantly affected water use quality.	Water policy and management, factors affecting water use
Olivier and Singels [56]	The study's objective was to examine the extent to which water use efficiency (WUE) in irrigated sugarcane production in South Africa can be enhanced through improved agronomic practices. Additionally, the study aimed to better understand the mechanisms underlying crop response to these factors.	Over four years, an overhead irrigated field experiment was conducted near Komatipoort, South Africa, on a shallow, well-drained, sandy clay loam.	This study demonstrated that substantial reductions in water use and irrigation demands, along with improvements in water use efficiency (WUE), can be achieved by implementing a crop residue layer to cover the soil. The most significant water savings were observed in P crops, with reductions of 26% in crop water use (CWU) and 32% in irrigation requirements. However, significant savings of approximately 15% were also realized in R crops.	Farming techniques, soil, and crops changes
Lankford et al. [40]	The study examined the effects of hydrological variables such as irrigation area, irrigation efficiency, and water storage on the resilience of (primarily commercial) irrigated agriculture to drought in a semi-arid catchment in South Africa.	They formulated a conceptual framework termed 'Water, Efficiency, Resilience, Drought' (WERD) and an accompanying spreadsheet model.	For the case study, analyses showed that irrigators, with currently approximately 23,000 ha under irrigation, have historically absorbed and adapted to drought events through the construction of water storage and adoption of more efficient irrigation practices, resulting in a DDZ of 260 days. However, by not fully anticipating future climate and water-related risks, irrigators are arguably on a maladaptive pathway, resulting in water supply gains, efficiency, and other practices to increase irrigation command areas to 28,000 ha or more, decreasing their capacity to absorb future droughts. This area's growth increases water withdrawals and depletion, further stresses the catchment, and reduces future DDZs to approximately 130 days, indicating much lower drought resilience.	Efficiency and resilience in drought

Table A1. *Cont.*

Author/s	Objectives	Methods and Data	Findings	Remarks
Reinders [46]	The study aimed to assess the framework and compile guidelines for improved irrigation water management from dam wall release to root zone application.	The study analysed the new South African Framework for Improved Efficiency of Irrigation. Water Use covers four levels of water-management infrastructure: the water source, bulk conveyance system, the irrigation scheme, and the irrigation farm.	The guidelines are designed to support both water users and authorities in enhancing their comprehension of how irrigation water management can be improved. This initiative aims to bolster human capacity, enabling targeted investments with reduced social and environmental impacts.	Water management guidelines and improvement
Bennie and Hensley [33]	The study aimed to assess farmers' adoption of agricultural practices to maximize precipitation utilization and ensure production and economic and social sustainability.	They used precipitation use, efficiency parameter analysis, and various factors.	The utilization of precipitation has proven to be a valuable parameter for evaluating the efficacy of different production or management practices in dryland crop production or rangeland utilization. They are extending the fallow period before planting, which increases the pre-plant stored water in the soil, thereby reducing the risk of drought damage to crops and ultimately leading to improved yields. Deep drainage is observed primarily in sandy soils during wet seasons, with measurements indicating values as high as 20% of the annual precipitation during years with above-average rainfall.	Adoption of farming practices, changes in production
Musokwa et al. [54]	The study investigated the water distribution and water use efficiency (WUE) of maize crops rotated with two-year pigeon pea fallows compared to continuous maize cultivation without fertilizer application.	A randomized complete block design, replicated three times, was used with four treatments, which included continuous unfertilized maize, natural fallow-maize, pigeon pea + grass-pigeon pea-maize, and two-year pigeon pea fallow-maize.	Soil samples were analyzed using pressure plates to establish water retention curves, enabling the conversion of soil water tension to volumetric water content. The results indicated that maize rotated with two-year pigeon pea fallows exhibited higher dry matter yield (11,661 kg/ha) and water use efficiency (WUE) (20.78 kg/mm) compared to continuous maize cultivation (5314 kg/ha and 9.48 kg/mm, respectively).	Alternative crops
Walter et al. [47]	This study examined the current water allocation scenarios within and between regions in the Middle Olifants sub-basin of South Africa.	A non-linear optimization model was used for the study.	The results indicate more significant benefits from inter-regional water allocation. When reducing water supply levels to comply with sustainable water supply policies, it's observed that although water supply is decreased by around 50%, the total benefits derived from water use only drop by 5% and 11% for inter- and intra-regional allocation regimes, respectively.	Water transfers and trade, economic and social policy
Speelman et al. [42]	This study examined the effectiveness of water usage in small-scale irrigation schemes within the North-West Province of South Africa and investigated the factors influencing it.	The study used Data Envelopment Analysis (DEA) techniques, which compute farm-level technical efficiency measures and sub-vector efficiencies specifically for water use.	The study revealed significant technical inefficiencies among farmers, with 49% and 16% under Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) specifications, respectively. Moreover, sub-vector efficiencies for water were found to be even lower. This suggests that by enhancing efficiency with existing technology, it would be feasible to redistribute a portion of irrigation water to other water needs without compromising the viability of small-scale irrigation.	Water pricing and charges, information, and guidelines for the management

Table A1. *Cont.*

Author/s	Objectives	Methods and Data	Findings	Remarks
Tarrisse et al. [58]	This study presents a table matrix correlating yield projection per hectare (ha) with four different Water Use Efficiency (WUE) values and a Mean Annual Rainfall (MAR) gradient ranging from 250 to 600 mm. Additionally, projections of stored water in the biomass and methane yield associated with laboratory analysis of the spineless cactus's Anaerobic Digestion (AD) process will be evaluated.	The study used the energy yield from the anaerobic digestion of spineless cactus and the mean annual rainfall for South Africa, which used this formulation to generate a table matrix.	Approximately 50% of South Africa experiences Mean Annual Rainfall (MAR) ranging from 150 to 500 mm, covering a vast area of around 600,000 km^2 and resulting in an estimated annual rainfall volume of approximately 190 billion m^3. Spineless cacti have been utilized in this region for over a century as a form of drought insurance by livestock farmers; however, their full potential has remained largely untapped until now.	Intensive cultivation methods, alternative crops
Du Preez and Van Huyssteen [37]	This study aimed to assess the risks posed to South Africa's soil and water resources, which are crucial for maintaining sustainable food production.	The study evaluated various physical, chemical, and biological factors that could threaten soil and water resources.	From a physical standpoint, significant concerns arise from wind and water erosion, structural decay, subsoil compaction, and soil surface crusting. Chemically, acidification, salinization, and pollution are primary areas of worry, with acidification predominantly affecting the humid eastern regions and salinization concentrated in the arid western parts of South Africa. Biological degradation primarily stems from declining organic matter, further diminishing South African soils' already low organic carbon content.	Threats to soil and water resources, climate
Munro et al. [50]	This paper evaluates sustainability and offers guidance for achieving sustainable, efficient, and equitable water utilization.	The study made use of a water footprint assessment.	Among the citrus varieties analyzed, lemons exhibited the lowest blue and combined green-blue water footprint per ton of production across all climatic years. Following lemons, soft citrus, valencias, and navels were ranked in ascending order regarding their water footprint. Moreover, valencias demonstrated the lowest greywater footprint, particularly associated with inorganic nitrogen, while navels exhibited the highest greywater footprint in this context.	Water licensing, environmental sustainability and benefits of water footprint analysis
Dalin and Conway [34]	The study aimed to assess the virtual food-water trade for various countries and the effect of climate variability on the food trade.	In this study, they integrated simulations from a global hydrological model with international food trade data to measure the water resources embedded in international food trade. Their analysis also focused on assessing the impacts of socio-economic changes and climatic variability on agricultural trade and the embedded water resources over this period.	Their findings suggest that regional food trade demonstrates efficiency in terms of water use; however, it may need to be more sustainable due to the reliance of water-productive exporters, such as South Africa, on increasingly stressed water resources. Notably, the role of imports from other parts of the world in meeting the region's food supply needs becomes significant, particularly during severe droughts.	Trade of water-related goods, climate shocks, productivity of water use

These were the 30 articles that were reviewed for the systematic review. These articles discussed various aspects that affect farmers' agricultural production. It further mentioned their strategies and techniques to withstand the factors. The factors identified from the review were climate conditions and related adaptation strategies, water policy and pricing, production management, and methods. The abovementioned factors impact agricultural producers' water use behaviour and efficiency. Farmers change their production practices to adapt to the influencing factors to improve their water use. A better understanding of the factors could assist stakeholders, management boards, policymakers, and farmers with their decision-making regarding water use.

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