The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

CHAPTER

8 Advances in water research: Enhancing sustainable water use in irrigated agriculture in South Africa

Luxon Nhamo[a,d], **Sylvester Mpandeli**[a,b], **Stanley Liphadzi**[a,b], **Samkelisiwe Hlophe-Ginindza**[a], **Mpho Kapari**[a], **Jennifer Molwantwa**[a] and **Tafadzwanashe Mabhaudhi**[c,d]

[a] *Water Research Commission of South Africa, Lynwood Manor, Pretoria, South Africa,* [b] *School of Environmental Sciences, University of Venda, Thohoyandou, South Africa,* [c] *International Water Management Institute (IWMI), Weavind Park, Silverton, Pretoria, South Africa,* [d] *Centre for Transformative Agricultural and Food Systems (CTAFS), School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Scottsville, Pietermaritzburg, South Africa*

8.1 Introduction

Unsustainable overexploitation of water resources (over-withdrawn aquifers, seasonally flowing rivers, disappearing lakes, and wetlands) has become one of the challenges facing humankind (Falkenmark et al., 2019; Mabhaudhi et al., 2018). This is particularly evident in arid and semi-arid regions where water scarcity has become a real challenge threatening livelihoods and economies (Nhamo et al., 2016; Nhamo et al., 2020c). Interventions that have been undertaken to minimize water scarcity in these countries include regulating water for food production, and domestic use, among other uses (Boretti & Rosa, 2019). Traditionally, these interventions have been practiced at a small scale, managed locally, and are hydrologically independent and self-regulating (Vågsholm et al., 2020). Annual rainfall, runoff, and recharge regimes would set the limits to annual use. There has been a paradigm shift in recent years due to the proliferation of large-scale storage-based systems, damming, and technological advances that have eased increased water withdrawals and created interdependence and competition across new and generally unregulated boundaries (Zeiringer et al., 2018). However, these transformations have often been accompanied by the exploitation of non-renewable resources whose governance is usually beyond the scope of local and traditional institutions (Nhamo et al., 2022).

This new norm of water governance which is compounded by increased demand has called for new innovative approaches and has witnessed the proliferation of novel concepts that promote the efficient use of water, including water productivity (WP) and water use efficiency (WUE) (Fernández et al., 2020; Molden et al., 2010).

Progress in Sustainable Development: Sustainable Engineering Practices.
DOI: https://doi.org/10.1016/B978-0-323-99207-7.00007-5
Copyright © 2023 Elsevier Inc. All rights reserved.

FIGURE 8.1

An irrigated vineyard in the Western Cape Province. Vineyards are known for their high-water consumption if not well managed.

These innovations promote and enhance the consumption of less water, treatment of wastewater for reuse, the promotion of the circular economy in the water sector, and that whatever water is available should be used as productively as possible (Naidoo et al., 2021a; Zvimba et al., 2021). The innovations are envisaged to promote the release of more water to other uses and to achieve more production per unit of water supplied (Levidow et al., 2014).

In the case of South Africa, over 60% of the available freshwater resources are used in agriculture and mostly on 1.3 million hectares of irrigated area (Phakathi & Wale, 2018). This is happening when almost 98% of the available freshwater resources are already allocated, leaving little room for irrigation expansion (Magidi et al., 2021b). Yet, agriculture is under pressure to meet the food requirements of a growing population, and the country is the 30th driest country in the world with an average rainfall of between 460 mm and 840 mm per annum (Mahlalela, Blamey, Hart, Reason 2020). The challenge is compounded by the production of non-indigenous crops that use a substantial amount of water; these include grapes, apples, macadamia, and plums, among others (Fig. 8.1).

Projections indicate that agricultural productivity will need to double from current production levels by 2050 to feed a projected population of about 80 million people in South Africa in the same period (Masipa, 2017). The challenges are exacerbated by climate change and scarce energy resources as rising temperatures result in increased evapotranspiration rates (Magidi et al., 2021b; Mpandeli et al., 2018). At the same time, climate change results in increasing rainfall variability, droughts, and floods, making the need to better manage water use in agriculture an urgent priority (Nhemachena et al., 2020). Given that South Africa's water resources are fully or over-allocated in most catchments, there is a need to adopt innovative irrigation technologies to enhance the sustainable use of water that allows irrigation expansion to continue to ensure water and food security.

Huge quantities of freshwater resources are already being used in irrigated agriculture, and the demand from the sector will only increase to continue producing enough food for the growing population (Magidi et al., 2021b). To counter the triple challenges of water scarcity, land degradation, and food insecurity, agriculture must become more crop-water productive, efficient, and environmentally friendly. Therefore, resilience-based interventions in irrigated agriculture are multidisciplinary and inherently interdisciplinary, including specialist fields of engineering, hydrology, climatology, and geology, which should consider institutional, policy, and management issues through applied social sciences (Polasky et al., 2019). Neglecting these specialist areas during interventions will only provide partial solutions and sector efficiencies at the expense of other equally important sectors.

It is on this background of the urgent need to build the resilience of the agriculture sector that most of the developmental goals are based as articulated in the African Union (AU) Agenda 2063 and the United Nations' 2030 Sustainable Development Goals (SDGs) (AU, 2015; UNGA, 2015). Based on these frameworks, the AU, through the 2014 Malabo Declaration, defined the immediate growth of African economies around agricultural growth and transformation (AU, 2014). This was followed by a series of other frameworks and declarations that promote the adoption of sustainable irrigation and agricultural water management as well as the widespread and rapid expansion of irrigation, particularly among smallholder farmers, including the Strategic and Operational Plan, 2014–2017, fostering the African Agenda on Agricultural Growth and Transformation and Sound Environmental Management, AU/DREA January 2014) and Regional Economic Communities (RECs: IGAD, ECOWAS, among others), in National Investment Plans (NIP) and National Agricultural Investment Plans (NAIP). These augment the high level of political and strategic will on agriculture as expressed in the Comprehensive African Agriculture Development Program (CAADP) of the New Partnership for Africa's Development (NEPAD) (NEPAD, 2003). Pillar 1 of the CAADP focuses on land and water management, with irrigation as one main sector that is well highlighted. The AU's Framework for Irrigation Development and Agricultural Water Management (IDAWM) was conceived against the backdrop of increasing climatic shocks with associated negative agricultural production impacts and reduced livelihoods capacities of rainfed agriculture in the African continent (AU, 2020).

In South Africa, these objectives are articulated in the National Development Plan (NDP), where agriculture is highlighted as one of the key pillars to spearhead economic growth and its development is regarded as key to food security and employment creation (NDP, 2013). Agriculture remains an important sector in South Africa as it accounts for 3% of the National Gross Domestic Product (GDP) and 7% of formal employment and plays an important role in food security (Cai et al., 2017; Meyer & Auriacombe, 2019). The NDP (NDP, 2013) sets to stimulate economic growth in sectors like agriculture with special emphasis on irrigation expansion and employment creation (Magidi et al., 2021b). The NDP emphasizes improving smallholder farmers and reducing their vulnerabilities to climate change. However, there are challenges to targeted agricultural policies and investment in a dynamic environment where changes are constantly occurring, and water resources management for the agriculture sector for all-inclusive and pro-poor interventions is hotly debated (Cai et al., 2017).

Based on this background, the Water Research Commission of South Africa (WRC) and its research partners have been developing and promoting efficient water use technologies for more than 50 years, contributing to water savings in the agriculture sector. Although the WRC has developed innovative technologies to enhance water-use efficiency in irrigated agriculture, more needs to be done to enhance the uptake of these technologies, particularly in climate modelling, mapping irrigated areas, weather forecasting, and operationalizing them. These interventions are critical for comprehending water-use behavior and devising effective institutions to manage water in times of intensifying scarcity.

8.2 Use and misuse of water productivity and water use efficiency terms

The terms WUE and WP are often used interchangeably, yet they are different altogether (Fernández et al., 2020). The use and confusion of the two terms are generally based on whether one is an agronomist or an agricultural engineer (Parra et al., 2020). Agronomists generally consider the WUE and WP as the same, yet in actual terms, they are distinct and, therefore, should be applied differently (Parra et al., 2020; Van Halsema & Vincent, 2012). Water productivity is the yield to water supplied and is expressed in weight units of yield (kg or g) to the amount of water used (m^3), for example, kg/m^3 (Molden et al., 2010; Nhamo et al., 2016). Yet, in general terms, efficiency refers to a ratio or percent, that is, the percentage or ratio of output divided by input, both with the same units (Fernández et al., 2020; Van Halsema & Vincent, 2012). For example, in irrigation, if one adds 10 mm of water to the plant and the plant consumes 8 mm through the root water system followed by transpiration and 2 mm is lost by drainage below the root zone or via bare soil evaporation from the surface. The water use efficiency here is 80%. Irrigation efficiency aims to assess the irrigation system's performance (Fernández et al., 2020; Levidow et al., 2014). In irrigation terms, WUE is described as the ratio between the volume of water used by a crop, including the whole evapotranspiration process, and the volume that reaches the irrigated field, and is expressed as (Levidow et al., 2014; Parra et al., 2020):

$$\mathrm{WUE} = \frac{\mathrm{WU}}{\mathrm{WS}} \tag{8.1}$$

where WUE represents water use efficiency (dimensionless), WU is water that is eventually used by crops (m^3), and WS is water supplied to the irrigated field (m^3).

The difference between WUE and WP is that WP refers to yield produced from a unit of input. There are two types of WP, physical and economic productivity (Nhamo et al., 2016). Thus, WP can be defined as the physical mass of production or the economic value of production measured against gross inflow, net inflow, depleted water, process depleted water, or available water and is be expressed as (Molden et al., 2010; Nhamo et al., 2016):

$$\mathrm{WP} = \frac{\mathrm{CY}}{\mathrm{WC}} \tag{8.2}$$

where WP represents water productivity, CY is crop yield (kg/m^3 or \$/m^3), and WC is the water consumed (m^3).

Therefore, WUE and WP are water accounting terms essential for monitoring the efficiency with which water is supplied to the field and the rate at which the plant converts water into food, respectively (Hatfield & Dold, 2019). The concept of WP is critical in both rainfed and irrigated sub-sectors. It monitors and assesses water use efficiency in crop production (Parra et al., 2020). The main aim of WP is to increase crop yield per unit of water used, hence the term "more crop per drop" (Molden et al., 2010). Attaining the production of more crops with less water is possible through (1) increasing the marketable yield of the crops for each unit of water transpired, (2) reducing water losses, or (3) enhancing the effective use of rainfall, and the water stored in the soil (Molden et al., 2010). The first option represents the need to improve crop yield, the second aims to increase the beneficial use of water (transpiration) against the non-beneficial losses (evaporation), and the third option stands for the efficient utilization of water resources. All these options associated with WP, coupled with modern irrigation technologies, are essential for improving on-farm crop water management practices as they facilitate the use of less water in both rainfed and irrigated systems, reduce water losses through evaporation, optimize the use of chemicals, minimize energy consumption and enhance soil conditions (Molden et al., 2010; Nhamo et al., 2016). These practices are important in water-scarce regions as farmers are always constrained to apply deficit irrigation strategies and to manage water supply in relation to the sensitivity of crop's growing stages to water stress (Nhamo et al., 2020a). Therefore, improved WUE catalyzes WP and both improve economic return from the investments in irrigation water supply.

8.3 Innovations enhancing water use in irrigation

8.3.1 Irrigation technologies

As demand for water in the agriculture sector is set to increase in the coming years amidst climate change and worsening depletion, degradation, salinization, and scarcity, irrigation technologies are envisaged to play a critical role in ensuring water use efficiency and building a resilient irrigation sector (Nhemachena et al., 2020). However, the sustainability of irrigated agriculture depends on initiatives aimed at reducing environmental effects and the capability to maintain the adopted innovations (Vågsholm et al., 2020). Negative environmental impacts from food systems have deleterious effects in some regions (Clark et al., 2019). Food systems are one of the major contributors to greenhouse gasses (GHG) (Crippa et al., 2021). Irrigation expansion should be implemented and managed in the context of overall river basin management and regional development plans (Clarke & Crane, 2018; Mabhaudhi et al., 2018). Thus, adopting integrated approaches in irrigation planning is a prerequisite for achieving sustainability in the irrigation sub-sector (Mabhaudhi et al., 2018; Naidoo et al., 2021b; Nhamo et al., 2020b).

Innovative irrigation systems and technologies enhance crop-water productivity, a pathway to producing more with lower water supplies (Levidow et al., 2014).

Table 8.1 Difference between water use efficiency and water productivity.

Water use of efficiency (WUE)	Water productivity (WP)
A dimensionless ratio of the total amount of water used to the total amount of water applied	Relationship between crop yield and water consumed
Applies to the efficiency of water used suppled to a field	Refers mainly to the benefits from a system (rainfall or irrigated)
Refers to the performance of crops	Refers to the performance of the production system as a whole
It is an assessment of the amount of water taken up by the plant	It refers to the best returns from applied water
Does not consider losses	Loss accounted for through supply or depletion

Innovative practices in irrigation and the rest of the food system value chain are envisaged to provide an economic advantage while reducing environmental impacts such as excessive water abstraction, energy use, and pollutants (Levidow et al., 2014). The WRC and partners have developed or adapted novel technologies that enhance efficiencies in resource use in agriculture, particularly water (Table 8.2). Examples of such technologies include the guidelines and improved mechanisms to determine water used in irrigation and create benchmarks from which water resources management institutions and farmers can set targets to become more efficient and water productive. The guidelines and technologies are available online at www.watermeter.org.za.

8.3.2 Smart water management

Smart water management in agriculture is defined as using information and communication technology (ICT) and (near) real-time data and responses to measure, control, and distribute agricultural water to save water and energy. The WRC has developed such innovations through its funded research, as in Table 8.2. Spatial and temporal agricultural water management (Fig. 8.2) is critical in irrigated agriculture, wherein challenges of agricultural water mismanagement and scarcity persist and undermine livelihoods that mainly depend on irrigated agriculture.

The WRC has funded innovative smart water management research (Table 8.1). For example, a WRC-funded research model estimates crop evapotranspiration, yield, and water-use efficiency in each quinary catchment for small grains such as soybean and sorghum. The model is essential for rural farming communities as it guides the best agronomic practices to maximize attainable yield. Another WRC-funded project developed an operationalization model to increase water use efficiency and resilience in irrigation (OPERA), a technology that allows direct mapping of soil water (as done with in-situ observations, air- or space-borne radar), crop water stress by thermal infrared sensors and modeling of the crop/soil/atmosphere continuum. When adequately fused with terrestrial measurements, these mapping tools offer decision support for improved agricultural water management.

To counter salinity challenges, a WRC study developed a decision support system (DSS) and guidelines for technology transfer to manage irrigation-induced salinity with precision agriculture. A related project developed an integrated bioeconomic

Table 8.2 Selected water-use efficiency innovations developed through WRC funding.

Innovation title	**Innovation description**
Water use of drought-tolerant food crops	Crop models for underutilized indigenous crops
Improving livelihoods and scheme productivity on smallholder canal irrigation schemes	Provided insights on Chinese cabbage and green maize irrigation scheduling and three integrated crop and livestock production guidelines
The water use of selected fruit tree orchards	First-time use of sap flow measurements to determine transpiration of fruit trees in an orchard
Impact of wastewater irrigation by wineries on soils, crop growth, and product quality	Contributed to the Department of Water and Sanitation's revision of the General Authorisations and supported the sustainable management of winery wastewater
Water use of cropping systems adapted to bio-climatic regions in South Africa and suitable for biofuel production	Developed software to disseminate stream flow output from the ACRU model and assess land-use change impact on feedstock cultivation on downstream water availability
Development of technical and financial norms and standards for drainage of irrigated lands	Developed testing and adaptation of models to determine the technical and financial feasibility of drainage in South Africa
Adaptive interventions in agriculture to reduce the vulnerability of different farming systems to climate change in South Africa.	Developed several coping and climate change adaptation practices based on the different agro-ecological cones (AEZ) and agricultural commodities
The current rain-fed and irrigated production of food crops and its potential to meet the year-round nutritional requirements of rural poor	Provided new knowledge about water harvesting practices and systems for the delivery of water to gardens to reduce drudgery for women are essential to enable food production in more homes
Water use and crop parameters of pastures for livestock grazing management	Developed a clearer understanding of efficient irrigation management practices for selected pastures.
Determining water use of indigenous grain and legume food crops	Developed an interactive digital archive about indigenous crops and their characteristics relevant to crop water use and sustainable farming practices (intercropping) under rainfed conditions and crop water-use model
The optimization of electricity and water use for sustainable management of irrigation farming systems	Guidelines for farmer advisory services and irrigation system designs were developed
Modelling of rainy season characteristics and drought in relation to crop production	Developed a decision support tool to provide agro-climatological risk information to farmers
Quantifying citrus water use and water stress at the tree and orchard scale	Developed a decision support tool that improves the estimating of evapotranspiration and irrigation scheduling

(*continued on next page*)

Table 8.2 Selected water-use efficiency innovations developed through WRC funding—cont'd

Innovation title	Innovation description
Seamless forecasting of rainfall and temperature for adaptation of farming practices to climate variability	A powerful Delft-FEWS system tool to enable hydrological forecasting. Also used to forecast crop yield
Enhancing food security, nutrition, and production efficiency of high-yielding grain legumes	The identification of pigeon pea-maize and cowpea-maize varieties most suitable for Limpopo Province
Development and testing of a smartphone application for predicting near-real-time water requirements of fruit tree orchards	The project developed a mobile phone application (both android and IOS) that use agro-meteorological data to predict crop water requirements for apple orchards seven days in advance
A SAPWAT assessment tool on water use of selected water-stressed irrigation schemes in humid, semi-humid, semi-arid, and arid areas	Developed a procedure to determine irrigation water requirements for water allocation in irrigation areas
Evaluation of the management and impact of the quantity and quality of water for new Agri-parks in selected provinces of South Africa	Developed a water and nutrient balance tool (WNB) that estimates the production potential of an Agri-Park
Development of a risk-based approach for assessing livestock watering and aquaculture water quality guidelines	Software-based tools (technology demonstrators) that provide water quality guidance on fitness for use to aquaculture water users and animal (livestock) watering users
Developing a smartphone app for small-scale fish farmers and government aquaculture extension officers	Smartphone app (Buna Africa) for small-scale fish farmers and government aquaculture extension officers
Operationalizing the increase of water use efficiency and resilience in irrigation (OPERA)	A water budget procedure for farmers to view the soil probes' results and results from FruitLook and weather
School-based vegetable gardens:	A climate-smart production system, the bag system can cultivate a considerably higher number of areas utilized for crop production
Water use of avocado and macadamia orchard	Developed a predictive model to inform farmers on weekly weather patterns, water use of orchards, and when irrigation should be optimal
Guidelines for technology transfer to manage irrigation-induced salinity with precision agriculture	SAPWAT4, an easy-to-use computer application for planning irrigation water requirements and the program, is available in South Africa
Economic management of water and salt stress for irrigated agriculture: A precision agriculture case study	A bio-economic model to economically manage site-specific water and salt stress in irrigated agriculture and linked to a transient-state soil-water-crop model for enhancing spatial soil water and salinity management
Enhancements to the site-specific, risk-based decision support system for assessing irrigation water quality	Site-specific, risk-based decision support system for assessing irrigation water quality

(*continued on next page*)

Table 8.2 Selected water-use efficiency innovations developed through WRC funding—cont'd

Innovation title	**Innovation description**
Investigating the potential of fixed and draped netting technology for increasing water use productivity and water savings in full-bearing apple orchards	Developed models that reduce water-use of full-bearing apple orchards under shed-nets in different phenological stages
Water use and physical as well as economic productivity of indigenous herbal teas in the winter rainfall region	A crop water use model under different scenarios of climate change
The application of national scale remotely sensed evapotranspiration (ET) estimates to quantify water use and differences between plantations in commercial forestry regions of South Africa	Developed the rapid object collection and analysis tool (ROCAT), which they used to estimate water use
Developing a web-based and GIS-enabled WEF nexus integrative model	The study developed a WEF nexus model or tool that is web-based and GIS-enabled

model to economically manage site-specific water and salt stress in irrigated agriculture. This was achieved by linking the transient state soil-water-crop model (SWAMP) to an economic model and an optimization procedure to evaluate site-specific water and salinity management.

As part of digital technologies in irrigation, smartphone applications (Apps) have been developed to guide on-farm irrigation scheduling (Fig. 8.3). These web-based and mobile applications are adapted to each crop, including indigenous underutilized crops. Guidelines on using the Apps are available to provide step-by-step instructions to farmers. These user-friendly irrigation applications are particularly relevant because most crops' water requirements are now documented. An example is a developed smartphone App being used to forecast orchard water requirements in apple orchards a few days in advance using readily available data as inputs. This orchard water use App improves irrigation scheduling and water allocation planning by providing detailed forecasts of the actual orchard evapotranspiration and its components. Although currently used in apple orchards, the App can be adapted to other orchards.

A project conducted in the Inkomati-Usuthu Water Management Area (IUWMA) developed a framework for conjunctive groundwater and surface water use for solar-driven smallholder irrigated agriculture. The framework supports the implementation of conjunctive groundwater and surface water use in areas suited for implementing solar pumps for the first time in smallholder irrigated agriculture in South Africa.

The WRC has also pioneered research on drone applications in agricultural water management, focusing on how drones can be used to inform smart water management and precision agriculture in smallholder farm settings. This pioneering research, initiated in 2018, has already developed useful applications for real-time crop health monitoring, yield forecasting and irrigation scheduling.

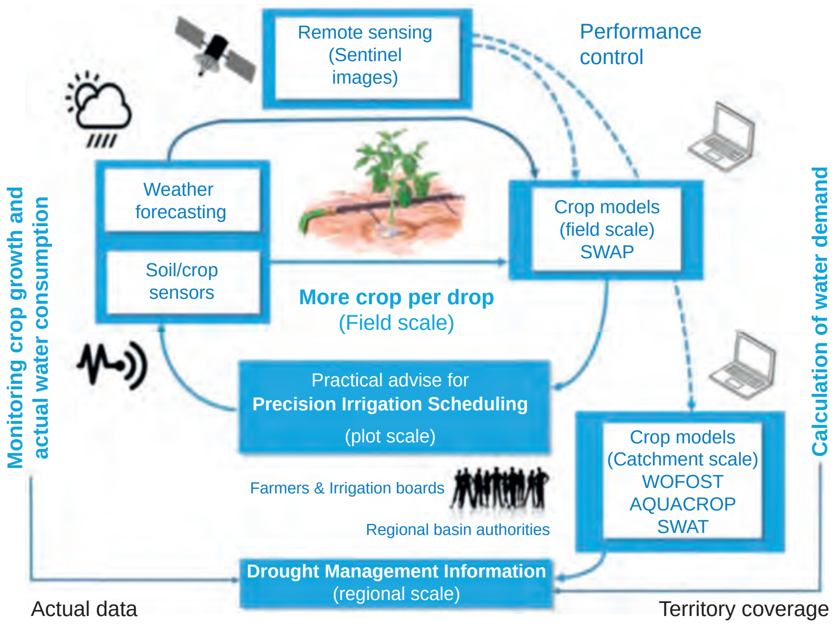

FIGURE 8.2

Linking weather, remote sensing, in-situ crop and soil sensors, crop and soil models, and stakeholders to synthesize case study results in a concept for an operational support of precision irrigation (OPERA) system at field scale and water saving at catchment scale.

8.3.3 Climate-smart agricultural practices

The WRC is also actively funding research promoting climate-smart irrigation (CSI) practices. Climate-smart irrigation (CSI), powered by innovative technologies, forms an important part of the transition towards more sustainable and regenerative agricultural practices. Increasing water efficiency in agriculture would translate into fewer emissions, while better fertilizer efficiency means fewer agrochemicals entering soils and water cycles. Climate-smart irrigation practices are part of integrated approaches to managing irrigated areas and address the interlinked challenges of food insecurity and accelerating climate change. CSI practices aim to simultaneously achieve three outcomes:

- Increased productivity: irrigated agriculture should always strive to produce (1) more with fewer resources, and (2) better food to improve nutritional security and boost incomes
- Enhanced resilience: efficiencies in irrigated agriculture reduce vulnerability to drought, pests, and diseases. It enhances the adaptive capacity to produce enough amidst longer stress periods and shortened seasons.
- Reduced emissions: innovative irrigation practices promote lower greenhouse gas emissions for each calorie or kilo of food produced, avoid deforestation from agriculture and promote carbon sequestration.

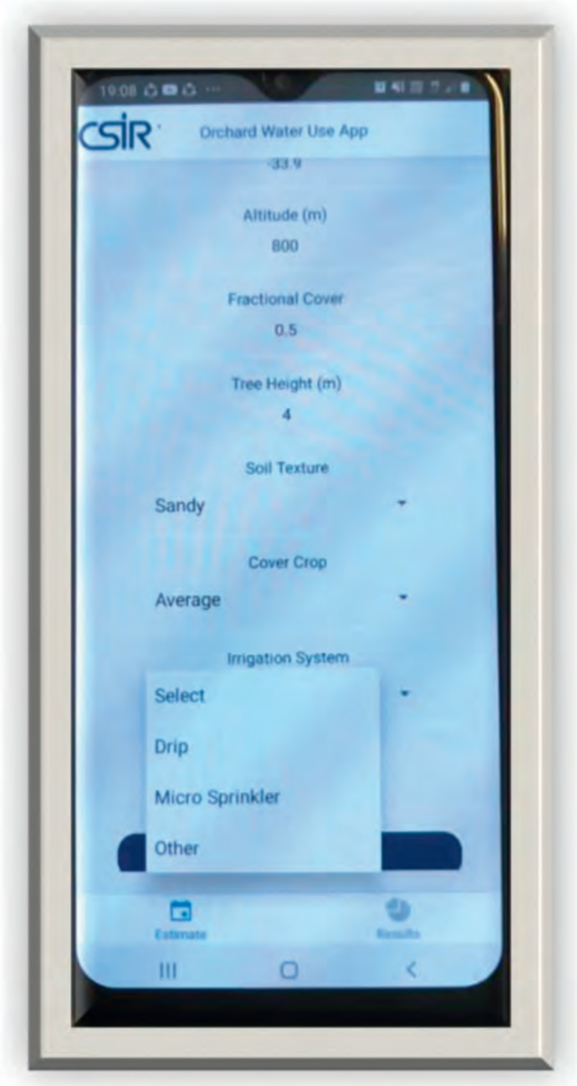

FIGURE 8.3

Smartphone application (App) being used to forecast orchard water requirements in apple orchards.

Therefore, CSI practices have many benefits, including addressing climate change and systematically considering the synergies and trade-offs between productivity, adaptation, and mitigation. Innovative technologies at both the off-farm level (water transport infrastructure and irrigation system distribution) and on-farm level (water applications, adoption of efficient irrigation technologies) are critical for enhancing water and food security. In particular, irrigation and improved irrigation technologies

Table 8.3 Environmental impacts of irrigation development and practical solutions.

Environmental impacts	Mitigatory solutions
Waterlogging and salinization	Situating irrigated lands where negative impacts are minimal
Changes and alterations to ecosystem services	Restoring degraded irrigated lands rather than establishing new ones
Water-borne and water-related diseases	Improving the efficiency of existing irrigation schemes
Destruction of natural habitats	Recycle wastewater for use in irrigation

are strategic instruments at the on-farm level to enhance the sustainability of irrigation and water resources.

8.4 Potential environmental impacts of irrigation development

Besides the many benefits of irrigation and its expansion, many trade-offs accompany its development, including increased soil degradation and erosion; pollution of both surface and groundwater; degradation of water quality; increased eutrophication due to high nutrient levels in the irrigation and drainage water resulting in algal blooms in irrigation canals and downstream waterways (Malakar et al., 2019). Irrigation projects that impound or divert river water may cause environmental disturbances and can be a health risk due to hydrology and limnology changes in river basins (Kibret et al., 2021). Alterations in river flow regimes can potentially result in saltwater intrusion in river systems and into the groundwater of nearby agricultural lands (Richter & Thomas, 2007). If not well planned, river diversion to irrigated lands reduces the water supply for downstream users. Some of the environmental impacts and possible solutions are shown in Table 8.3.

8.5 Role of accurate spatial data on irrigation development

Regional and national policy frameworks and strategies have earmarked increasing and developing newly irrigated areas. Irrigated area mapping is an integral part of basin characterization, hydrological modeling, smallholder agriculture resilience, and agriculture planning, but there are still significant challenges to producing accurate irrigated area maps (Cai et al., 2017). Therefore, accurate irrigation statistics are central for decision-making as national and regional policies have been set to expand areas under irrigation to meet the increasing food demand and enhance the resilience of smallholder farmers to climate change (Magidi et al., 2021b; Shiferaw et al., 2014; van Koppen et al., 2017).

While irrigation plays an important part in ensuring food security, its expansion should be done in the framework of nexus planning to avoid shifting problems to other sectors and manage trade-offs properly (Mabhaudhi et al., 2018; Nhamo et al., 2018). As already alluded to, national and regional food security targets are often built on irrigation development; for example, the CAADP sets to expand the area under irrigation on the continent by at least 5 million ha (Mha) by 2025 (NEPAD, 2003). In South Africa, the NDP aims to increase the area under irrigation by at least 145,000 hectares by 2030 (NDP, 2013). Food and water security issues have dominated the development agenda of many countries. At the global level, the United Nations have prioritized these through the SDGs, specifically Goals 1, 2, and 6 on poverty alleviation, zero hunger, and provision of clean water and sanitation, respectively (UNGA, 2015).

Adoption and implementation of policies in developing countries are often hindered by a lack of data and information on the status of existing irrigation (Cai et al., 2017). Current reporting systems on which global data sets on irrigated areas, such as the Food and Agriculture Organization of the United Nations (FAO) AQUASTAT database, are based, are often estimates and aggregates coming through layers of national administrative systems. These results are often subject to errors and biases (Cai et al., 2017; Siddiqui et al., 2016). The advent of remote sensing has systematically allowed the mapping of irrigated areas and is now used to support water resources and agricultural development. Valid for application at multiple scales, such as global scale (Thenkabail et al., 2007), regional scale (Xiao et al., 2006), and basin-scale (Magidi et al., 2021a), the remote sensing approach can map large areas within a short period and at low cost. The WRC has developed irrigated area maps of South Africa, including forested areas using machine learning algorithms (Magidi et al., 2021a).

8.6 Conclusion

Irrigation remains vital to ensure the continued provision of food and water resources in the advent of climate change and increasing depletion and degradation. The role of irrigated agriculture in enhancing crop production, water-use efficiency, and water productivity remains indisputable. Various agronomic, engineering, and water management innovations have recently been developed to reduce water losses in irrigated agriculture. This is mainly based on the fact that irrigated agriculture is recognized by the CAADP and the Southern Africa Development Community's (SADC) Regional Agriculture Policy (RAP) and South Africa's Agricultural Policy and the Strategic Plan, as a sustainable climate adaptation strategy. Therefore, the call to increase irrigated agriculture in Africa has been very much pronounced as agriculture is the backbone of many African economies. Whilst increasing the land under irrigation is a prerequisite to enhancing food and water security, policy should adopt holistic and integrated approaches when implementing irrigation strategies to avoid policy spillovers or attain unintended outcomes. Innovations that promote water use efficiencies are critical for the resilience and adaptation of the agriculture sector that it continues to provide the food requirements of an increasing population. However, the uptake of innovative technologies in the sectors has been very slow. While acknowledging the importance of innovative technologies for the sustainability of irrigation, it is equally critical to recognize trade-offs and synergies associated with irrigation expansion. This knowledge brings the importance of transformative and holistic approaches to irrigation expansion and development. The fundamental questions that need to be addressed include the availability of water and energy resources in the case of South Africa and other water-scarce countries.

References

AU, (2014) Malabo declaration on accelerated agricultural growth and transformation for shared prosperity and improved livelihoods. African Union (AU), Adis Ababa, Ethiopia, p. 12.

AU, (2015) Agenda 2063: The Africa we want. African Union (AU), Adis Ababa, Ethiopia, p. 24.

AU, (2020) Framework for irrigation development and agricultural water management in Africa. African Union (AU), Adis Ababa, Ethiopia, p. 38.

Boretti, A., & Rosa, L. (2019). Reassessing the projections of the world water development report. *NPJ Clean Water, 2*, 1–6.

Cai, X., Magidi, J., Nhamo, L., van Koppen, B., (2017) Mapping irrigated areas in the Limpopo Province, South Africa. International Water Management Institute (IWMI), Colombo, Sri Lanka, p. 42.

Clark, M. A., Springmann, M., Hill, J., & Tilman, D. (2019). Multiple health and environmental impacts of foods. *Proceedings of the National Academy of Sciences, 116*, 23357–23362.

Clarke, A., & Crane, A. (2018). Cross-sector partnerships for systemic change: Systematized literature review and agenda for further research. *Journal of Business Ethics, 150*, 303–313.

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food, 2*, 198–209.

Falkenmark, M., Wang-Erlandsson, L., & Rockström, J. (2019). Understanding of water resilience in the anthropocene. *Journal of Hydrology X, 2*, 100009.

Fernández, J., Alcon, F., Diaz-Espejo, A., Hernandez-Santana, V., & Cuevas, M. (2020). Water use indicators and economic analysis for on-farm irrigation decision: A case study of a super high density olive tree orchard. *Agricultural Water Management, 237*, 106074.

Hatfield, J. L., & Dold, C. (2019). Water-use efficiency: Advances and challenges in a changing climate. *Frontiers in Plant Science, 10*, 103.

Kibret, S., McCartney, M., Lautze, J., Nhamo, L., & Yan, G. (2021). The impact of large and small dams on malaria transmission in four basins in Africa. *Scientific Reports, 11*, 1–12.

Levidow, L., Zaccaria, D., Maia, R., Vivas, E., Todorovic, M., & Scardigno, A. (2014). Improving water-efficient irrigation: Prospects and difficulties of innovative practices. *Agricultural Water Management, 146*, 84–94.

Mabhaudhi, T., Mpandeli, S., Nhamo, L., Chimonyo, V. G., Nhemachena, C., Senzanje, A., …, & Modi, A. T. (2018). Prospects for improving irrigated agriculture in southern Africa: Linking water, energy and food. *Water, 10*, 1881.

Magidi, J., Nhamo, L., Mpandeli, S., & Mabhaudhi, T. (2021a). Application of the random forest classifier to map irrigated areas using google earth engine. *Remote Sensing, 13*, 876.

Magidi, J., van Koppen, B., Nhamo, L., Mpandeli, S., Slotow, R., & Mabhaudhi, T. (2021b). Informing equitable water and food policies through accurate spatial information on irrigated areas in smallholder farming systems. *Water, 13*, 3627.

Mahlalela, P., Blamey, R., Hart, N., & Reason, C. (2020). Drought in the Eastern Cape region of South Africa and trends in rainfall characteristics. *Climate Dynamics, 55*, 2743–2759.

Malakar, A., Snow, D. D., & Ray, C. (2019). Irrigation water quality: A contemporary perspective. *Water, 11*, 1482.

Masipa, T. (2017). The impact of climate change on food security in South Africa: Current realities and challenges ahead. *Jàmbá: Journal of Disaster Risk Studies, 9*, 1–7.

Meyer, N., & Auriacombe, C. (2019). Good urban governance and city resilience: An afrocentric approach to sustainable development. *Sustainability, 11*, 5514.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M. A., & Kijne, J. (2010). Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management, 97*, 528–535.

Mpandeli, S., Naidoo, D., Mabhaudhi, T., Nhemachena, C., Nhamo, L., Liphadzi, S., …, & Modi, A. (2018). Climate change adaptation through the water-energy-food nexus in southern Africa. *International Journal of Environmental Research and Public Health, 15*, 2306.

Naidoo, D., Nhamo, L., Lottering, S., Mpandeli, S., Liphadzi, S., Modi, A. T., …, & Mabhaudhi, T. (2021a). Transitional pathways towards achieving a circular economy in the water, energy, and food sectors. *Sustainability, 13*, 9978.

Naidoo, D., Nhamo, L., Mpandeli, S., Sobratee, N., Senzanje, A., Liphadzi, S., …, & Mabhaudhi, T. (2021b). Operationalising the water-energy-food nexus through the theory of change. *Renewable and Sustainable Energy Reviews, 149*, 10.

NDP, (2013) National development plan: Vision 2030. National Planning Commission (NDP), Pretoria, South Africa, p. 489.

NEPAD, (2003) Comprehensive Africa Agriculture Development Programme (CAADP). New Partnership for Africa's Development (NEPAD), Midrand, South Africa, p. 116.

Nhamo, L., Ebrahim, G. Y., Mabhaudhi, T., Mpandeli, S., Magombeyi, M., Chitakira, M., …, & Sibanda, M. (2020a). An assessment of groundwater use in irrigated agriculture using multi-spectral remote sensing. *Physics and Chemistry of the Earth, Parts A/B/C, 115*, 102810.

Nhamo, L., Mabhaudhi, T., & Magombeyi, M. (2016). Improving water sustainability and food security through increased crop water productivity in Malawi. *Water, 8*, 411.

Nhamo, L., Mabhaudhi, T., Mpandeli, S., Dickens, C., Nhemachena, C., Senzanje, A., …, & Modi, A. T. (2020b). An integrative analytical model for the water-energy-food nexus: South Africa case study. *Environmental Science and Policy, 109*, 15–24.

Nhamo, L., Magidi, J., Nyamugama, A., Clulow, A. D., Sibanda, M., Chimonyo, V. G. P., & Mabhaudhi, T. (2020c). Prospects of improving agricultural and water productivity through unmanned aerial vehicles. *Agriculture, 10*.

Nhamo, L., Mpandeli, S., Liphadzi, S., & Mabhaudhi, T. (2022). Securing land and water for food production through sustainable land reform: A nexus planning perspective. *Land, 11*, 974.

Nhamo, L., Ndlela, B., Nhemachena, C., Mabhaudhi, T., Mpandeli, S., & Matchaya, G. (2018). The water-energy-food nexus: Climate risks and opportunities in Southern Africa. *Water, 10*, 567.

Nhemachena, C., Nhamo, L., Matchaya, G., Nhemachena, C. R., Muchara, B., Karuaihe, S. T., & Mpandeli, S. (2020). Climate change impacts on water and agriculture sectors in Southern Africa: Threats and opportunities for sustainable development. *Water, 12*, 2673.

Parra, L., Botella-Campos, M., Puerto, H., Roig-Merino, B., & Lloret, J. (2020). Evaluating irrigation efficiency with performance indicators: A case study of citrus in the east of spain. *Agronomy, 10*, 1359.

Phakathi, S., & Wale, E. (2018). Explaining variation in the economic value of irrigation water using psychological capital: a case study from Ndumo B and Makhathini, KwaZulu-Natal, South Africa. *Water SA, 44*, 664–673.

Polasky, S., Kling, C. L., Levin, S. A., Carpenter, S. R., Daily, G. C., Ehrlich, P. R., …, & Lubchenco, J. (2019). Role of economics in analyzing the environment and sustainable development. *Proceedings of the National Academy of Sciences, 116*, 5233–5238.

Richter, B. D., & Thomas, G. A. (2007). Restoring environmental flows by modifying dam operations. *Ecology and Society, 12*(1), 12–38.

Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B., & Menkir, A. (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes, 3*, 67–79.

Siddiqui, S., Cai, X., Chandrasekharan, K., (2016) Irrigated area map Asia and Africa (International Water Management Institute). International Water Management Institute (IWMI), Colombo, Sri Lanka.

Thenkabail, P., GangadharaRao, P., Biggs, T., Krishna, M., & Turral, H. (2007). Spectral matching techniques to determine historical land-use/land-cover (LULC) and irrigated areas using time-series 0.1-degree AVHRR pathfinder datasets. *Photogrammetric Engineering & Remote Sensing, 73*, 1029–1040.

UNGA, (2015) Transforming our world: The 2030 agenda for sustainable development, resolution adopted by the General Assembly (UNGA). United Nations General Assembly, New York, p. 35.

Vågsholm, I., Arzoomand, N. S., & Boqvist, S. (2020). Food security, safety, and sustainability: Getting the trade-offs right. *Frontiers in Sustainable Food Systems, 4*, 16.

Van Halsema, G. E., & Vincent, L. (2012). Efficiency and productivity terms for water management: A matter of contextual relativism versus general absolutism. *Agricultural Water Management, 108*, 9–15.

van Koppen, B., Nhamo, L., Cai, X., Gabriel, M. J., Sekgala, M., Shikwambana, S., …, & Manyama, D. (2017) Smallholder irrigation schemes in the Limpopo Province, South Africa. International Water Management Institute (IWMI), Colombo, Sri Lanka.

Xiao, X., Boles, S., Frolking, S., Li, C., Babu, J. Y., Salas, W., & Moore, B., III (2006). Mapping paddy rice agriculture in South and Southeast Asia using multi-temporal MODIS images. *Remote Sensing of Environment, 100*, 95–113.

Zeiringer, B., Seliger, C., Greimel, F., & Schmutz, S. (2018). *River hydrology, flow alteration, and environmental flow: Riverine ecosystem management* (pp. 67–89). Springer Cham.

Zvimba, J. N., Musvoto, E. V., Nhamo, L., Mabhaudhi, T., Nyambiya, I., Chapungu, L., & Sawunyama, L. (2021). Energy pathway for transitioning to a circular economy within wastewater services. *Case Studies in Chemical and Environmental Engineering, 4*, 100144.