

Comprehensive Guidelines for Capacity Building for Irrigation Managers in Water Management within Modern Irrigation Technologies

Birhanu Zemadim, Adebayo Oke, Tinashe Lindel Dirwai, Zeleke Admasu, Dennis Junior Choruma, Jonathan Dickson, Valere Nzeyimana, and Mohsin Hafeez

June 2026



The Authors

Birhanu Zemadim, Deputy Country Representative, and Senior Researcher – Water and Land Management, International Water Management Institute (IWMI), Accra, Ghana

Adebayo Oke, Senior Regional Researcher IWMI, Accra, Ghana

Tinashe Lindel Dirwai, Senior Regional Researcher IWMI, Pretoria, South Africa

Zelege Admasu, Research Officer II – Scaling Solar in Agriculture IWMI, Addis Ababa, Ethiopia

Dennis Junior Choruma, Senior Regional Researcher Land-Water and Soil Solutions, IWMI, Harare, Zimbabwe

Jonathan Dickson, Consultant, Digital Illustrator – IWMI, Accra, Ghana

Valere Nzeyimana, Senior Water Development and Management Officer– Food and Agriculture Organization of the United Nations (FAO) Regional Office for Africa, Accra, Ghana

Mohsin Hafeez, Strategic Program Director – Water, Food and Ecosystems, IWMI, Lahore, Pakistan

Conceptualization: [Birhanu Zemadim, Adebayo Oke, Valere Nzeyimana, Mohsin Hafeez]; Methodology: [Birhanu Zemadim, Adebayo Oke, Valere Nzeyimana, Mohsin Hafeez]; Validation: [Birhanu Zemadim, Adebayo Oke, Tinashe Lindel Dirwai, Zelege Admasu, Dennis Junior Choruma]; Formal analysis: [Birhanu Zemadim, Adebayo Oke, Tinashe Lindel Dirwai, Zelege Admasu, Dennis Junior Choruma]; Investigation: [Birhanu Zemadim, Adebayo Oke, Tinashe Lindel Dirwai, Zelege Admasu, Dennis Junior Choruma, Valere Nzeyimana]; Resources: [Birhanu Zemadim, Valere Nzeyimana]; Data curation: [Adebayo Oke, Tinashe Lindel Dirwai, Zelege Admasu, Dennis Junior Choruma]; Writing – original draft: [Birhanu Zemadim, Adebayo Oke, Tinashe Lindel Dirwai, Zelege Admasu, Dennis Junior Choruma]; Writing – review & editing: [Birhanu Zemadim, Jonathan Dickson, Mohsin Hafeez]; Visualization: [Birhanu Zemadim, Jonathan Dickson]; Supervision: [Valere Nzeyimana, Mohsin Hafeez]; Project administration: [Birhanu Zemadim, Valere Nzeyimana]; Funding acquisition: [Birhanu Zemadim, Valere Nzeyimana, Mohsin Hafeez].

Acknowledgments

This was carried out under the CGIAR Policy Innovations Program and with financial support from the Food and Agriculture Organization of the United Nations (FAO Regional Office for Africa) in Accra, Ghana. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund (www.cgiar.org/funders).

The authors would like to express their sincere appreciation to all stakeholders from Ghana, Ethiopia, and South Africa who contributed to the preparation of this document. Special recognition is extended to the stakeholders in Ghana who participated in validating the comprehensive guideline and provided invaluable insights and recommendations for implementing the capacity-building program for irrigation managers in modern irrigation technologies.

CGIAR Policy Innovations Program

CGIAR's Policy Innovations Program delivers science-based evidence to strengthen policies, markets, and institutions. The initiative supports coherent policies across food, land, and water systems by analyzing policy synergies and trade-offs, the political economy of natural resources system transformation, just transition, and co-creating solutions in partnership with policy makers and think tanks for effective, impactful, and equitable policymaking. Learn more about the program: <https://www.cgiar.org/cgiar-research-portfolio-2025-2030/policyinnovations>

Citation

Zemadim, Birhanu, Adebayo Oke, Tinashe Lindel Dirwai, et al. 2026. *Comprehensive Guidelines for Capacity Building for Irrigation Managers in Water Management within Modern Irrigation Technologies*. International Water Management Institute (IWMI).

© 2026 International Water Management Institute. Some rights reserved. This work is licensed under a Creative Commons Attribution License (CC BY 4.0)

Front cover photo: Center Pivot irrigation system at Wonji-Shoa Sugar Estate in Ethiopia (*photo*: Zelege Admasu/IWMI) Back cover photo: Kpong multipurpose reservoir in Ghana (*photo*: Birhanu Zemadim/IWMI)

Disclaimer

This publication has been prepared as an output of the CGIAR Policy Innovations Program and has not been independently peer reviewed. Responsibility for opinions expressed and any possible errors lies with the authors and not the institutions involved. Boundaries used in the maps do not imply the expression of any opinion whatsoever on the part of CGIAR concerning the legal status of any country, territory, city, or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Borders are approximate and cover some areas for which there may not yet be full agreement.

Contents

Acronyms	iv
Summary	v
Chapter 1 - Modern Irrigation Technologies and Water Management:	1
1. Introduction	2
1.1. Objectives	2
1.2. An Integrated Capacity-Building and Governance Framework	3
1.3. Methodology	4
Chapter 2 - Definition and Description of Modern Irrigation Technologies	5
2. Introduction	6
2.1. Drip (Micro) Irrigation Systems	6
2.2. Sprinkler Irrigation Systems	7
2.3. Center-Pivot Irrigation Systems	7
2.4. Solar-Powered Irrigation Systems (SPIS)	8
2.5. Smart and Digital Irrigation Technologies	9
2.6. Subsurface Irrigation Systems	10
Chapter 3 - Guidelines for Irrigation Systems Selection and Planning	11
3. Introduction	12
3.1. Drip (Micro) Irrigation Systems	12
3.2. Sprinkler Irrigation Systems	12
3.3. Center-Pivot Irrigation Systems	13
3.4. Solar-Powered Irrigation Systems (SPIS)	13
3.5. Smart and Digital Irrigation Technologies	13
3.6. Recommendation Framework for Selecting Appropriate Irrigation Technologies	15
3.6.1. Key Considerations for Technology Selection	15
3.7. Recommendation - Summary	16
Chapter 4 - Operation and Maintenance of Modern Irrigation Systems	19
4. Introduction	20
4.1. Standard Operating Procedures	20
4.2. Documentation, Reporting, Review, and Continuous Improvement	21
4.2.1. A guide to scheduling maintenance operations	21
4.2.2. SOPs for support systems to modern irrigation systems	27
4.2.3. Deployment and Recuperation of Irrigation Infrastructure	31
Chapter 5 - Case Studies and Best Practices	32
5. Case Studies	33
5.1. Ghana	33
5.1.1. Stakeholder Engagement and Field Visit	33
5.1.2. Kpong Irrigation Scheme Key Features	33
5.1.3. Operation and Maintenance Features	34
5.2. Ethiopia	36
5.2.1. Stakeholder Engagement and Field Visit	36
5.2.2. Ethiopian Irrigation Scheme Key	36
5.3. South Africa	41
5.3.1. Stakeholder Engagement and Field Visit	41
5.3.2. South African Irrigation Scheme Key Features	41
5.4. Zambia	44
5.4.1. Zambian Irrigation System Key Features	45
5.4.2. Supplier-led irrigation systems and after-sales support	46
5.4.3. Solar-powered irrigation and asset financing models	46
5.4.4. Motorised pump irrigation and farmer-led groundwater use	46
5.5. Nigeria	46
5.5.1. Commercial Center-Pivot Irrigation: The Nasarawa Sugar Company example	47
5.5.2. Operation and Maintenance	47
Chapter 6 - Successful Capacity-Building Models	48
6. Commonly Applied Capacity Building Models in the Irrigation Sector	49
6.1. South Africa	50
6.2. Zambia	51
6.3. Conclusions	51
Annex. Focus Group Discussion (FGD) Guide - FAO-IWMI Project.	54

ACRONYMS

BMS	Battery Management System
CBO	Community-Based Organization
CPI	Center Pivot Irrigation
CBCD	Competency-Based Capacity Development
CSA	Climate Smart Agriculture
EIDC	Ethiopian Irrigation Development Commission
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus Group Discussion
GIDA	Ghana Irrigation Development Authority
IDE	International Development Enterprises
IWMI	International Water Management Institute
MILLS	Ministry of Irrigation and Lowlands
MIT	Modern Irrigation Technologies
MoA	Ministry of Agriculture (MoA)
MoWE	Ministry of Water and Energy (MoWE)
NSC	Nasarawa Sugar Company
O&M	Operations and Maintenance
PAYG	Pay-As-You-Go
PV	Photovoltaic
PPE	Personal Protective Partnership
PPP	Public Private Investment
SABI	South African Irrigation Institute
SPIS	Solar-Powered Irrigation Systems
SOPs	Standard Operating Procedures
SBCD	Systems-Based Capacity Development
ToT	Training-of-Trainers
VRI	Variable Rate Irrigation
WUAs	Water User Associations

SUMMARY

Sub-Saharan Africa holds substantial untapped irrigation potential, yet the performance of many existing irrigation systems remains below expectations. Despite increasing investments in modern irrigation technologies, numerous schemes continue to underperform due to weak operation and maintenance (O&M), limited technical capacity, and inadequate institutional governance. These constraints reduce water-use efficiency, diminish the returns on infrastructure investments, and weaken the sector's resilience to climate change. At the same time, escalating climate variability, rising energy costs, increasing groundwater stress, and persistent food security pressures are intensifying the urgency for more effective irrigation management.

Addressing these challenges requires a strategic shift from a narrow focus on infrastructure delivery toward capacity-driven, performance-oriented irrigation management. This FAO-IWMI initiative responds directly to this need by developing comprehensive, scalable guidelines to strengthen the human and institutional systems that underpin the performance of modern irrigation schemes. The overarching objective is to equip irrigation managers, extension agents, scheme operators, and Water User Associations (WUAs) with the competencies, tools, and governance frameworks required to plan, operate, maintain, and scale modern irrigation technologies efficiently, equitably, and sustainably.

The guidelines are being developed through a robust, evidence-based process that integrates:



comprehensive desk reviews of global and regional best practices in modern irrigation and capacity development;



case studies and irrigation system performance assessments;



and stakeholder consultations involving irrigation authorities, engineers, extension services, farmers, and private-sector actors to identify practical capacity gaps and implementation constraints.

The guidelines cover a broad range of modern irrigation technologies, including drip irrigation, sprinkler systems, center-pivot irrigation, solar-powered irrigation systems (SPIS), smart and digital irrigation solutions, and subsurface irrigation technologies. Successful irrigation systems require more than hardware alone; they also depend on skills development, effective institutional arrangements, and supportive market incentives. The case studies documented in this report, therefore, offer several lessons directly relevant to the development of capacity-building guidelines for irrigation managers.

Across the reviewed capacity-building models, several cross-cutting lessons emerge. First, capacity building must be multi-actor and systemic, targeting farmers, extension personnel, technicians, and suppliers simultaneously. Second, one-off training events are insufficient; sustained learning requires follow-up, mentoring, and accessible technical support. Third, capacity building is most effective when embedded within functional irrigation service ecosystems that integrate technology supply, finance, markets, and governance mechanisms.

In particular, the cases from Zambia and South Africa demonstrate that successful capacity development for modern irrigation technologies requires a shift from fragmented, technology-centric training toward integrated, systems-oriented approaches. Capacity-building guidelines should therefore emphasize competency-based training frameworks that are differentiated by actor type and irrigation scale. Particular attention should be given to strengthening the capacity of suppliers and technicians, reforming extension curricula, and embedding water-management principles across all training modalities.

Overall, the guidelines outlined in this report aim to enhance technical proficiency, operational effectiveness, and institutional capacity, thereby supporting sustainable water use, improved agricultural productivity, and climate-resilient irrigation development across Sub-Saharan Africa.

The comprehensive capacity-building guideline complements the Food and Agriculture Organization (FAO) PRISM tool by strengthening the human and institutional capacities needed to act on PRISM’s diagnostics. While PRISM identifies performance gaps and prioritizes irrigation modernization interventions, the guideline translates these priorities into practical competencies, training modules, and operational procedures for irrigation managers, scheme operators, and Water User Associations. It equips stakeholders with the skills to interpret PRISM indicators, implement recommended improvements (e.g., in water delivery, scheduling, and O&M), and sustain performance gains. In this way, PRISM provides the “what to improve,” and the capacity-building guideline delivers the “how to improve and sustain it,” ensuring that modernization efforts are effectively implemented and scaled.



photo: CGIAR photoshelter

Chapter 1

Modern Irrigation Technologies and Water Management



photo: Freepik.

1. Introduction

Water is vital for agricultural productivity, food security, and sustainable development. However, increasing water scarcity, climate change, and growing food demand necessitate the adoption of efficient water management practices in agriculture. Modern irrigation technologies have emerged as transformative tools to optimize water use, enhance crop yields, and reduce environmental impacts. Despite their potential, the adoption and effective management of these technologies remain limited due to a lack of technical expertise and capacity among irrigation managers. Efforts have been made towards farmer-led, private-driven irrigation systems¹. The private farmer-led irrigation systems require investment in modern irrigation technologies, instrumentation, and capacity development. Modern irrigation systems (advanced, efficient systems that enable precise water application) have been shown to be more efficient, to have lower energy demand, and to improve profitability.

Modern irrigation systems deliver water efficiently across fields, reducing water wastage and improving crop yields. They are particularly suitable for large-scale farming and cluster farms in different regions. However, their successful implementation requires specialized knowledge of system design, operation, maintenance, and water management. Many irrigation managers in sub-Saharan Africa lack the technical expertise to operate and maintain modern irrigation systems effectively. Common challenges include:

- i. limited understanding of system components and functionality,
- ii. inadequate knowledge of water requirements for different crops,
- iii. poor maintenance practices leading to system inefficiencies,
- iv. lack of skills in integrating modern irrigation systems with other water management strategies, and
- v. inadequate equipment supply chain that lacks prompt access to spare parts.

Addressing these gaps through targeted capacity-building initiatives is essential to maximizing the benefits of modern irrigation technologies.

Hence, the Food and Agriculture Organization (FAO) of the United Nations (UN) contracted the International Water Management Institute (IWMI) to develop comprehensive guidelines for the capacity building of irrigation managers in water management, in the context of modern irrigation technologies and agricultural water management. The guidelines provide a coherent, practical, and adaptable framework that strengthens the knowledge and skills of irrigation managers—particularly extension staff and scheme operators—responsible for planning, operating, and maintaining irrigation systems to ensure efficient, equitable, and sustainable use of water resources for agricultural productivity and build resilience towards impacts of climate change.

1.1. Objectives

The guidelines will therefore serve as a strategic tool to:

- Promote the adoption and effective utilization of modern irrigation technologies.
- Strengthen water management practices at both farm and system levels to optimize water use efficiency, productivity, and resilience to climate variability.
- Foster participatory and inclusive management of all groups (women and vulnerable groups included) by enhancing the capacities of water user associations, farmer groups, and local institutions in governance, operation, and maintenance of irrigation schemes.
- Support knowledge sharing and learning through practical training materials, case studies, and adaptable modules tailored to local contexts.

¹Izzi, G., J. Denison and G.J. Veldwisch, eds. 2021. *The Farmer-led Irrigation Development Guide: A what, why, and how-to for intervention design*. Washington, DC: World Bank.

1.2. An Integrated Capacity-Building and Governance Framework

The guidelines will help build users' technical proficiency and confidence among—extension agents, scheme operators, and farmers,—by providing step-by-step guidance on system selection, design considerations, installation, operation, maintenance, and troubleshooting. In addition, the capacity-building framework will emphasize understanding the suitability of each technology to different agro-ecological, hydrological, and socio-economic contexts. It will promote climate-smart irrigation practices that enhance water-use efficiency, reduce energy costs, and improve crop productivity. By integrating digital tools and data-driven decision-making, irrigation managers, scheme operators, and farmers will be better equipped to monitor water distribution, schedule irrigation more precisely, maintain system performance, and respond adaptively to changing weather and crop conditions.

Furthermore, the guidelines will highlight the importance of linking technology adoption with institutional strengthening, access to financing, and local innovation systems to ensure long-term sustainability. This integrated approach will empower irrigation stakeholders to move beyond the introduction of technology toward effective management, ownership, and scaling of modern irrigation solutions across Sub-Saharan Africa. Establishing a strong institutional governance framework is critical for managing irrigation systems at all scales. In this aspect, the framework for irrigation scheme management, operation, and maintenance is illustrated in Figure 1.

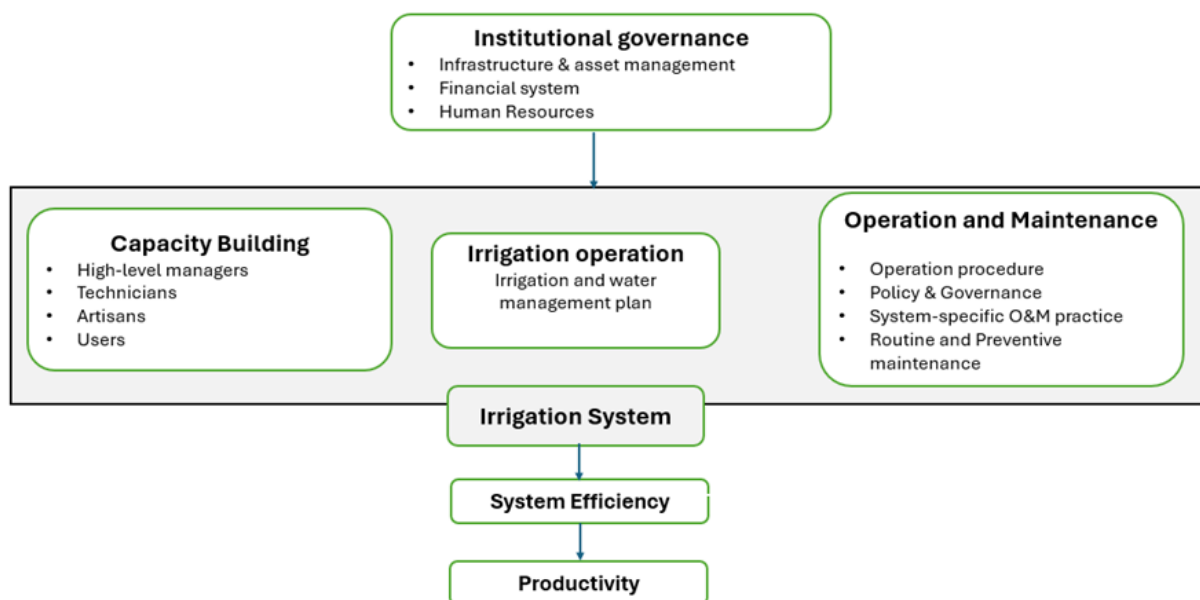


Figure 1. Framework for irrigation scheme management, operation, and maintenance.

According to the South African Irrigation Institute (SABI²), irrigation system efficiency is a complex undertaking that should always consider irrigation as a system and never as a stand-alone, and should be performed by professionals. An irrigation system's performance is guided by three main components:

- i. capacity building,
- ii. irrigation operation, and
- iii. operation and maintenance (Figure 1)

²Irrigation Design Manual 2025 – SABI

In formal irrigation schemes, an effective management structure must integrate infrastructure and asset management, human resources, financial systems, and operational mechanisms. However, the absence of a well-defined organizational and functional governance structure often contributes to the low performance observed in many formal irrigation systems. Weak or non-functional institutional arrangements directly affect the quality of operations and maintenance, resulting in inadequate system upkeep and limited operator capacity to meet performance targets and sustain productivity. Across sub-Saharan Africa, there is a growing push to deploy modern irrigation technologies that promise improved efficiency and enhanced crop yields. Yet achieving these outcomes requires well-coordinated operations and maintenance practices that align with technical standards and are driven by competent, adequately trained managers.

1.3. Methodology

The methodology adopted in developing the guidelines includes the following key activities:

Desk Review: Review of the scientific literature (published and grey), case studies, and best practices on modern irrigation technologies and water management in Africa and identify successful capacity-building models from other regions or countries.

Field Visits: Visits to irrigation areas where modern irrigation technologies are implemented to observe and learn from the country's experiences. Engagement with relevant stakeholders, including farmers, irrigation managers, and technicians, was critical for gathering insights into the implementation of modern irrigation technology, operational and maintenance challenges, and best practices.

Stakeholder Engagement: Collaborate with government agencies, extension services (including managers and irrigation engineers), academia, research institutions, and private sector partners to gather their feedback on capacity needs, operational and maintenance (O&M) issues, and investment options.



Chapter 2

Definition and Description of Modern Irrigation Technologies



2. Introduction

Irrigation systems need to be modernized to address contemporary challenges, including climate variability, water scarcity, rising energy costs, and the need for more efficient and sustainable agricultural production. Modern irrigation technologies are advanced, efficient, and scientifically designed systems and tools that enable the precise, controlled application of water to crops, optimizing water use, energy efficiency, and agricultural productivity. Unlike traditional surface irrigation methods—which often result in high water losses through evaporation and runoff—modern irrigation technologies to deliver water directly to the root zone, at the right time and in the right quantity, using automated or semi-automated systems. These technologies integrate engineering innovations, renewable energy solutions, and digital monitoring tools to improve the management, operation, and sustainability of irrigation systems. They also play a vital role in climate-smart agriculture by reducing water and energy wastage, increasing resilience to droughts, and supporting sustainable intensification of agricultural production. The major categories of modern irrigation technologies are listed below.

2.1. Drip (Micro) Irrigation Systems

Drip irrigation delivers water directly to the root zone of plants through a network of pipes, valves, emitters, and tubing. It allows for high precision and efficiency by minimizing evaporation and deep percolation losses. This system is especially suitable for horticultural crops, orchards, and smallholder farming systems where water is scarce. Fertilizer application can also be integrated with irrigation (fertigation) to optimize nutrient use efficiency. An illustration of a drip irrigation layout is shown in Figure 2.



Figure 2. Drip irrigation layout in a newly established farm of Agoro West in Western Kenya.

Source: Birhanu Zemadim/IWMI

³Zemadim, B.; Mwangi, O.; Adamtey, N.; Gebrezgabher, S. 2025. Overcoming scarcity: how local innovations are transforming Western Kenya's agricultural landscapes. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Multifunctional Landscapes Program. 12p. <https://hdl.handle.net/10568/179048>

2.2. Sprinkler Irrigation Systems

Sprinkler systems simulate natural rainfall by distributing water through pressurized pipes and nozzles. They are suitable for a wide range of crops and soils and can be adapted for both small and large-scale farms. Variants include portable, semi-permanent, and permanent installations. Sprinkler irrigation promotes uniform water distribution and reduces soil erosion, though it requires proper maintenance and energy input. An illustration of a sprinkler irrigation layout is shown in Figure 3.



Figure 3. Sprinkler irrigation layout in a newly prepared land in Ibadan, Nigeria.

Source: Birhanu Zemadim/IWMI

2.3. Center-Pivot Irrigation System

A center-pivot system is a mechanized irrigation technology that uses motorized towers and pipelines mounted on wheeled structures to apply water uniformly across large fields. The systems use galvanized steel structures. Typically powered by either diesel engines or the electricity grid. However, investment in solar energy is increasingly being adopted to address the challenges posed by the high operating costs of fuel-powered engines. The center-pivot system is primarily implemented on large-scale farms exceeding 50 hectares. These systems are particularly effective for cereal crops and large-scale commercial farming operations. When equipped with variable rate irrigation (VRI) systems and sensors, they can optimize water use based on soil moisture, crop type, and field conditions. An illustration of a center-pivot irrigation layout is shown in Figure 4.



Figure 4. Center Pivot irrigation layout in Ethiopia.

Source: Zeleke Admasu/IWMI

2.4. Solar-Powered Irrigation Systems (SPIS)

Solar-powered irrigation uses photovoltaic (PV) panels to generate electricity for pumping water from surface or groundwater sources. SPIS offers a clean, renewable, and cost-effective alternative to diesel- or grid-powered systems, particularly in off-grid rural areas. When combined with efficient water distribution systems such as drip or sprinkler irrigation, SPIS can significantly reduce operational costs and environmental impacts. An illustration of a SPIS layout is shown in Figure 5.

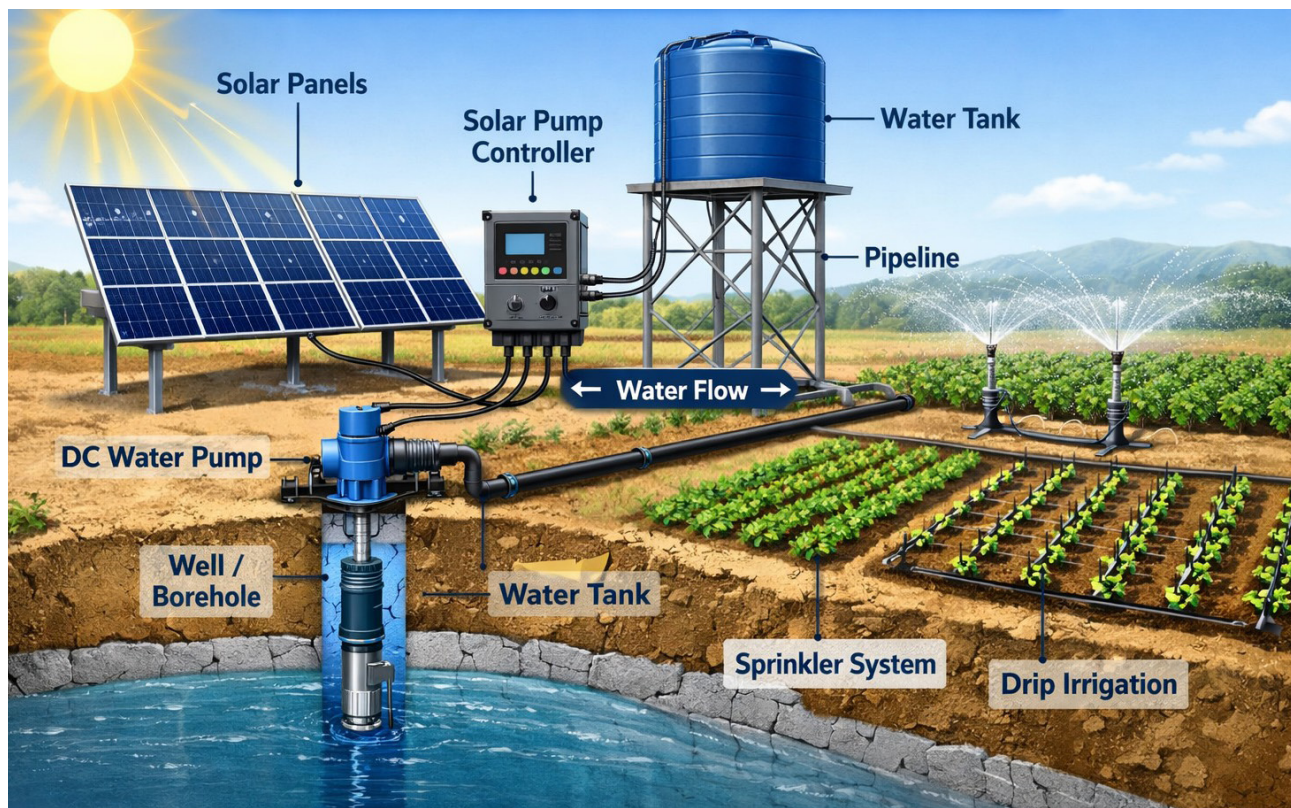


Figure 5. Solar-Powered Irrigation Systems layout.

Source: Generated using AI

2.5. Smart and Digital Irrigation Technologies

Smart irrigation technologies leverage sensors, automated controllers, Internet of Things (IoT) devices, and data analytics to optimize irrigation scheduling and water management. Soil moisture sensors, weather stations, and satellite-based remote sensing provide real-time data that help farmers make informed decisions on when and how much to irrigate. Mobile applications and cloud-based platforms further enhance accessibility and monitoring, supporting precision agriculture and adaptive management. An illustration of a smart and digital irrigation technologies layout is shown in Figure 6.



Figure 6. Smart and digital technologies irrigation systems layout.

Source: Generated using AI

2.6. Subsurface Irrigation Systems

Subsurface irrigation involves delivering water below the soil surface through buried drip lines or porous pipes. This approach minimizes evaporation, improves root water uptake, and is particularly effective in areas with high evaporative demand or saline soils. It is also compatible with automation and fertigation systems. An illustration of a sub-surface irrigation system layout is shown in Figure 7.

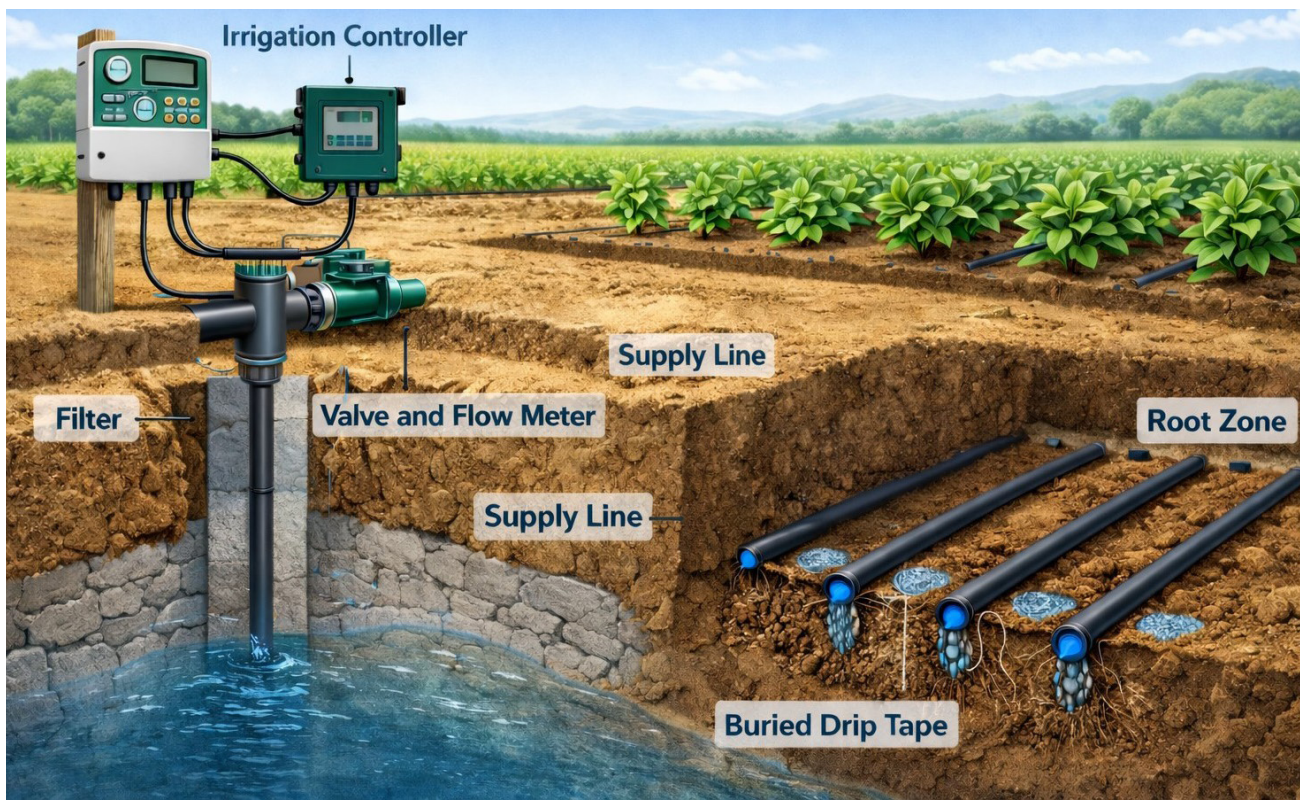


Figure 7. Subsurface irrigation systems layout.

Source: Generated using AI

Chapter 3

Guidelines for Modern Irrigation Systems Selection and Planning



3. Introduction

The choice of irrigation systems can be influenced by economic, social, or environmental factors. Economic objectives aim for maximum yield on the investment (the highest cost-benefit ratio) or maximum net benefit from the development. Social objectives may include benefits such as lower risk of theft, ease of operation and management, reduced stress in a farmer's life, and the use of locally manufactured equipment that supports economic development. Environmental objectives may include the responsible use of resources such as soil and water. Hence, the selection and deployment of modern irrigation technologies in Sub-Saharan Africa must consider not only their technical performance but also their economic feasibility and environmental sustainability. Each technology has unique strengths and limitations depending on agro-ecological conditions, farm size, institutional capacity, and water source availability. The following assessment provides an overview of the adequacy and appropriateness of key irrigation technologies under these three dimensions (Technical, Economic, and Environmental).

3.1. Drip (Micro) Irrigation Systems

Technical Sustainability: Drip irrigation systems are highly efficient, delivering water directly to the root zone and reducing water loss through evaporation and deep percolation. Technically, they are suitable for high-value crops (vegetables, fruits, and orchards) and water-scarce environments. However, their performance depends on water quality (to avoid emitter clogging), proper system design, and regular maintenance – often requiring user training and reliable access to spare parts and energy to lift under a pressurized system.

Economic Sustainability: Initial capital costs are relatively high compared to traditional irrigation methods, which may limit adoption among smallholders unless supported through subsidies, credit facilities, or collective investment. Over time, drip systems can generate significant savings in water, fertilizer (through fertigation), and labor costs, thereby improving profitability and return on investment when managed appropriately. Labor costs in drip irrigation systems are generally lower than in traditional irrigation methods because water delivery is automated and precise, reducing the need for manual field operations; however, some skilled labor is still required for system installation, monitoring, and maintenance.

Environmental Sustainability: Drip irrigation minimizes water wastage, reduces soil erosion, and enhances nutrient-use efficiency. It is particularly effective in regions facing water scarcity and salinity issues, as it maintains optimal soil moisture without over-irrigation. However, improper disposal of plastic components and drip lines can pose environmental challenges unless recycling options are available.

Overall Adequacy: Highly appropriate for small to medium-scale farms growing high-value crops in water-limited areas, provided that maintenance support and financing are accessible.

3.2. Sprinkler Irrigation Systems

Technical Sustainability: Sprinkler systems provide uniform water distribution and can be adapted to various crops and soil types. They are technically suited for undulating terrain and moderate wind speeds. However, they require reliable energy sources and periodic maintenance of nozzles and pipes to ensure uniform pressure and flow.

Economic Sustainability: Moderate initial investment and operational costs make sprinkler systems more accessible to medium-scale farmers. Energy costs can be high, depending on the power source. The flexibility of portable or semi-permanent systems increases their cost-effectiveness for diversified farms and crop rotations.

Environmental Sustainability: Sprinkler systems reduce runoff and erosion but may increase evaporation losses compared with drip systems, particularly in hot, windy areas. When managed properly, they promote efficient water use and can be combined with fertigation. Over-irrigation may increase risks of waterlogging and nutrient leaching.

Overall Adequacy: Technically and economically appropriate for medium-sized farms with moderate water and energy availability, less ideal for very arid or windy zones.

3.3. Center-Pivot Irrigation Systems

Technical Sustainability: Center-pivot systems are highly mechanized and suitable for large, uniform fields. They ensure consistent and automated water application, reducing labor demand. However, they require skilled operation, precise engineering, and consistent energy supply. Terrain unevenness and small plot fragmentation, common in Sub-Saharan Africa, may limit their applicability. Center-pivot systems, though costly upfront, reduce labor through automation and deliver uniform, efficient water application. They cover large areas with minimal management, are energy-efficient per hectare, and integrate with precision technologies. These advantages lead to improved productivity, lower long-term costs, and more reliable irrigation compared to conventional sprinkler systems.

Economic Sustainability: These systems entail substantial capital and maintenance costs, making them better suited to commercial farms and cooperatives. The long-term benefits include reduced labor, increased yields, and more efficient use of inputs, which can offset costs under favorable conditions. Public-private partnerships or shared ownership models can enhance accessibility.

Environmental Sustainability: When appropriately managed, pivot systems optimize water and fertilizer use and reduce erosion. However, they may not be sustainable in regions with groundwater depletion or energy constraints. Integration with renewable power (solar or hybrid systems) can improve environmental performance.

Overall Adequacy: Highly efficient for large-scale commercial operations; less suitable for smallholder settings unless adapted through collective schemes or government-supported programs.

3.4. Solar-Powered Irrigation Systems (SPIS)

Technical Sustainability: SPIS uses solar photovoltaic (PV) energy to power irrigation pumps, providing a reliable, clean alternative to diesel systems. Technically, they are adaptable to both surface and groundwater sources and can power drip, sprinkler, or pivot systems. Proper system sizing and storage options (e.g., tanks) are essential for efficiency, given variable solar radiation.

Economic Sustainability: While the upfront costs are high due to panels, pumps, and installation, operating costs are minimal because solar energy is free. The systems have long lifespans (10–20 years) and low maintenance requirements, leading to high economic sustainability over time. Access to financing and after-sales service remains a key constraint in many regions.

Environmental Sustainability: SPIS drastically reduces greenhouse gas emissions and dependency on fossil fuels. It promotes sustainable groundwater abstraction when linked with smart controllers and water-use monitoring. Without regulation or requisite incentives, however, the risk of over-pumping surface or groundwater exists, emphasizing the need for governance and monitoring frameworks. IWMI has worked on payment for electricity generated to incentivize farmers not to over-pump.

Overall Adequacy: Highly appropriate for off-grid, sunny regions with moderate water resources and institutional support to manage water sustainably.

3.5. Smart and Digital Irrigation Technologies

Technical Sustainability: Smart irrigation technologies integrate digital sensors, IoT devices, and automated control systems to optimize water application based on real-time soil moisture, weather, and crop data. They enhance precision, reduce human error, and support adaptive management. However, they require robust network connectivity, reliable power, and user technical literacy. Simple soil moisture sensors do not require power, which could influence farmers' behavior in adopting them.

Economic Sustainability: High initial investment and the need for technical expertise can limit smallholder adoption. However, operational cost savings through optimized water and energy use can be significant. When adopted through cooperatives or service providers (e.g., data-sharing platforms), they offer high long-term economic returns.

Environmental Sustainability: These technologies significantly improve resource-use efficiency, reduce over-irrigation, and support climate resilience by integrating predictive analytics. The ecological footprint is minimal, though electronic waste management should be addressed. Digital systems can also support monitoring of groundwater and surface water use at landscape scales.

Overall Adequacy: Most appropriate for progressive farms, cooperatives, or irrigation agencies with access to digital infrastructure and capacity. Similarly, simple soil moisture sensors do not require digital literacy or infrastructure. Smart and digital technologies offer high sustainability potential when integrated with other irrigation systems.

A summary of the comparative assessment of modern irrigation systems based on technical, economic, and environmental suitability is presented in Table 1.

Table 1. Comparative Assessment of Modern Irrigation Technologies.

Technology	Technical Suitability	Economic Feasibility	Environmental Sustainability	Overall Adequacy in SSA
Drip systems				
Drip (Surface) Irrigation	High (for high-value crops)	Moderate-High (costly but efficient)	Very High	Highly suitable for small/medium farms
Drip (Sub-surface) Irrigation	high-value crops;	moderate to high	very high;	highly suitable for small and medium-scale farms
Sprinkler systems				
Sprinkler Irrigation	Moderate-High	Moderate	Moderate-High	Suitable for medium farms, moderate climates
Gun sprinklers	Moderate-High	Moderate	Moderate-High	Suitable for medium farms, moderate climates
Spray tubes	Moderate-High	Moderate	Moderate-High	Suitable for medium farms, moderate climates
Center - Pivot	High (for large uniform fields)	Low-Moderate (high capital)	High if powered sustainably	Suitable for large commercial farms
Surface Irrigation: using the semi-California system ⁴ ; either gravity-fed or low-pressure conveyance approaches.	Suitable for most crops Easy to adapt	Low to moderate (minimum capital)	Moderate-High	Suitable for smallholder farmers,
Surface Irrigation semi-California system and other gravity-fed conveyance approaches.	Low - Moderate	Low-moderate (not costly)	Moderate	Suitable for smallholder farmers,

⁴Included at a request of validation workshop participants outlined “a semi-Californian system as a low-pressure irrigation network where water is conveyed through buried PVC pipes, and distributed via outlets into furrows or basins, improving efficiency compared to open canal systems.”

3.6. Recommendation Framework for Selecting Appropriate Irrigation Technologies

The selection of modern irrigation technologies in Sub-Saharan Africa must align with local biophysical conditions, socio-economic contexts, and management capacities. This framework provides practical guidance to decision-makers and irrigation managers (extension staff and farmers) on identifying and promoting suitable irrigation solutions that maximize water productivity, energy efficiency, and long-term sustainability.

3.6.1. Key Considerations for Technology Selection

- 1. Agro-ecological and Climatic Conditions:** Rainfall patterns, temperature, and evaporative demand strongly influence irrigation water requirements and system design.
 - Technologies such as drip and subsurface irrigation perform better in arid and semi-arid areas, while sprinkler and pivot systems suit areas with moderate humidity and a stable water supply.
- 2. Water Source and Availability:** The adequacy of irrigation water source – quantity and quality of either surface or groundwater – determines the reliability of the irrigation plan.
 - The method of water lifting depends on the type of water sources and the site's physiographic characteristics. The SPIS are compatible with different irrigation systems, especially in high-solar-insolation areas.
 - The choice of an irrigation method depends on the available water supply. Drip irrigation is ideal in water-scarce areas where higher water-use efficiency is demanded compared with sprinkler and center-pivot systems.
- 3. Farm Size and Land Configuration:** The scale of the project (planned irrigated area) and the shape of agricultural plots influence the type of irrigation system and how it can be efficiently deployed and implemented.
 - Pumping systems – SPIS, and other pumping technologies – work with drip, sprinkler, and center-pivot systems of different capacities to meet the requirements of planned irrigation areas. The Nasho Irrigation Scheme in Rwanda provides an illustrative example. Located around Lake Nasho, this large-scale solar-powered irrigation project consists of 63 center-pivot irrigation systems covering approximately 1,173 hectares and serving about 2,099 smallholder farmers. The system is powered by a 3.3 MW solar power plant, complemented by a 2.4 MW battery storage system, which powers the irrigation pumps and ensures a reliable, year-round water supply.
- 4. Crop Type and Cropping Pattern:** High-value horticultural crops (vegetables, fruits, spices) benefit most from drip irrigation, while cereals and fodder crops can efficiently utilize pivot or sprinkler systems.
 - Mixed or rotational systems may require flexible technologies (e.g., portable sprinklers).
- 5. Energy Access and Cost:** Reliable and affordable energy is essential for pumping and pressurized irrigation.
 - SPIS provides an optimal renewable option in off-grid areas, while smart control systems require dependable power and internet connectivity.
- 6. Institutional and Management Capacity:** Adequate technical knowledge, maintenance skills, and governance mechanisms are critical for system longevity.
 - Smart/digital irrigation and pivot systems require higher institutional support compared to simpler systems like drip or sprinklers.
- 7. Economic and Financing Conditions:** Access to credit, subsidies, or collective financing arrangements can influence adoption.
 - Economies of scale favor pivot and digital systems, while group ownership models can enhance affordability for smallholders.

3.7. Recommendation - Summary

Modern irrigation technologies each hold unique potential in Sub-Saharan Africa, but no single system fits all contexts. Table 2 outlines typological recommendations for irrigation system selection and planning. A simplified logical framework to decide the type and suitability of modern irrigation technologies is outlined below (Figure 8):

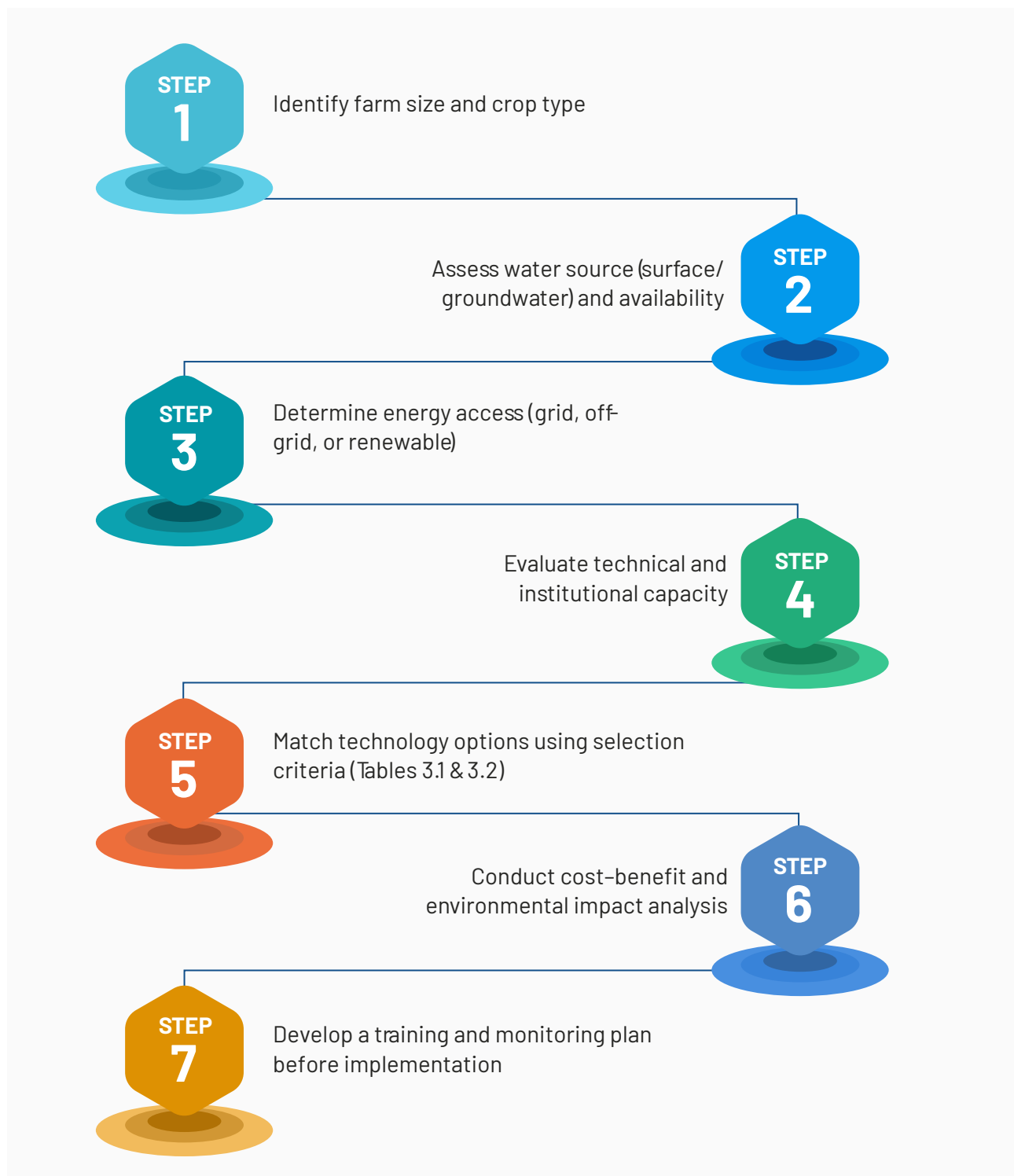


Figure 8. Framework to decide the suitability of modern irrigation systems.
Source: Authors' creation

Table 2. Recommended Modern Irrigation Technologies by Context.

Context / Condition	Energy Sources	Water Conveyance	Water Application Methods	Rationale	Disadvantage/risk
Smallholder farms (<5 ha)	Solar-powered irrigation	Pressurized PVC/HDPE pipes, small distribution lines	Drip irrigation with a necessary filtration system	Efficient use of limited water; low O&M costs; suitable for high-value crops; renewable energy option	Limited irrigated area;
Medium-scale farms (5–50 ha)	Solar-powered or grid electricity	Pressurized pipe networks with necessary control systems	Sprinkler irrigation	Flexible and cost-effective; moderate capital requirement; improves water distribution efficiency	Energy is needed for high pressure required to operate sprinklers
Large-scale commercial farms (>50 ha)	Grid electricity, diesel, or solar hybrid	Large pressurized pipeline network with necessary control systems	Center-pivot, lateral move irrigation	High mechanization; labor efficiency; suitable for large uniform fields; supports advanced management	The energy requirement is high
Arid and semi-arid zones	Solar-powered irrigation	Pressurized pipes with necessary control systems	Drip or subsurface irrigation with an adequate filtration system	Minimizes evaporation losses; precise water application; renewable energy reduces operating costs	Management of salinity is crucial
Humid or sub-humid zones	Grid electricity or diesel pumps	Pipe distribution networks	Sprinkler, pivot, or lateral move systems	Suitable for diverse crops; provides uniform water distribution under moderate water demand	Energy cost could be a major challenge
Off-grid or remote areas	Solar-powered irrigation systems (SPIS)	Small-scale pipe conveyance systems	Drip irrigation	Independent of fossil fuels; simple operation; appropriate for decentralized farming	Cloudiness may limit available solar energy, impacting pumping
Water-scarce or drought-prone regions	Solar or energy-efficient pumps	Pressurized pipeline systems	Drip or subsurface irrigation	High water-use efficiency; reduces wastage; supports precise irrigation scheduling	Salinity problem
Areas with poor water quality (high sediment or salinity)	Grid or diesel pumps	Pipes with filtration systems	Sprinkler or pivot irrigation	Less prone to emitter clogging compared to drip systems	Prone to pump breakdown. Crop physiology and growth may be affected
Regions with strong digital infrastructure	Solar-grid hybrid systems	Automated pipeline networks	Smart irrigation (drip/sprinkler with sensors)	Enables precision irrigation, monitoring, and data-driven water management	Require internet access
Community-managed irrigation schemes	Solar-powered collective pumping systems	Shared pipeline conveyance	Sprinkler systems	Facilitates shared management; manageable maintenance; suitable for collective farming	A strong and structured water user association is critical

Box 1 presents the South African experience in selecting an appropriate irrigation system by considering factors such as the availability of technical skills, spare parts, and funding, and by aligning these with the operational requirements of a specific irrigation technology⁵.

BOX 1. Irrigation Systems Selection Guidelines: South African Experience

Water: The amount of available water, the quality of the water, and the cost thereof may influence the choice of an irrigation system. If the amount of available water is a limiting factor for the area to be irrigated, it might be more profitable to select a micro-irrigation system with high water-use efficiency. Where irrigation contains harmful chemical substances that could burn the plant's leaves or affect the quality of the product, overhead irrigation systems that wet the foliage should be avoided.

Soil: For micro-irrigation of soils with a very high sand fraction, micro-sprayers would be preferable to drippers. However, if the soil has a very high clay fraction and a low infiltration rate, a dragline system might be more suitable than a large center pivot is, and an overhead system is to be installed.

Topography: Topography plays an important role in selecting irrigation systems.

Climate: In very hot climatic conditions, water applied by sprinkler irrigation that wets plant leaves may burn them. Under such conditions, it would be better to use a micro-irrigation or flood-irrigation system.

Energy costs: Energy requirements and, therefore, operating costs of some systems, such as the high-pressure sprinkler and pivot, are considerably higher than those of low-pressure systems, such as drip irrigation, and should therefore be taken into consideration when selecting a system.

Crop: The crop to be irrigated will highly influence the choice of an irrigation system. It would be ineffective to irrigate wheat with a drip system, which is only suitable for row crops.

Labour: A labour shortage may force the farmer to use self-propelled or permanent systems rather than movable systems.

Capital cost: Micro irrigation systems are generally more expensive than, for instance, portable systems. The farmer may, for economic reasons, select the cheaper portable system, even though it might not be the ideal system for the application.

Personal considerations: Although each system has its own field of application, the final choice rests with the user. The user's preferences are influenced by various factors, for instance, whether the system is adaptable to farming practices, the level of training of his labourers, whether the system can be adapted for other uses, and the reliability of the supplier. In the smallholder system, particularly, the ease of operation across gender is equally critical. High-tech systems often require training adaptable to all genders.

Maintenance and management considerations: Irrigation system maintenance and management involve four major efforts: calibration and auditing, preventive maintenance, corrective maintenance, and record keeping. Personnel charged with maintaining an irrigation system face numerous challenges. Irrigation audits can be conducted to assess the system function, ensuring that the irrigation system works reliably and is cost-effective. Good system management starts with good preventive maintenance procedures and recordkeeping. Corrective maintenance is simply the act of fixing what is broken, ranging from cleaning a clogged orifice to a complete renovation of the irrigation system.

⁵Irrigation Design Manual 2025 – SABI

Chapter 4

Operation and Maintenance of Modern Irrigation Systems



4. Introduction

Different irrigation systems are designed to follow established principles for efficient operation. The performance of an irrigation system depends on the efficiency of its operation processes and the attention given to maintaining its various components. Essentially, the operation, management, and maintenance of irrigation systems involve the regular processes required to use and maintain irrigation infrastructure, equipment, and other installations to ensure the system continues to perform optimally, reliably, and efficiently, meeting users' expectations. The process of operation and maintenance varies depending on the particular irrigation system. In modern irrigation systems—such as center pivots, sprinklers, and drip systems—the components are more sophisticated and require constant attention and technical skills compared to traditional surface irrigation practices. It is generally believed that one primary factor contributing to the low profitability of formal irrigation schemes across many countries in sub-Saharan Africa is poor operational, management, and maintenance, practices, as well as technical skills.

Operation processes refer to all actions taken to operate the equipment and manage the facilities - including water lifting, conveyance, delivery, system monitoring, and control devices - aiming at efficient system functionality in accordance with design and crop requirements.

Maintenance refers to all actions undertaken to ensure that irrigation infrastructure and equipment remain functional, safe, and efficient throughout their design life. It encompasses routine, preventive, corrective and predictive measures aimed at sustaining reliable system performance, extending asset lifespan, and ensuring uniform and efficient water delivery over time. The following sections present a structured, practical overview organized by system type and maintenance category.

Operation and maintenance practices (O & M) refer to daily or regular activities, routine technical procedures, management, and human support strategies adopted to ensure physical assets—such as equipment and infrastructure—operate efficiently, safely, and reliably, depending on the system type, equipment configuration, and manufacturers' design specifications.

Effective operation begins with a clear understanding of the system, its operating conditions, technical requirements, and all other specifications outlined in the design documents or provided by the manufacturer. In practice, the operation, maintenance, and management of irrigation schemes involve three interrelated elements:

- **System hardware** - the physical infrastructure, instruments, equipment, and components that lift, convey, deliver, and control water.
- **System software** - the procedures, protocols, data, and decision-support tools required to operate the hardware effectively.
- **System operators** - the people responsible for managing, operating, maintaining, and monitoring the system.

Best O&M practices therefore recognize that sustainable performance depends not only on hardware and software but also on personnel's capacity, coordination, and accountability.

4.1. Standard Operating Procedures

Irrespective of the irrigation systems and scale, the basic approach to ensuring that operators and users adhere to and translate principles into day-to-day practices is to develop Standard Operating Procedures (SOPs). Developing SOPs for irrigation systems involves creating clear, practical, and systematic guidelines that ensure efficient operation, proper maintenance, and the long-term sustainability of water-delivery infrastructure. The process begins with a detailed assessment of the irrigation technology in use—such as center pivots, drip systems, sprinklers, pumps, and canals—to understand their operational requirements, risks, and maintenance needs. SOPs development also requires consultation with engineers, farm managers, Water User Associations (WUAs), and equipment manufacturers to capture context-specific practices and safety standards. The procedures must outline step-by-step operational tasks, preventive maintenance schedules, troubleshooting methods, water-use protocols, and governance roles, ensuring consistency and compliance across all users. Ultimately, well-developed SOPs improve water productivity, reduce system breakdowns, support equitable water distribution, and enhance the overall performance and lifespan of irrigation systems.

Operating efficient SOPs ensures that irrigation systems deliver:

- Optimal water delivery
- Reduced system downtime
- Prolonged lifespan of equipment
- Improved water productivity and crop yield
- Reliable data and valuable information on system performance

Documentation, reporting, review, and continuous improvement are essential for successful O&M practices. Further details are provided below.

4.2. Documentation, Reporting, Review, and Continuous Improvement

As part of O&M, it is essential to establish a clear and consistent system for documenting and reporting all aspects of irrigation operations, maintenance activities, and related processes. Effective O&M documentation ensures that every action – water delivery and irrigation events, facility inspections, equipment servicing, repairs, part replacements, and observed faults – is appropriately recorded and easily traceable. Comprehensive reporting enables operators, managers, and institutions to track system performance over time, identify recurring problems, plan preventive maintenance, allocate resources efficiently, and make informed decisions. A structured documentation system also enhances accountability, supports transparency, strengthens institutional memory, and contributes to the long-term sustainability and reliability of irrigation schemes. Basic documentation practices include:

- Maintain daily log sheets.
- Record water delivery and system performance.
- Document repairs, spare parts usage, and inspections.
- File annual O&M plans and budget documents.

The review and continuous improvement included conducting an annual review of system performance and updating SOPs in response to new equipment, design updates, or operator feedback. Additionally, there is a need to integrate new technologies into O&M procedures as the case may be.

4.2.1. A guide to scheduling maintenance operations

As a complement to the SOPs and part of the maintenance governance structure, it is essential to develop a maintenance checklist – a structured guide that ensures all crucial inspection, routine servicing, and repair tasks are systematically outlined, keeping the irrigation systems operating efficiently and safely. It provides a step-by-step list of routine activities—such as checking pumps, cleaning filters, inspecting electrical panels, verifying sensor accuracy, lubricating moving parts, and confirming safe operating conditions—to help operators detect problems early and prevent costly breakdowns. A well-designed maintenance checklist promotes accountability by recording completed tasks, dates, responsible personnel, and any faults identified, enabling efficient follow-up and tracking of system performance over time. By standardizing maintenance procedures, the checklist enhances reliability, extends the lifespan of irrigation infrastructure, and ensures the safe and efficient delivery of water to crops.

Table 3 provides the irrigation system standard of practice for the common types of irrigation systems (drip, sprinkler, and center-pivot). A guide to scheduling maintenance operations, along with the checklist of key activities, is provided in Table 4. The procedure outlines actions required during preparatory checks, operating procedures, routine maintenance, and precautionary safety issues.

Table 3. Irrigation Systems Operating Procedures.

Irrigation System Standard of Practice	Purpose	Preparatory checks	Operation Procedure	Routine Maintenance	Safety
Drip and Fertigation System	Ensure proper operation of drip, micro-irrigation, and fertigation systems to maximize water-use efficiency	<ul style="list-style-type: none"> - Inspect filter units (screen, sand, disc filters) - Flush laterals and manifolds - Confirm pressure regulators are functional - Prepare fertilizer solution and verify injector calibration 	<ul style="list-style-type: none"> - Open the main line and gradually pressurize the system - Maintain recommended operating pressure - Introduce fertilizer only after lines are fully pressurized - Flush system after fertigation cycle 	<ul style="list-style-type: none"> - Clean filters daily during irrigation season - Chemically treat system (acid/chlorine) monthly to prevent clogging - Check and replace emitters as needed - Verify fertigation pump calibration 	<ul style="list-style-type: none"> - Use PPE (Personal Protective Equipment) when handling fertilizers - Prevent backflow contamination through checkvalves
Sprinkler Irrigation System	Guide the operation and maintenance of hand-move, portable, and fixed sprinkler systems	<ul style="list-style-type: none"> - Inspect sprinklers for cracks or blockages - Ensure risers are firmly positioned - Check pump pressure and pipeline integrity 	<ul style="list-style-type: none"> - Start the pump gradually - Maintain operating pressure within the specified range <ul style="list-style-type: none"> - Monitor sprinklers overlap and adjust spacing if required 	<ul style="list-style-type: none"> - Clean sprinkler nozzles weekly - Inspect risers and gaskets - Drain pipelines before long idle periods 	<ul style="list-style-type: none"> - Avoid directing jets toward electrical components - Secure pipes to avoid whip injuries
Center Pivot	To ensure proper operation, alignment, and maintenance of center pivot systems for uniform water application	<ul style="list-style-type: none"> - Inspect electrical components, cables, and tower boxes <ul style="list-style-type: none"> - Confirm water pressure and pump readiness - Check tyre pressure, tower alignment, and drive units - Verify nozzle package and end-gun settings 	<ul style="list-style-type: none"> - Start the pump and ensure adequate system pressure - Engage pivot movement: set desired speed (%) or rotation time - Monitor tower synchronization and alignment - Avoid operation during high winds (>15 km/h) - Check for uniform spray pattern 	<ul style="list-style-type: none"> - Grease drive shafts and tower joints weekly - Inspect gearboxes monthly and change oil annually - Flush pipes at the start of the season - Replace worn nozzles and regulators 	<ul style="list-style-type: none"> - Lock out electrical sources before servicing - Prohibit climbing pivot structures

Table 4. A guide to scheduling maintenance operations and a checklist of key activities.

Schedule: Operation and Maintenance	Canal and sluice gates	Pumping System	Pipelines and water controls	Sprinklers systems	Center Pivot system	Drip System	IoT
Daily O&M Checklist							
Operation	<ul style="list-style-type: none"> - Open gates, sluice, and gate valves to a determined level - Record daily water levels and discharge 	<ul style="list-style-type: none"> - Inspect the pump components - Ensure adequate priming - Open the intake, discharge, and bypass valves following SOP 	<ul style="list-style-type: none"> - Confirm gate and valve settings - Check for unusual pressure drops 	<ul style="list-style-type: none"> - Ensure stability of sprinkler stands - Check operating pressure - Monitor sprinkler discharge and distribution uniformity 	<ul style="list-style-type: none"> - Ensure flow, pressure, and power supply are up to standard - Inspect sprinklers, control valves, switches - Monitor sprinkler discharge - Ensure safety shut-off switches are functioning properly 	<ul style="list-style-type: none"> - Observe leaks and breaks - Inspect emitters, valves, and control devices - Observe filters and fertigation components 	<ul style="list-style-type: none"> - Ensure perfect installation of sensors, controllers, and internet connectivity - Perform calibrations following design protocol - Ensure data transmission from the field sensor to data storage platforms
Maintenance	<ul style="list-style-type: none"> - Check canal and pipeline leakage - Verify intake screens and remove debris 	<ul style="list-style-type: none"> - Inspect pumps for noise, vibration, and temperature 	<ul style="list-style-type: none"> - Ensure flow distribution follows the schedule 		<ul style="list-style-type: none"> - Tower alignment - Check and fix faulty hoses/pipes, sprinklers - Check electrical fittings, and pumping components 	<ul style="list-style-type: none"> - Monitor pressure regulator and check valves 	<ul style="list-style-type: none"> - Physical inspection of sensors, controllers - Check apps, data logging apps and related system components

Schedule: Operation and Maintenance	Canal and sluice gates	Pumping System	Pipelines and water controls	Sprinklers systems	Center Pivot system	Drip System	IoT's
Weekly /Monthly Maintenance Checklist							
Maintenance Checklist	<ul style="list-style-type: none"> - Inspect canals for sediment build-up - Lubricate the sluice gates' moving parts - Check digital control devices 	<ul style="list-style-type: none"> - Lubricate pump components per schedule 	<ul style="list-style-type: none"> - Inspect flow meters and gauges - Check gate/ valve integrity 	<ul style="list-style-type: none"> - Check the sprinkler springs, nozzles, and connectors to the laterals 	<ul style="list-style-type: none"> - Check the tower structures, gear boxes, wheels, and repair accordingly - Lubricate drive shafts, joints, and bearings regularly. - Inspect and correct the alignment of towers to prevent structural stress 	<ul style="list-style-type: none"> - Clean screens, gravel, and sand media filters - Flush pipelines - Inspect flow meters and gauges 	
Seasonal & Annual Maintenance	<ul style="list-style-type: none"> - Desilt canals and drains before the rainy and dry seasons - Repair canal lining and structures 	<ul style="list-style-type: none"> - Overhaul pumps and motors - Conduct major system inspections - Repair or replace all unwholesome components with failing functions 	<ul style="list-style-type: none"> - Recalibrate flow-measurement devices - Conduct major system inspections - Repair or replace all unwholesome components with failing functions 	<ul style="list-style-type: none"> - Ensure proper storage of the mobile facility - Update asset registers 	<ul style="list-style-type: none"> - Conduct major system inspections - Repair or replace all unwholesome components with failing functions 		<ul style="list-style-type: none"> - Service generators and solar units - Inspect electrical systems for safety

Schedule: Operation and Maintenance	Canal and sluice gates	Pumping System	Pipelines and water controls	Sprinklers systems	Center Pivot system	Drip System	IoT's
Weekly /Monthly Maintenance Checklist							
Water Distribution & Scheduling Checklist	<ul style="list-style-type: none"> - Confirm water allocation plan for all blocks - Maintain rotation schedules - Monitor discharge at each offtake - Prevent unauthorized abstraction, tapping, or any wrong connection - Adjust scheduling during rainfall events - Ensure the use of suitable applications 						
Environmental & Safety Checklist	<ul style="list-style-type: none"> - Check for erosion and land degradation due to the wrong water application rate - Monitor waterlogging and salinity - Enforce operator Personal Protective Equipment (PPE) and afford exposure to hazards - Inspect electrical systems for safety 						
WUA Operation Responsibilities	<ul style="list-style-type: none"> - Collect water fees - Manage minor repairs - Maintain records of meetings - Ensure fair allocation - Manage conflict resolution 						
Financial O&M Checklist	<ul style="list-style-type: none"> - Prepare annual O&M budget - Track expenditures - Maintain fee collection records - Allocate funds for major maintenance - Update cost-recovery plans 						
Record-Keeping Templates	<ul style="list-style-type: none"> - Daily log sheets - Weekly inspection forms - Seasonal maintenance records - Water distribution schedules - Asset management registers 						



4.2.2. SOPs for support systems to modern irrigation systems

Modern irrigation systems require a combination of elements, including pumping stations for water lifting; structures (e.g., a dam) to create adequate head for water conveyance in a canal system; a pipe network in a pressurized irrigation system (often preferred to an open canal); an energy source to power equipment; electrical systems; sensors to detect soil moisture status, water levels, flow rates, and pressure; as well as facilities for monitoring weather conditions. For successful irrigation solutions, these components require adherence to the standard operating procedures outlined in Boxes 2–8.

Box 2. Pumping station.

Purpose	To ensure efficient and safe operation of pumping stations supplying water to the irrigation systems
Preparatory checks	<ul style="list-style-type: none"> - Inspect pump casing, valves, and suction line - Verify lubrication and coolant levels - Confirm electrical safety and grounding - Control and monitoring indicator
Operation procedure	<ul style="list-style-type: none"> - Start the pump with valves partially closed - Monitor suction/head pressure - Avoid dry running - Check for abnormal vibration or noise - Monitor meter readings, sensor outputs, dashboard alerts, and control indicators
Routine maintenance	<ul style="list-style-type: none"> - Lubricate bearings - Replace worn impellers - Inspect alignment of motor-pump coupling - Regular check on the control, monitors and sensor systems
Safety	<ul style="list-style-type: none"> - Lockout system before repairs - Use PPE for electrical work

Box 3. Irrigation Canal System.

Purpose	To provide guidelines for managing water flow, distribution, and canal infrastructure
Preparatory checks	<ul style="list-style-type: none"> - Inspect gates and regulators - Clear canal of vegetation and debris - Check embankments for erosion
Operation procedure	<ul style="list-style-type: none"> - Open/close gates based on discharge schedule - Monitor water levels at key points - Maintain equitable water distribution
Routine maintenance	<ul style="list-style-type: none"> - Desilt canals regularly - Repair cracks and seepage zones - Maintain embankment vegetation
Safety	<ul style="list-style-type: none"> - Provide safe access for operators - Use warning signs near deep or fast-flowing water

Box 4. Solar System (Solar PV, Inverters, Charge Controllers, Solar Pumps).

Purpose	To ensure optimal performance, maximum energy output, and long service life of solar power systems supporting irrigation pumps and electrical components
Preparatory checks	<ul style="list-style-type: none"> - Inspect solar panels for dust, shading, cracks, or loose mounting bolts - Check the connectors and wiring for corrosion or overheating - Ensure inverter or charge controller indicator lights show readiness - Verify solar array voltage matches pump/system requirements - For systems with batteries, check electrolyte levels or Battery Management System (BMS) status
Operation procedure	<ul style="list-style-type: none"> - Switch on the DC isolator to energize the solar array - Start the inverter or solar pump controller - Monitor system output: voltage, current, inverter temperature, and pump performance - Adjust panel tilt or clear shading if energy output is low - Shut down the system properly by following the reverse order if maintenance is needed
Routine maintenance	<ul style="list-style-type: none"> - Clean solar panels weekly or after rainfall/dust storms - Tighten panel mounting bolts monthly - Inspect wiring, junction boxes, and connectors for insulation integrity - Test grounding and lightning protection systems quarterly - Service inverter cooling systems and update firmware annually - For battery systems: clean terminals, maintain electrolyte levels, and avoid deep discharge
Safety	<ul style="list-style-type: none"> - Never touch panels or connectors with wet hands - Avoid working on solar arrays during peak sun hours (risk of electric shock) - Use insulated tools and non-metallic ladders - Disable DC isolators before any wiring work - Ensure proper earthing to prevent lightning-related hazards

Box 5. Electrical Systems.

Purpose	To ensure safe, reliable, and efficient operation of electrical panels, switchgear, wiring, and power supply units that support irrigation pumps and control systems
Preparatory checks	<ul style="list-style-type: none"> - Verify stable power supply (grid, generator, or solar inverter) - Inspect control panels for loose wires, corrosion, moisture, or burnt smell - Confirm grounding/earthing integrity - Check cable insulation for cuts or rodent damage - Ensure all breakers and overload relays are in good condition
Operation procedure	<ul style="list-style-type: none"> - Switch on the main isolator and confirm the voltage level - Energize pump starters and control circuits sequentially - Monitor ammeter/voltmeter for normal load behavior - Operate pumps within recommended voltage and current limits - Shut down equipment immediately if abnormal noise, heat, or sparks occur

Routine maintenance	<ul style="list-style-type: none"> - Tighten terminals and electrical connections monthly - Clean electrical panels and remove dust, insects, or moisture - Test overload relays, surge protectors, ELCBs, and safety devices quarterly - Inspect conduit systems and replace worn-out cables - Conduct annual grounding resistance tests
Safety	<ul style="list-style-type: none"> - Follow Lock-Out/Tag-Out (LOTO) before servicing - Use insulated gloves, safety boots, and rated tools - Keep water away from all electrical components unless IP-rated enclosures are used - Never bypass fuses, breakers, or protective devices - Ensure electrical diagrams are displayed in pump houses - Ensure the electrical installation is grounded correctly and perfectly earthing in accordance with electrical safety standards

Box 6. Sensor System (Soil Moisture, Water Level, Flow, Pressure, Weather Stations).

Purpose	To ensure sensors provide accurate, consistent, and real-time data for irrigation scheduling, water level control, and flow/pressure monitoring
Preparatory checks	<ul style="list-style-type: none"> - Inspect sensor probes, cables, and connectors for damage - Confirm sensors are installed at the correct depth, position, and orientation - Check battery levels or power supply connections - Verify communication link with data loggers, IoT gateways, or display units - Ensure calibration data is up to date
Operation procedure	<ul style="list-style-type: none"> - Turn on the sensor controller or data logger - Observe readings on the display or dashboard (soil moisture %, water level, pressure, flow) - Compare automated readings with occasional manual measurements - Adjust irrigation schedules based on validated sensor data - Ensure uninterrupted data transmission to mobile/central platforms
Routine maintenance	<ul style="list-style-type: none"> - Clean sensors (probes, flow sensors, weather station components) weekly - Re-calibrate soil moisture and flow sensors seasonally - Replace batteries every 6-12 months - Update firmware/software regularly for IoT-enabled devices - Inspect mounting poles, housings, and data cables for weather or animal damage
Safety	<ul style="list-style-type: none"> - Do not remove sensors while the system is energized or pressurized - Use waterproof tools and gloves when handling field-mounted sensors - Avoid placing metal tools near communication antennae - Keep sensor cables away from moving equipment or vehicle paths - Prevent chemical contamination of probes during fertigation events

Box 7. Water Management Practices.

Purpose	To ensure adequate water allocation, distribution, and application to meet crop irrigation water requirements and the gross water requirements of different blocks.
Preparatory checks	<ul style="list-style-type: none"> - Have a clear water demand by sectors, blocks, and areas based on the scheme plans - Ensure that water conveyance (canals, pipe network), controls (sluice gates, valves, hydrants etc.), and the delivery system are in a good state - Develop proper irrigation water distribution and delivery schedule - Follow best practices in determining irrigation time
Operation procedure	<ul style="list-style-type: none"> - Follow the agreed SOP in the irrigation operation - Make sure irrigation water is applied for the estimated irrigation time - Monitor delivery at the field level – sprinklers, emitters, field channel etc. - Establish rating curves and train WUA on basic water allocation and distribution
Routine maintenance	<ul style="list-style-type: none"> - Clear sediments and other debris from the primary, secondary, and tertiary canals - Amend cracks across canals - Repair all gates, control valves, distribution boxes, and other structures
Safety	<ul style="list-style-type: none"> - Ensure that the water source(s) will meet gross water requirement of cultivated areas - Place all necessary warnings and cautionary instructions along canals, gates, and other structures to guide against any tragedy. - Maintain a safe distance from primary and secondary canals. - Guide against swimming or recreational activities beyond what is safely permitted. - Prevent all illegal tampering, bank cutting, and all unapproved or non-professional intervention

Box 8. Pipe and pipeline network.

Purpose	<ul style="list-style-type: none"> - To ensure the integrity of the pipe conveyance network, to deliver the expected discharge and pressure across the command area
Preparatory checks	<ul style="list-style-type: none"> - Conduct physical inspections where possible, checking for underground bursts, breaks, and other compromises in the network - Ensure the valves, pressure gauges, and flexible connections are all properly and firmly connected - Inspect the integrity of all monitoring applications and devices
Operation procedure	<ul style="list-style-type: none"> - Ensure that the discharge and all other line valves are opened - Monitor the pressure gauges and watch out for pressure and/or flow rate drop
Routine maintenance	<ul style="list-style-type: none"> - Repair minor leaks to avoid bursts - Fix all pipe breaks - Check the valves, gauges and monitoring devices. Ensure replacement where necessary
Safety	<ul style="list-style-type: none"> - Follow all necessary safety precautions during repairs. - Avoid carrying heavy loads/pipes during repair or installation, instead employ the use of cranes

4.2.3. Deployment and Recuperation of Irrigation Infrastructure

Irrigation systems can be deployed either for supplemental or year-round use. The choice of how irrigation technologies are deployed depends on the environmental variables, such as rainfall availability, distribution, and pattern. In the dry Sub-Saharan Africa, irrigation is an integral component of the farming system and is practiced almost entirely year-round. Similarly, in Northern Africa, irrigation sustains the production of high-value crops and is used year-round.

Therefore, irrigation systems should be designed as part of the farm infrastructure, deployed when rainfall is inadequate or prolonged drought occurs, and used to enable year-round production. Irrigation deployments can be permanent, mobile, portable, or semi-permanent. The modes apply to various irrigation systems or components, such as pumps, sprinklers, and drips.

Permanent Systems: Permanent irrigation systems are planned with components that are designed, installed, and operated at a fixed location. The pumping unit, pipe network, primary and secondary laterals, sprinklers, drip system, and all other components in a permanent irrigation system are not moved throughout the production season or over the years. Permanent systems require careful, long-term planning, significant initial investment, and high technical capacity. It is also more adaptable to plantation crops. A major example of a permanent irrigation system is the Center Pivot. However, Sprinklers and Drip could also be deployed on large commercial farms as permanent systems.

Mobile or Portable Systems: These refer to a design in which components of the irrigation system are not fixed but can be moved from one place to another or stored when the system is not in use. A mobile system allows a farmer to move water-lifting and application equipment from one plot to another. This usually applies to smallholder irrigation systems – pumping units, sprinklers, traveling guns, smallholder drip systems – for limited plot sizes.

During the recuperation of portable systems:

- Care must be exercised to ensure equipment is safely removed from the field, transported to another farm plot, farmyard, or designated stores.
- Equipment must be thoroughly cleaned of dirt and debris.
- Ensure the moving metal parts are lubricated to avoid corrosion.
- Components must be properly stored so that each part can be identified when the time comes for installations in the new season. For example, pumps and accessories, sprinklers and connectors, hose and clips, driplines and drippers, and valves must be separated and adequately placed in the store, with necessary labels to ensure easy identification and access at all times.

Semi-permanent system: a system design that incorporates principles from both permanent and mobile systems. While some components are permanently fixed in the field, others are mobile and can be moved as the farm operations require. In many instances, the pump, water sources, main line, lateral lines, and hydrant points can be fixed in the field, while irrigation water application equipment, such as drips and sprinklers, can be semi-permanent systems.

The semi-permanent system allows for flexibility in field management, multi-crop irrigation, and deployment of different mechanization equipment. It is adaptable to small, medium, and large-scale cultivation.

- The operation and maintenance practices for permanent and portable systems are adoptable in the management of semi-permanent systems as well.
- Other field operations – land clearing, cultivation, etc. – must be systematically integrated with the installation of irrigation.

Chapter 5

Case Studies and Best Practices



5. Case Studies

5.1. Ghana

Ghana has an estimated 1.9 million hectares of potentially irrigable land, of which about 226,000 hectares have been developed through Farmer-Led Irrigation Development (FLID), commercial and private initiatives, and public irrigation schemes. Public schemes contribute roughly 17,000–18,000 hectares, though only about half of this area is fully operational. The Ghana Irrigation Development Authority (GIDA)—established in 1977—is the sole national institution mandated to plan, develop, and manage irrigation systems nationwide. In recent years, GIDA has intensified efforts to modernize irrigation infrastructure, shifting from open-channel conveyance to closed-pipe systems to improve water-use efficiency and reduce losses. Among the better-performing public schemes is the Kpong Irrigation Scheme, which also hosts the commercial operations of Golden Exotics Ltd. (GEL), a large banana producer using advanced drip and sprinkler technologies. Additionally, a major center-pivot irrigation development is underway in the Afram Plains in the Ashanti Region, featuring 18 pivot units, each capable of irrigating 50 hectares. The center-pivot irrigation system in the Afram Plains (expected to be commissioned by June 2026) pumps water from the Volta River, marking a significant public-private partnership and a step toward expanding modern mechanized irrigation in Ghana.

5.1.1. Stakeholder engagement and field visit

Facilitated by GIDA, a field visit to the Kpong and Afram Plains irrigation schemes was conducted in December 2025. Discussions were held in Accra and in the fields, in the presence of GIDA management and the technical team, which included water managers, engineers, and agronomists. A standard questionnaire (Annex-1) was developed to guide the discussion and acquire thoughtful insights on modern irrigation technologies in Ghana.

5.1.2. Kpong Irrigation Scheme key features

- **Location and water source:** Situated in southeastern Ghana, the scheme draws water from the Volta River through a controlled diversion system (Figure 9).
- **Management:** Operated and overseen by the Ghana Irrigation Development Authority (GIDA), the Kpong irrigation scheme is one of the most effectively managed public irrigation schemes in the country. The main supply canal is 16.3 km long, of which 2.5 km is lined. All branches and laterals are concrete-lined, and the system is transitioning from manual gauges to automatic. Automation of flow meters and valves is under operation.
- **Modernization Efforts:** The system is under rehabilitation and modernization. Ongoing upgrades are shifting from traditional open channels to closed-pipe distribution systems, enhancing water-use efficiency and reducing conveyance losses.
- **Infrastructure and Layout:** Features structured canal networks, pumping stations, and farm access roads, enabling organized plot distribution and reliable water delivery (Figure 10).
- **Demonstration of Best Practices:** Serves as a national example of combining public infrastructure, smallholder support, and commercial-scale modern irrigation technologies within one scheme.
- **Scale and Beneficiaries:** A total of 2,500 hectares of land has been under rice cultivation by the smallholder farmers. With the integration of commercial farming, the Kpong irrigation scheme hosts Golden Exotics Ltd. (GEL), which operates on 2,000 hectares of land using advanced irrigation technologies such as drip and sprinkler systems. GEL is one of Ghana's leading commercial banana producers, operating extensive plantations within the Kpong Irrigation Scheme area. It utilizes modern drip and sprinkler irrigation technologies to ensure precise water application, optimize water-use efficiency, and sustain high crop productivity. With the integration with Public Irrigation Infrastructure, GEL benefits from the reliable water supply provided by the Kpong Irrigation Scheme, demonstrating effective collaboration between public irrigation investments and private-sector agriculture.
-

5.1.3. Operation and maintenance practices

Operation practices

- **Efficient water distribution:** Gravity-based water distribution for rice and drip irrigation for bananas.
 - Water is diverted from the Kpong reservoir into the Akuse Main Canal and then distributed through secondary and tertiary canals to rice fields.
 - Gravity flow reduces pumping costs and simplifies system operation.
 - Water is delivered directly to the root zone of banana plants through drip emitters, allowing precise water application and improved water-use efficiency.
- **Water scheduling:** Precision irrigation scheduling for bananas.
 - Irrigation is scheduled according to crop water requirements, improving productivity and reducing water waste.
- Water allocation for rice fields managed through WUAs and scheme management.
 - Farmers are organized into WUAs that coordinate water distribution at canal levels.
 - WUAs participate in water scheduling and ensure equitable allocation among farmers.
 - Pumping for higher elevation areas
 - Some areas above the gravity command require pumping water to storage reservoirs before distribution.

Maintenance practices

- **Strong institutional management:** Canal maintenance and desilting, maintenance of roads and infrastructure
 - Regular dredging and clearing of canals and drainage structures to remove sedimentation and vegetation
 - Access roads, bridges, and canal embankments are maintained to ensure easy movement of machinery and farmers.
- **Infrastructure rehabilitation**
 - Periodic rehabilitation of irrigation infrastructure (e.g., canals, pipes, gates) under development programs such as the Ghana Commercial Agriculture Project.
- **Regular inspection of drip systems**
 - Checking emitters, pipes, and filters to prevent clogging and maintain uniform water distribution.
- **Pump and filtration system servicing**
 - Routine servicing of pumps and filters ensures reliable water delivery and protects drip emitters from sediment.
- **Vegetation and weed control**
 - Regular weeding and vegetation management prevent damage to irrigation infrastructure and maintain field accessibility.
- **Preventive maintenance**
 - Early repair or replacement of damaged pipes, valves, and irrigation components to avoid system failures.
- **Cost recovery through water fees**
 - O&M costs are partly financed through water and land use fees collected from farmers, although collection rates may vary.



Figure 9. Installed water pumps at the Kpong irrigation scheme to abstract water from the Volta River.
photo: Birhanu Zemadim/IWMI



Figure 10. Kpong irrigation main canal.
photo: Birhanu Zemadim/IWMI

5.2. Ethiopia

Ethiopia has an estimated 5–6 million hectares of potentially irrigable land, making it one of the countries with the largest irrigation potential in Sub-Saharan Africa. To date, approximately 1.2–1.5 million hectares have been developed through a mix of smallholder farmer-led irrigation, medium- and large-scale public schemes, and private commercial investments. Small-scale irrigation—using rivers, shallow groundwater, and small reservoirs—accounts for the largest share, while medium- and large-scale public schemes contribute a smaller but strategically important proportion of the total irrigated area.

Irrigation development and management fall under the mandates of the Ministry of Water and Energy (MoWE) and the Ministry of Agriculture (MoA), with implementation support from regional bureaus and River Basin Authorities. In 2021, the Ministry of Irrigation and Lowlands (MILLs) was established to ensure sustainable development by expanding irrigation infrastructure and improving the lives of citizens living in lowland areas. The Government of Ethiopia has increasingly emphasized modernization of irrigation systems, promoting a transition from traditional open-canal and flood irrigation to pressurized and water-efficient technologies, alongside improved scheme management, operation, and maintenance.

5.2.1. Stakeholder engagement and field visit

Facilitated by IWMI Ethiopia, a series of field visits to the Wonji Dodota and Elfora Shallo–Melge irrigation schemes was conducted in late February 2026. The mission began in Addis Ababa with strategic discussions involving the technical advisors of MoWE, the CEO of Elfora (MIDROC Investment Group), senior farm managers from both schemes, and a senior former staff member of the Wonji-Shoa Research Team, who now serves as a national resource person with extensive experience in modern irrigation in Ethiopia.

Following these discussions, the team conducted on-site engagements at both locations, including FGDs with Managers and technical leaders from the Civil, Irrigation, Electromechanical, Farm, and Production divisions, as well as farmers' representatives. The sessions also incorporated inputs from agronomists, irrigation managers, field scheme operators, and out-growers. To complement the discussions, the team undertook transect walks across the irrigated fields to observe the infrastructure firsthand and documented the visit through site photography. This was also strengthened by collecting the farm field data sheets and the layout system.

5.2.2. Ethiopian irrigation scheme key features

Several irrigation systems demonstrate relatively strong performance when modernization and institutional support are applied. In the Central Rift Valley and Oromia Region, solar-powered pump irrigation combined with drip systems has shown strong results among smallholders producing vegetables and horticultural crops, significantly improving water-use efficiency and farm incomes. In the Awash Basin, large public schemes such as Tendaho benefit from a regulated water supply from reservoirs and are gradually incorporating improved conveyance and on-farm water-control technologies. Overall, Ethiopia's irrigation sector is steadily moving toward modern, climate-smart irrigation, with growing use of solar energy, drip and sprinkler technologies, and improved conveyance systems. Based on field performance, scalability, and alignment with climate-smart agriculture goals, the best-performing modern irrigation solutions across Ethiopia are outlined below.

Wonji-Shoa modernized large-scale irrigation schemes with controlled water delivery

The Wonji-Shoa Sugar Estate in Ethiopia—one of the country's oldest irrigated agro-industrial zones—has pioneered a climate-resilient, data-driven approach to managing irrigation systems. The factory underwent a major modernization in 2013, increasing its crushing capacity to 6,250 tons of cane per day (TCD). To feed this expanded factory, the sugarcane estate was extended into new areas, notably Dodota and Wake Tiyo. These new lands, with their varied topography and soils, necessitated the adoption of pressurized irrigation systems, including drag-line and center-pivot sprinklers (Figure 11). The Dodota site integrates both dragline sprinkler (1,650.5 ha) and center pivot sprinkler (538.7 ha) systems, while Wake Tiyo (535.4 ha) utilizes dragline sprinkler technology exclusively.

The irrigation systems at Dodota and Wake Tiyo rely primarily on surface water from the Awash River, supplemented by groundwater in some areas. Water is diverted through intake structures at both sites, passed through sedimentation basins, and conveyed via main canals to pumping stations.

The system integrates irrigation with climate intelligence, enabling pivots to operate only during low-demand microclimate periods, dramatically reducing wind drift and midday evaporation losses. There has been substantial potential to reduce water loss (up to 11.55%) by irrigating in the early morning and late afternoon. Hence, by reducing water losses and improving uniformity, the system supports sustainable sugarcane yields and prevents waste of critical water supplies. The large-scale irrigation scheme at Wonji-Shoa creates a national benchmark for Ethiopia by providing a scientifically validated model for:

- i. pivot design and evaluation,
- ii. climate-adapted operation,
- iii. integration with meteorological services, and
- iv. enhancing center-pivot suitability under the Ethiopian climate variability.

Key features in operation and maintenance

- **Institutional support:** Irrigation operations are managed through the Wonji Shoa Sugar Factory's organizational structure. The irrigation department is responsible for water management across all its schemes, including the main surface scheme, Dodota, and Wake Tiyo.
 - The irrigation department includes irrigation engineers, technicians, and field-level operators responsible for the daily operation and maintenance of irrigation systems. Field-level activities are coordinated by section heads and supervisors who oversee irrigation operations and crop management.
 - Well-trained irrigation specialists and project managers.
- Routine catch-can uniformity testing (morning, midday, late afternoon) to assess water distribution and losses.
- Irrigation scheduling at both Dodota and Wake Tiyo was designed to be guided by crop water requirement principles derived from the FAO crop evapotranspiration framework. The database utilizes the nearby Awash Melkasa automatic weather station. In some cases, the practical irrigation scheduling is guided by manual observation.
- Flexibility in operational adjustments (timing, pressure, tower travel speed) to minimize drift and evaporation.
- Labor saving: System operation requires less labor input.
- Reduced salinity and efficient fertilization application rates.
- Continuous diagnosis of pivot mechanics, including nozzle performance, pressure deviations, and travel speed variations along the pivot span.
- **Scheduled inspection:**
 - Cleaning and part replacement for all critical components: pumps, filters, valves, hydrants, pipe couplings, and sprinkler nozzles.



Figure 11. Center Pivot irrigation system at Wonji-Shoa Sugar Estate in Ethiopia.

photo: Zeleke Admasu/IWMI

Elfora Shallo–Melge Irrigation Scheme

The Elfora Shallo–Melge irrigation scheme (Figure 12) is notable example of large-scale commercial irrigation farms adopting pressurized irrigation technologies in Ethiopia. The farm integrates several irrigation methods, including center-pivot, dragline sprinkler, drip, and surface furrow irrigation, to support diverse crop production. The irrigation system relies primarily on groundwater, supplemented by surface water from the Tikurwuha River along the Shashemene–Hawassa road in the West Arsi Zone, Oromia Region, Ethiopia. Groundwater is abstracted through a network of boreholes distributed across the farm. In total, seventeen boreholes were drilled to supply irrigation water, of which sixteen are currently operational.

Key features in operation and maintenance

- Strong institutional support for farm operations. Irrigation operations at the farm are managed through a structured organizational system consisting of a general farm manager, irrigation division leadership, technical specialists, and field-level operators.
 - The irrigation division includes senior irrigation experts, electro-mechanical technicians, and irrigation operators responsible for the daily operation and maintenance of irrigation systems.
 - Field-level activities are coordinated through unit leaders and supervisors who oversee irrigation operations and crop management activities.
- **Water supply system:** Well-designed network of pipelines that deliver water either directly to the pivot systems or through intermediate storage reservoirs equipped with booster pumping stations. Irrigation infrastructure is therefore highly dependent on a reliable energy supply for pumping operations. In Ethiopia, on-grid electricity is the most cost-effective energy source for irrigation pumping when transmission infrastructure is available.
- Blended technology adoption for multi-purpose functionality. The irrigation infrastructure uses a combination of technologies (center-pivot, dragline sprinkler, drip irrigation) to support diversified agricultural production. The irrigation infrastructure forms part of a broader integrated farming system that combines crop and livestock production, poultry farming, greenhouse cultivation, and animal feed processing.

- Irrigation scheduling is guided by crop water requirements and practically implemented with the support of on-site irrigation technicians.
- **Higher Water Use Efficiency:** When properly managed, the pressurized system achieves application efficiencies of over 75%, significantly higher than the average 50% typical of surface irrigation.
- **Crop Diversification:** The infrastructure setup enables production of a wider range of crops, including high-value vegetables that may be difficult to irrigate with surface methods at a reduced labor input.
- **Climate Resilience:** Water is applied precisely according to crop needs, and this provides greater resilience to climate variability and drought conditions, a critical advantage in Ethiopia's variable rainfall environment.
- Focus group discussions and key informant interviews with the key actors highlighted that the Elfora Shallo–Melge farm benefits from its pressurized irrigation systems through higher water use efficiency, crop diversification, reduced labor, climate resilience, and compatibility with precision agriculture tools. These advantages position the farm as a model for scaling modern irrigation technologies in Ethiopia by solving the key challenges faced in the operation, specifically reliable power, irrigation automation, and treatment water quality, in which pressurized systems can be integrated with sensors, fertigation units, and automated scheduling for precision farming.



Figure 12. Center Pivot system at Elfora Shallo–Melge Irrigation Scheme.

photo: Zeleke Admasu/IWMI

Solar-powered pump irrigation with drip systems (smallholder-led)

Solar-powered pump irrigation systems equipped with drip irrigation, implemented in Oromia, the Central Rift Valley, Amhara, Sidama, and Southern Ethiopia, have effectively improved water-use efficiency and demonstrated practical irrigation service delivery in areas far from the electricity grid. This makes the technology highly suitable for emerging farmers producing high-value crops in off-grid locations. (Figure 13).

Key features in operation and maintenance

- Solar photovoltaic (PV) powered water pumps (diesel-free operation).
- Low-pressure drip irrigation delivers water directly to the crop root zones.
- Water savings of 30–60% compared to traditional surface irrigation.
- Reduced operational and maintenance costs.
- Suitable for shallow groundwater, rivers, and small reservoirs.
- Easily scalable through individual or cooperative ownership models.
- High water-use efficiency, increased cropping intensity, climate resilience, and lower greenhouse gas emissions.

Example: In Dore Bafana kebele of the Sidama region, 750 farmers (40% women) benefit from a 145kW solar-powered pumping system that aims to boost sustainable crop production. The system enables irrigation for up to 150 hectares of land (Figure 13).



Figure 13. Solar-powered irrigation system in the Sidama region of Ethiopia.

photo: UNDP⁶/2024

⁶Solar-Powered Pump System to Boost Irrigation for Farming Communities | United Nations Development Programme

5.3. South Africa

South Africa's irrigation landscape comprises a wide range of technologies operating under diverse agroecological and institutional contexts. Irrigation is critical for high-value horticultural production, commercial field crop systems, and smallholder livelihoods, particularly amid increasing water scarcity and rising energy costs. Irrigation technologies vary across production systems. Drip and micro-irrigation dominate in high-value horticulture, while center-pivot and large-scale sprinkler systems are widely used in commercial field crop production. Increasingly, these systems are integrated with digital monitoring tools (e.g., soil moisture sensors and weather stations), automated scheduling platforms, and energy-efficient pumping solutions, including solar and hybrid systems.

5.3.1. Stakeholder engagement and field visit

The South Africa stakeholders' engagement was facilitated by the IWMI office in Pretoria during the first week of March 2026. In Pretoria, consultations were held with the Water Research Commission (WRC), the Ministry of Agriculture (MoA), the Agricultural Research Council (ARC), and the Virtual Irrigation Academy (VIA). Academic stakeholders at the University of KwaZulu-Natal (UKZN) in Pietermaritzburg were also consulted, as UKZN hosts the SABI Chair. SABI is South Africa's premier irrigation and water-saving organization, providing technical support and promoting knowledge exchange, expertise, and innovation across South Africa and the broader African continent. The organization accredits irrigation designers and promotes water conservation and optimal irrigation practices in both agricultural and landscape settings. Field visits were further organized to the Tugela and Jozini irrigation schemes in the KwaZulu-Natal province, where discussions were held with irrigation engineers, scheme operators, and farmers.

5.3.2. South African irrigation scheme key features

Irrigation management in South Africa operates within a formal water allocation and licensing regime that requires measurement, reporting, and regulatory compliance. Consequently, system performance is closely linked to sound engineering design, effective operation and maintenance, and the integration of irrigation scheduling with energy and agronomic decision-making. Three broad categories of irrigators were distinguished:

- i. commercial farmers operating capital-intensive systems,
- ii. emerging and smallholder farmers adopting modern irrigation technologies, and
- iii. farmers operating within public and semi-public irrigation schemes (Serote et al., 2023)⁷.

These categories differ in terms of infrastructure quality, technical capacity, and institutional support, resulting in wide variation in irrigation performance and sustainability outcomes.

Commercial irrigation systems

Commercial irrigation systems are predominantly based on center-pivot and large-scale sprinkler technologies, particularly for field crops (Figure 14). These systems are increasingly equipped with soil moisture sensors, telemetry, and automated scheduling tools to improve irrigation precision, reduce over-application, and optimize pumping operations. Digital monitoring supports more efficient water use, reduces labour requirements, and enhances compliance with licensing and reporting requirements. In high-value horticulture, drip and micro-irrigation systems are widely adopted for citrus, grapes, and vegetable production. These systems enable the precise application of water and nutrients and are often integrated with fertigation. Although drip irrigation typically entails higher energy and filtration requirements, it delivers superior water productivity, improved yield stability, and enhanced product quality. Performance depends strongly on system design, professional operation, and routine maintenance, including filtration management and emitter monitoring.

⁷<https://doi.org/10.3390/agriculture13020246>



Figure 14. Center Pivot Irrigation at Vaalharts-Irrigation-Scheme in South Africa.

photo : Dennis Choruma/IWMI

Emerging and smallholder farmers and irrigation schemes

Emerging and smallholder irrigation systems in South Africa operate under mixed production and institutional arrangements, including individually managed plots and participation in irrigation schemes. Technology adoption includes drip kits, micro-irrigation, and portable sprinkler systems, primarily for vegetables and other high-value crops. Evidence indicates that irrigation schemes supporting emerging and smallholder farmers achieve better outcomes where modernization is accompanied by structured training, mentoring, and consistent technical advisory services. In better-performing schemes, trained irrigation managers can interpret soil moisture data and translate it into effective irrigation scheduling, resulting in reduced water losses and improved crop performance. However, in contexts with limited managerial capacity and weak extension support, digital irrigation tools are often underutilized or misapplied. Additional constraints include unreliable energy supply, pump breakdowns, inconsistent water delivery, and limited access to spare parts and repair services. These factors reduce the effectiveness and sustainability of irrigation modernization investments unless institutional and technical capacity strengthening is addressed alongside infrastructure provision.

Public or semi-public irrigation schemes

Public and semi-public irrigation schemes constitute an important component of smallholder irrigation infrastructure in South Africa (Figure 15). Where water user institutions are functional and management arrangements are effective, irrigation water distribution is more reliable and equitable, and scheme maintenance is more consistent. Conversely, weak governance and unclear operational responsibilities contribute to poor service delivery, delayed repairs, and low productivity. Ongoing rehabilitation and revitalization efforts focus on infrastructure upgrades (e.g., canal lining, pump replacement, and improved control structures), improved water measurement, and adoption of energy-efficient pumping solutions, including solar technologies. Long-term scheme performance, however, depends on strengthening management institutions, sustaining technical advisory support, and improving market linkages to ensure profitability and cost recovery.



Figure 15. Tegula irrigation scheme in the province of KwaZulu-Natal.

photo: Birhanu Zemadim/IWMI

Key features in operation and maintenance

A tale of two sectors defines current operations and maintenance practices in South Africa: commercial farms apply advanced technologies and management; most smallholder and scheme systems do not. This contrast is the primary driver of demand for a modernization-focused capacity-building program (Table 5 and 6).

Table 5. Key features in the operation and maintenance of commercial irrigation sectors.

Domain	Commercial sector practice	Performance outcome	Technology/tool used ⁸
Irrigation technologies	Center-pivots, linear move, travelling irrigators; drip	Water savings 30–50% vs flood; yield stability under drought	Netafim, Rivulis, local suppliers
Precision scheduling	Soil-moisture probes, weather-based controllers, automated loggers senseit+1	20–30% further water savings; optimized crop-stage application	AquaCheck, Sense-It, DFM Technologies
Digital decision support	SASRI MyCanesim: real-time field-specific irrigation scheduling for sugar canefarmers	Yield forecasting; SMS alerts; adopted by commercial and pilot small-scale growers	MyCanesim web/mobile platform
System efficiency	National WRC Framework: water-balance approach	Performance benchmarking; loss identification and targeting	WRC framework tools
Flow measurement	Electronic meters, SCADA systems	Accurate allocation; tariff basis; loss detection	Commercial metering suppliers
O&M practices	Proactive maintenance schedules; professional contractors	Extended asset life; 85%+ system uptime	Private maintenance firms

Key insight: Commercial irrigation systems are not experimental, they are proven at scale in South African conditions.

⁸The listing of a brand name is for reporting and not a recommendation of any brand or product

Table 6. Key features in the operation and maintenance of smallholder and public irrigation schemes.

System dimension	Current smallholder practice	Performance outcome	Gap from commercial O&M practices
Water application	Constant depth regardless of crop stage; no scheduling practice	Over-irrigation early season, under-irrigation at peak demand; yields 30–60% below potential	No access to SAPWAT, weather data, soil moisture tools, or extension support
Conveyance systems	Ageing concrete canals; no flow measurement at source/distribution/farm	Conveyance efficiency ≈40% vs design 85%; severe head-end/tail-end inequity	No metering; no performance diagnostics; reactive repairs only
Scheme utilisation	Limpopo study: ⅓ fully used, ⅓ partially, ⅓ idle	Capital stock under-utilised; farmers cite dilapidated infrastructure, no markets, insecure tenure	Infrastructure without operational support or market linkages
Rehabilitation outcomes	Sophisticated sprinkler/floppy/pivot systems were installed, then deteriorated within 2 to 5 years	"Build-and-abandon" cycle; repeated capital investment, no sustained performance	IMT transferred assets without O&M capacity, revenue model, or spare parts supply
WUA functionality	Study of 45 schemes: 28 claimed WUAs, only 1 functionally active; water fees paid by governments	No rule enforcement; no cost recovery; head-end capture; conflicts unresolved	A legal framework exists; local institutions lack governance, financial management, and conflict resolution skills
Extension support	Generic crop advice; limited irrigation-specific expertise	Farmers cannot adopt modern practices; scheduling tools are unusable without support	Extension officers not trained in irrigation water management, SAPWAT, or WUA facilitation
Gender & inclusion	Women, ≈67% of smallholder farmers, are more technically efficient, but have weaker market access and governance voice	Technical potential undermined by exclusion	WUA committee's are male-dominated; women lack formal training and decision-making power

Key insight: Smallholder schemes have received significant capital investment but minimal operational capacity-building. This is the central modernization failure.

5.4. Zambia

Modern irrigation in Zambia encompasses a range of technologies operating at different scales, from low-cost micro-irrigation kits for smallholders to center-pivot systems serving medium- and large-scale commercial farms. The most prominent technologies include drip irrigation systems, sprinkler and center-pivot irrigation, and solar-powered or motorized pumping systems that access surface and groundwater resources. Drip irrigation systems have attracted particular attention in Zambia due to their potential to deliver precise water application, reduce conveyance losses, and improve water productivity. Sprinkler and center pivot systems are more prevalent among commercial producers, benefiting from stronger access to capital, professional design services, and structured operation and maintenance regimes. Solar-powered irrigation systems have emerged as a promising innovation for reducing energy costs and enabling off-grid irrigation, though challenges remain in system sizing, groundwater sustainability, and technical maintenance. Table 7 summarizes the case studies and best practices in the Zambian irrigation sector.

Table 7. Summary of best practices in modern irrigation systems in the Zambian irrigation sector.

Thematic Area	Technologies Utilized	Best Practices & Innovations	Key Insight
Climate-Smart Agriculture (CSA)	Solar-powered pumps, drip irrigation kits, and mulching	Technology Bundling: Delivering irrigation with weather information and drought-tolerant seeds	High success rate when innovations are sold as a holistic package rather than solo
Community-Based Development	Low-cost weirs (simple & permanent), gravity canals	Farmer-to-Farmer Extension: Using lead farmers to demonstrate "simple weir" construction	Minimal CAPEX and zero fuel costs make this highly sustainable for remote provinces
Inclusive PPP Models	Bulk water pumping, center pivots, and hydrant systems	Three-Tier Governance: Smallholders pool land to access commercial-grade bulk infrastructure	Stabilizes income for smallholders while providing scale for commercial "hub" farms
Equipment Supply Chain	Solar PV, borehole pumps, digital Pay-As-You-Go (PAYG)	Localized Technical Hubs: Integrating repair services and spare parts within the supply chain	The "Repair Economy" is currently the biggest gap in the solar irrigation market
Labor & Efficiency	Manual suction treadle pumps, PVC piping	CBO Ownership: Community-based organizations (CBOs) manage maintenance and scheduling	Reduced watering time from 6 hours (buckets) to under 2 hours; a significant labour saver
Market Linkages	Treadle pumps, gravity-fed furrow, small motor pumps	Recouping Costs at Sale: Provision of irrigation infrastructure on credit, repaid via crop yields.	Outgrower models (e.g., COMACO) are the most scalable for reaching the "rural poor."

5.4.1. Zambian irrigation system key features

Low-cost drip irrigation system

One of the most widely documented case studies of modern irrigation in Zambia is the low-cost drip irrigation technology. International Development Enterprises (iDE) and allied development organisations have played a central role in introducing affordable drip kits, low-pressure sprinklers, treadle pumps, and plastic water storage tanks. These interventions aimed to enable irrigating high-value horticultural crops using shallow groundwater, surface water, or harvested rainwater. In Zambia, simplified drip systems enabled smallholders to transition from labour-intensive bucket irrigation to more efficient water application, reducing labour burdens while stabilising dry-season production. However, the sustainability of these systems depended heavily on training in system layout, filtration, routine maintenance, and basic repairs. Where such capacity support was absent, clogging, uneven water distribution, and system abandonment were common. A critical best practice emerging from these case studies is the bundling of technology dissemination with hands-on training, demonstration plots, and market linkages. Low-cost drip irrigation performed best where farmers had clear incentives to intensify production for local or urban markets, rather than subsistence consumption alone. This underscores the importance of integrating water management technologies with broader livelihood and market development strategies.

5.4.2. Supplier-led irrigation systems and after-sales support

Another important set of case studies in Zambia is the supplier-led irrigation development model, in which private irrigation companies such as Agrico and SARO provide not only equipment but also design, installation, and technical support services. Zambia hosts a growing number of irrigation equipment suppliers, including companies offering drip irrigation, sprinkler systems, center pivots, and solar pumping solutions. These suppliers are predominantly concentrated in the capital city and other major urban centers.

Case studies reviewed by Choruma et al., (2025)⁹ show that farmers participating in out-grower schemes or operating near urban centers benefit significantly from supplier-provided after-sales services, including system calibration, maintenance, and rapid access to spare parts. For example, commercial and emerging farmers linked to large irrigation suppliers reported reduced downtime and improved system performance due to timely technical assistance. The best practice emerging from these cases is the centrality of reliable operation and maintenance arrangements to irrigation sustainability. Supplier-led models are most effective when they include decentralised service networks, trained local technicians, and clear maintenance protocols (Choruma et al., 2025). Without these elements, even technically sound irrigation systems experience a rapid decline in performance.

5.4.3. Solar-powered irrigation and asset financing models

Solar-powered irrigation systems represent a rapidly expanding segment of Zambia's irrigation landscape, driven by declining photovoltaic costs and the high expense of diesel fuel. Solar irrigation packages typically include solar panels, submersible or surface pumps, and distribution systems that supply drip or sprinkler irrigation. These systems have been promoted through donor-supported asset financing programmes, including initiatives associated with the Millennium Challenge Corporation and commercial banks.

5.4.4. Motorised pump irrigation and farmer-led groundwater use

Best practices in motorised pump irrigation include basic training in irrigation scheduling, promoting efficient application methods, and collective water management arrangements for multiple users dependent on shared water sources. These findings point to the need for capacity-building interventions that go beyond hardware provision to address water governance and resource stewardship.

5.5. Nigeria

In Nigeria, modern irrigation technologies, including conventional impact and gun sprinklers as well as Center Pivot Irrigation (CPI), are increasingly being adopted. CPI systems are increasingly recognized in Nigeria, with over 20 documented projects, multiple units of varying capacities, and a total irrigated area of about 9,000 hectares. Investments are initiated by the Federal and State governments, often through the River Basin Development Authority, or by commercial agricultural enterprises. Commercial farm-owned CPI operations – including crop selection, irrigation scheduling, irrigation water application, and all other operations – are managed exclusively by the enterprise. The CPI system encourages all-year-round cultivation, optimizes crop yields, improves water management, and mitigates runoff and soil erosion commonly associated with traditional surface irrigation practices. The expansion of CPI in Nigeria represents significant progress toward the adoption of efficient, modern irrigation systems adaptable to diverse crops, thereby promoting higher water-use efficiency and environmentally sustainable practices.

⁹Choruma, D. J., Dirwai, T. L., Matchaya, G., Kasoma-Pele, W., & Mutenje, M. (2025). Exploring the smallholder irrigation equipment supply landscape in Zambia: a scoping review. *Discover Sustainability*, 6(1). <https://doi.org/10.1007/S43621-025-01370-Y>

5.5.1. Commercial center-pivot irrigation: the Nasarawa Sugar Company example

The Nasarawa Sugar Company (NSC) is an example of a privately managed, modern irrigation system focused on providing raw materials for industrialization. It also shows the efficiency and productivity that the private-sector-driven investment brings into the agricultural sector. It is a subsidiary of Dangote Refinery PLC., and a key part of the group's "Backward Integration Project" aimed at achieving sugar self-sufficiency in Nigeria. The 78,000-hectare site, which includes 665 ha of CPIs, in Tunga, Awe Local Government Area, Nasarawa State, is a strategic investment in Nigeria's irrigation expansion.

5.5.2. Operation and maintenance

The NSC gets its water from the River Benue, the second-largest river system in Nigeria. To manage such a large scale, the project employs modern irrigation infrastructure, including:

- **Pivot Irrigation:** automated Center-pivot system – 665 ha for the irrigation of sugar cane nursery fields.
- **Canals and Pumping Stations:** A network of canals distributes water across the 68,000-hectare site from the river. The canals are fed with high-calibre vertical turbine pumps. The first phase of the NSC, comprising 22,000ha, was completed in 2023.
- **Strong institutional support:** The NSC CPI systems are managed by a team of professionals trained and supported by the company. The NSC management committed significant investment to staff and manager training and skill acquisition for the irrigation systems as part of the company's backward integration strategy. This commitment to skill and professional development ensures that the management of NSC CPI and other irrigation investments continues to align with the company's aspirations.
- **Strategic and sustained investment in capacity building:** The NSC irrigation scheme set an example of efficient operation and maintenance of high-tech irrigation systems through strategic and sustained investment in training and skill acquisition of in-house managers and technical team.

Chapter 6

Successful Capacity-Building Models



6. Commonly Applied Capacity Building Models In The Irrigation Sector

Irrigation development, operation, management, and maintenance require a high level of information, technical knowledge, capacity, and proficiency. From institutional management structures to field-level activities, a range of professional and practical skills is essential for operators to ensure system efficiency and sustainability. However, in many cases, insufficient attention is given to equipping operators with the required competencies. Traditional gravity-driven surface irrigation systems are often perceived as simple. Yet, effective management of a gravity irrigation scheme involves far more than merely opening sluice gates and allowing water to flow through canals. Proper operation requires precise water allocation, hydraulic control, monitoring, maintenance, and an understanding of system dynamics to achieve equitable distribution and optimal performance. Similarly, the design, installation, operation, management, and maintenance of modern irrigation technologies require distinct skill sets.

Capacity building for experts and actors in irrigation systems refers to the process of strengthening the technical knowledge, practical skills, professional competence, and institutional capacities required to design, operate, manage, and maintain efficient and sustainable irrigation infrastructure. It goes beyond basic training by developing advanced expertise in areas such as irrigation engineering, water management, hydraulics, agronomy, soil-water-plant interactions, system diagnostics, digital monitoring technologies, and climate-resilient irrigation practices. However, the effective management of modern irrigation systems requires a broad range of personnel and complementary skills. The most commonly applied capacity-building models in irrigation development, management, and operation are described below.

Competency-Based Capacity Development Model (CBCD): The CBCD model focuses on imparting the precise technical skills and problem-solving abilities required to operate and manage advanced irrigation technologies. The training goes beyond knowledge transfer to developing competencies in irrigation scheduling, system maintenance, and water-saving practices using real-time data and decision-support tools. This model ensures practitioners are equipped to address contemporary irrigation management challenges with practical, demonstrable competencies that improve water-use efficiency and sustainability.

Systems-Based Capacity Development Model (SBCD): In the SBCD model, Irrigation management takes a holistic perspective, recognizing that irrigation performance depends on interactions within organizational, environmental, technical, and policy systems. Capacity development under this model enhances institutional frameworks, stakeholder collaboration, and adaptive management strategies to respond to complex, dynamic water resource challenges. By strengthening the systems and networks involved in irrigation governance and operations, the approach supports sustainable, scalable irrigation development that aligns with ecosystems and community needs. This model focuses on systems thinking across: People – Institutions – Policies – Infrastructure – Finance – Environment.

The Training-of-Trainers (ToT) Cascade Model: The ToT model is especially effective for scaling irrigation capacity development across large agricultural regions. In this model, master trainers receive comprehensive training in modern irrigation technologies and practices, who then train intermediate trainers, who subsequently train farmers or irrigation managers. This cascade facilitates the rapid dissemination of innovation and skills, building widespread proficiency in the installation, operation, and maintenance of irrigation systems. However, maintaining quality and consistency across layers is critical for achieving the desired impact. The method is a highly practical model for rapidly scaling irrigation competencies across regions.

Experiential / Demonstration-Based Learning Model: This model plays a crucial role in irrigation development by providing hands-on learning opportunities through farmer field schools, demonstration plots, and on-farm trials. This model helps farmers and irrigation practitioners to directly apply new technologies such as drip or solar-powered irrigation, test irrigation scheduling techniques, and observe water-saving benefits in real time. Such participatory and experiential approaches improve understanding, adoption, and adaptation of irrigation innovations appropriate to local conditions and challenges. Capacity is built through learning by doing.

As the focus of the FAO-IWMI assignment documented in this study is on strengthening the capacity of irrigation managers in water management within modern irrigation technologies, two successful and practical competency-based capacity-building models from South Africa and Zambia are presented here. These models highlight how capacity has been developed, who delivers the training, which competencies are prioritized, and why certain approaches have proven relatively successful while others have underperformed.

6.1. South Africa

South Africa's irrigation sector is characterised by relatively advanced technical capacity, professionalised service provision, and institutionalised training pathways compared to most countries in sub-Saharan Africa (Nhamo et al., 2024)¹⁰. Capacity building for modern irrigation technologies and water management has evolved over several decades, shaped by strong private-sector participation, formal water governance arrangements, and sustained investment in agricultural education and training. As a result, capacity development in South Africa extends beyond ad hoc project-based training to encompass structured professional qualifications, continuous skills upgrading, and compliance-oriented learning aligned with water regulations. Key capacity-building models that are common in South Africa are described below.

Professional certification and skills accreditation

South Africa's irrigation sector benefits from professional certification systems and skills accreditation mechanisms linked to industry bodies and vocational training frameworks. These certification pathways establish minimum competency standards for irrigation designers, installers, and technicians, contributing to consistent service quality and system performance. Certification requirements typically encompass system design principles, installation standards, safety considerations, and maintenance protocols. Best practices emerging from certification-based capacity building include aligning training content with industry standards and requiring periodic skills updates. These mechanisms promote continuous learning and adaptation to technological innovation, particularly as digital irrigation tools and automation become more prevalent.

Private-sector and industry-led capacity building

Private irrigation suppliers play a central role in capacity building through training embedded within equipment sales, installation, and maintenance services. Training commonly covers system operation, calibration, troubleshooting, and integration with monitoring tools. Empirical evidence suggests that supplier-led training is particularly effective when supported by decentralised service networks and clear maintenance agreements. Farmers and irrigation managers benefit from rapid access to technical expertise, reducing downtime and prolonging the lifespan of their systems. This model underscores the importance of recognising private-sector actors as core contributors to irrigation capacity development.

Continuous professional development within commercial farming systems

Commercial farming enterprises in South Africa often invest in in-house capacity-building through continuous professional development for irrigation managers and technical staff. This includes on-the-job training, exposure to new technologies through pilot trials, and participation in specialised short courses. Such investments are driven by the economic imperative to optimise water use, comply with regulatory requirements, and maintain competitiveness in export markets. A key lesson from this model is the value of linking capacity building directly to performance incentives. Where irrigation efficiency and compliance have clear financial implications, investment in skills development is sustained and strategically targeted.

Public extension and institutional capacity building

In South Africa, public extension services continue to play an important role in irrigation capacity building, particularly for emerging and smallholder farmers. While extension systems face resource constraints, targeted irrigation training programmes have been implemented to strengthen advisory capacity in modern irrigation technologies, water management, and compliance with water regulations. Successful extension-based models are characterised by collaboration with research institutions, private suppliers, and industry bodies. Such partnerships enhance the relevance and credibility of training content and facilitate knowledge exchange across sectors. The South African Irrigation Institute (SABI) is the recognised representative organisation of the irrigation industry in South Africa and, through its Irrigation Wise Academy, offers a broader range of irrigation training programs. The courses offered by SABI have been developed over more than 15 years and are aimed at both the agricultural and landscape irrigation industries and irrigation practitioners. Through a bi-monthly magazine issue (Figure 16), SABI shares irrigation knowledge to increase awareness of water conservation across agricultural, environmental, and broader public arenas.

¹⁰<https://doi.org/10.3390/AGRICULTURE14081218>



Figure 16. Bimonthly issues of SABI magazines sharing technical knowledge and news in irrigation.
Source: SABI Irrigation Design Manual 2025

6.2. Zambia

Supplier-led capacity building models, embedding technical training through irrigation suppliers

One of the most prominent capacity-building models in Zambia is supplier-led training embedded within irrigation equipment sales and installation processes. Private irrigation companies routinely provide basic training to irrigation managers and farmers at the point of system installation, covering system operation, routine maintenance, and troubleshooting. In some cases, this training is extended through follow-up visits and on-call technical support, particularly for commercial and emerging farmers located near urban centers. Empirical evidence suggests that this model is effective where training is iterative and supported by accessible after-sales services. Farmers linked to supplier-led outgrower schemes reported higher system uptime and better water management practices than those receiving one-off training sessions. A key lesson from this model is that capacity building is most effective when treated as a continuous service rather than a discrete event. Supplier-led models perform best when complemented by locally trained technicians, standardised maintenance protocols, and clear communication channels between farmers and service providers.

Public extension services: government extension services and irrigation training

Government extension services remain a critical, though constrained, vehicle for capacity building in Zambia's irrigation sector. Extension officers are often the primary source of technical advice for smallholder farmers. Where targeted training programmes have been implemented, often through donor-supported initiatives, extension officers have demonstrated improved advisory capacity and increased engagement with irrigating farmers. The principal lesson from public-sector capacity building is the importance of continuous professional development and curriculum reform. Irrigation training must be institutionalised within extension services, with explicit coverage of modern irrigation technologies, water management principles, and sustainability considerations.

6.3. Conclusions

Several cross-cutting lessons emerge from the experiences of South Africa and Zambia in capacity-building for irrigation managers. First, capacity building is most effective when it is embedded within formal institutions and professional networks that reinforce standards and accountability. Second, continuous learning and certification mechanisms are essential to keep pace with technological change. Third, integrating water governance competencies into technical training strengthens compliance and improves sustainability outcomes. Importantly, the successful models in South Africa and Zambia demonstrate that capacity building is not a standalone activity, but a core determinant of irrigation system performance. Skills development, institutional arrangements, and regulatory frameworks jointly shape the effectiveness of modern irrigation technologies. These experiences offer valuable insights for the design of capacity-building guidelines under the FAO-IWMI programme. While not all institutional features are directly transferable, key principles—such as competency-based training, professional certification, supplier engagement, and collective learning through water institutions—can be adapted to diverse contexts. This is illustrated in Table 8.

Table 8. Priority capacity-building package in water management within modern irrigation technologies.

Package	Target learners	Core training content	Rationale
Technology Selection & Management	<ul style="list-style-type: none"> - Scheme managers - Planners - Technology suppliers - Maintenance technicians 	<ul style="list-style-type: none"> - Translating commercial best management practices (drip, pivots, precision tools) into fit-for-purpose packages (modular drip, low-pressure sprinklers, gravity systems, solar pumps). - Basic hydraulics and performance diagnostics: flow measurement, canal loss assessment, and conveyance efficiency calculation. - Irrigation scheduling: Crop water requirements, Soil moisture interpretation using sensors (Chameleon and Wetting Front Detectors). - Simple infrastructure condition assessment and prioritisation of repairs based on type and efficiency 	<ul style="list-style-type: none"> - Irrigation schemes are equipped with sophisticated technologies (pivots, sprinklers, drip). Capacity gaps exist to choose, operate, or maintain the system. - Systems deteriorate within 2-5 years post-implementation. - This package ensures technology matches local skills, energy supply (load-shedding context), and financial capacity, preventing the "build-and-abandon" cycle.
Irrigation Systems Operational Fundamentals	<ul style="list-style-type: none"> - Irrigation Technicians - Technology suppliers - Scheme managers - Planners 	<ul style="list-style-type: none"> - Practice-focused training modules on different irrigation systems (Pumps, Surface, Sprinklers, Center Pivot, Drip). - Design and installation methods. - Development of SOPs. - Good agricultural practices and irrigation water management based on different systems. - Maintenance management. 	<ul style="list-style-type: none"> - The gap in the technical capacity of technicians, managers, and users of irrigation systems requires practical training. - This package will explore the basics of design, installation, management, and maintenance of key irrigation systems.
WUA Governance & Financial Sustainability	<ul style="list-style-type: none"> - WUA committee members - - Scheme managers - Local government extension services - Traditional leaders and lead farmers 	<ul style="list-style-type: none"> - Legal literacy on water use and rights. - Organisational development: WUA formation/reform, inclusive decision-making, gender and youth inclusion protocols. - Financial management: O&M cost estimation, tariff setting for cost recovery, budgeting, transparent accounting, and audit basics. - Conflict resolution and rule enforcement: developing local regulations, mediation skills, and head-end/tail-end allocation fairness. - Data collection and record-keeping for accountability. 	<ul style="list-style-type: none"> - In most irrigation schemes, WUAs operate at a limited capacity. In out of the 45 schemes, 44 were functionally inactive; water fees were paid by the government, not farmers; there was no rule enforcement or cost recovery. - This package creates the institutional foundation for sustainable irrigation operation, which forms the most critical missing element in modernization efforts.

<p>Extension & Advisory Services for Modern Irrigation Systems</p>	<ul style="list-style-type: none"> - Extension officers - Scheme managers - District agricultural advisors - NGO facilitators - Lead farmer trainers - College instructors 	<ul style="list-style-type: none"> - Irrigation water management fundamentals: crop water requirements, growth-stage scheduling, water-yield relationships, water productivity diagnostics. - Promoting the use of weather data in scheduling operations, soil moisture tools, and decision-support platforms. - Planning and efficiency benchmarking for schemes. - FLID support: business literacy for farmer-investors, light-touch regulation for local authorities. - Organisational facilitation skills: supporting WUA development, peer learning networks. - Gender-sensitive extension and youth engagement strategies. 	<ul style="list-style-type: none"> - Extension services currently provide generic crop advice; officers lack irrigation-specific expertise and cannot support modern scheduling practices or WUA development. - Farmers apply constant depths across crop stages because extension cannot teach alternatives. - This package transforms the extension from a generic advisor to an irrigation modernization enabler.
<p>Smart irrigation systems</p>	<ul style="list-style-type: none"> - Irrigation Technicians - Technology suppliers - Scheme managers - Planners - Lead farmer trainers 	<ul style="list-style-type: none"> - Focus on the integration and management of components for smart operations – internet of things elements (sensors, microcontrollers and radio or internet connectivity) in irrigation systems .Explore key applications/software, data analytics, decision-making, and support systems. - Learn from best management practices on IoTs integration, operation and maintenance in modern irrigation systems. 	<ul style="list-style-type: none"> - The use of IoTs is considered high tech that only feature in large scale, automated systems. - Use the IoTs and smart solutions can improved efficiency, reduce human resources needs and enable optimum water and energy use thus improving overall economic productivity. - This package will train on the basic of smart, IoT solutions.
<p>Artificial Intelligence and Digital Technologies</p>	<ul style="list-style-type: none"> - Use of AI and Digital technologies in smart irrigation scheduling and optimization, precision and variable rate irrigation, - Development of a resource conservation approach to irrigation management using AI tools 	<ul style="list-style-type: none"> - Focus on AI-driven systems, such as IoT-enabled microcontrollers, that automatically adjust water flow in drip or pivot irrigation systems - AI algorithms for analyzing real-time soil data from soil moisture sensors, weather forecasts, and satellite imagery to calculate the exact amount of water needed, preventing over- or under-watering. - AI driven protocol for analyzing historical data, soil health, and current growth conditions, for yield forecast and agricultural planning outcomes, which allow farmers to adjust their water management for optimal quality and quantity. 	<ul style="list-style-type: none"> - The advances in AI is enhancing data, decision, and system operations. - The package will consider applicable AI and digital tools that support smart irrigation technologies for system optimization and precision resource management.

Annex. Focus Group Discussion (FGD) Guide – FAO–IWMI Project

Project	Development of Comprehensive Guidelines for Capacity Building for Irrigation Managers in Water Management within Modern Irrigation Technologies
Partners	FAO – IWMI
Region	Sub-Saharan Africa
Purpose	To collect stakeholder insights, experiences, and recommendations on the adoption, operation, and maintenance of modern irrigation technologies, and related capacity-building needs.

Group: Irrigation Managers and Extension Officers

Theme	Guiding Questions	Expected Insights / Responses	Facilitator Notes
Role & Experience	Describe your current role in irrigation management	Identify functions and levels of responsibility	Note overlaps with other institutions
Technologies	What modern irrigation technologies are in use or promoted?	Technology range and performance	Identify best-performing systems
Capacity	How adequate is your team's technical capacity?	Training needs and gaps	Explore prior capacity-building initiatives
O&M Planning	Are there structured O&M plans and budgets?	Practices, tools, and funding mechanisms	Identify strengths and weaknesses
Monitoring	How do you monitor system performance and efficiency?	Current M&E tools used	Note indicators and reporting systems
Collaboration	How do you coordinate with farmers and WUAs?	Cooperation levels, communication gaps	Note success factors
Challenges	What are your main operational or institutional challenges?	Barriers to efficient irrigation management	Identify recurring issues
Best Practices	Share successful irrigation cases or innovations	Identify replicable practices	Collect case examples
Recommendation	What should be included in the guideline for your group?	Preferred tools, content, and delivery.	Include training and digital tool suggestions.



photo: Freepik



CGIAR is a global research partnership for a food-secure future. CGIAR science is dedicated to transforming food, land, and water systems in a climate crisis. Its research is carried out by 13 CGIAR Centers/Alliances in close collaboration with hundreds of partners, including national and regional research institutes, civil society organizations, academia, development organizations and the private sector. www.cgiar.org

To learn more about this program, please visit:
<https://www.cgiar.org/cgiar-research-portfolio-2025-2030/policyinnovations>

Contact

Birhanu Zemadim, Deputy Country Representative and Senior Researcher – Water and Land Management, International Water Management Institute (IWMI), Accra, Ghana (Z.Birhanu@cgiar.org)



CGIAR

POLICY
INNOVATIONS

IWMI
International Water
Management Institute



Food and Agriculture
Organization of the
United Nations