In collaboration with
Koç Holding

WORLD ECONOMIC FORUM

Harnessing Digital Technologies for Smarter Water Management in Agriculture

WHITE PAPER

JUNE 2025

Images: Getty Images

Contents

Foreword 3

Executive summary 4

Introduction 5

1 Closing the gap in agricultural water efficiency 9

1.1 Monitoring and assessing water resource availability 11

1.2 Optimizing irrigation efficiency with smart systems 13

1.3 Strategic crop selection for water resilience 16

1.4 Leveraging technology to maximize rainwater harvesting 18

2 Building the foundation for digital water solutions in agriculture 19

2.1 Establishing data infrastructure for smart agriculture 21

2.2 Expanding connectivity in rural areas 24

2.3 Upskilling farmers to leverage digital technologies 24

2.4 Making smart agriculture affordable and scalable 25

3 Conclusion 27

Contributors 29

Acknowledgements 29

Endnotes 31

Foreword

Helen Burdett
Head, Technology for Earth, World Economic Forum

Tania Strauss
Head, Food and Water, World Economic Forum

Hatice Yıldırım
Digital Transformation Program Manager, Koç Holding

Today, 2.2 billion people lack access to safe drinking water. Up to 700 million people could be forced to relocate due to water shortages by 2030.[1] Increasing global temperatures, unpredictable weather patterns and the growing frequency of droughts further strain freshwater resources, disrupting food security and threatening lives and livelihoods.

These pressures reflect a deeper systemic challenge: the global hydrological cycle itself being disrupted, amplifying existing vulnerabilities and destabilizing ecosystems.

Agriculture accounts for over 70% of global freshwater withdrawals and plays a key role in addressing the global water scarcity challenge.[2] However, many agricultural systems still rely on outdated irrigation methods and inefficient water practices, making them more vulnerable to climate-induced disruptions and reduced agricultural productivity. Meeting these challenges calls for a transition from reactive water management to forward-thinking, data-driven approaches to improve resilience and sustainability over the long run. Digital solutions offer a chance to bridge this gap by facilitating real-time monitoring, predictive analytics and precision irrigation methods that enhance water efficiency on a large scale. Without digital transformation, agriculture risks falling behind in addressing climate-induced water shortages.

This report, in collaboration with Koç Holding, explores how digital technologies can advance agricultural water management. Through practical use cases and applied strategies, it showcases how artificial intelligence (AI), internet of things (IoT), remote sensing and other advanced technologies can work together to monitor water availability, optimize irrigation and guide crop selection strategies in agriculture. Drawing on the insights of industry leaders, academia and members of the World Economic Forum's Tech for Climate Adaptation initiative, Water Futures Community and Food Innovation Hubs, the report is designed to help decision-makers navigate the intricacies of water management under climate change pressure. To that end, it presents actionable insights grounded in lived realities rather than theoretical models, as well as tools to advance implementation strategies and guide investment, policy and collaboration initiatives across the agricultural landscape.

The integration of cutting-edge digital technologies with a well-defined, strategic, multi-stakeholder framework presents a promising avenue for enhanced efficiency in agricultural water management systems. By advancing robust data infrastructure systems, capacity building and coordinated regulatory initiatives, it is feasible to accomplish a notable decrease in water waste and improved efficiency in agricultural water management. Findings validate the importance of stakeholder engagement through collaboration and shared knowledge to build long-term resilience to future water stresses and shocks. Embracing this holistic approach creates the essential conditions for effective deployment of digital solutions, ensuring that technology, policy and operational expertise are aligned. By the conclusion of this report, policy-makers, business leaders and water management experts will be equipped with actionable recommendations to increase water efficiency, reduce waste and enhance sustainability, driving long-term water security for future generations.

Executive summary

Digital technologies offer a pathway to enhance agricultural water efficiency, unlock water resilience and support long-term climate adaptation goals.

The disruption of hydrological cycles as a result of climate change contributes to more severe and frequent droughts in certain geographies.[3] Inefficient water strategies further drain natural water resources and undermine food security, putting immense pressure on major freshwater consumers. Agriculture sits at the heart of the crisis. Although the sector accounts for the majority of global freshwater withdrawals, inefficient irrigation, outdated infrastructure and poor visibility into water availability have historically resulted in significant waste and reduced resilience.

Digital technologies pave the way for a transformative approach to optimize water use, minimize waste and build resilience against water scarcity across agricultural systems. By integrating digital tools and data analytics into agricultural practices, farmers can make better-informed decisions in real time, addressing critical inefficiencies in agricultural operations, for example through:

– **Monitoring and assessing water availability:** Satellite imagery, IoT sensors and AI-driven analytics can help monitor soil moisture, groundwater levels and drought risks in real time. These technologies improve the visibility of water resources, enabling farmers to make data-driven decisions regarding irrigation and drought preparedness.

– **Optimizing irrigation:** IoT-enabled precision agriculture, powered by AI-driven irrigation scheduling and remote sensing technologies, can minimize water waste through optimized irrigation practices while boosting crop yields.

– **Strategic crop planning:** AI-powered satellite imaging can analyse climate, soil and hydrological data to match the right crops to water availability. Farmers can select their crops strategically by aligning crop types with water supply levels.

– **Rainwater harvesting optimization:** With geographic information systems (GIS)-driven site selection, smart allocation decisions and predictive analytics, rainwater collection can be optimized through efficient capture, storage and distribution. Harvested rainwater can then be used more effectively by implementing advanced geospatial analysis, AI-driven monitoring and drones.

Key building blocks accelerate the implementation of digital solutions for long-term resilience:

– **Data infrastructure:** Building systems that achieve seamless data exchange among platforms, tools and stakeholders.

– **Broadband coverage:** Guaranteeing continuous data access in remote locations through robust digital infrastructure.

– **Digital upskilling:** Equipping farmers with the digital training and tools to comprehend and act on digital insights.

– **Affordable access:** Overcoming financial barriers with public-private partnerships, financial incentives and shared infrastructure models.

Water scarcity calls for urgent action at all levels. By implementing digital water solutions together, governments, agribusiness and technology providers can improve water efficiency, drive sustainable growth and secure long-term food production. Governments can foster enabling conditions through open-data regulations and infrastructure investment, while agribusiness and technology providers offer the tools, field knowledge and innovation required to scale-up the impact. Such public-private partnerships can accelerate access to advanced irrigation technology, increase digital literacy and lower technology expenditures for farmers. Continued collaboration at this level will unleash shared value, increase adoption and enhance water resilience in agriculture, ensuring that water and food ecosystems are sustainable and adaptable to climate change.

Introduction

Effective water management in agriculture is the key entry point to achieving water resilience amid climate-driven disruptions.

Droughts are intensifying in length, frequency and severity. Between 2000 and 2022, droughts grew in number and duration by 29% compared to the previous two decades.[4] This alarming trend is likely driven by human-induced climate change, turning what was once a natural component of Earth's climate cycle into a persistent threat to ecosystems, economies and communities.

Unlike sudden climate disasters, droughts unfold gradually and often go unnoticed until their impact is extensive. Their gradual onset masks their severity, which manifests only when food security, economic stability and ecosystems are already strained.[5]

By 2025, 1.8 billion people are likely to face what the Food and Agriculture Organization (FAO) calls "absolute water scarcity" and two-thirds of the global population is expected to be grappling with water stress.[6]

United Nations

4

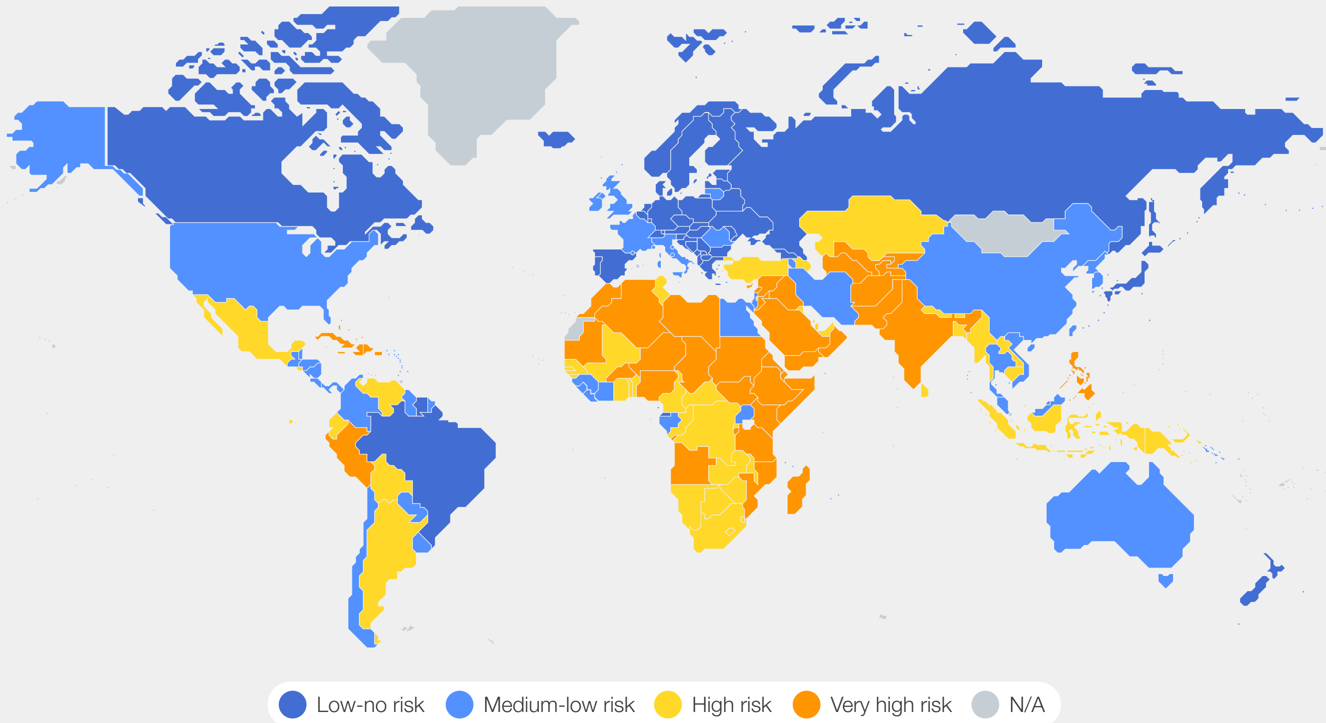
billion

people experience water stress for at least one month of the year

Four billion people experience water stress for at least one month of the year and countries with the fastest population growth are among the most impacted.[7] The World Bank estimates that global demand for freshwater will rapidly surpass supply, as growing populations, urbanization and shifting consumption trends drive up water withdrawals (see Figure 1).[8] Global water consumption is expected to increase by 20-50% over current figures by 2050, with industrial and domestic sectors growing at the highest rate.[9]

FIGURE 1 **Global water scarcity will intensify by 2050 as population growth accelerates demand**

Compound fertility and water stress



Note: This map overlays projected population growth with the availability of water by 2050.

Source: World Bank (2023).

While these recent shifts in natural cycles increase water scarcity, inadequate water management exacerbates the problem. Addressing the issue starts with a shared understanding of the key barriers to effective water use (see Table 1).

> **Over 32 billion m^3 of treated water is lost every year due to leaking pipelines and outdated distribution networks.**
> World Bank

TABLE 1 **Key barriers to effective water use**

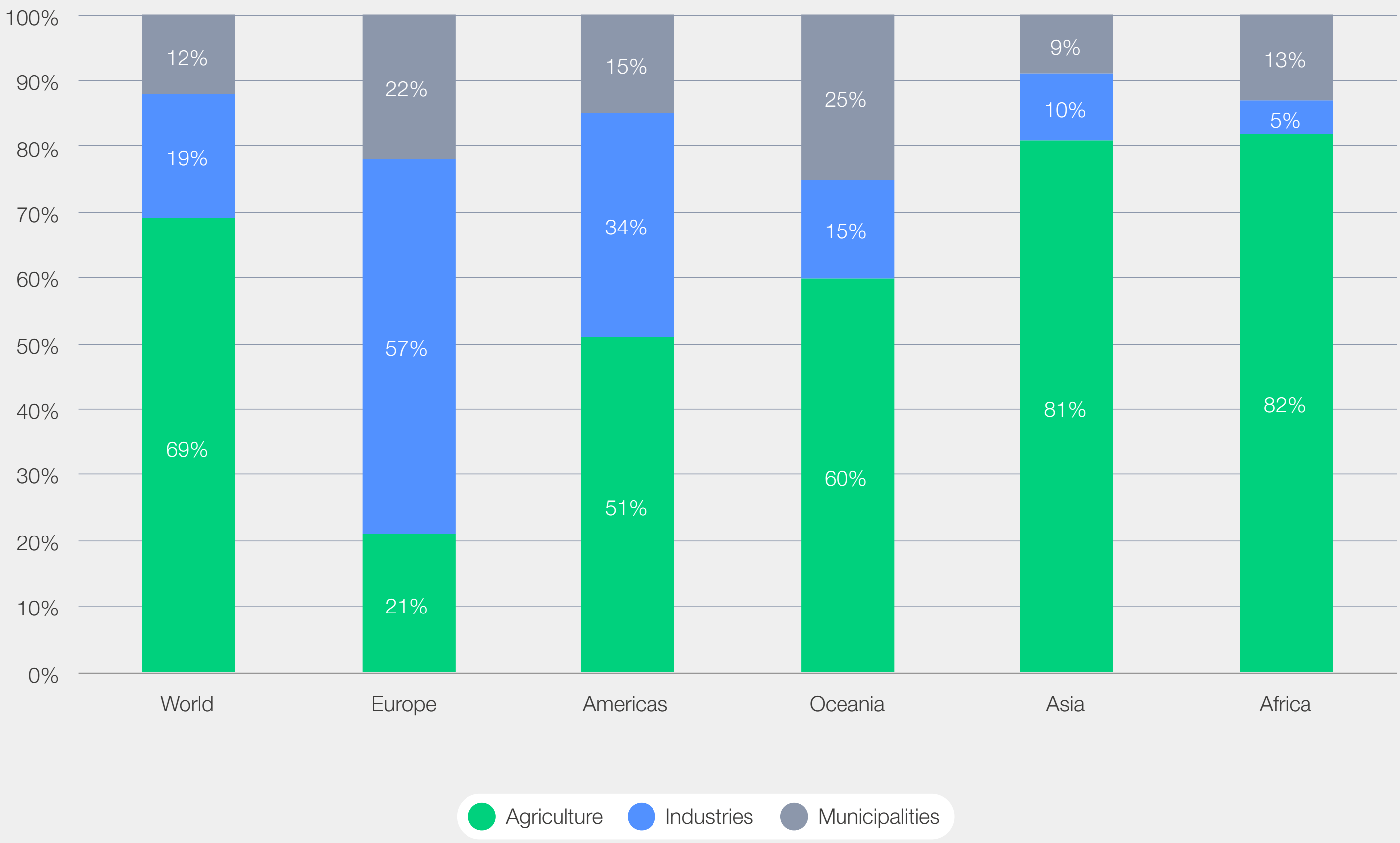
Challenge	Description
Ageing infrastructure	– A significant proportion of global water infrastructure was built decades ago and is currently unable to satisfy the demands of growing populations and climate variability. – The World Bank estimates that over 32 billion cubic metres (m^3) of treated water is lost every year due to leaking pipelines and outdated distribution networks.
Overextraction and groundwater depletion	– Overextraction of groundwater leads to land subsidence, making water management more complicated. – Global water withdrawals, driven mainly by overextraction through agriculture, have outpaced population growth over time. – Aquifers are being depleted more rapidly than they can naturally recharge, jeopardizing long-term water availability.
Pollution of freshwater resources	– Water pollution worsens scarcity by diminishing the volume of freshwater resources accessible for use. – Agricultural runoff, filled with pesticides and fertilizers, is a leading contributor to water pollution. – Industrial discharges containing untreated wastewater further degrade water quality, leading to hotspots with unusable resources.
Uncertainty from climate change	– With climate change altering rainfall patterns and intensifying drought cycles, managers encounter major challenges in preparing for upcoming water demands. – These shifts disrupt natural hydrological cycles, impacting how water is stored, flows and replenishes. Systemic disruption amplifies uncertainty. – Conventional forecasting methods fall short in anticipating drastic changes, leaving regions ill-equipped for extreme events.

Sources: World Bank, Food and Agriculture Organization of the United Nations (FAO), Global Commission on Economics of Water (GCEW).[10]

Agriculture stands out as the primary driver of global water stress across most continents (see Figure 2), accounting for approximately 70% of global water withdrawals from rivers, lakes and aquifers.[11] For this reason, improving water management in agriculture is essential to ensuring long-run food security and addressing water scarcity.

FIGURE 2 **Global water withdrawals are primarily driven by agricultural demand**

Water withdrawal ratios by continent



Source: FAO (2021).[12]

Irrigation is the predominant form of water use in agriculture and a major source of inefficiency, as many farmers still rely on traditional irrigation techniques such as surface or sprinkler irrigation, rather than more efficient systems such as drip or subsurface irrigation.[13] Widespread traditional irrigation leads to significant water wastage, reaching up to 10 gallons per minute per acre (93.5 litres per minute per hectare), compared to 3-7 gallons per minute per acre (28-65 litres per minute per hectare) for alternative techniques like drip irrigation.[14]

In many developing regions, access to modern irrigation systems remains limited due to underinvestment in water infrastructure. Even in areas where such solutions are available, adoption remains limited and many irrigation systems are outdated and poorly maintained, resulting in water loss due to evaporation, runoff and seepage. Inefficiencies in irrigation can drive long-term degradation as well. For example, overextraction of groundwater for irrigation during prolonged drought has caused over 2,200 sinkholes across farmlands in Turkey's Konya Basin.[15]

> **Approximately 60% of the water used in agriculture is wasted because of inefficiencies in irrigation systems and infrastructure, resulting in waterlogging and salinization, which have diminished the productivity of nearly 50% of the globe's irrigated areas.**[16]
>
> Food and Agriculture Organization

10%

decline in agricultural yields in drought-affected areas

The increasing frequency of extreme weather events, particularly heatwaves and droughts, has also intensified weather instability and unpredictability, posing significant challenges for agricultural operations. In recent years, drought-affected areas have experienced a 10% decline in agricultural yields during severe weather conditions,[17] while uncertain climate patterns have already led to significant declines in yields for crops such as wheat, maize, rice and soybeans.[18] Such disruptions jeopardize the consistency of the food supply chain, resulting in economic instability for countries where agriculture is a key part of the economy.

By 2035, severe heat and water scarcity are expected to lead to yearly fixed asset losses ranging from $42-45 million for an average agribusiness firm depending on the emissions scenario, highlighting the urgent necessity for effective water management strategies.[19]

World Economic Forum

Digital tools offer a pathway to drive efficiency by enabling faster, more informed decisions across agricultural systems.

Conventional agricultural systems lack the adaptability to respond to this increasing climate variability. Critically, they overlook the role of natural processes such as infiltration and transpiration to help retain moisture and support an effective water cycle. These ecosystem functions are disrupted through land degradation or poor water management, causing increase in evaporation and runoff. In certain regions, local communities have created nature-based solutions (NbS) to contribute to water resilience, such as glacier grafting, which uses seasonal water storage and regulated meltwater discharge to decrease runoff and enhance groundwater recharge.[20] Embracing these approaches offers essential context for pinpointing where technology can be best positioned to complement them.

Digital tools offer a pathway to drive efficiency by enabling faster, more informed decisions across agricultural systems. Rather than replacing conventional practices, these solutions enhance them, making water usage more precise, adaptable and resilient. Digital solutions provide valuable insights for smarter water management in agriculture, for example:

- IoT-driven real-time tracking of soil moisture levels.
- AI-enhanced predictive analytics that optimize irrigation schedules.
- Satellite imaging and remote sensing that improve evaluations of water availability in freshwater resources.
- Automation and precision irrigation systems that ensure optimal application of water in agricultural fields.
- AI-driven crop planning models that assist farmers in choosing water-efficient crops tailored to specific climate and soil conditions.
- Digital monitoring that supports rainwater harvesting by pinpointing the best collection and storage techniques.

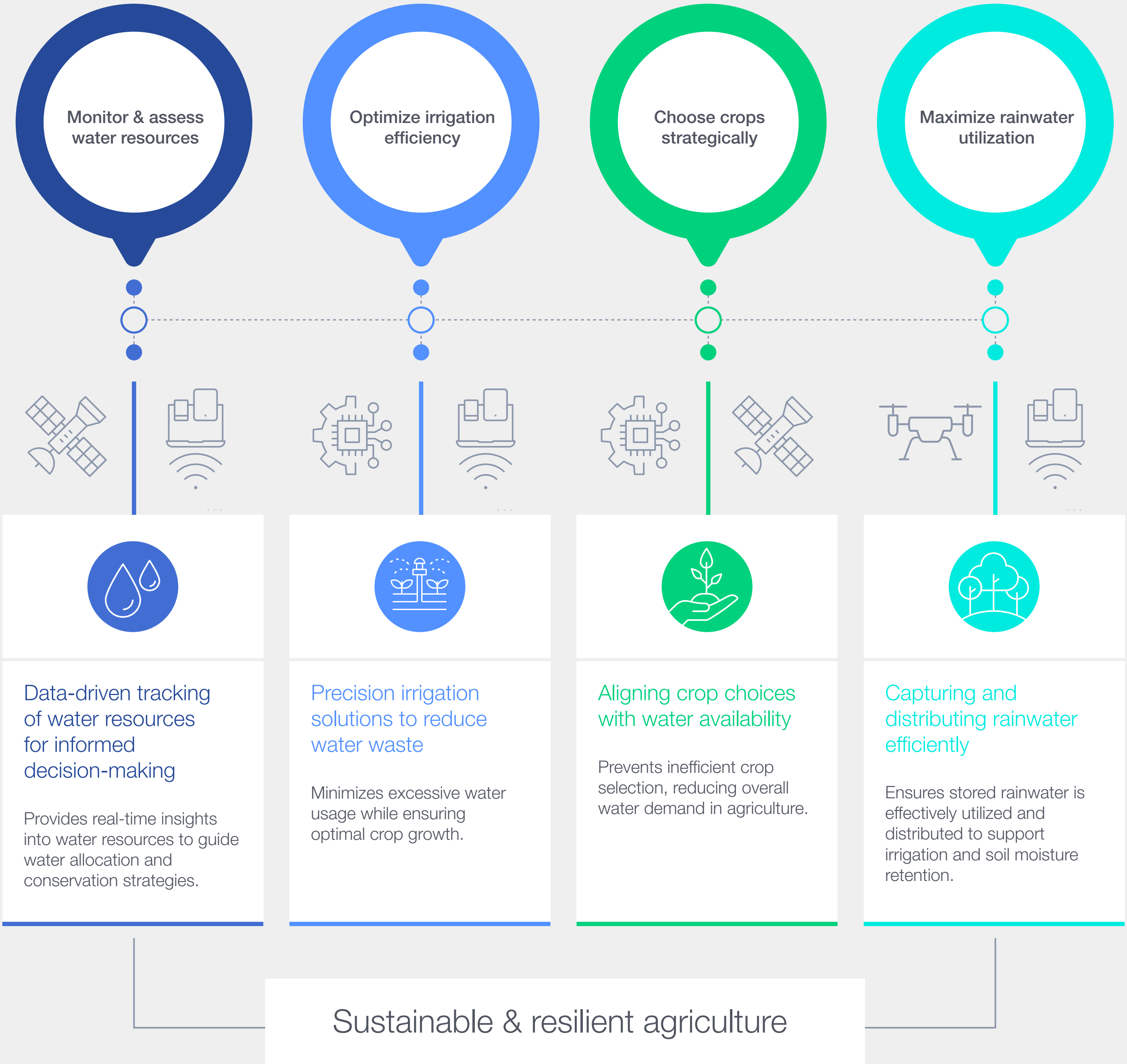
The integration of these technologies empowers agricultural operations to make informed, data-driven decisions, reduce water loss and build resilience in response to changing water availability.

1 Closing the gap in agricultural water efficiency

Digital technology unlocks significant efficiency gains in agricultural water use through targeted, scalable solutions across agricultural landscapes.

Effective water management in agriculture is vital since crop yields, food security and ecosystem longevity all depend on its outcome. As far-reaching impacts of climate change put crop production at tremendous risk, farmers must increasingly rely on smarter solutions to avoid depleting water resources. By leveraging digital technologies in irrigation, they can prevent water wastage while boosting crop productivity.

FIGURE 3 **Key strategies for optimizing water use in agriculture**



1.1 Monitoring and assessing water resource availability

Water usage in agriculture relies on precise water availability data. Without this information, irrigation planning and water management efforts fail to be effective, particularly in areas with limited water resources.

Temperature changes, extreme weather events and increasing water variability require the monitoring of water in real time to guarantee sustainable resource distribution. Surface water bodies (e.g. rivers, lakes, reservoirs) serve as primary water sources for agriculture, but their availability varies with seasonal changes and climate patterns. Soil moisture levels act as early indicators of drought and plant stress, directing water allocation decisions prior to the onset of noticeable harm. Table 2 showcases how digital technologies can measure water availability by tracking critical indicators.

TABLE 2 **Role of digital technologies in measuring water availability**

Key monitoring aspect	Technology used	Function	Decision-making impact
Tracking surface water availability	– Satellite imaging – GIS mapping	– Monitors changes in lakes, rivers and reservoirs	– Supports irrigation planning and water resource allocation
Measuring soil moisture levels	– Passive microwave satellites – IoT soil sensors	– Detects moisture variations in topsoil	– Enables early drought detection and optimized irrigation scheduling
Analysing water cycle patterns	– AI-driven time-series analysis	– Identifies anomalies in seasonal water trends	– Predicts water shortages and enhances climate resilience planning
Assessing water extraction needs	– Satellite-GIS integration – Algorithm-based assessments	– Evaluates surface water fluctuations and soil moisture trends	– Guides reservoir management and sustainable water use

Satellite imagery enhances broader water management initiatives by providing a dependable, real-time capture of water resources.

Satellite imagery offers a daily overview of surface water bodies, detecting changes in lakes, rivers and reservoirs. Satellite data, utilizing passive microwave sensing, also gauges soil moisture content in the top 10cm of the soil, forecasting water stress and drought susceptibility.

By combining satellite images with GIS mapping, algorithms can assess surface water changes. This enables operations managers to swiftly identify if streams are flowing or if lakes and ponds have receded. These understandings can guide extraction methods and support more informed allocation decisions – particularly when paired with real-time soil moisture data – ensuring that water is applied only when and where crops need it.

In Punjab, India, for example, scientists measured the rate of groundwater change by using data from NASA's twin GRACE (Gravity Recovery and Climate Experiment) satellites. The data revealed a dramatic loss of groundwater between 2002 and 2008, which has provided significant insights into groundwater depletion in the region.[21]

Satellite imagery enhances broader water management initiatives by providing a dependable, real-time capture of water resources – forming a basis on which to build digital agriculture solutions. Publicly accessible data platform initiatives, such as FAO WaPOR[22] and NASA SERVIR,[23] are of vital importance to highly data-scarce regions, by providing near real-time satellite data that supports water availability assessments. Satellite data can assist governments, utilities and agribusinesses in monitoring water resources and informing decisions on:

– Where to focus investments on irrigation infrastructure.

– When to implement drought contingency plans.

– How to optimize reservoir and groundwater usage.

Our daily satellite observations, combined with custom algorithms, allow us to detect changes in surface water extents. This information is critical not only for agricultural planning but also for ensuring that water is managed efficiently across entire regions.

Andrew Zolli, Planet Labs

CASE STUDY 1

NASA's satellite monitoring for sustainable groundwater management in California's Tulare Basin

Challenge

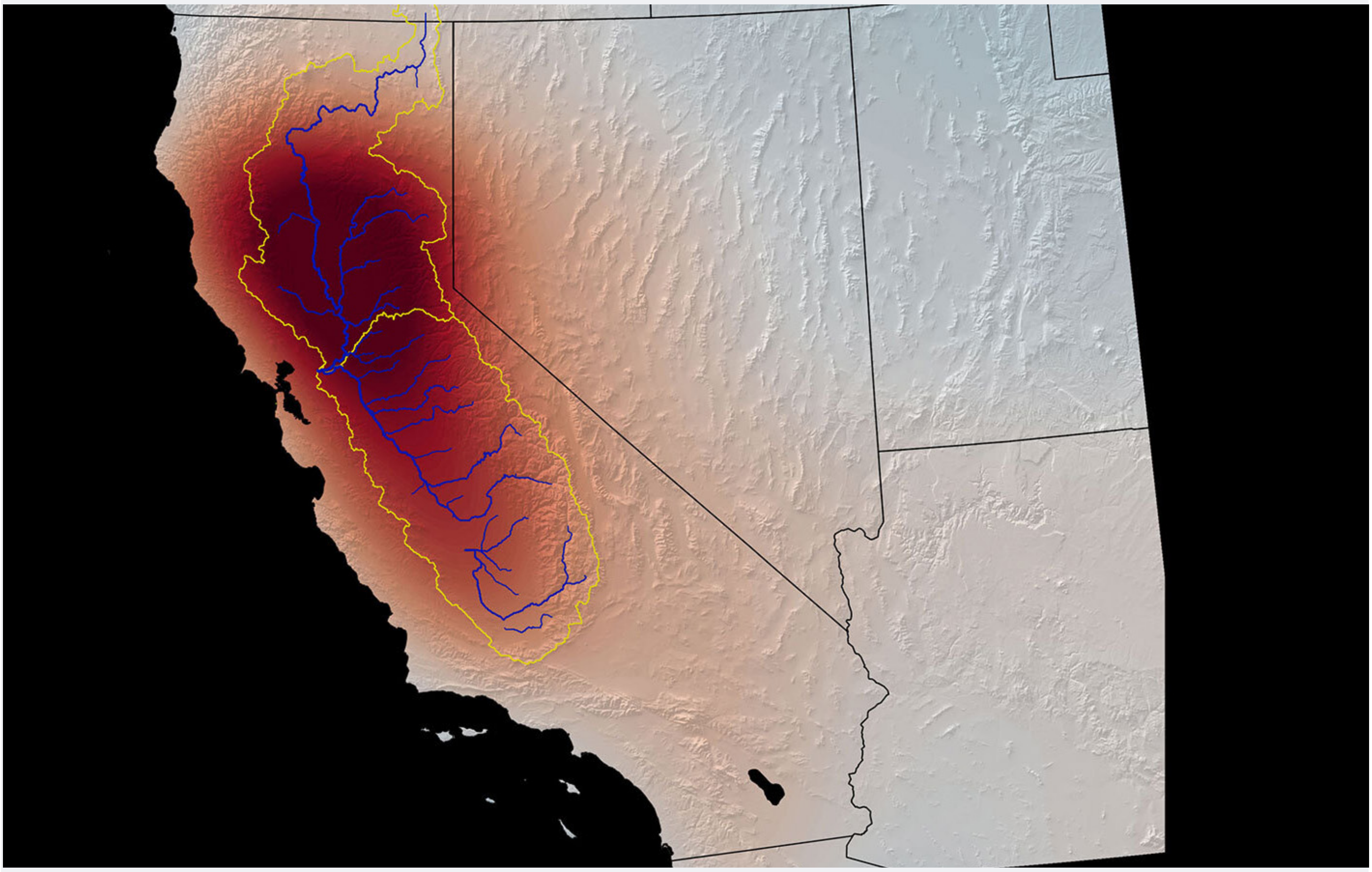
The Tulare Basin in California, a vital agricultural region within the Central Valley, has been experiencing significant groundwater depletion due to years of intensive irrigation practices. During drought periods, more than 80% of irrigation water is sourced from underground, exerting considerable pressure on water supplies. Farmers have resorted to drilling wells as deep as 3,500 feet (1,000+ metres) to access water; however, the lack of clear information regarding groundwater availability has complicated effective management. Conventional water monitoring techniques were unable to differentiate between water extracted from aquifers (which may not replenish) and water from the water table (which can be restored through rainfall). This gap in understanding resulted in inefficient water usage and irreversible land subsidence.

Solution

In response to this issue, NASA's Jet Propulsion Laboratory and the Lawrence Berkeley Laboratory of the U.S. Department of Energy developed a satellite-based approach to more accurately monitor underground water loss. This innovative method integrated:

- **US-European GRACE and GRACE Follow-On satellites** to assess overall changes in groundwater levels.
- **European Space Agency's Sentinel-1 satellite** to identify minor shifts in land surface elevation.
- **Numerical modelling of soil composition** to differentiate between water loss from aquifers and the water table.

By examining patterns of ground subsidence, researchers could ascertain whether water loss was temporary (resulting from seasonal pumping) or permanent (due to excessive extraction from deep aquifers). This provided farmers and policy-makers with real-time data to enhance groundwater sustainability.



Note: This map shows changes in the mass of water, both above ground and underground, in California from 2003 to 2013, as measured by NASA's GRACE satellite. The darkest red indicates the greatest water loss. The Central Valley is outlined in yellow; the Tulare Basin covers about the southern third. Extreme groundwater depletion has continued to the present.

Source: NASA/GSFC/SVS.

Implementation

- Researchers constructed a numerical model of the Tulare Basin's soil structure, distinguishing between rigid clay aquifers and more permeable unconfined soils that respond quickly to rainfall and pumping activities.
- By eliminating long-term subsidence trends, they developed a dataset that focused on short-term groundwater fluctuations, enabling precise monitoring of water movement.
- The model underwent validation through comparisons with weather events, GPS data and a limited number of well measurements, demonstrating its effectiveness in accurately locating underground water sources.

Impact

- Enabled farmers to differentiate between sustainable and unsustainable groundwater sources, facilitating improved water conservation strategies.
- Provided policy-makers with high-resolution groundwater monitoring, which is essential for the implementation of water regulations and recharge initiatives.
- Laid the foundation for global adaptation, as similar models can be applied in other agricultural areas experiencing groundwater depletion.

This case study highlights the potential of remote sensing, satellite data and numerical modelling to support data-driven water management decisions in agriculture, ensuring the long-term sustainability of critical water resources.

Source: NASA (2022).[24]

1.2 Optimizing irrigation efficiency with smart systems

IoT sensors detect when soil moisture levels fall below a threshold value to deliver the exact amount of water required.

Precision irrigation is a tech-based transformative approach in agricultural water management. The primary benefit of precision irrigation is to enable farmers to deliver the optimal quantity of water to crops, in the right location and at the desired time. Water is evenly distributed across the land surface by achieving precise delivery of water to the roots of plants. Efficient precision irrigation methods such as drip or micro-irrigation deliver much lower volumes of water, carefully calibrated to be sufficient for crops to grow, unlike conventional pop-up sprinkler systems where water is over-sprayed on plants in excessive volumes. Targeting precise water application to growing plants is critical to efficiently combat water scarcity. By integrating digital technologies into irrigation systems, farmers can optimize water usage and grow healthy crops across semi-arid regions.

Preventing inefficient water use through real-time soil monitoring

IoT sensors play a crucial role in precision irrigation as a key enabler of monitoring soil moisture levels. Real-time moisture data transmitted from these sensors to centralized platforms prevents farmers from over-irrigating. Sensors embedded into soil collect data on nutrient levels and crop health as well. For example, Yara's Water Solution is enabling farmers to track ongoing soil moisture and nutrient levels, assisting them in preventing over-irrigation while ensuring crop health.[25] By combining real-time data with historical weather data, evapotranspiration rates and crop requirements, AI-driven algorithms can forecast the water requirements of plants. Meanwhile, the early signs of water stress in crops can be detected by analysing these models, enabling proactive solutions to mitigate drought impacts and improve sustainability.

Automating irrigation to deliver water with precision

In addition to real-time soil and crop monitoring, IoT sensors are directly integrated with automated irrigation systems. In drip irrigation, IoT sensors are used to detect when soil moisture levels fall below a threshold value, automatically triggering smart valves and pumps to deliver the exact amount of water required. In this way, irrigation systems that are remotely controlled by IoT platforms can deliver water distribution that minimizes water waste and reduces human intervention.

Utilizing geospatial data to define irrigation zones

Remote sensing technologies, provided through satellite imagery and drones, provide detailed geospatial data across large agricultural fields. This high-resolution data consists of water stress conditions, crop health and soil moisture levels, which highlight the inputs required to deploy precision irrigation practices as efficiently as possible.

Farm-level irrigation planning based on water-stress assessments

Drones and satellites can capture high-resolution images of crops, which are then analysed with machine learning algorithms to enable farmers to target only those areas requiring water. Allocating resources to stressed zones leads to reduced water consumption without negatively impacting yields. Real-time maps showing soil types, topography, crop types and water requirements can be created by GIS platforms, merging data obtained from satellite and drones. Based on analysis of these maps, farmers can divide vast fields into separate irrigation zones, each having different water requirements. When GIS data is fed into precision irrigation systems, location-based decisions regarding where and how much water to apply can be swiftly made by pinpointing certain areas in need, making it easier to apply irrigation more efficiently across different areas.

> **With high-resolution thermal imaging satellites, we can detect crop water stress much earlier than conventional technologies. This allows farmers to optimize irrigation strategies before visual symptoms appear in the field, potentially reducing water usage by up to 30%.**
>
> Beate Tempel, constellr

Optimizing irrigation schedules for maximum efficiency

AI models can generate irrigation schedules across agricultural fields to provide optimized water usage for crops. The power of AI models in irrigation lies in their ability to adapt to changing environmental conditions by continuously learning from large data sets of historical irrigation events, weather forecasts and soil moisture levels. Processing real-time data from IoT sensors and remote sensing, AI can predict the optimal time and precise irrigation amount depending on local weather conditions and crop growth stages. For instance, AI-driven digital tools developed by ClimateAi can integrate crop types, soil conditions and historical weather data to fine-tune irrigation timing, diminishing water usage without sacrificing yield.[26] This predictive ability of AI prevents both under- and over-irrigation, fostering water conservation and crop health.

BOX 1

Digital platform for precision irrigation

GrowSphere™, developed by a global provider of sustainable irrigation solutions, is a precision irrigation management system focusing on optimized water usage in farming by incorporating real-time data, automation and remote access features. By integrating hydraulic, agronomic and operational data, the system enables farmers to make informed decisions that enhance irrigation efficiency and crop yield.

The system collects data from soil moisture sensors, weather stations and hydraulic sensors, channelling this data into a centralized platform which allows for:

- **Automated irrigation and fertigation** tailored to the specific water requirements of each crop type.
- **Remote control and monitoring** via a desktop and mobile interface.
- **AI-powered decision support** for optimizing irrigation schedules.
- **Notifications and anomaly detection**, minimizing water wastage stemming from leaks or inefficiencies.

Source: Netafim.[27]

CASE STUDY 2

AWS revolutionizes precision irrigation with AI and cloud computing

Challenge

Conventional irrigation techniques often depend on visual indicators of crop stress, which manifest too late for timely intervention. This results in either over-watering, which not only wastes freshwater but also heightens pollution risks, or under-watering, which diminishes yields and places additional stress on crops. A key challenge for many farmers is obtaining real-time, accurate soil data to enhance their irrigation strategies.

Solution

To tackle this issue, a leading agri-tech company has collaborated with Amazon Web Services (AWS) to create a cloud-based, AI-driven irrigation management system. This innovative solution combines real-time data from in-soil sensors with satellite imagery, weather forecasts and hydraulic models, facilitating data-driven water management decisions. AWS supplies the required computational power, scalability and secure data infrastructure to efficiently process and analyse extensive soil and climate data in real time.

Implementation

- **IoT-enabled soil sensors:** The agri-tech company has installed thousands of in-soil IoT sensors on farms globally. These sensors provide continuous monitoring of moisture levels, temperature and salinity, sending real-time data to AWS cloud servers.

- **AI-powered analytics on AWS:** The data gathered is analysed using machine learning algorithms hosted on AWS, enabling farmers to identify soil trends, forecast irrigation requirements and enhance water efficiency. The AI models consider factors such as crop type, soil composition, historical weather data and evapotranspiration rates to offer accurate irrigation suggestions.

- **Cloud-based decision support:** AWS serves as the computational foundation for the agri-tech company's digital platform, facilitating efficient data storage, real-time processing and secure access for farmers around the globe. The system consolidates various data layers, including topography, weather forecasts and satellite imagery, into a single, intuitive platform that can be accessed through mobile and web applications.

- **Automation and remote management:** The integration with AWS cloud services empowers farmers to manage irrigation systems remotely, decreasing dependence on manual labour while ensuring effective water distribution and resource management.

Impact

- **40% reduction in water usage** across various crop types, promoting sustainable water conservation.

- **10% increase in crop yields**, enhancing food security while maintaining sustainability.

- **Reduced fertilizer runoff**, helping to prevent soil and water contamination.

- **Lower operational expenses** by minimizing energy, labour and equipment requirements for irrigation.

- **Scalable implementation**, with over 9,000 sensors deployed across 1,200 farms worldwide, profiting farmers, agrochemical companies, irrigation equipment manufacturers and crop insurers.

The partnership between AWS and the agri-tech company highlights the potential of AI, IoT and cloud computing to enhance water efficiency in agriculture. By utilizing AWS's robust cloud infrastructure alongside the agri-tech company's advanced irrigation analytics, farmers are able to minimize water waste, optimize crop yields and respond effectively to climate variability. This case study illustrates the significant impact of digital technologies in upgrading irrigation practices and fostering agricultural resilience in a water-scarce world.

Source: AWS (2020).[28]

1.3 Strategic crop selection for water resilience

> Farmers can minimize water losses if crop types are aligned with rainfall patterns, soil composition and seasonal water availability.

Selecting the right crops in agriculture is a critical strategy to achieving optimized water usage, specifically in drought-prone regions. Farmers can minimize water losses if crop types to be produced are accurately aligned with environmental factors including rainfall patterns, soil composition and seasonal water availability. Digital technologies such as satellite-based crop modelling and AI-powered agronomic planning platforms now allow farmers to make these decisions with increased accuracy. Integrating data into crop planning enables informed crop choices to be made in advance, rather than responding to losses after they occur, promoting more sustainable production across water-scarce regions in the long run.

Matching crops to resources

AI-driven machine learning models examine historical climate data, soil conditions and water resources to recommend the most suitable crops for a particular area.

- **Drought-prone areas:** AI systems utilize climate models and evapotranspiration data to identify areas experiencing significant water stress. Based on the water scarcity level, AI might recommend sorghum, millet or chickpeas, as they require considerably less irrigation compared to corn or soybeans.

- **Saline or degraded soil:** Combining remote soil spectroscopy with electro-conductivity sensors, AI models can identify salinity levels. After being mapped, machine learning algorithms can match these soil conditions with crops such as quinoa and barley, which naturally endure high salinity and require less water compared to conventional grains.

- **High-rainfall zones:** AI platforms can evaluate regions experiencing heavy rainfall by analysing historical precipitation and hydrology data. By correlating crop needs with water table levels, AI can suggest water intensive crops such as rice, sugarcane and bananas to maximize yield. This enables optimal utilization of abundant water resources.

High resolution crop suitability analysis

Remote sensing technologies provide real-time, high-resolution data on soil moisture, terrain and plant health to guide smarter crop decisions. AI-powered satellite imaging can lead farmers to transition to less water-intensive crops utilizing real-time environmental data. For example:

- **In the Indian states of Punjab and Haryana**, groundwater depletion has been severe, driven in large part by the widespread use of flood irrigation in rice farming, which consumes excessive water. Mapping soil moisture levels with satellite imagery can highlight regions that are better suited for pulses and oilseeds instead, which require lower irrigation demand than rice cultivation.

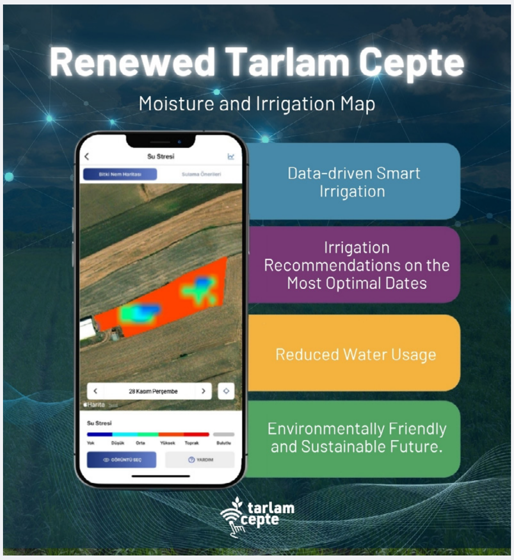
- **In drought-prone regions of California**, such as almond orchards in Central Valley, thermal emission and vegetation indices can be monitored via remote sensing. Using that data, farmers can identify feasible areas to transition into pistachios, bringing down their water footprint with more sustainability.

- **In North Africa**, where declining groundwater is at critical level, groundwater depletion mapping through remote sensing can guide shifts from wheat production towards drought-tolerant legumes such as lentils and chickpeas that thrive in arid climates.

BOX 2 | **Empowering farmers through advanced technologies**

Turkey's leading agricultural machinery manufacturer, TürkTraktör, developed a digital platform called "Tarlam Cepte" to help farmers make data-driven decisions. The platform provides moisture and crop water stress maps that allow farmers to effectively monitor fields and plant health. The system visually indicates water stress levels through colour coding, helping farmers address potential issues.

The platform uses satellite imagery, machine learning and AI to analyse real-time water-stress data and provide actionable insights. With over 170,000 users, it supports various agricultural activities, including satellite-based plant health monitoring, fertilizer and pesticide pricing, commodity exchange rates, water management in critical areas and a 24/7 agricultural chatbot, "Trakbot".



Source: TürkTraktör (2021).[29]

Key features and applications:

– **Plant water stress map:** Satellite data creates detailed plant health maps, highlighting water and moisture stress in leaves. For example, when a corn field has water stress, the platform notifies the farmer, helping them determine whether irrigation has been applied and if certain areas of the field have been over- or under-irrigated.

– **Irrigation recommendations:** Based on historical and real-time data, the application analyses user inputs (e.g. crop type, irrigation method, soil type) and gives data-based recommendations for the next irrigation cycle. AI models regularly update irrigation strategies based on satellite data, adjusting to dynamic conditions.

– **Agricultural notifications:** The application sends real-time notifications based on meteorological data, keeping farmers informed of essential agricultural activities to consider for their fields.

– **Corn yield prediction**: AI and machine learning analyse the number of corn cobs and seeds by capturing photos before harvest, providing approximate yield predictions.

By enabling farmers to track and manage water stress remotely, Tarlam Cepte helps optimize water usage. This approach demonstrates how digital technologies can enhance agricultural resilience to climate change while improving overall water efficiency.

1.4 Leveraging technology to maximize rainwater harvesting

By collecting rainwater from rooftops, fields and catchments, farmers can overcome dependence on groundwater and secure a resilient crop water supply.

Rainwater harvesting is a critical strategy to mitigate water scarcity and promote sustainable agricultural practices. Using the rainwater collected from rooftops, fields and other catchment zones, farmers can overcome dependence on over-extracted groundwater resources and secure a resilient water supply for their crops.

For example, "Bhungroo", a rainwater harvesting technology developed by Indian company Naireeta Services, filters, injects and stores excess stormwater in a large underground reservoir for later use by farmers. All the rainwater falling on a piece of land can be harvested in a Bhungroo, which would be sufficient to supply water to irrigate at least four times the area of the land used for harvesting. In January 2024, Bhungroo was awarded top innovator in the Zero Water Waste Challenge, launched by the Aquapreneur Innovation Initiative, a project of the World Economic Forum's UpLink with HCL Group.[30]

Digital technologies can improve rainwater harvesting further by optimizing key steps of the process. By utilizing AI, sensors, drones and satellites, rainwater harvesting has evolved from a passive collection method into a dynamic data-driven water management technique, ensuring enhanced efficiency, resilience and long-term sustainability. From collection to utilization, farmers can minimize wastewater and adjust to changing weather patterns, ensuring that collected water is efficiently stored and allocated.

Some critical factors for effective rainwater harvesting are highlighted below:

Site selection

- AI-driven geospatial analysis methods can be utilized for site selection. By processing GIS and satellite data, optimal locations for farm ponds, recharge wells and check dams used as rainwater harvesting structures can be identified.
- Runoff patterns and soil permeability can be predicted by implementing machine learning models. Ultimately, the aim is to ensure that rainwater infiltrates harvesting systems effectively without being lost as surface runoff.

Catchment monitoring

- By monitoring rainwater harvesting systems with drones, erosion-prone areas and sediment build-up can be detected through their thermal and multispectral imaging features.
- Drones can provide high resolution maps by surveying drainage pathways and vegetation cover over regions. These maps can be used to optimize bunds and retention structures.
- Early indications of leaks, clogs, cracks or deterioration in rainwater storage structures can be captured with automated drone inspections or AI platforms. IoT sensors installed in rainwater collection systems can monitor storage tanks, pipelines and filtration components.
- Providing immediate notifications to farmers minimizes water wastage and curbs operational interruptions.

Storage and distribution

- Smart storage tanks equipped with AI algorithms and IoT sensors can adjust water retention levels and prevent overflow.
- Water quality in storage tanks can be evaluated by AI-driven filtration systems that measure their suitability for irrigation, preventing contamination risk.
- Based on soil conditions, weather predictions and water demand of crops, automated water release systems can optimize when and where to distribute stored rainwater.
- IoT sensors can assess soil moisture levels, stages of crop growth and rates of water usage. AI powered platforms can utilize this data to determine which sections of the farm need harvested rainwater most, ensuring water goes to areas with the greatest demand.

Rainfall forecasting

- Satellite-driven climate models utilizing historical weather data and real-time atmospheric monitoring can provide precise rainfall forecasts, which alert farmers to adjust rainwater storage capacity ahead of storms.
- AI-driven cloud-seeding analytics measuring atmospheric moisture levels can suggest optimal conditions for artificial rain enhancement, particularly for arid regions.

2 Building the foundation for digital water solutions in agriculture

Deploying digital technologies in agriculture depends on strengthening system readiness through robust data infrastructure, capacity building and financing mechanisms.

Building resilience against water scarcity in agriculture requires a robust foundation of interconnected digital solutions that facilitate sustainable water management on a large scale. While digital technologies can enhance water efficiency, their long-term success depends on essential factors such as data systems, connectivity, farmer training and affordability. These building blocks form the backbone of impactful and scalable digital adoption. Figure 4 depicts this ecosystem, highlighting the components needed to successfully integrate digital tools into agricultural water management.

> **It's not enough to have AI and big data, we need an integrative framework where human expertise structures and contextualizes technology. Otherwise, we risk creating models that lack real-world adaptability.**
>
> Masatoshi Funabashi, Sony CSL

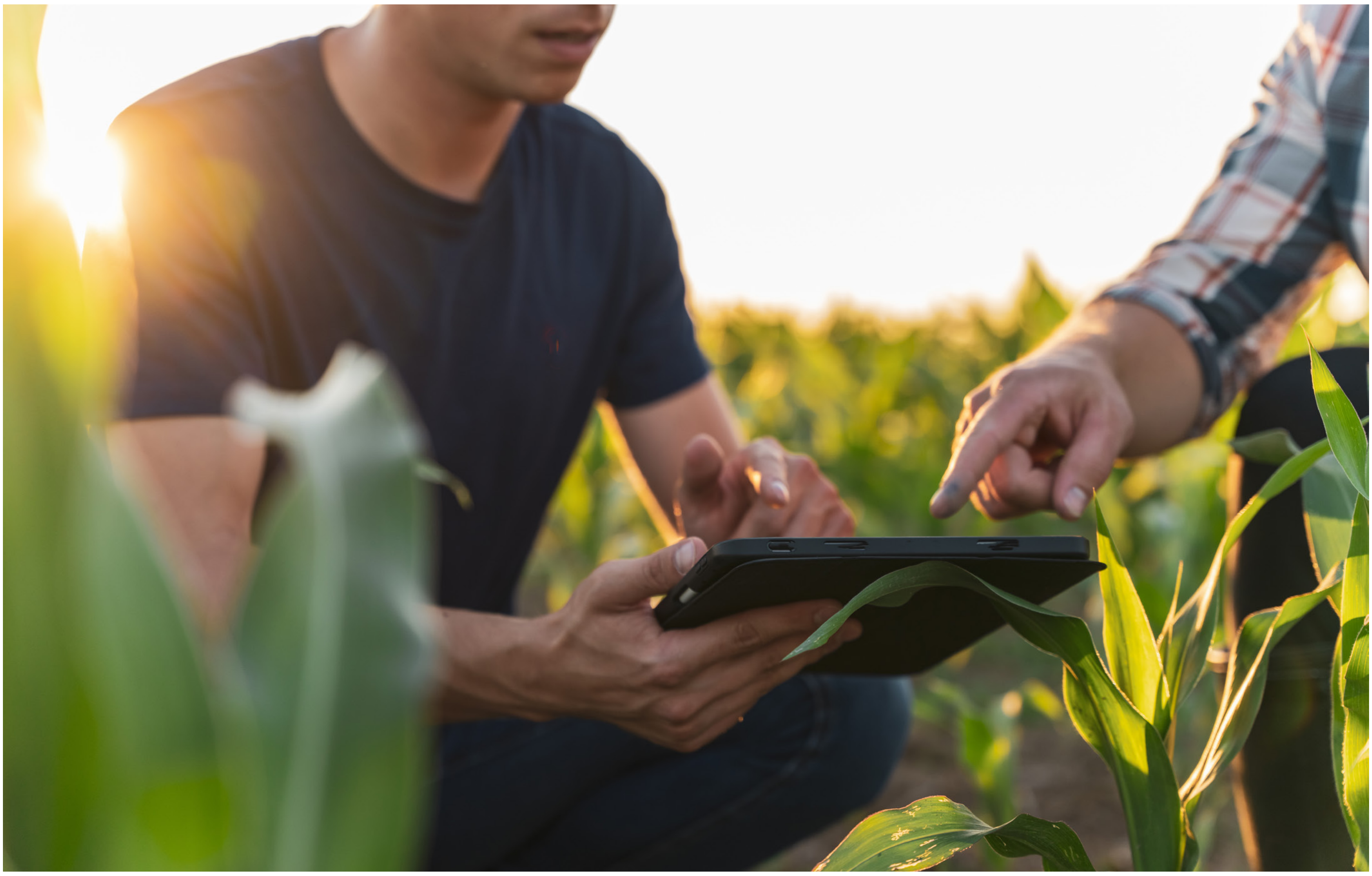


FIGURE 4 | **Building blocks for agricultural water resilience**

1

Key challenge:
Lack of accessible, high-quality public data.

- Build a multi-source data collection system
- Ensure accuracy & consistency
- Create standardized data-sharing frameworks
- Improve interoperability

Example
Kenya Agricultural Data-Sharing Platform enables real-time access to water, crop and weather data for farmers.

Example
Edge computing in India's irrigation projects allows real-time AI decisions without constant internet reliance.

2

Key challenge:
Weak internet infrastructure in remote farming areas.

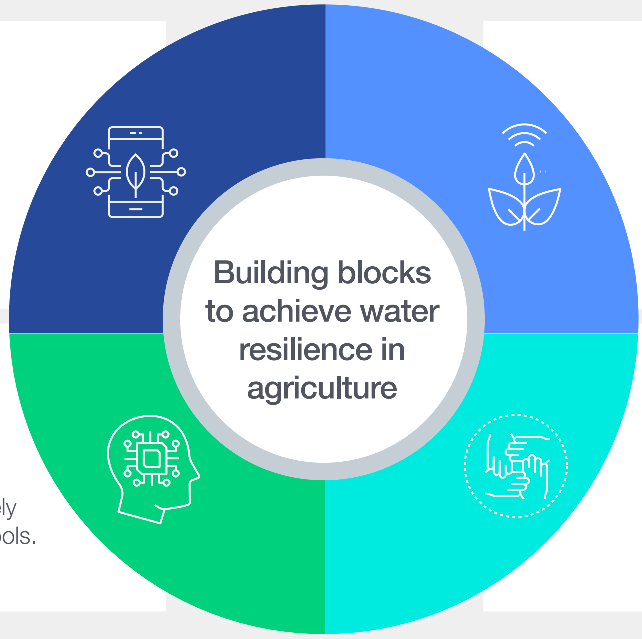
- Deploy LPWAN[1] & satellite-based IoT networks
- Adopt edge computing for offline analytics
- Invest in rural broadband expansion & cloud integration
- Encourage public-private collaborations for last-mile connectivity

Establish data infrastructure for smart agriculture

Lay the digital foundation for data-driven water management.

Expand connectivity in rural areas

Ensure seamless digital communication & data flow across farms.



Upskill farmers to leverage digital technologies

Build farmer capacity to effectively use smart water management tools.

Make smart agriculture affordable & scalable

Reduce financial barriers & drive widespread adoption of water-smart solutions.

Key challenge:
Low adoption due to lack of technical knowledge.

- Develop hands-on digital literacy programmes
- Create mobile-friendly training modules
- Establish farmer-led knowledge-sharing groups
- Integrate advisory services into public agricultural programmes

3

Example
Ethiopia's national soil & agronomy data-sharing policy integrates AI recommendations into farmer training.

Example
PepsiCo's Precision Conservation Management programme funds irrigation tech for farmers in Nebraska.

Key challenge:
High cost of IoT sensors & digital solutions.

- Introduce water credit mechanisms
- Develop shared infrastructure models
- Expand public-private financing programmes
- Scale-up modular, affordable IoT solutions

4

Note: 1. LPWAN stands for Low-Power Wide-Area Network, a type of wireless communication technology designed for long-range, low-data-rate communication between IoT devices.

2.1 Establishing data infrastructure for smart agriculture

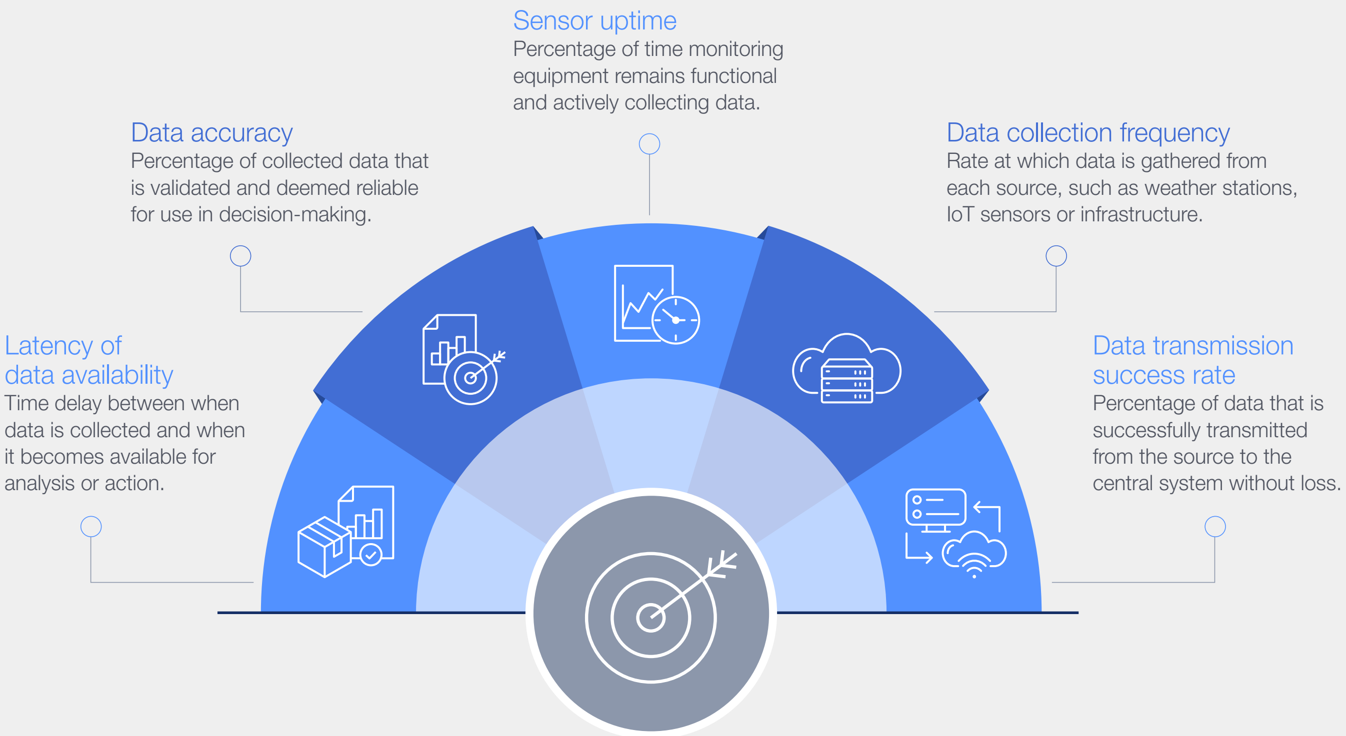
Implementing digital agricultural water management strategies demands a strong data ecosystem. These technologies cannot operate efficiently at scale without dependable data collection and integration processes.

Data collection

To achieve effective water management, data needs to be gathered from a variety of sources, including existing water infrastructure, weather stations, IoT sensors and satellites. Core data parameters include precipitation amounts, soil moisture levels, crop-specific data, groundwater levels and water consumption patterns. Relevant and up-to-date data gathering should be carried out in real time, enabling accurate monitoring of water conditions and overall operational performance.

The challenges to be considered are data inconsistencies across various data sources, data gaps in remote areas and possible downtime of sensors and monitoring equipment. The key performance indicators (KPIs) highlighted in Figure 5 can address these challenges.

FIGURE 5 **KPIs for agricultural data collection systems**



As pointed out in the World Economic Forum's March 2025 publication, *Water Futures: Mobilizing Multi-Stakeholder Action for Resilience*, developing shared metrics for defining and measuring success is significant for effective data governance.[31] Participatory methods play a key role in this process by addressing data fragmentation and enhancing coordination across water actors. Data ecosystems can be further strengthened through the integration of citizen science, which enhances local data granularity while embedding data equity principles to ensure that the voices of smallholder farmers and marginalized regions are reflected from the outset.

> **Farmers often assume they have enough local data to make informed decisions, but water systems don't operate in isolation. Understanding regional trends such as what's happening with groundwater or neighbouring farms requires integrating multiple data sources to get the full picture.**
>
> Arik Tashie, Climate Ai

BOX 3 **Bridging the gap with data-sharing policies**

The performance of digital technologies in agriculture depends on precise and detailed datasets involving soil health, hydrological charts, weather trends and water supply figures. In numerous regions, these datasets are often disjointed or only accessible by certain government agencies. Clear data-sharing policies and frameworks can help agri-tech firms, research organizations and farmers gain access to these datasets and use them to maximize water efficiency.

– **Kenya's Agricultural Data-Sharing Platform (KADP)** serves as a prime example of a shared data ecosystem in an agricultural landscape. The platform allows both private entities and government to have access to shared agricultural data categories encompassing crops, livestock, weather, soil, pest and diseases.[32]

– **India's Agricultural Data Exchange (ADeX)** is a collaborative initiative by the Government of Telangana, the Indian Institute of Science (IISc) and the World Economic Forum's Centre for the Fourth Industrial Revolution (C4IR) India, serving as India's first data exchange platform. This infrastructure enables secure data-sharing based on governance rules and a robust data management framework. The aggregated data is then used to develop new digital services for farmers, reducing the cost of data collection and service delivery.[33]

– **Ethiopia's Ministry of Agriculture** has created a national soil and agronomy data-sharing policy to enable a structured data-sharing framework in agriculture. In collaboration with the International Centre for Tropical Agriculture (CIAT) and GIZ Ethiopia, stakeholders consolidated dispersed datasets that were scattered across multiple institutions to provide fertilizer recommendations and guide farmers to optimize inputs that boost productivity on degraded lands.[34]

> Unified water analysis depends on integrating data from various sources, including historical records, IoT sensors and weather forecasts, into a single, accessible system.

Data integration

Once data is collected, it must be integrated into a unified and standardized system. Agricultural water management relies on data obtained from various sources including historical records, IoT sensors and external data such as weather forecasts. Creating a unified analysis of water resources depends on integrating these disparate sources into a single, accessible system.

The main challenge in data integration is handling the vast, unstructured amounts of data generated by IoT.[35] This calls for pre-processing and cleaning requirements before AI algorithms are used to extract meaningful insights. Some priorities include the following:

– **Data interoperability and portability:** The agrifood ecosystem exhibits limited interoperability and portability among its various data-driven tools and platforms, requiring farmers to engage with multiple platforms daily. Fragmentation of data sources (e.g. from satellites, IoT sensors, private data providers) makes integration difficult. The absence of standardized, machine-readable and openly accessible data makes interoperability across platforms more challenging.

– **Data quality:** In addition to relevance, data should meet a level of quality sufficient to support real-time decision-making. Ensuring data quality becomes harder when large-scale IoT deployments are required, as data must be rapidly processed to achieve real-time decision-making. Synchronized data must be cleaned and standardized to make sure its quality is at the desired level.

As described in the World Economic Forum's December 2024 publication, *Food and Water Systems in the Intelligent Age*, community engagement involving local farmers, researchers, extension workers, governments and water managers through mobile apps can play a significant role in providing manual data validation and feedback to achieve data efficacy.[36] Even though farmers might possess fundamental data regarding on-farm water usage, they often lack insight into wider hydrological patterns, including regional groundwater depletion, recharge rates and long-term impacts from climate change. In the absence of standardized, integrated datasets, evaluating risks and optimizing large-scale water usage becomes challenging.

AI-driven data integration tools can assist in addressing this challenge by consolidating, standardizing and assessing various datasets, such as satellite imagery, IoT sensor outputs and historical climate data. AI models, for instance, can enhance physics-based climate models by downscaling them, which improves long-term water forecasts and delivers insights tailored to specific locations. This functionality is especially valuable for anticipating extreme weather occurrences, monitoring variations in soil moisture and determining the best irrigation timings.

AI-driven risk assessment models can identify water-scarce regions for investment, guaranteeing that areas experiencing significant depletion or regulatory challenges receive focused support. Enhancing data accessibility and interoperability through digital infrastructure can connect on-the-ground decision-making with broader resource planning efforts.

> Through investment in digital infrastructure that enhances data interoperability, agriculture can shift from reactive to proactive water management.

Nonetheless, combining various data sources remains difficult, requiring both technical know-how and stakeholder collaboration. This underscores the importance of open-data platforms and collaboration across sectors to guarantee that farmers, policy-makers and investors can access practical insights. Establishing supportive governance frameworks and policy enablers, such as regulatory incentives for data-sharing, is critical to foster the adoption and influence of open-data platforms in agriculture.

Hybrid modelling methods, in which AI improves physics-based hydrological models, can assist in forecasting water supply, optimizing irrigation timelines and bolstering drought resilience. Through investment in digital infrastructure that enhances data interoperability, agriculture can shift from reactive water management to proactive, data-driven decision-making that brings advantages to both individual farmers and broader water basins.

Table 3 outlines key implementation approaches to build a robust data infrastructure in agriculture.

TABLE 3 **Strategies for robust data infrastructure in agriculture**

Implementation approach	Practical strategies and benefits
Standardized data frameworks	Establish common data formats and protocols to facilitate seamless integration and communication between multiple digital agriculture platforms, enhancing interoperability and usability.
Infrastructure for data-sharing	Develop data infrastructure that enables integration and sharing of data from various data owners, while complying with a set of binding governance conditions.
Decentralized data storage	Leverage blockchain or distributed cloud storage to secure agricultural data against loss or damage, ensuring consistent data availability in rural regions with unreliable connectivity.
Public-private data partnerships	Create open-data initiatives, fostered by supportive policies, that combine farmer-generated insights with satellite imagery, enabling more accurate agricultural forecasting, resource allocation and proactive decision-making.

BOX 4 **Data interoperability through agriculture data spaces**

The shift towards digital agriculture relies on accessible data, seamless integration and effective governance so that farmers and agribusinesses can make informed choices regarding water utilization, crop health and irrigation management. The fragmentation of data platforms leads farmers to operate with multiple, non-integrated systems.

To tackle this issue, various initiatives are creating shared digital environments – called "agriculture data spaces" – where farmers, agribusinesses, policy-makers and researchers can securely exchange data, while retaining control over how their data is used.

These frameworks, which are endorsed by a broader initiative of the European Commission[37] to promote common European data spaces in crucial sectors, seek to:

- **Standardize agricultural data formats** for smooth integration across various platforms.
- **Enable farmers to have data sovereignty**, ensuring they retain authority over their data.
- **Improve collaboration between agriculture and other sectors**, such as manufacturing, energy and logistics.
- **Promote trust and transparency** via blockchain-driven data-sharing agreements.

Agriculture data spaces enhance data access and interoperability, which streamlines precision irrigation, soil moisture tracking and predictive water utilization analytics, thereby making smart agriculture more efficient, scalable and accessible. Initiatives such as GEOGLAM (Group on Earth Observations Global Agricultural Monitoring) Crop Monitor[38] provide open, timely and science-driven classification schemes on crop conditions by leveraging Earth observation data to provide unified, interoperable and farmer-accessible data systems. Similarly, GODAN (Global Open Data for Agriculture and Nutrition)[39] promotes open sharing of agricultural and nutritional data to enhance informed decision-making across the value chain.

2.2 Expanding connectivity in rural areas

Numerous smart agricultural solutions rely on cloud computing, IoT networks and remote monitoring. However, inadequate connectivity in rural regions prevents large-scale adoption. Real-time data transmission becomes difficult without reliable broadband. A strong digital infrastructure is essential for digital tools to deliver actionable insights. This encompasses dependable connectivity, sufficient computational capacity and seamless data flow to turn raw agricultural data into decision-ready information. Table 4 highlights key digital solutions tackling connectivity gaps.

TABLE 4 **Potential technologies for better connectivity**

Technology	Low-power wide-area networks (LPWANs)	Satellite-based IoT connectivity	Edge computing
Advantage	LPWANs offer long-distance, low-energy connectivity, enabling IoT sensors in distant areas to send soil moisture, rainfall and crop health information without needing continuous internet access.	By linking remote farms to cloud platforms, unreliable cellular networks can be overcome for instant decision-making. This allows data-based agriculture in regions lacking current internet infrastructure.	Rather than depending on continual internet connectivity, edge computing handles data locally at the farm level. This means AI-generated insights can be provided instantly, even in offline settings.

Enhancing rural connectivity infrastructure requires considerable upfront investment, which often poses a challenge for private entities because of minimal short-term profits in remote agricultural regions. Public-private partnerships can mitigate investment risks and establish viable business models by merging public financial support or subsidies with private-sector innovation.

Emerging technologies such as edge computing demonstrate that focused, scalable investment can bring long-term benefits.[40] Advanced connectivity through data-driven water management not only boosts agricultural productivity but also promotes rural economic growth, making a strong rationale for multi-stakeholder engagement.[41]

2.3 Upskilling farmers to leverage digital technologies

Engaging farmers and rural communities in effective water management should consist of promoting and supporting the adoption of technologies that enhance water efficiency.[42] However, farmers require technical expertise to successfully implement digital water management systems. In the absence of training, even the most advanced technologies are not fully utilized.

> **The real challenge isn't just making data available; it's about turning that data into actionable insights that smallholder farmers can use in real time.**
>
> Minoo Rathnasabapathy, MIT Media Lab

> National free digital literacy programmes tailored specifically for farmers can help bridge the digital knowledge gap.

Digital literacy gaps in agriculture persist across many rural communities, which makes training and advisory services crucial for implementation.[43] Large-scale public initiatives can serve a pivotal role in accelerating this. National free digital literacy programmes tailored specifically for farmers can help bridge the digital knowledge gap, enabling both smallholders and large-scale farmers to effectively utilize AI-driven advisory platforms and IoT-based irrigation systems. Several regional and global initiatives are already advancing this agenda. For example, the Digitalisation for Agriculture (D4Ag) initiative advocates farmer-centred digital literacy building through customized training and tools.[44]

The role of public-private partnerships is critical in such initiatives, as collaboration among governments, agribusinesses and technology providers can facilitate the provision of open-access educational resources, hands-on training and user-friendly digital platforms for farmers. For instance, the Saagu Baagu pilot, developed in partnership with the Government of Telangana and Digital Green through the World Economic Forum's AI for Agriculture Innovations (AI4AI) initiative, has increased yields in the chilli value chain by 21% for over 7,000 farmers in the Khammam district by enabling digital agriculture focused on evidence-based learning and scalable impact.[45]

Table 5 outlines some key methods to provide farmers with the necessary digital skills.

TABLE 5 **Methods to equip farmers with digital skills**

Method	Targeted challenge	Training approach
Localized training initiatives	– Limited digital literacy among farmers. – Difficulty understanding and implementing complex digital water management solutions on-site.	– In-person workshops, mobile education units and farmer collectives designed to provide hands-on training, enabling practical experience with IoT sensors, AI-driven advisory tools and digital irrigation platforms.
Digital learning hubs	– Lack of continuous access to up-to-date technological resources. – Difficulty visualizing practical benefits of digital solutions.	– Community spaces featuring engaging digital modules, live sensor data displays and interactive dashboards. – These hubs facilitate regular access to technology demonstrations, enhancing familiarity with real-time data analytics in agriculture.
Farmer-led knowledge exchange	– Resistance to technology adoption due to uncertainty or risk aversion. – Limited dissemination of practical experience in local contexts.	– Establish collaborative peer networks where experienced farmers share practical insights, best practices and lessons learned from implementing digital water management technologies. – Peer-to-peer mentoring sessions can encourage greater trust and faster adoption rates.

2.4 Making smart agriculture affordable and scalable

Affordability is a major barrier for widespread adoption of digital agriculture, particularly for smallholder farmers. Without innovative financing and cost-sharing approaches, or clear policy incentives, scalability remains a significant challenge.

Common constraints include:

- **High upfront costs** of IoT sensors and maintenance.
- **Limited last-mile distribution and adoption** beyond high-value crops like fruits and vegetables.
- **Lack of incentives for farmers** to transition to efficient water use.

To unlock broader adoption, digital solutions should resonate with farmers' economic realities. Table 6 presents some strategies to lower barriers to adoption.

TABLE 6 | **Strategies to lower barriers**

Strategy	Method	Action	Impact
Water credit mechanisms	– Incentivize effective water usage through financial rewards, motivating farmers to implement precision irrigation techniques.	– Farmers receive financial incentives for conservation.	– Encourages adoption of water-efficient practices.
Public-private partnerships	– Fund digital solutions for water management through collaborations between government and private sector.	– Tech companies & governments subsidize IoT infrastructure.	– Lowers adoption cost for smallholders.
Blended climate finance	– Leverage concessional capital, guarantees, or results-based financing to de-risk investments in agricultural technologies.	– Financial institutions and donors co-invest to reduce upfront risks and encourage private sector participation.	– Unlocks larger-scale investment in agri-tech and supports inclusive adoption in vulnerable regions.
Shared infrastructure models	– Set up cooperatives for shared utilization of IoT sensors, irrigation systems and AI-based advisory services.	– Farmers jointly invest in shared digital assets, reducing individual costs.	– Boosts tech adoption, improves water efficiency and productivity.
Scalable IoT deployments	– Create modular, affordable sensor networks that farmers can implement gradually.	– Low-cost sensors adapted for rural settings.	– Expands access to data-driven irrigation management.

BOX 5 | **Index insurance enhances financial security for farmers**

Many smallholder farmers struggle to afford advanced technologies. Index insurance bridges this gap by providing financial safeguards against climate risks such as droughts and unpredictable rainfall. When specific indicators for rainfall or temperature hit defined thresholds, payments trigger automatically.

Leveraging satellite and historical climate data, insurers create cost-effective, tailored products that meet smallholder farmers' needs. This lowers administrative expenses and ensures timely compensation, allowing farmers to reinvest swiftly and adopt sustainable practices. Digital platforms and mobile technologies expand access even in remote regions. Farmers can receive fast payments directly to their phones, strengthening their resilience against adverse weather conditions.

Source: EOS Data Analytics.[46]

Public-private partnerships are essential for enhancing the accessibility of digital solutions to farmers. In Nebraska, US, a combination of government initiatives, industry collaborations and competition-based incentives has aided farmers in upgrading their irrigation systems:

- PepsiCo funds irrigation upgrades in Nebraska through the Precision Conservation Management programme, which incentivizes farmers to adopt computerized scheduling tools, telemetry and autonomous pivots.[47]
- The Nebraska Department of Natural Resources provides funding via the Surface Water Irrigation Infrastructure Fund to enhance irrigation systems, while the state's Natural Resources Districts supply monetary assistance for telemetry flow meters, soil moisture sensors and irrigation scheduling devices to optimize water management on farms.[48]

3

Conclusion

Targeted stakeholder engagement accelerates digital transformation and drives measurable results in water-smart agriculture.

Tackling water challenges in agriculture offers a significant opportunity to enhance both operational efficiency and long-term resilience. Effective deployment of digital technologies fosters smarter water management, assisting farmers in minimizing waste, enhancing yields and adjusting to shifting climate conditions. To unlock their full potential, stakeholders should collaborate on implementing strategies that integrate policy support, infrastructure development and investment, and farmer-centred innovation. These strategies rely on four implementation levers:

Lever 1

Build a robust data ecosystem

- Digital water solutions in agriculture rely on precise, real-time and compatible data gathered from various sources such as IoT sensors, satellite imagery, weather forecasts and on-farm inputs.
- Implementing standardized data-sharing platforms and edge computing technologies in rural regions will enable farmers and decision-makers to respond quickly to water availability, irrigation strategies and drought threats.
- Broadening access to hydrological datasets will significantly improve predictive analytics for sustainable water management.

Lever 2

Bridge the connectivity gap

- Digital water solutions depend on high-speed connectivity and dependable infrastructure; however, rural agricultural regions frequently encounter restricted broadband access and ageing water systems.
- The development of low-power IoT networks, satellite connectivity and cloud-based platforms will allow a greater number of farms to utilize real-time monitoring, precision irrigation and remote sensing technologies.
- Collaborations between public and private sectors will help finance scalable connectivity solutions to address this digital gap.

Lever 3

Empower farmers with digital upskilling and financial access

- The effectiveness of digital solutions in water management relies significantly on the willingness of farmers to adopt these technologies.
- Providing farmers with practical training, digital literacy initiatives and AI-driven advisory tools will encourage them to incorporate precision irrigation, rainwater harvesting and predictive analytics into their everyday practices.
- Financial incentives such as water credit systems, micro-financing options for IoT devices and pay-as-you-go irrigation schemes will help smallholder farmers overcome financial barriers and facilitate broader adoption.

Lever 4

Strengthen policies & partnerships

- Governments, agribusinesses and research institutions must collaborate to develop supportive policy frameworks for the adoption of digital solutions.
- Key actions include promoting climate-smart agricultural practices, incorporating water efficiency metrics into agricultural policies and setting regional benchmarks for water usage.
- Enhancing collaborations among multiple stakeholders throughout the food supply chain will encourage investment in scalable digital innovations.

Successfully implementing these measures at scale demands a multi-stakeholder approach, where each participant plays a vital role by taking the following actions.

Government agencies

- Create water management policies that promote precision irrigation, AI-based forecasting and digital water monitoring in the agricultural sector.
- Support the expansion of broadband and IoT connectivity in rural regions to enhance the implementation of data-driven agricultural practices.
- Enable access to agricultural and hydrological databases and standardize digital tools for water reporting.

Agribusinesses and technology providers

- Scale up IoT-based irrigation systems, AI-powered agricultural analytics and remote sensing technologies to enhance water efficiency on farms.
- Offer cost-effective and scalable digital solutions for smallholder farmers via pay-as-you-go options, water credit initiatives, or technology-driven cooperatives.
- Partner with governmental bodies and financial organizations to create sustainable business frameworks that promote the adoption of digital water solutions.

Farmers and cooperatives

- Utilize precision irrigation techniques, soil moisture monitoring and digital advisory platforms to improve water efficiency and crop management.
- Join data-sharing networks and participate in knowledge exchange programmes to strengthen resilience to drought conditions.
- Engage in farming networks to gain access to shared digital resources, funding opportunities and educational materials.

NGOs and multilateral organizations

- Implement capacity-building initiatives that equip farmers with training in digital literacy and strategies for adapting to climate change.
- Promote the establishment of regional benchmarks for water usage and regulatory frameworks to enhance digital water governance.

Water scarcity is a growing global emergency that extends beyond borders and sectors. It requires urgent, collective action before its effects become manifest. This report calls for a systemic transformation in how we manage water in agriculture, through engaging governments, private sector and civil society organizations to craft sustainable water policies. By tackling the challenges head-on and applying strategies to effectively manage water resources, the impacts of drought can be mitigated and a more sustainable future can be secured.

Contributors

Lead author

Ege Bilaloğlu
Fellow, World Economic Forum; Expert Business Analyst, Yapı Kredi Teknoloji, Koç Holding

World Economic Forum

Valentin Golovtchenko
Lead, Climate Technology

Ruth McLachlin
Lead, Climate Technology

Koç Holding

Ömer Coşkun
Digital Transformation Manager

Acknowledgements

Tech for Climate Adaptation Working Group, World Economic Forum

Ameekar Charan
Assistant Vice President, HCLTech

Masatoshi Funabashi
Research Director, Transboundary Research, Sony CSL

Max Gulde
Co-Founder and Chief Executive Officer, constellr

Dava Newman
Director, MIT Media Lab

Minoo Rathnasabapathy
Research Engineer & Program Lead, MIT Media Lab

Arik Tashie
Staff Data Scientist, ClimateAI

Beate Tempel
Vice President of Product Management, constellr

Andrew Zolli
Chief Impact Officer, Planet Labs

100 Million Farmers Community, World Economic Forum

Laura Gentry
Director, Water Quality Research, Precision Conservation Management

Koç Holding

Selin Orçunsel Güneri
Senior Specialist, TürkTraktör

Şebnem Güneş Söyler
Expert Data Scientist, KoçDigital

World Economic Forum

Shreejit Borthakur, Noopur Desai, Gill Einhorn, Abhay Pareek, Pepe Puchol-Salort, Federico Ronca, Jean-Philippe Salcedo

Production

Michela Liberale Dorbolò
Designer, World Economic Forum

Jonathan Walter
Freelance editor

Endnotes

1. United Nations Development Programme (UNDP). (2025). *At the core of sustainable development*: WATER. https://www.undp.org/water.
2. Worldometer. (2025). *Water Use Statistics*. https://www.worldometers.info/water/.
3. World Meteorological Organization (WMO). (2024, 7 October). *WMO report highlights growing shortfalls and stress in global water resources* [Press release]. https://wmo.int/news/media-centre/wmo-report-highlights-growing-shortfalls-and-stress-global-water-resources.
4. United Nations Convention to Combat Desertification (UNCCD). (2022). *Drought in numbers, 2022.* https://www.unccd.int/resources/publications/drought-numbers.
5. Intergovernmental Panel on Climate Change (IPCC). (2023). *Climate Change 2023: Synthesis Report.* https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_FullVolume.pdf.
6. United Nations Environment Programme (UNEP). (2024). *As shortages mount, countries hunt for novel sources of water.* https://www.unep.org/news-and-stories/story/shortages-mount-countries-hunt-novel-sources-water.
7. United Nations Children's Fund (UNICEF). (2025). *Water scarcity: Addressing the growing lack of available water to meet children's needs.* https://www.unicef.org/wash/water-scarcity.
8. World Bank Group. (2023). *Droughts and Deficits: The Global Impacts of Droughts on Economic Growth.* https://www.worldbank.org/en/news/immersive-story/2023/09/12/droughts-and-deficits-the-global-impacts.
9. Office of the Director of National Intelligence, United States Government. (2021). *The Future of Water: Water Insecurity Threatening Global Economic Growth, Political Stability.* https://www.dni.gov/index.php/gt2040-home/gt2040-deeper-looks/future-of-water.
10. Sources:
    - Kingdom, B., Liemberger, R., Marin, P. (2006). *The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries. How the Private Sector Can Help: A Look at Performance-Based Service Contracting.* World Bank Group. https://documents1.worldbank.org/curated/en/385761468330326484/pdf/394050Reducing1e0water0WSS81PUBLIC1.pdf.
    - Food and Agriculture Organization of the United Nations (FAO). (2010). *AQUASTAT - FAO's Global Information System on Water and Agriculture: Water use.* https://www.fao.org/aquastat/en/overview/methodology/water-use.
    - Global Commission on the Economics of Water (GCEW). (2024). *The Economics of Water: Valuing the Hydrological Cycle as a Global Common Good.* https://economicsofwater.watercommission.org/.
11. Food and Agriculture Organization of the United Nations (FAO). (2025). *Water: One Health.* https://www.fao.org/one-health/areas-of-work/water/.
12. Food and Agriculture Organization of the United Nations (FAO). (2021). *AQUASTAT - FAO's Global Information System on Water and Agriculture: Water use.* https://www.fao.org/aquastat/en/overview/methodology/water-use.
13. CANAMEK. (2023). *Agricultural Water Management: Challenges And Solutions.* https://canamek.ca/blogs/articles/agricultural-water-management-challenges-and-solutions?srsltid=AfmBOooiTh4UJrB3hg6JP9jGuN33xJfbwSrmk-t4blaSNVVp8A3hpH9R.
14. Jarrett, A. (2023). *Agricultural Water Needs and Sources Water Supply.* PennState Extension: https://extension.psu.edu/agricultural-water-needs-and-sources-water-supply.
15. Bouscaren, D. (2022). Massive sinkholes appear in farmers' fields in central Turkey due to climate change and drought. *The World.* https://theworld.org/stories/2022/01/14/massive-sinkholes-appear-farmers-fields-central-turkey-due-climate-change-and.
16. Food and Agriculture Organization of the United Nations (FAO). (2021). *Water and Food Security.* https://www.fao.org/4/x0262e/x0262e01.htm.
17. World Economic Forum. (2024). *The Cost of Inaction: A CEO Guide to Navigating Climate Risk.* https://www.weforum.org/publications/the-cost-of-inaction-a-ceo-guide-to-navigating-climate-risk/.
18. Heino, M., Kinnunen, P., Anderson, W. et al. (2023). Increased probability of hot and dry weather extremes during the growing season threatens global crop yields. *Scientific Reports*, 13, 3583. https://doi.org/10.1038/s41598-023-29378-2.
19. World Economic Forum. (2024). *Business on the Edge: Building Industry Resilience to Climate Hazards.* https://www.weforum.org/publications/business-on-the-edge-building-industry-resilience-to-climate-hazards/.
20. United Nations Development Programme (UNDP). (2023). *Glacier Grafting – An Indigenous Practice for Water Conservation* [YouTube video]. https://www.adaptation-undp.org/resources/videos/glacier-grafting-indigenous-practice-water-conservation-november-2023.
21. National Aeronautics and Space Administration (NASA). (2011). *Precipitation Education: India's Disappearing Water.* https://gpm.nasa.gov/education/videos/indias-disappearing-water.
22. Food and Agriculture Organization of the United Nations (FAO). (2025). *WaPOR, remote sensing for water productivity.* https://www.fao.org/in-action/remote-sensing-for-water-productivity/en.
23. National Aeronautics and Space Administration (NASA). (2025). *SERVIR (Regional Visualization and Monitoring System).* https://science.nasa.gov/category/missions/servir/.

24. Rasmussen, C. (2022, 5 April). *NASA Finds New Way to Monitor Underground Water Loss* [Press release]. Jet Propulsion Laboratory, National Aeronautics and Space Administration (NASA). https://www.jpl.nasa.gov/news/nasa-finds-new-way-to-monitor-underground-water-loss/.

25. Sources:
   - CropX. (2025). *The Complete Digital Agronomy Platform*. https://cropx.com/.
   - YARA. (2025). *Farmer's toolbox: Yara Water Solution*. https://www.yara.com.au/crop-nutrition/farmers-toolbox/yara-water-solution/.

26. ClimateAi. (2025). *Get ahead of tomorrow's extreme weather events today*. https://climate.ai/industries/agriculture/.

27. Netafim. (2025). *Automated Irrigation Management for small holders*. https://www.netafim.uk/digital-farming/digital-farming222/.

28. AWS. (2020). *CropX Runs Soil Sensor Application on AWS to Help Global Farmers Enable Sustainability*. https://aws.amazon.com/solutions/case-studies/cropx-case-study/.

29. TürkTraktör. (2025). *TürkTraktör Showcasing New Modern Agriculture Products at the Adana Agriculture Fair*. https://www.turktraktor.com.tr/about-us/our-news/2021/turktraktor-showcasing-new-modern-agriculture-products-at-adana-agriculture-fair.

30. World Economic Forum, Uplink. (2025). *Revolutionizing agriculture by preserving rainwater resources*. https://uplink.weforum.org/uplink/s/uplink-contribution/a012o000002he1SPAAY/revolutionizing-agriculture-by-preserving-rainwater-resources.

31. World Economic Forum. (2025). *Water Futures: Mobilizing Multi-Stakeholder Action for Resilience*. https://www.weforum.org/publications/water-futures-mobilizing-multi-stakeholder-action-for-resilience/.

32. Kenya Agricultural Data Sharing Platform (KADP). (2025). *Welcome to the Kenya Agricultural Data Sharing Platform (KADP)*. https://kadp.kalro.org/home.

33. ADeX, Government of Telangana and World Economic Forum. (2025). *Agricultural Data Exchange – ADeX: Unleashing Data to support sustainable and efficient Agriculture*. https://adex.org.in/.

34. International Water Management Institute. *New Ethiopian Ministry of Agriculture data sharing policy supported by WLE/CIAT and GIZ to improve food production while building landscape health*. https://archive.iwmi.org/wle/news/new-ethiopian-ministry-agriculture-data-sharing-policy-supported-wle-ciat-and-giz-improve-food/.

35. IoT Central. (2024). *Challenges of Artificial Intelligence and IoT Integration*. https://www.iotcentral.io/blog-all/challenges-of-artificial-intelligence-and-iot-integration.

36. World Economic Forum. (2024). *Food and Water Systems in the Intelligent Age*. https://www.weforum.org/publications/food-and-water-systems-in-the-intelligent-age/.

37. Sources:
   - Demeter. (2021). *How to Deploy a Real-World Agriculture Data Space*. https://h2020-demeter.eu/how-to-deploy-a-real-world-agriculture-data-space/.
   - European Commission. (2018). *ELISE - European Location Interoperability Solutions for e-Government: Glossary, European data space*. https://interoperable-europe.ec.europa.eu/collection/elise-european-location-interoperability-solutions-e-government/glossary/term/european-data-space.

38. Group on Earth Observations Global Agricultural Monitoring. (2025). *GEOGLAM Crop Monitor*. https://www.cropmonitor.org/.

39. Global Open Data for Agriculture and Nutrition. (2025). *Transforming Food Systems Through Open Data*. https://www.godan.info/.

40. Cameron, J. (2025). *Edge Computing in Agriculture and Smart Farming. Simply NUC*. https://simplynuc.com/blog/edge-computing-for-agriculture-and-smart-farming/.

41. Swansea Bay City Deal. (2025). *Rural connectivity: A catalyst for thriving farming*. https://digital.swanseabaycitydeal.wales/newsroom/2025/rural-connectivity-a-catalyst-for-thriving-farming/.

42. World Economic Forum. (2025). *Water Futures: Mobilizing Multi-Stakeholder Action for Resilience*. https://www.weforum.org/publications/water-futures-mobilizing-multi-stakeholder-action-for-resilience/.

43. Abate, G. T., Abay, K. A., Chamberlin, J., Kassim, Y., Spielman, D. J., & Tabe-Ojong, M. P. Jr. (2023). Digital tools and agricultural market transformation in Africa: Why are they not at scale yet and what will it take to get there? *Food Policy*, 116, 102439. https://www.sciencedirect.com/science/article/pii/S0306919223000374.

44. Digitalisation for Agriculture (D4Ag). (2025). *Digitalisation for Agriculture (D4Ag) – the intersection of digital innovations for agriculture; big data and analytics; innovative business development; and the enabling environment*. https://d4ag.com/.

45. World Economic Forum. (2024). *AI for agriculture: How Indian farmers are harvesting innovation*. https://www.weforum.org/impact/ai-for-agriculture-in-india/.

46. Elijah, R. (2023). *Index-Based Insurance: Types, Benefits, And Solutions*. EOS Data Analytics. https://eos.com/blog/index-based-insurance/.

47. "Autonomous pivots" are centre-pivot irrigation systems that can operate automatically using remote controls or pre-set programmes. They adjust water application based on real-time data such as soil moisture or weather, reducing the need for manual intervention. Source: Mitchell, L. (2023, 13 April). *PCM and PepsiCo Partner To Increase Conservation Adoption in Illinois, Kentucky and Nebraska* [Press release]. ILCORN. https://www.ilcorn.org/news-and-media/current-news/article/2023/04/pcm-and-pepsico-partner-to-increase-conservation-adoption-in-illinois-kentucky-and-nebraska.

48. Nebraska Department of Natural Resources. Water Today. *Water Tomorrow*. https://dnr.nebraska.gov/.

COMMITTED TO IMPROVING THE STATE OF THE WORLD

The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation.

The Forum engages the foremost political, business and other leaders of society to shape global, regional and industry agendas.

World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org