International Water Management Institute

Innovation Brief

Digital Twins for river basin water management

1. Introduction

Freshwater systems are vital to sustaining human life around the world, but when they are overused, polluted or impacted by extreme events such as floods and droughts, they can also threaten lives, livelihood security and ecosystems. In the face of climate change and pressures from urbanisation and overuse, freshwater systems must be intelligently managed.

Digital twins – virtual representations complex systems used to facilitate intelligent decision-making – offer a solution that has been applied in many industrial and urban settings (Figure 1).

For a digital twin to work in lower-to-middle income countries many barriers must be overcome, including: sparse and unevenly distributed water monitoring systems; limited resources for water monitoring; lack of technical capacity; large geographical footprint of water systems; and complex governance and socioeconomic contexts.

IWMI's Digital Twin for River Basin Water Management provides a single, modular ecosystem in support of overcoming these barriers. Unlike conceptual pilots, these tools are already operational in live deployments, such as the Limpopo River Basin Digital Twin in southern Africa, adopted by the Limpopo Watercourse Commission (LIMCOM) for transboundary water management and the Somali Region Digital Twin in Ethiopia, supporting humanitarian and climate resilience planning.

The Digital Twin framework delivers direct value to donors by enabling measurable progress toward SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals). It fosters resilience, strengthens cross-border cooperation and creates digital public goods that can be rapidly scaled to other regions The IWMI Digital Twin for Water

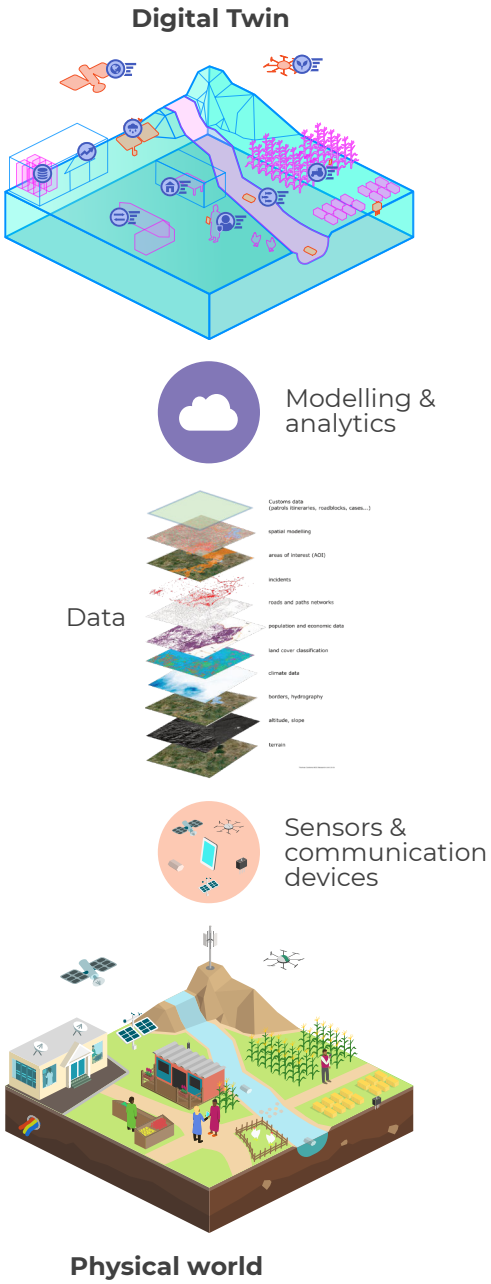

Figure 1. Illustration of Digital Twin for river basin water management (*source*: author's creation)

2. Approach

The IWMI Digital Twin for Water Management framework overcomes implementation barriers through:

i. **Co-design:** Working with end-users and stakeholders through structured co-design processes to ensure solutions address real-world decision making needs. This approach has shaped both the Limpopo and Somali Digital Twins, aligning tools with local governance structures and planning cycles.

ii. **Innovation:** Filling critical data gaps with a radically innovative mix of earth observation data, hydrological and machine learning models, drone-based mapping and citizen science. For example, in Limpopo, machine learning estimates reservoir volumes from satellite-derived surface area, while in Somali, flood maps are integrated with key infrastructure and access roads for pro-active response planning.

iii. **Interactivity:** Leveraging Artificial Intelligence (AI), 3D models, augmented reality and dynamic data visualisations to make science-based insights intuitive and accessible. AI Water Agents (WaterCopilot) integrate directly with live Digital Twin APIs, enabling natural language queries that return maps, charts and forecasts in seconds.

iv. **Inclusion:** Partnering with local organisations to build community capacity and incentivise participation in data collection and use. Initiatives like MiniSASS and Enviro-Champs link citizen science contributions to the Digital Twin in real time, with youth engagement supported by UNICEF Yoma's blockchain-based skills recognition.

v. **Enabling environments:** Deploying open-access datasets, documented methodologies and APIs within a responsible data governance and ethical AI framework, supported by HydraFound as the knowledge repository to ensure replicability and scalability.

Through this approach (Figure 2), Digital Twins are already operational and delivering value in the Limpopo River Basin in Southern Africa and the Somali Region of Ethiopia. These deployments demonstrate a highly flexible, modular solution with the potential to support complex water system management worldwide.

Potential applications include:

i. **Transboundary drought early warning systems** linking seasonal forecasts, reservoir modelling and citizen science to coordinate water availability planning.

ii. **Humanitarian planning dashboards** integrating real-time flood depth data, evacuation routes and infrastructure risk for disaster response in climate-vulnerable zones.

iii. **Agricultural water productivity monitoring** using satellite-derived evapotranspiration, AI classification of irrigated areas and the potential for scenario modelling for sustainable irrigation expansion.

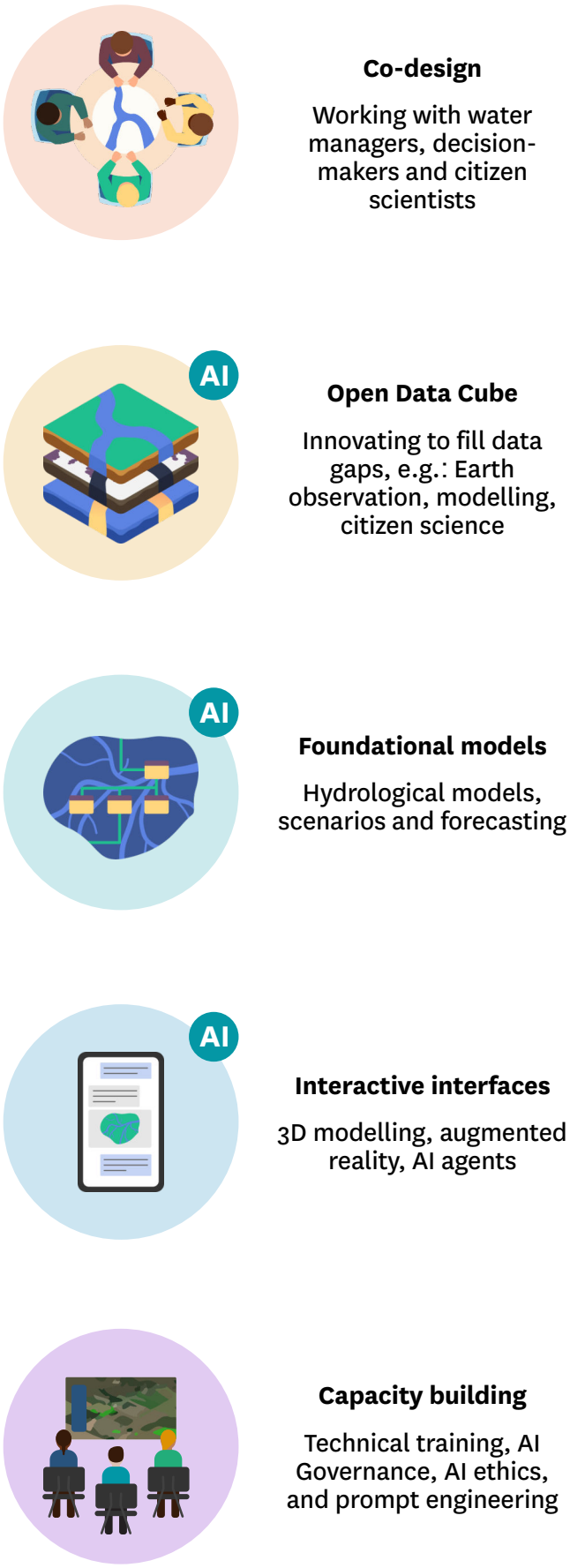

Figure 2. The IWMI Digital Twin for Water Management approach. (*source:* author's creation)

3. Impact

3.1. Limpopo River Basin Digital Twin for transboundary water management (Figure 3)

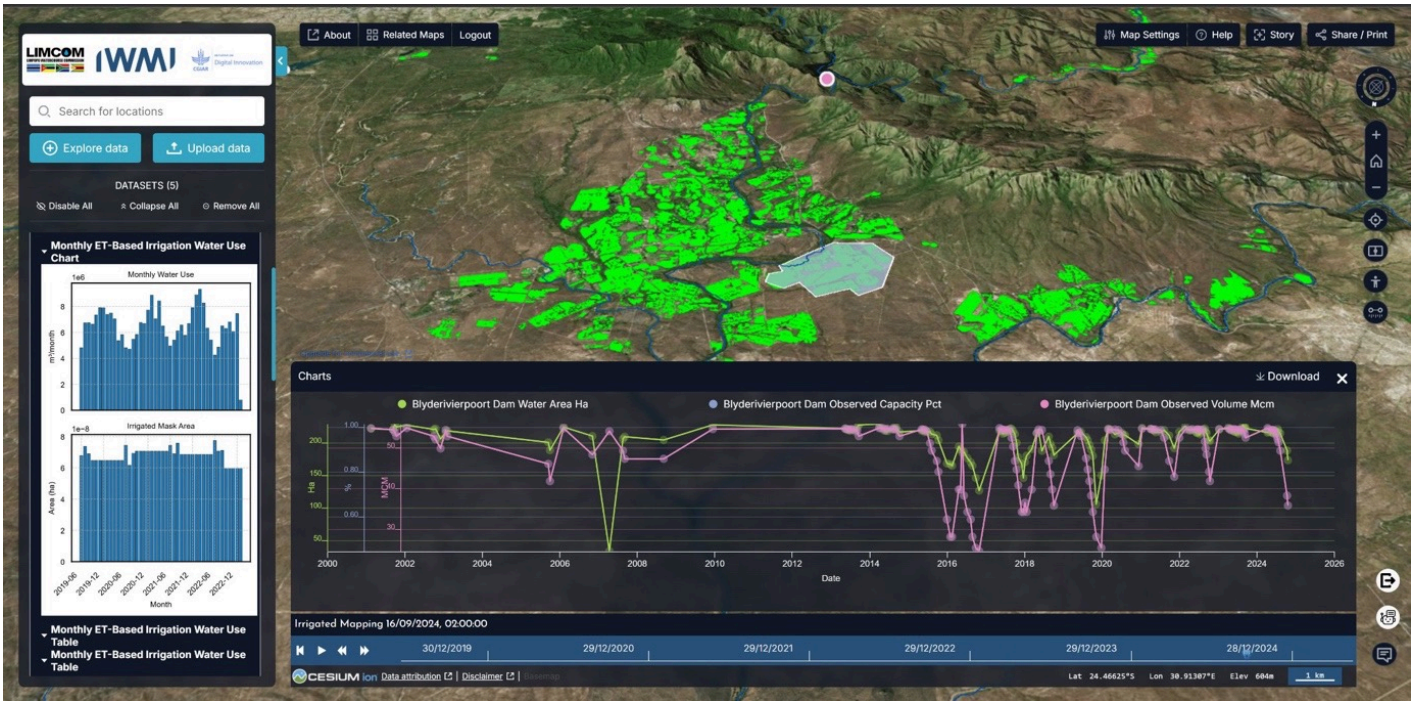

Figure 3. **Limpopo Digital Twin interface showing machine learning–delineated irrigated agriculture areas (green) with estimated monthly water use and changes in irrigated area (ha) over time**

Challenge

The Limpopo River Basin traverses South Africa, Botswana, Zimbabwe and Mozambique, supporting 18 million people who rely on its waters for domestic use, agriculture, industry, and ecosystems. The basin faces increasing pressures from overuse, pollution, drought and flooding. Coordinating water management across four national jurisdictions is complex, requiring near real-time data, shared forecasting tools and an inclusive platform for decision-making

Solution

IWMI, in partnership with LIMCOM, developed the Limpopo River Basin Digital Twin to enable science-based, transboundary decision making. The system integrates 3D modelling, near-realtime monitoring, seasonal forecasting, scenario modelling and interactive visualisations allowing water managers to easily query and act on complex real-time data and forecasting thanks to a complete virtual representation of the basin supported by an AI Water Agent democratising information for all people of different backgrounds and disciplines.

The project started with a co-design workshop involving stakeholders from all four countries to define functional requirements. A SWAT hydrological model of the basin was developed to integrate:

- Real-time and forecasted hydrological data across 1,408 river channels
- Data from 303 rainfall stations and 305 discharge stations,
- Daily water availability updates for 1,424 waterbodies and 96 dams.

To close the gaps, IWMI and partners deployed innovative methods: from sensors attached to fish to using machine learning to estimate reservoir volume from satellite imagery data. To include communities, a smartphone application (MiniSASS) was developed to digitise citizen science and verify data with machine learning, while the UNICEF Yoma platform is used to provide training and incentives for young people to participate.

In 2024, the Digital Twin was formally handed over to LIMCOM for adoption, with ongoing development adding new features such as drought early warning dashboards, expanded reservoir forecasting and cross-border capacity building.

> "The development of the Digital Twin prototype for the Limpopo Basin, which runs alongside LIMCOM's own management information systems, is a big leap forward for the Basin and the region, as it allows innovative management of river basin resources by testing and using new, cutting-edge, technologies."
>
> **Eddie Riddell, Regional Coordinator, LIMCOM UNDP-GEF7 project**

3.2. Somali Region of Ethiopia: A Digital Twin for flood preparedness, response and resilience building (Figure 4)

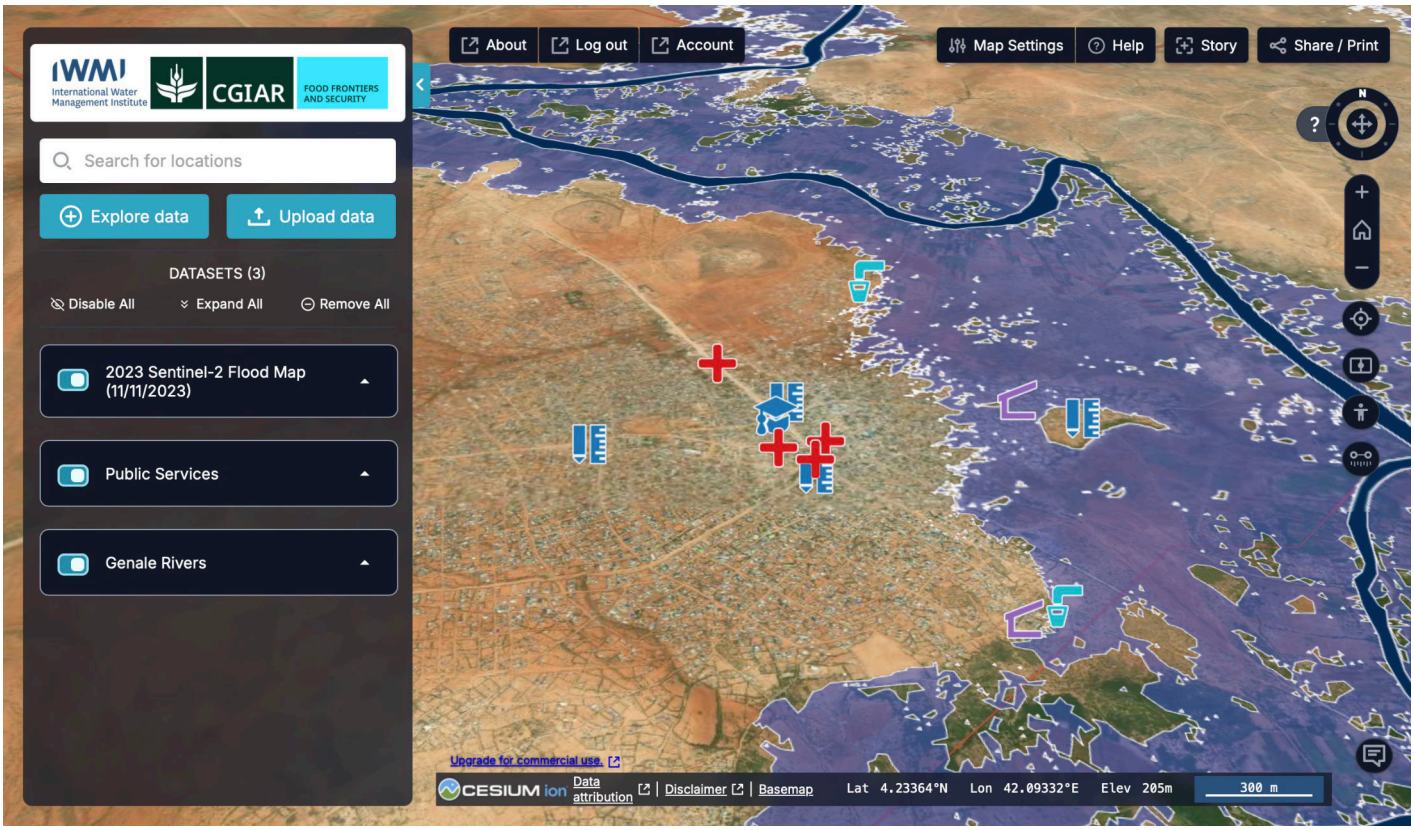

Figure 4. **Somali Digital Twin interface showing public services and previously flooded areas in the Dolo Ado flood corridor.**

Challenge

The Dolo Ado district in Ethiopia's Somali Region hosts over 200,000 refugees and local community members in one of East Africa's most climate-vulnerable humanitarian zones. The area experiences repeated displacement, chronic water scarcity and escalating climate shocks. In 2023 alone, record breaking floods affected more than 1.5 million people across the region, overwhelming existing planning and response mechanisms.

Effective humanitarian action requires real-time data, predictive modelling and tools that can be used locally to test and coordinate interventions.

Solution

IWMI, in collaboration with UNHCR, WFP and Somali Region authorities, has developed the Dolo Ado Digital Twin is an interactive platform that simulates the region's water systems, infrastructure networks and demographic dynamics in real-time. Users can explore "what-if" scenarios for flooding, drought or settlement growth, visualising the potential impact on communities, infrastructure and resources.

In 2025, a full co-design process aligned the system with the needs identified by the partners UNHCR, WFP, and Somali Region authorities to define how the Digital Twin can support humanitarian and climate resilience planning in the region. Core spatial datasets were developed, including water point inventories, flood hazard zones, settlement footprints and infrastructure layers.

The platform includes a 3D topographic prototype for visual scenario testing and is being expanded to integrate:

i. **Real-time flood depth modelling** from hydrological and remote sensing data

ii. **Evacuation route mapping** optimised for refugee and host communities

iii. **Key infrastructure vulnerability assessments** for roads, bridges, and water supply

The roadmap includes deploying the Digital Twin across multiple refugee camps and vulnerable host communities, train local planners and humanitarian actors on how to use the tool and integrate real-time data for flood depth modelling, evacuation route mapping and infrastructure vulnerability assessments.

Once fully functional and with additional financial support, the system can be scaled to other fragile and conflict-affected contexts, creating a regional humanitarian planning and climate resilience network. In Dolo Ado, for example the digital twin could be further developed into a one-stop-shop operational planning portal including an AI chatbot and scenario builder.

4. Components

4.1. Digital Twin

The Digital Twin is a live, data driven virtual model of a river basin that integrates monitoring, modelling, forecasting and decision-support tools into a single, accessible platform.

IWMI has created a large, and growing, catalogue of components and innovations that can be used to develop Digital Twin deployments (Table 1).

The foundation of the Digital Twin is a SWAT hydrological model running in near real time, augmented with a three-month seasonal forecast capability.

At the front end, the Digital Twin provides advanced user interfaces such as an interactive web portal (Figure 5), AI agent (Figure 6), and virtual reality tours (Figure 7).

Figure 5. All model outputs, along with other integrated datasets are accessible through a web portal built on open standards. This portal includes an interactive visualisation application that allows users to explore trends spatially and temporally through maps, charts and scenario tools.

Table 1. Components of the Limpopo River Basin Digital Twin.

COMPONENT	DESCRIPTION	DETAILS/STATISTICS
Drone Solutions	High-resolution Lidar, multi-spectral imaging, and submergible drones for river mapping	Used for high resolution accurate environmental flow (e-flow) determinations
Open Data Cube (ODC)	Robust open-source software package supporting the digital twin by providing access to satellite and geospatial data for analysis	Built on Digital Earth Africa best practices, cloud-based AWS architecture, adheres to FAIR data principles, incorporates seven products
River Discharge & Environmental Flow (e-flow) Charts	Specialised charts displaying natural and present-day river discharge and environmental flows	Enables analysis of water availability and compliance for river E-flow sites
Reservoir Volume Monitoring	Machine learning-based tool for near-real time insights into water storage	Daily updates on 1,424 waterbodies and 96 dams
Reservoir Forecasting	Predictive tool using experimental machine learning for future reservoir levels	Currently available for Middelburg Dam and Loskop Dam, aids in planning for water shortages/surpluses
Environmental Framework Assessment (EFA) Tool	User-friendly tool to test river management scenarios and assess social/environmental risks	Allows users to generate and test environmental flow scenarios in the Limpopo River Basin under various hydrological conditions.
FISHTRAC	Real-time fish tracking solution with sensors for river health and water quality data	Provides realtime, fish activity, discharge and water quality data. Triggering alerts in Digital Twin for environmental problems, particularly around flows and pollution
Drought Monitoring	Monitoring Tool for monthly analysis of drought conditions	Uses Standardised Precipitation Index (SPI) for rainfall deficiency and Vegetation Condition Index (VCI) for vegetation health to aid decision-making
Irrigated Mapping Areas	Irrigated Mapping Tool using machine learning to identify and map irrigated areas in the Limpopo River Basin	Analyses satellite imagery to differentiate irrigated and non-irrigated land, enhances land-use classification, supports sustainable agricultural planning
MiniSASS	Citizen science biomonitoring tool for assessing river health and water quality through macroinvertebrate sampling	Uses a mobile and web app with machine learning for real-time macroinvertebrate identification,.

Figure 6. The Digital Twin has an embedded AI Water Agent, enabling users to query in plain language and receive instant, science-based insights from based on data and tools from the river system in question.

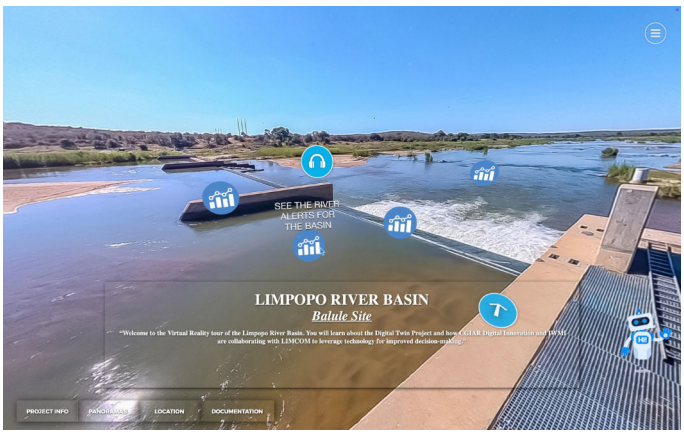

Figure 7. Immersive virtual reality tours allow exploration and spatial understanding of key water resources.

4.2. The AI-powered future of river basin management (Figure 8)

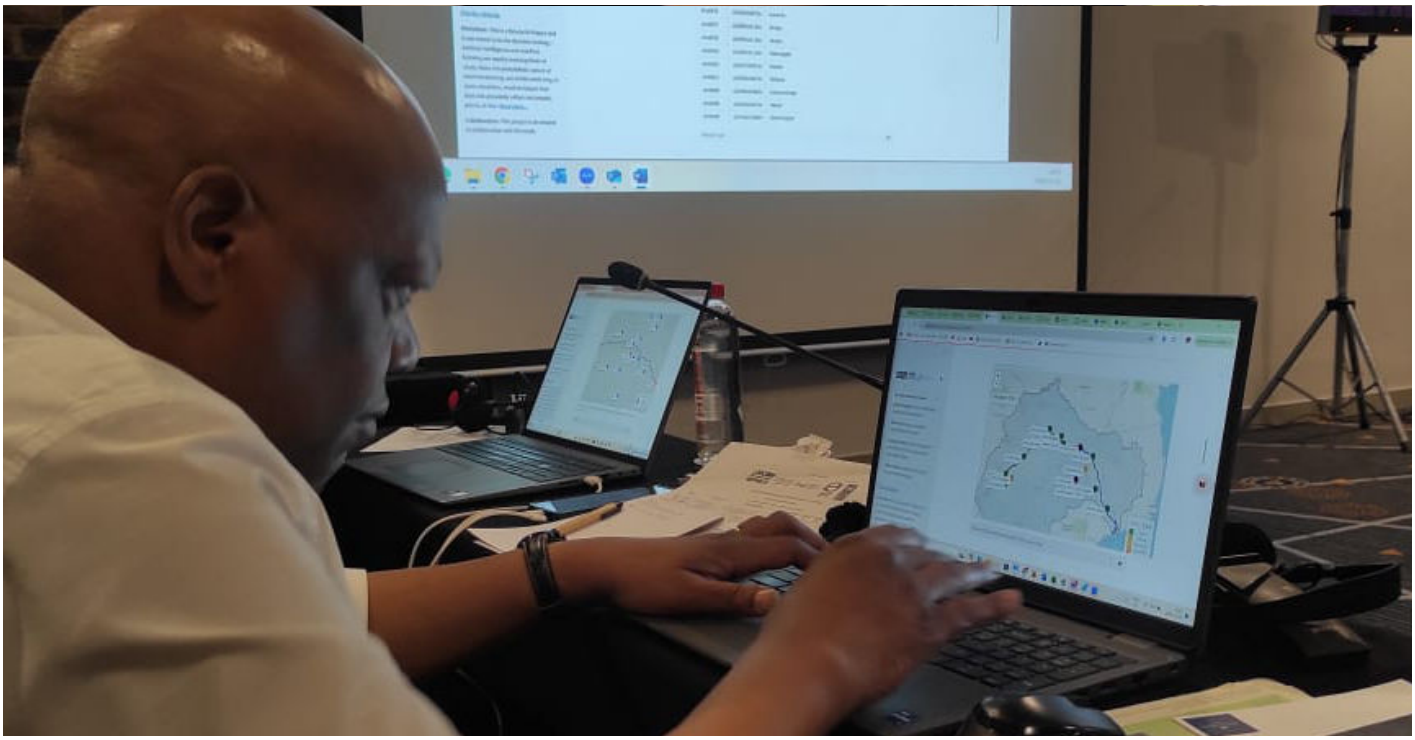

Figure 8. **A water manager from the Limpopo River Basin interacts with the AI assistant at a capacity building workshop (*photo:* IWMI)**

To enable instantaneous, science-based insights for decision-making, IWMI has developed southern Africa's first AI assistant for river basin management. Fully integrated into the Water Navigator ecosystem, it draws directly from live data streams, predictive models and knowledge repositories housed in the Digital Twin.

Through a simple, natural language interface, users can ask questions about the current or forecasted status of water resources and receive clear, actionable answers — supported by automatically generated maps, charts, and data visualisations. This makes advanced modelling and monitoring capabilities accessible to decision-makers, planners and community stakeholders without requiring specialist technical skills.

How it works

1. The AI assistant consists of a web interface for user interaction, and the CoPilot agent
2. The CoPilot agent is built on a pre-trained GPT-4 large language model , enhanced with validated plugins that act as secure data access points.
3. Plugins connect directly to the Digital Twin's APIs and external knowledge sources (including external plugins such as Microsoft Azure AI Search to index documents.)
4. When a user submits a query, the agent reviews the descriptions of available plugins, selects the appropriate one(s), executes the call and returns a fact-based summary with visual outputs.

This plugin-based architecture ensures modularity, new tools can be added rapidly and minimises hallucinations by restricting the AI to authoritative, real-time datasets.

Capacity building is built into deployment, training end-users on prompt design, ethics, and accountability in AI use. The system has been co-developed with LIMCOM and Microsoft to meet the real-world operational needs of water managers.

The AI assistant was developed by IWMI in collaboration with Microsoft, adopting cutting-edge tools to meet the real-world needs of water managers. It will be delivered as a mobile app with real-time capabilities and streamlined development processes.

Looking ahead, IWMI envisions scaling the AI-driven approach across regions, such as Middle East and North Africa (MENA) and South Asia, creating a single, adaptable platform for data-driven water governance worldwide.

> "The Water CoPilot is a great tool, I find it even more user-friendly because it is now site-specific. It was already generated with the Limpopo River Basin information."
>
> **Vuledzani Thenga**
>
> **South Africa Member State Representative LIMCOM**

4.3. A transboundary citizen science network for southern Africa (Figure 9)

Figure 9. **Community members from South Africa use the MiniSASS assessment tool to score water quality.** ***photo:*** **Groundtruth**

Water quality is a crucial source of data for the Limpopo River Basin Digital Twin, directly informing environmental flow compliance, pollution alerts and ecosystem health monitoring. Yet conventional laboratory testing is too slow and costly to scale across an entire region.

To address this, IWMI works directly with communities most affected by water quality issues, transforming them into empowered data providers. Citizen science networks, such as the Envirochamps, partner with IWMI's longstanding collaborator Groundtruth to use simple but effective field tests for large-scale water quality monitoring.

To integrate this data into the Digital Twin, the MiniSASS smartphone application was developed to collect readings, which involve recording the presence and absence of macroinvertebrate life in the water for example. The MiniSASS app uses the smartphone camera and leverages AI vision recognition to confirm the measurements taken by citizen scientists, automatically geo-tagging them and uploading them to cloud storage (Figure 10). It also serves as a hub for training content, sampling protocols, and navigation to monitoring sites.

With funding from Belgian international cooperation agency Enabel, IWMI is expanding this approach to connect citizen science groups across multiple southern African countries , delivering training in digital monitoring tools and establishing a regional data pipeline feeding directly into the Water Navigator ecosystem.

Through research and a partnership with the UNICEF Yoma, IWMI is exploring how to incentivise local communities to participate by recognising their skills in a digital CV and providing tangible benefits for the data they provide. This creates a sustainable, inclusive model where community-led monitoring strengthens transboundary cooperation, supports SDG 6 and SDG 13 targets and builds climate resilience from the ground up.

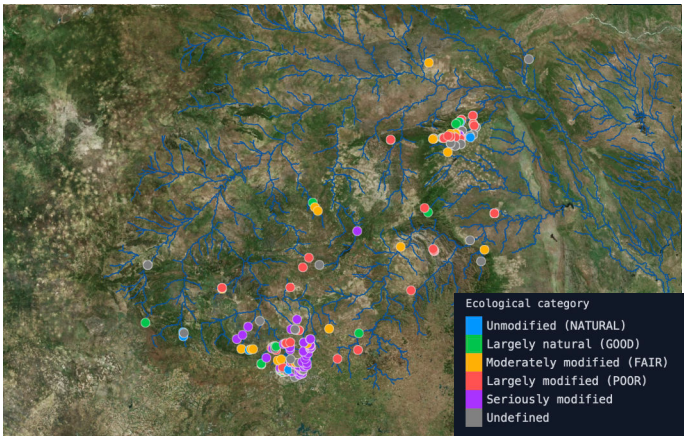

Figure 10. **Map of sites monitored for water quality using citizen science through the MiniSASS mobile phone application.**

5. How Digital Twins can transform water management on a global scale

IWMI's Digital Twin framework offers a modular, field-tested solution that can be replicated in basins worldwide.

Built through a co-design process with end users, the IWMI Digital Twin delivers digital public goods, open methodologies, and validated datasets that enable rapid adaptation by other development teams and national agencies.

The urgency is clear: climate change and human pressures on freshwater systems are escalating threats to food security, disaster resilience, livelihood security and peace.

These challenges are particularly acute in sub-Saharan Africa, the MENA region and South Asia, where many water resources are shared across national borders and vulnerable to extreme events that cause displacement and conflict.

Scaling out Digital Twins for river basin management makes it possible to embed data- and science-driven decision-making , even where formal water monitoring infrastructure is limited or unevenly distributed.

Through integrated capacity building, governments and basin authorities can:

i. **Achieve water resilience** by anticipating and mitigating droughts, floods and water scarcity

ii. **Meet climate commitments** by aligning adaptation strategies with real-time environmental intelligence

iii. **Strengthen transboundary cooperation** through shared, trusted data and transparent scenario testing

With the right investment, the IWMI Digital Twin for River Basin Management can expand from current operational deployments in the Limpopo River Basin and Somali Region to a global network of interconnected Digital Twins, enabling equitable, climate-smart water governance across continents.

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