

# Capacity-Building Workshop Part 1: AI-Driven Digital Twin for Water Management for the Limpopo River Basin and Inclusive Integration with Citizen Science

Gaborone, Botswana | June 9, 2025

Surajit Ghosh, Hugo Retief, and Mariangel Garcia Andarcia

December 2025



## Authors

**Surajit Ghosh**, Regional Researcher - Integrated Water Data Science, IWMI, Colombo, Sri Lanka

**Hugo Retief**, Senior Researcher and Development Manager, Association for Water and Rural Development (AWARD), Hoedspruit, South Africa

**Mariangel Garcia Andarcia**, Research Group Leader - Water Futures Data and Analytics, International Water Management Institute (IWMI), Colombo, Sri Lanka

## Acknowledgements

This work was conducted as part of the CGIAR Accelerator for Digital Transformation. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund ([www.cgiar.org/funders](http://www.cgiar.org/funders)).

We gratefully acknowledge the leadership and technical contributions of the International Water Management Institute (IWMI) and our regional partners, including the Limpopo Watercourse Commission (LIMCOM) and Digital Innovations for Water Secure Africa (DIWASA). We also recognize the collaboration and knowledge support provided by Digital Earth Africa, Enabel, GroundTruth, Association for Water and Rural Development (AWARD), UNICEF, and Microsoft, whose engagement and technical inputs have strengthened the overall impact of this work.

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## Suggested Citation

Ghosh, S.; Retief, H.; Garcia Andarcia, M. 2025. *Capacity-Building Workshop Part 1: AI-Driven Digital Twin for Water Management for the Limpopo River Basin and Inclusive Integration with Citizen Science*. Report of the Capacity-Building Workshop (Part 1) on AI-Driven Digital Twin for Water Management for the Limpopo River Basin and Inclusive Integration with Citizen Science, Gaborone, Botswana, 9 June 2025. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Accelerator for Digital Transformation. 17p.

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# Summary

On June 9, 2025, the International Water Management Institute (IWMI) hosted the first day of a three-day capacity building workshop in Gaborone, Botswana, in partnership with the Limpopo Watercourse Commission (LIMCOM), DIWASA, Enabel, and the CGIAR Digital Transformation Accelerator. Titled "AI-Driven Digital Twin for Water Management for Limpopo River Basin and Inclusive Integration with Citizen Science". The workshop's primary objective was to disseminate IWMI's Artificial Intelligence (AI) innovations developed for the Limpopo River Basin (LRB) and elicit substantive feedback from representatives of the Limpopo Watercourse Commission (LIMCOM) member states: South Africa, Botswana, Mozambique, and Zimbabwe who constitute the primary end-users of these decision-support technologies along with the local communities dependent on the LRB to sustain their livelihoods. Day 1 focused on introducing digital twin technologies for river basin management. Participants from Botswana, Mozambique, South Africa, and Zimbabwe engaged in presentations, live demonstrations, and hands-on sessions exploring critical applications such as environmental flow monitoring, dam surveillance, irrigated area mapping, and seasonal forecasting.

Key achievements included the launch of a formal IWMI-LIMCOM partnership for citizen science integration and the establishment of a Digital Twin Task Team. Hands-on activities utilized the Limpopo Digital Twin platform, built on TerriaJS, to provide practical insights into data visualization and analysis. Feedback from participants highlighted the tools' potential for enhancing transboundary water management. As of December 2025, these initiatives have led to expanded access to the Digital Twin and AI tools, supporting evidence-based decision-making in the basin. Discussions revealed significant transboundary challenges including fragmented hydrological data, limited real-time monitoring capacity, variable institutional readiness, and a strong demand for harmonized digital tools to support policy, planning, and operational decision-making. Participants gained actionable skills in navigating the Digital Twin, interpreting model outputs, generating time-series analytics, and applying remote sensing products for irrigation and surface water assessments. The day concluded with structured feedback through the MDII Survey, capturing insights on accessibility, inclusivity, user experience, and social implications of digital tools. These reflections will guide improvements in platform usability, data integration, and capacity-building strategies.

In addition to introducing new digital tools, Day 1 played a critical role in establishing a shared technical language among LIMCOM member states. By collectively engaging with the Digital Twin platform, participants moved toward a common understanding of basin-wide hydrological conditions, data limitations, and analytical possibilities. This shared framing is particularly important in a transboundary basin such as the Limpopo, where decision-making often relies on nationally fragmented datasets and disparate analytical approaches. Day 1 therefore served not only as a training exercise, but as a foundational step toward harmonized, evidence-based water governance across the basin.

# Overview

The workshop was convened to address pressing water management challenges in the Limpopo River Basin, a transboundary system spanning Botswana, Mozambique, South Africa, and Zimbabwe. Home to over 18 million people, the basin faces issues like water scarcity, droughts, floods, and pollution, exacerbated by climate change and fragmented data systems. IWMI, as the lead organizer, aimed to build capacity among LIMCOM member states through innovative technologies, fostering collaboration for sustainable, inclusive solutions.

Day 1, themed "Digital Twin for River Basin Management," emphasized exploring digital twin technologies via live demonstrations and case studies. The venue was the Permanent Okavango River Commission (OKACOM) Secretariat Boardroom in Gaborone, with hybrid participation via Zoom.

Objectives for the day:

- Recap digital twin concepts and define a vision for scaling integrated water management across Africa.
- Conduct listening to sessions on data and capacity challenges.
- Demonstrate and provide hands-on experience with the Digital Twin platform for monitoring environmental flows, dams, irrigated areas, and forecasts.
- Launch the Digital Twin Task Team and gather feedback via MDII surveys.

The schedule as detailed in the workshop materials, is outlined below: Sessions included presentations (P), demonstrations (D), and hands-on activities (H).

**Table 1.** Day 1 Agenda

Time	Description
08:30-09:00	Registration
09:00-10:00	Welcome: Opening remarks by IWMI and LIMCOM; Keynote from Hosting Member; Enabel remarks; Launch IWMI-LIMCOM Citizen Science Partnership
10:00-11:00	Overview of Digital Twin Project: Concepts recap, vision for scaling; Listening Session on data/capacity challenges; Launch Digital Twin Task Team
11:00-11:30	Group Photo and Tea
11:30-12:00	Digital Twin Technology in Water Management: Live demo of platforms, UI, functionalities, data integration
12:00-13:00	Hands-On Digital Twin Applications: Case studies on environmental flow, dam monitoring, water availability, seasonal forecast
13:00-14:30	Lunch
14:30-15:30	Hands-On Digital Twin Applications: Case studies on irrigated area mapping, drought monitoring
15:30-15:40	Break
15:40-17:00	Feedback Session: MDII Survey; Q&A; Participant feedback; Decision on country capacity building dates

The day began with registration and concluded with a feedback session, setting the stage for subsequent days on AI and citizen science. Managing water resources in the Limpopo River Basin presents unique institutional and governance challenges due to its transboundary nature. Each member state operates under distinct legal frameworks, monitoring capacities,

and data management practices, often resulting in uneven access to hydrological information and delayed coordination during extreme events. These structural complexities underscore the need for shared digital platforms that can integrate diverse datasets and present them in a consistent, accessible manner. Against this backdrop, the focus on Digital Twin technologies on Day 1 was designed to address not only technical gaps, but also long-standing coordination challenges across the basin (Fig 1).



**Figure 1.** Participants during Day 1.

The Limpopo Digital Twin platform addresses basin challenges by mapping ecological risks, monitoring flows, and alerting on e-flow compliance. Post-workshop, the site requires registration for access, with updates including enhanced citizen science data layers as of October 2025. The technology's social implications were discussed, ensuring inclusivity for rural communities, women, youth, and those with minimal education through the MDII Framework, which evaluates accessibility, ethical innovation, and potential harms. The Limpopo Digital Twin, as demonstrated in the workshop, is an operational, cloud-based platform built on TerriaJS with a 3D Cesium engine, offering a highly intuitive environment for basin-scale exploration. Key interface elements include a fully interactive 3D globe, a dynamic time slider, pop-up charts, multi-layer overlays, polygon drawing tools, and customized feature templates. The system's backend integrates diverse data streams—Sentinel-2 imagery, IoT sensor networks, SWAT+ hydrological models, rainfall and ET anomalies, reservoir storage forecasts, GeoMAD composites, and citizen science datasets—into an OGC-compliant environment supporting WMS and WFS. A detailed architectural workflow illustrates how data ingestion, model integration, machine learning modules, and AWS-hosted processing pipelines power real-time and historical analytics within the Digital Twin. This multi-layered data fusion allows managers to transition “from raw data to actionable insights,” supporting scenario modeling, validation exercises, and decision-support tools for environmental flows, seasonal water availability, and drought tracking.

### **Partnership and Agreement Highlights**

A highlight of Day 1 was the launch of the IWMI-LIMCOM partnership for citizen science, formalized through a landmark agreement signed during the welcome session. This collaboration aims to integrate community-collected data into the Digital Twin, empowering stakeholders for equitable, climate-resilient decisions.

Quote from Sergio Siteo, LIMCOM Executive Secretary: "The integration of Enviro Champs data into the Digital Twin will significantly enhance modeling, forecasting, and scenario planning."

The agreement outlines activities such as community engagement, use case development, capacity workshops, and data embedding. A Digital Twin Task Team was also launched to identify data needs, build regional capacity, and promote cross-team collaboration.

The official IWMI–LIMCOM partnership, supported by Enabel, was formally launched during the welcome session. A detailed activities plan includes:

- Citizen scientist network establishment.
- Use-case development.
- Capacity-building workshops.
- Full data embedding into the Digital Twin.

The Digital Twin Task Team's formation is also documented, listing focal members from all four countries and outlining objectives such as collaborative data identification, capacity-building, and operational coordination.

## **Detailed Agenda for Day 1**

### **Session Details: Welcome and Partnership Launch**

The day commenced with opening remarks from IWMI's Henry and LIMCOM's Sergio, emphasizing the need for innovative tools in transboundary water governance. The keynote from Botswana's hosting member highlighted local challenges like water stress in sub-basins. Enabel's online remarks focused on digital inclusivity. Speakers highlighted the critical need for innovative, data-driven approaches to improve transparency, accelerate decision-making, and strengthen trust among member states. The opening session underscored that the Limpopo River Basin—shared by Botswana, South Africa, Zimbabwe, and Mozambique—requires coordinated, forward-looking solutions that transcend national boundaries and technical silos. It was against this backdrop that the official launch of the IWMI–LIMCOM Citizen Science Partnership took place. The session culminated in the partnership launch, signing the MoU to integrate citizen science data, such as from Enviro Champs, into the Digital Twin. This set a collaborative tone, aligning with LIMCOM's strategy for evidence-based management impacting millions. Leaders from IWMI and LIMCOM expressed a shared vision: that community-generated data, when combined with scientific models and remote sensing products, can substantially improve the accuracy and legitimacy of basin-wide water assessments. The session concluded with recognition of the partnership's long-term goals, including enhancing citizen participation, improving hydrological data networks, and supporting sustainable water management with strong institutional backing. Throughout the opening session, speakers consistently emphasized themes of urgency, transparency, and trust as guiding principles for digital transformation in water management. The remarks highlighted the increasing pressure on the Limpopo River Basin from climate variability, competing water demands, and data fragmentation, while also underscoring the opportunity to address these challenges through collaborative innovation. This framing helped align participant expectations and set a constructive tone for the technical discussions that followed, reinforcing the idea that technology must serve shared governance goals.

### **Session Details: Overview of Digital Twin Project**

The vision for Africa-wide scaling was discussed, including paths to integrate with platforms like Digital Earth Africa. A listening session identified challenges: data fragmentation, limited

capacity, and access issues. Participants from member states shared insights, leading to the Digital Twin Task Team's formation. This team aims to prioritize use cases and enhance efficiency through knowledge sharing.

Following the opening remarks, the facilitators presented an in-depth conceptual overview of the Limpopo Digital Twin, describing it as a living, evolving virtual representation of the basin that integrates remote sensing imagery, hydrological models, climate observations, community datasets, ground sensors, and forecasting systems into a single accessible platform. The session explored the theoretical underpinnings of Digital Twins, tracing the concept from its origins in industrial engineering to its rapid adoption in environmental and urban systems management. Participants learned how the Digital Twin differs from traditional decision-support tools: rather than providing static maps or periodic reports, it continuously incorporates new data, supports real-time exploration, and enables predictive simulations that help anticipate emerging challenges such as declining flows, reservoir stress, or seasonal drought conditions. The facilitators positioned the Digital Twin as a bridge between science and policy—an interface where complex hydrological processes could be visualized, interrogated, and translated into actionable decisions.

A key element of this session was an interactive listening exercise designed to surface the data, capacity, and coordination challenges experienced by water managers across the member states. Participants openly shared the difficulties they face, including fragmented datasets scattered across institutions, divergent formats and standards, inconsistent access to monitoring networks, slow validation cycles for field data, and limited capacity to analyze satellite products or hydrological model outputs. These insights highlighted those structural constraints, rather than lack of interest or motivation, often impede the adoption of advanced digital tools. The discussion reaffirmed that a Digital Twin must be co-developed with its end-users to ensure its long-term relevance and usability. Building on this shared understanding, the facilitators announced the formation of the Digital Twin Task Team, a multi-country working group tasked with identifying priority datasets, harmonizing data-sharing practices, and co-designing operational use cases. The session closed with a collective recognition that the Digital Twin is not merely a technological artifact but a collaborative process that requires sustained engagement across institutions and borders.

### **Session Details: Digital Twin Technology Demonstration**

live demo showcased the platform's interface, starting with login at <https://digitaltwins.demos-only.iwmi.org>. Key elements included the 3D globe, time slider for historical data, and WPS for analytics. Demonstrations covered system components like multi-layer overlays and CSV exports, illustrating how raw data transforms into insights.

Participants explored quick demos of features, such as polygon tools for spatial analysis, preparing them for hands-on sessions. After establishing the conceptual foundation, participants were guided through a detailed live demonstration of the Digital Twin platform. The facilitators began by showing the platform's interactive 3D globe interface, which allows users to zoom, tilt, and navigate seamlessly across the basin, revealing terrain patterns, catchment boundaries, and hydrological networks. Participants observed how the time-slider feature enables historical playback of rainfall patterns, discharge fluctuations, and reservoir dynamics, transforming complex temporal datasets into intuitive visual sequences. The demonstration highlighted the system's ability to overlay multiple data layers—from rainfall anomalies and land cover classifications to modelled stream flows and water accounting components—allowing users to explore relationships between climatic signals, river system responses, and water availability trends.

The facilitators then showcased the platform’s analytical capabilities, explaining how Web Processing Services (WPS) allow users to draw polygons or select points of interest to generate on-demand calculations such as irrigated area statistics, surface water extent, or time-series extractions. Participants watched as the platform produced charts showing natural flows, present flows, and e-flow requirements, as well as graphs of reservoir storage and rainfall anomalies for specific sites. Questions from participants focused on data update frequencies, metadata availability, integration of local datasets, and the possibility of customizing visualizations for country-level reporting. The demonstration highlighted the platform’s transparency, emphasizing that every dataset includes embedded metadata, source descriptions, and processing notes (Fig 2). By the end of the session, participants had gained a clear understanding of how the Digital Twin blends satellite observations, hydrological modeling, community monitoring, and computational tools into an integrated system capable of supporting both routine planning and emergency response.



**Figure 2.** Environmental Flow Compliance & Water Availability

The first hands-on exercise introduced participants to the Digital Twin’s environmental flow (e-flow) monitoring capability, allowing them to explore whether present river flows across the Limpopo Basin meet required ecological thresholds. Using tools that compare natural flow, observed flow, and required e-flow targets, participants gained a clear view of how hydrological alterations propagate across the basin. The visualizations, presented through a 3D basin interface, helped users quickly identify spatial patterns and imbalances in environmental water allocation.

Participants then evaluated basin-wide e-flow alerts for the 2024–2025 hydrological year, which the system automatically generates based on deviations from required thresholds. The alert system displayed colour-coded risk indicators for ecological and socio-economic vulnerabilities associated with insufficient environmental flows. This interactive component enabled users to immediately interpret the status of multiple gauging stations, reinforcing the importance of near-real-time decision support for transboundary water governance. Through this session, practitioners were able to appreciate the value of integrated hydrological data—combining historical records, modeled flows, and ecological benchmarks—to support policy decisions. Discussions highlighted how deviations in flow conditions affect downstream users, aquatic ecosystems, and drought resilience. The exercise also demonstrated how consistent use of the e-flow tool can help basin authorities prioritize monitoring sites, anticipate stress conditions, and communicate risks across countries.

## **Session Details: Hands-On Applications – Environmental Flow and Dam Monitoring**

Use Case 1: Environmental Flow Compliance – Participants checked flows against e-flow targets at basin sites, summarizing alerts for the 2024-2025 hydrological year. Maps highlighted risks from insufficient flows, comparing natural, present, and required levels.

Use Case 2: Dams and Surface Water Monitoring – Analysis of Massingir Dam's surface extent changes over six months, incorporating rainfall projections and anomalies via SWAT models and machine learning. This revealed seasonal water body dynamics, aiding drought preparedness.

The hands-on portion of the workshop deepened participants' practical understanding of how the Digital Twin can support operational water management. The first practical exercise focused on environmental flow compliance, a critical aspect of river basin management that balances ecological health with human water use. Participants selected various environmental flow sites across the basin and examined real-time and historical flow data, comparing natural flow simulations with present-day observations and required e-flow thresholds. Through the platform's visual cues and alert indicators, they were able to identify locations where flows were below ecological requirements, signalling heightened risks to aquatic ecosystems and dependent communities. The exercise illustrated how the Digital Twin condenses complex hydrological information into user-friendly visualizations, making it easier for managers to diagnose non-compliant zones, investigate potential drivers, and consider mitigation strategies.

The second exercise examined dam and surface water body monitoring, with a focus on the Massingir Dam. Participants explored the dam's surface water extent over the past six months, observing patterns of expansion and contraction influenced by rainfall, upstream inflows, and seasonal evapotranspiration. The platform allowed them to juxtapose satellite-derived surface water area with rainfall anomaly charts and storage status indicators, creating an integrated understanding of reservoir dynamics. The facilitators explained how changes in water extent can inform drought risk assessments, irrigation scheduling, and decisions about reservoir releases. Participants noted how the Digital Twin could be used to harmonize dam operation discussions across countries by providing a consistent, basin-wide representation of hydrological conditions. By the end of this exercise, it was evident that the Digital Twin serves as both an analytical and a communication tool, enabling technical teams and policymakers to work from a shared evidence base.

### **Dam & Surface Water Body Monitoring**

The second hands-on session focused on dam and surface water body dynamics, using Massingir Dam as the primary case study. Participants examined monthly changes in surface water extent, derived from a combination of SWAT+ hydrological model outputs and machine-learning enhancements, which differentiate between persistent and seasonal water bodies. The Digital Twin provided layered temporal visualizations that allowed participants to observe trends over the previous six months and assess hydrological stability.

In addition to water extent mapping, the platform enabled analysis of rainfall projections for upcoming months, providing foresight into potential inflow variations. Participants compared rainfall anomalies between the current and previous year, gaining insights into ongoing drought conditions and their implications for reservoir storage. By integrating rainfall, hydrological simulations, and surface-water indicators, the tool demonstrated how multiple data streams converge to form a coherent understanding of basin hydrology. This session sparked discussions about the operational management of dams under uncertainty, including release planning, drought preparedness, and cross-border coordination. Participants emphasized how

such integrated visuals could support national water authorities in anticipating shortages or surpluses, improving communication with downstream users, and enhancing water security during climate-related extremes. The exercise illustrated how Digital Twin tools advance evidence-based water governance by enabling timely, multi-source monitoring.

### **Session Details: Hands-On Applications – Irrigated Area Mapping and Drought Monitoring**

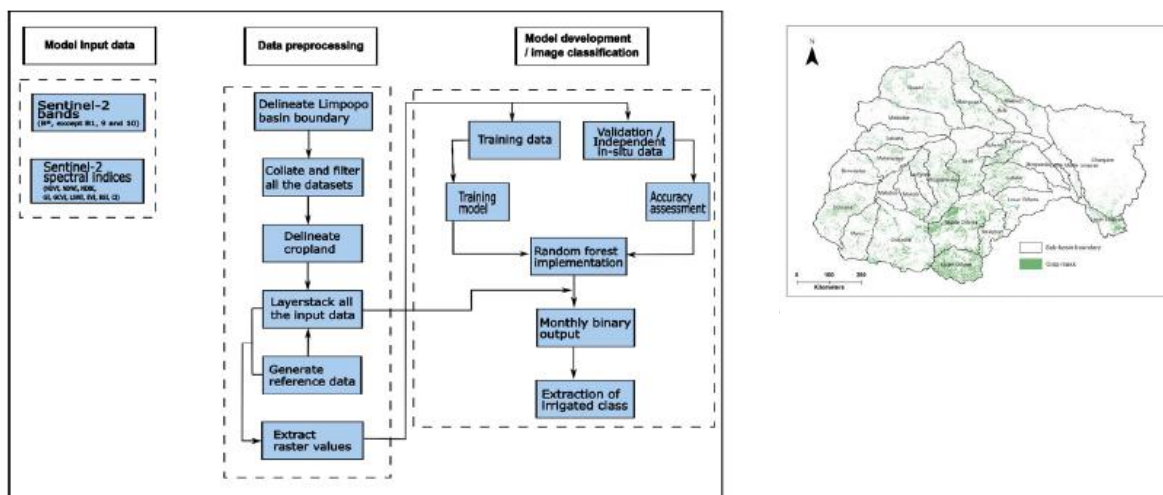
Irrigated area mapping using Sentinel-2 imagery (10m resolution, 5-day revisit). Methods included NDVI/GI index computation, time-lagged regression to filter false positives, and field surveys of 120 plots.

Key findings: Irrigated areas ~0.4% of the basin, concentrated in Middle Olifants, declining from 2019-2024, with peaks in May/June and high water use in May/September. Minimal irrigation in sub-basins like Lotsane and Changane.

Tutorials provided:

- **Tutorial 1: Visualize an Irrigation Scheme** – Access the site, register/login, search locations (e.g., 25.2°S, 29.4°E), activate "Irrigated Mapping" layer under Natural Basin Characteristics, explore metadata pop-ups (raw, filtered, probability maps), adjust settings, add layers like rainfall anomalies, use timeline for time comparison, and export views.
- **Tutorial 2: Use WPS for Time Series** – Select "Water Use Time-series (Irrigated Areas) (Polygon)" in Water Use Monitoring folder, draw polygons, and run analysis for charts of irrigated trends and water use.

Tips addressed performance, troubleshooting, and legend interpretation. Drought monitoring integrated GeoMAD imagery for rolling monthly assessments. The final hands-on session delved into irrigated agriculture and drought monitoring, two interconnected domains that significantly influence food security and water allocation in the basin. The facilitators began by explaining the methodological framework used to generate monthly irrigated area maps. Participants learned that the Digital Twin integrates Sentinel-2 imagery with vegetation indices (NDVI, GI, and NGI), random forest classification models, and time-lagged regression techniques to distinguish irrigated fields from rainfed agriculture. This approach reduces false positives by analyzing how vegetation responds to rainfall over time, enabling the system to detect irrigation even in semi-arid areas with irregular precipitation patterns. The facilitators also described how field surveys of 120 agricultural plots were used to validate the model and improve its accuracy. Participants then navigated the platform to locate irrigation schemes within their countries, activating the irrigated mapping layers and interacting with the filtered, raw, and probability maps. They explored metadata entries detailing classification confidence, temporal coverage, and data processing notes. Using the polygon-drawing tool, participants practiced generating custom water use analyses, extracting irrigated area statistics and associated evapotranspiration-derived water consumption estimates. The exercise demonstrated how the Digital Twin supports routine monitoring of agricultural expansion, seasonal water demand, and long-term trends in irrigation. This information proved highly valuable for participants concerned with drought preparedness, agricultural planning, and allocation of limited water resources. The session (Fig 3) closed with reflections on how irrigated area monitoring could help address existing data gaps, strengthen agricultural policy, and guide climate adaptation strategies.



**Figure 3.** Method for mapping irrigated agriculture

### Tutorial 1 — Visualizing Irrigation Schemes in the Limpopo Digital Twin

The first tutorial introduced participants to the core navigation and visualization functions of the Limpopo Digital Twin, guiding them through each step required to access, register, and begin exploring the platform’s interactive 3D environment. After visiting the Digital Twin portal and completing the login process, participants engaged with the introductory interface tour, which provided orientation on the basin-wide map, search tools, and data catalogue. This was an essential foundation for new users, ensuring that everyone understood the layout of the interface, the purpose of the control panels, and how to manipulate the 3D globe—through zooming, tilting, and panning—to locate specific areas of interest.

Once comfortable with navigation, participants proceeded to activate the Irrigated Mapping layer, one of the Digital Twin’s flagship datasets. Using the left-hand data catalogue panel, they located the layer under Natural Basin Characteristics → Land Cover and Land Use and observed how irrigated fields appeared on the map as colour-coded markers representing different measurement types (raw, filtered, and probability outputs). The tutorial also introduced the concept of feature metadata: by clicking directly on an irrigated field, participants accessed detailed attributes such as time-stamped records, derived spectral probabilities, and multi-date band information. These metadata pop-ups demonstrated how individual irrigated pixels are validated and classified using long-term Sentinel-2 imagery.

To deepen the analysis of experience, participants were shown how to modify visualization properties such as layer opacity, time filters, and symbology settings. They also experimented with adding supplementary layers—rainfall anomalies, GeoMAD composites, land use categories, and reservoir datasets—which allowed them to contextualize irrigation patterns within broader hydrological and climatic conditions. The time slider tool at the bottom of the interface enabled month-by-month comparison, helping users visualize dynamic changes in irrigation activity. The tutorial concluded with exporting and sharing map views through the built-in screenshot and share-link tools, demonstrating how field officers, basin managers, and researchers can communicate insights efficiently. Overall, this session illustrated the Digital Twin’s capability to support transparent, repeatable, and data-rich visual assessments of irrigated agriculture.

### Tutorial 2 — Running WPS Time-Series Analytics for Irrigation Water Use

The second tutorial introduced participants to one of the most advanced analytical features of the Digital Twin. This component allows users to perform server-side geospatial analyses without specialized software or programming skills. Participants accessed the Water Use Time-series (Irrigated Areas) (Polygon) tool within the Water Use Monitoring and Analysis folder and reviewed its documentation, which describes how irrigated area masks and evapotranspiration datasets are integrated to estimate agricultural water consumption. This tutorial highlighted the Digital Twin's role not merely as a visualization platform, but as a computational environment capable of generating actionable metrics through automated workflows.

Participants were then guided through the process of drawing custom polygons on the map to define areas of interest—such as irrigation schemes, sub-basins, or administrative zones. After finalizing these polygons, they triggered the WPS workflow using the Run Analysis button, which executed a backend script that combined satellite-derived irrigated area maps with WaPOR evapotranspiration data to compute monthly water-use values. In just a few moments, the platform generated interactive time-series charts showing trends in irrigated extent and crop-water consumption across multiple years. These outputs provided an intuitive understanding of seasonal patterns, peak irrigation months, and fluctuations associated with drought or water scarcity.

The tutorial concluded with a demonstration of how users can download charts and data tables for offline reporting, modeling, or integration into water allocation planning. Participants observed how WPS analytics extends the Digital Twin's functionality from passive viewing to active analysis, enabling decision-makers to quantify water demand, compare irrigation efficiency across regions, and evaluate long-term sustainability of water use in agriculture. The ability to customize polygons and instantly receive server-generated insights demonstrates the Digital Twin's potential to support scenario development, basin planning, and cross-border coordination. This session highlighted the operational value of cloud-based analytics for water resource management and underscored the importance of integrating EO data with hydrological decision tools.

### **Session Details: Feedback Session**

Nicole and Felix facilitated the Multidimensional Inclusive Index (MDII) Survey, focusing on ethical innovation, accessibility, and impacts. Q&A clarified technical aspects, with feedback praising practicality. Decisions included setting dates for country-specific trainings, ensuring follow-up capacity building.

The final session of the day centered on structured reflection guided by the Multi-Dimensional Digital Inclusivity Index (MDII). Facilitators prompted participants to assess the Digital Twin not only as a technical system, but as a tool that must remain equitable, accessible, and responsive to the diverse needs of basin stakeholders. Participants discussed the potential risks of digital exclusion, noting that individuals with limited formal education, limited digital literacy, or restricted access to internet-enabled devices could be unintentionally marginalized if support structures are not embedded into project design. Women and youth representatives voiced the importance of culturally sensitive interfaces, local languages, and simplified visualizations that can broaden participation beyond technical specialists. Several participants pointed out that trust must be intentionally cultivated; users need to understand where data comes from, how models work, and what uncertainties are involved.

Discussions also addressed ethical considerations, including privacy concerns associated with integrating citizen science data, the need for transparent data-sharing agreements, and the responsibility of maintaining high data quality to avoid misinformation or harmful decision outcomes. Participants emphasized that while the Digital Twin is a powerful tool, its value depends on sustained capacity building, clear governance frameworks, and

opportunities for collaborative learning across member states. The feedback session concluded with a consultation on future national-level trainings, with participants expressing strong interest in continued engagement and deeper exploration of specific use cases relevant to their institutional mandates. The insights gathered during this session will shape future platform refinements, capacity-building strategies, and regional cooperation frameworks.

## **Key Highlights from Presentations**

Presentations emphasized stakeholder engagement (governments, farmers, utilities) and problems like delayed responses. Visuals included basin maps, water accounting frameworks identifying negative balances, and partnership photos. Social considerations via MDII ensure tools avoid inequalities and resource degradation. Participant mentioned that the tool is practical for monitoring irrigated areas and visualizes transboundary impacts effectively."

The presentations on Day 1 provided a comprehensive introduction to the Limpopo Digital Twin, emphasizing its importance as a modern, integrated tool for strengthening transboundary water governance in the Limpopo River Basin. Presenters highlighted the basin's growing exposure to droughts, shifts in rainfall patterns, and competition among agricultural, domestic, and ecological water uses. Through maps, diagrams, and data visualizations, the sessions illustrated how these challenges require decision-making approaches founded on real-time information, harmonized datasets, and shared analytical platforms accessible to all four member states.

A central theme was the persistent fragmentation of hydrological data across the basin. Presenters explained that while satellite products, climate datasets, and hydrological models are increasingly available, users continue to face coordination challenges, inconsistent data formats, and limited access to real-time monitoring networks. The Digital Twin was positioned as a solution that unifies diverse data sources—including remote sensing products, climate indicators, model outputs, and eventually citizen science observations—into a single interactive system. This integration allows water managers to visualize complex processes, run time-series analyses, and assess environmental flows or reservoir dynamics in ways that were previously difficult or time-consuming. Across the presentations, a consistent message emerged: effective water management in the Limpopo River Basin requires shared information, shared tools, and shared responsibility. Speakers repeatedly emphasized that technological solutions alone are insufficient without collaboration, trust, and institutional alignment. The Digital Twin was thus framed not only as a technical platform, but as a mechanism for fostering collective understanding and coordinated action in the face of shared risks and uncertainties.

The presentations also stressed the importance of co-design and collaboration. The Digital Twin Task Team (Fig 4), introduced during the workshop, will play a central role in guiding future development, ensuring that platform enhancements reflect national priorities, operational needs, and local knowledge. Presenters underscored that digital transformation must be inclusive, with tools designed for diverse users, not just technical experts. This aligns with the broader vision of democratizing access to information across the basin. Ultimately, the presentations made clear that the Digital Twin's value lies not only in its technological sophistication, but in its ability to support trust-building, shared understanding, and collective action among the four countries that rely on the Limpopo River Basin.



**Figure 4.** Feedback session.

## **Conclusion**

Day 1 successfully introduced participants to the foundational concepts, capabilities, and strategic relevance of the Limpopo Digital Twin. Through a combination of presentations, demonstrations, hands-on exercises, and open discussions, participants developed a clearer understanding of how integrated digital tools can improve transparency, enhance early warning, strengthen environmental flow monitoring, and support collaborative decision-making across the basin. The launch of the IWMI–LIMCOM Citizen Science Partnership and establishment of the Digital Twin Task Team signalled a strong institutional commitment to sustaining this innovation beyond the workshop. The insights gathered from the listening session and the MDII framework emphasized the importance of inclusivity, accessible design, and continuous capacity building to ensure that the Digital Twin benefits all users—technical and non-technical alike. Day 1 laid the groundwork for deeper exploration of AI applications, governance considerations, and user-centered design approaches that would follow in the subsequent sessions. The three-day workshop employed a structured thematic approach, with each day addressing distinct but interconnected components of AI for water management. By the end of Day 1, participants had established a common reference point for discussing basin conditions, data challenges, and analytical approaches. The shared experience of engaging with the Digital Twin helped align expectations and vocabulary across countries and institutions, laying the groundwork for deeper technical and governance discussions in

subsequent sessions. In this sense, Day 1 functioned as both an introduction to digital tools and a critical step toward building a cohesive regional community of practice around data-driven water management. With Day 1 focused on Digital Twin foundations and hands-on case studies, Day 2 was scheduled to examine AI governance frameworks, ethical considerations, prompt engineering, and training on IWMI's WaterCopilot—further expanding participants' understanding of emerging digital tools for sustainable water management in the Limpopo River Basin.





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Contact

Mariangel Garcia Andarcia, Research Group Leader, Water Futures Data & Analytics (WFDA), IWMI ([M.GarciaAndarcia@cgiar.org](mailto:M.GarciaAndarcia@cgiar.org))



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