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TECHNICAL BRIEF

From rainfall forecasts to anticipatory action: a flood digital twin at work in Dolo Ado, Ethiopia

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November 2026



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Acknowledgments

This work was conducted as part of the CGIAR Accelerator for Digital Transformation and the International Water Management Institute's Digital Innovations for Water Secure Africa (DIWASA) project. We gratefully acknowledge the generous financial support of The Leona M and Harry B. Helmsley Charitable Trust. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund (www.cgiar.org/funders/).

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Suggested citation

Haile, Alemseged Tamiru, Eden Seifu Gebre, Getahun Kebede Mengistie, Abel Negussie Alemu, and Hugox Retief. 2026. *From Rainfall Forecasts to Anticipatory Action: A Flood Digital Twin at Work in Dolo Ado, Ethiopia*. International Water Management Institute.

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Front cover photo: The participants of the Flood bulletin validation workshop (photo by Rahel Mesganaw/IWMI).
Back cover photo: Flood bulletin designed by workshop participants (photo by Rahel Mesganaw/IWMI).

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Key messages

From rainfall to impact. The Dolo Ado Digital Twin combines data with hydrological and hydraulic models to show where floods may strike and who or what is at risk.

Co-created, so it's used. Stakeholders shaped the system and bulletin through workshops, training, validation and feedback, so outputs match local decision-making needs.

Automated, so it's actionable. A modular workflow produces standardized, multilingual bulletins that link flood severity and impacts to preparedness and anticipatory actions.

Technology alone isn't enough. A routine service needs institutional ownership, better monitoring, agreed triggers, effective dissemination and dedicated funding.

1. Context

Floods are among Ethiopia's most frequent and damaging natural hazards. Impacts are particularly severe in Dolo Ado town, Liben Zone, Somali Region, where riverine flooding threatens refugee and host communities (Haile et al., 2025), damaging shelters, infrastructure and public services, disrupting livelihoods and humanitarian operations, and increasing vulnerability. Flood forecasts and predefined triggers can prompt anticipatory action, such as releasing resources so people can protect themselves without distress asset sales (Gros et al., 2019).

Despite advances in prediction, modelling and Earth observation, operational flood early warning still faces challenges in making the most of available data, producing accurate predictions, translating forecasts into effective warnings and administering an operational service (Pagano et al., 2014). Warnings must reach decision-makers in timely, actionable formats.

A Digital Twin addresses these challenges by creating a digital replica of the floodplain and catchments, with two-way data exchange from multiple sources. Through automated workflows, the Dolo Ado Digital Twin continuously generates flood forecasts and impact information, supporting early warning, visualization, scenario analysis and evidence-based decision-making. Warnings reach flood managers and communities, who report observed conditions back. Digital Twins also improve coordination by giving stakeholders a shared visualization platform (Ge and Qin, 2025), and are increasingly applied to flood early warning (Bhati et al., 2026). Co-creation with stakeholders is essential for operational use (Garcia et al., 2024), ensuring outputs are timely, location-specific, impact-oriented, easy to interpret and linked to preparedness and response.

IWMI and government, humanitarian and technical partners co-created a Digital Twin that generates a Flood Early Warning Bulletin for Dolo Ado district. Stakeholders selected the district in an early needs assessment for its recurrent flood risk, underscored by the severe El Niño-driven floods of October–December 2023. The Digital Twin generates early warning information; the bulletin translates it into clear, decision-ready warnings and guidance.

This brief documents the co-creation process and technical workflow, how stakeholder engagement shaped the bulletin, and key technical, institutional and operational lessons for wider adoption in Ethiopia and beyond.'

2. Study area

The study area is Dolo Ado, Liben Zone, in Ethiopia's Somali Region, near the confluence of the Genale and Dawa rivers, where riverine processes interact closely with settlements, farmland and low-lying, flood-prone terrain. Rather than relying solely on hydrological or topographic delineation, local and sectoral stakeholders identified and agreed on the flood-modelling boundary (Figure 1) through consultation.

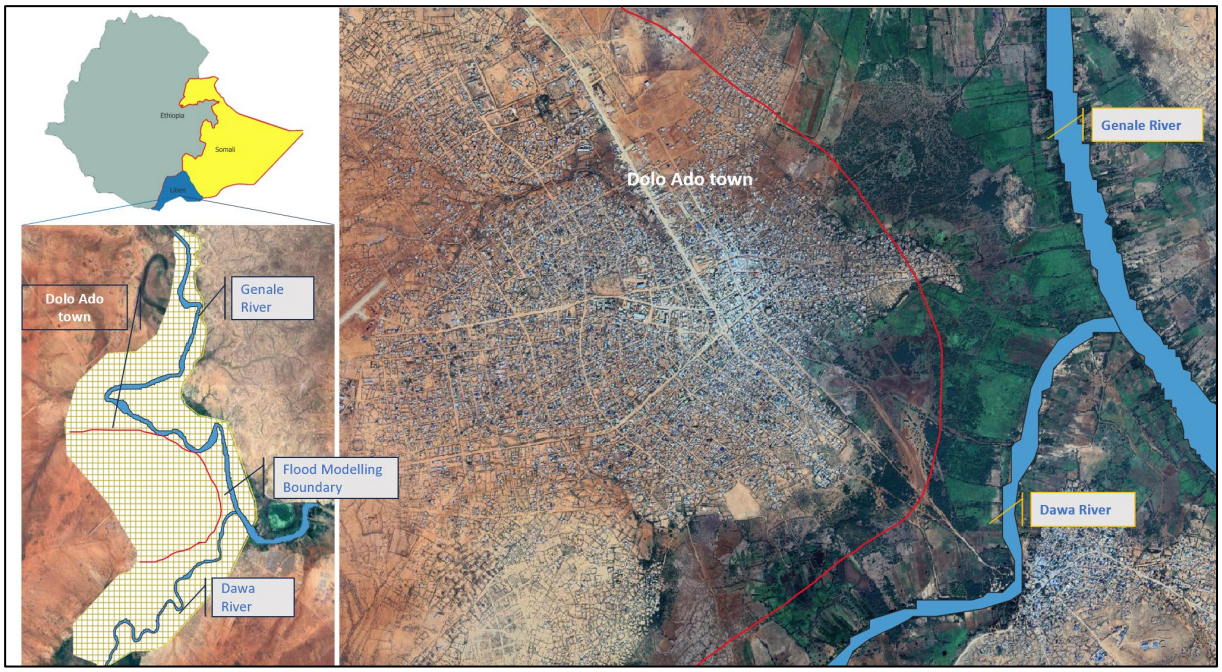


Figure 1. Location of the Digital Twin pilot area in Dollo Ado, Somali Region, Ethiopia within the Genale -Dawa River Basin, selected through a stakeholder consultation process due to its recurrent flood risk and humanitarian significance.
Source: Author's

3. Co-creation framework

The Digital Twin was developed through co-creation (Figure 2): rather than presenting a finished product, the project engaged stakeholders throughout design, development, validation and refinement. Participants spanned the entire forecasting-to-early-warning chain, including technical experts from the Ethiopian Meteorology Institute (EMI) and the Ministry of Water and Energy (MoWE), regional and local Disaster Risk Management (DRM) bureaus, researchers and flood-modelling specialists from research institutes and universities, and development and humanitarian organizations such as the World Food Programme (WFP) and the United Nations High Commissioner for Refugees (UNHCR).

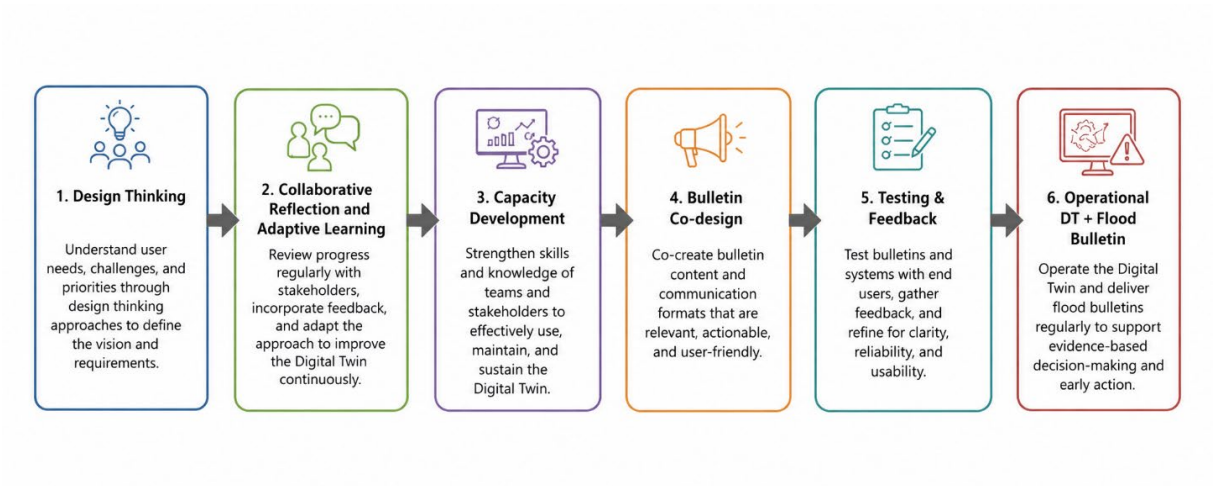


Figure 2. Stakeholder co-creation process adopted for the development of the Digital Twin and Flood Early Warning Bulletin.

The co-creation framework consisted of several complementary activities as outlined in this section.

3.1 Design thinking

Co-creation began with Design Thinking, a human-centred, iterative method that let stakeholder needs, rather than a predefined technical solution, shape the system from the outset. It adapted IWMI's co-design approach for the Limpopo River Basin Digital Twin (Garcia et al., 2024) to flood preparedness and early warning in Dolo Ado (Haile et al., 2025), following the Empathize, Define, Ideate, Prototype and Test stages.

At an initial two-day workshop, about 40 participants from district and regional DRM bureaus, EMI, MoWE, WFP, UNHCR and research institutions developed personas of key Digital Twin users, using role-play and structured interviews to explore their responsibilities, frustrations and desired outcomes (Haile et al., 2025). Participants then identified priority problems, generated solutions through brainwriting and ranked them on an impact–effort matrix to separate quick, high-impact wins from interventions needing more development. A demonstration of an early prototype let participants react to initial outputs and confirm that development matched their priorities. This grounded the Digital Twin and bulletin in users' operational realities.

3.2 Collaborative reflection for adaptive learning

Building on the Design Thinking priorities, the project team developed an initial Digital Twin architecture, models, automated forecasting workflows and visualization tools. Rather than finalizing these independently, the team held review workshops with the same stakeholders, combining short presentations and live demonstrations with open discussion. Participants related technical developments to their institutional experience and operational challenges in flood preparedness and response, and repeatedly asked whether the Digital Twin accurately reflected conditions in Dolo Ado.

Stakeholders compared outputs with past floods, including the 2023 event, to check whether models reproduced observed conditions and to identify areas needing further calibration. They recommended extending forecasting beyond the October–December (OND) season to cover the March–May wet season, advised on sensor locations based on local knowledge of flood-prone areas and monitoring gaps, and reviewed data collection and forecasting procedures for operational practicality. The sessions also clarified IWMI and MoWE's data-sharing responsibilities and roles in sustaining the Digital Twin beyond the project. This adaptive learning cycle kept stakeholders engaged between development phases, ensuring their feedback shaped the Digital Twin up to the version presented in later capacity-building and bulletin co-design activities.

3.3 Capacity-building activities

Capacity building was integral to co-creation rather than stand-alone technical support, with content and sequence aligned to stakeholder needs and local flood preparedness priorities. Sessions progressed from Digital Twin concepts and terminology to data integration and visualization, hydrological and hydraulic model integration, and automated forecasting workflows. This gave participants a shared understanding of how observations, models, forecasts and visual products connect, preparing them to contribute meaningfully to later co-design activities. The interactive format combined short presentations, live demonstrations of the IWMI Digital Twin platform, hands-on exercises and facilitated discussions, in which participants raised practical questions about data availability, uncertainty, forecast interpretation and institutional responsibilities.

The activities went beyond knowledge transfer. Participants linked Digital Twin outputs to their operational responsibilities, identified applications within their institutions and agreed on improvements, including refining sensor coverage, extending forecasts to the second wet season and clarifying hosting and maintenance roles. The sessions established a common technical language, built confidence in using Digital Twin outputs and increased institutional ownership. Discussions on which institution should host, operate and maintain the system showed participants looking beyond the technology toward its sustainable, coordinated use.

3.4 Bulletin co-design

Following the capacity-building activities, stakeholders moved directly into the collaborative design of the Flood Early Warning Bulletin. This sequence ensured that the bulletin reflected the practical information needs of participating institutions rather than relying on a generic template.

Defining purpose, content, and users

Participants worked in four groups, each representing a Digital Twin user persona from the earlier co-design workshop, such as DRM bureaus, water bureaus and other flood-response institutions. Each group defined the bulletin's main purpose from its persona's perspective and identified the information needed to act on a flood warning. This grounded the bulletin's content in the decision-making needs and local priorities of different users, avoiding a one-size-fits-all design.

Co-designing format and messages

Each group sketched a paper prototype of a bulletin for its persona on an A3 sheet, deciding on the layout, infographics and language needed to clearly communicate risk levels, maps, thresholds and recommended actions. This let stakeholders shape both the bulletin's content and its visual presentation, supporting quick, confident decisions during floods.



Picture of key stakeholders co-designing the flood bulletin
Photo by Rahel Mesagaw/IWMI

Refining the bulletin through feedback

Each group presented its prototype for structured peer feedback on content gaps, visual clarity and fit with each persona's operational needs. The review distinguished shared components from persona-specific requirements, guiding consolidation into refined versions. Through this iterative process, intended users shaped and validated the bulletin, strengthening its relevance for timely decisions and anticipatory action.

3.5 Validation and refinement

The project team combined the persona-based prototypes into a draft Dolo Ado Flood Early Warning Bulletin and shared it with all participating stakeholders, extending feedback beyond the workshop. Each institution reviewed the draft's content, clarity and usability against its own operational and

decision-making needs. The team incorporated this feedback, so the final bulletin reflected operational requirements rather than technical preferences alone. This cycle of drafting, review and refinement improved usability and built institutional confidence and ownership.

4. Data preparation and model setup

The Digital Twin links two physically based models: the HEC-HMS rainfall–runoff model, which converts catchment rainfall into river discharge upstream of the floodplain, and the HEC-RAS two-dimensional hydrodynamic model, which simulates river flow and overbank flooding across the floodplain.

The models draw on numerical weather prediction rainfall forecasts, satellite rainfall products, ground-based climate observations, river discharge measurements, high-resolution digital elevation models (DEMs), land-use and land-cover data, river geometry, hydraulic structures and Earth observation products. All datasets underwent standardized quality control and preprocessing for spatial and temporal consistency. CHIRP satellite rainfall was bias-corrected for use in simulation mode, and SWOT river water-surface elevations were used to estimate reference discharge, strengthening HEC-HMS calibration.

HEC-HMS was calibrated and validated to represent the river system's hydrology. HEC-RAS river cross-sections were derived from a 5 m DEM and refined with field observations, and model performance was evaluated against field inventory data and flood extents from Sentinel-1 and Sentinel-2 imagery. This validation increased confidence that the models reproduce observed flood dynamics and can generate reliable operational forecasts.

Discharge hydrographs from HEC-HMS feed into HEC-RAS, which simulates water levels, flow velocities, flood depths and inundation extents. These outputs are automatically integrated into the Digital Twin for visualization and analysis and translated into flood-hazard maps and Flood Early Warning Bulletins (Figure 3).

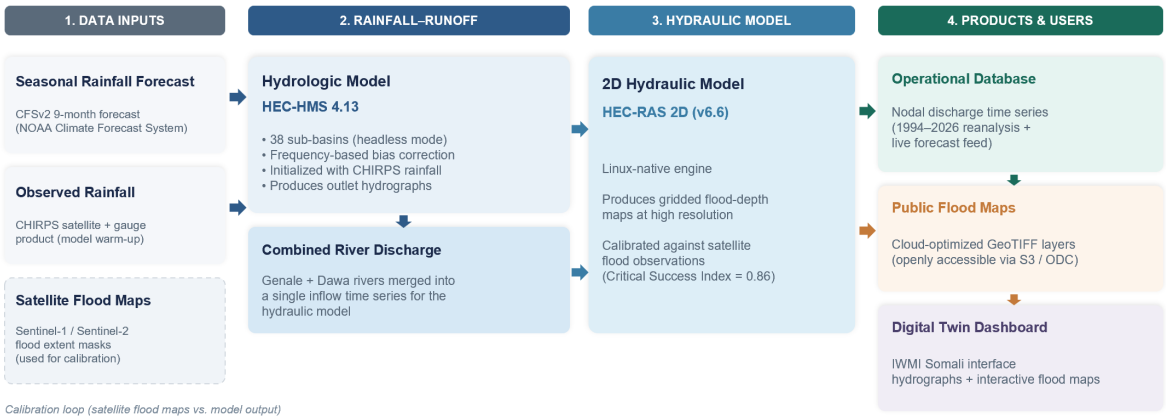


Figure 3. Overview of the Digital Twin forecasting architecture

5. Automation pipeline

Building on the calibrated rainfall–runoff and hydrodynamic models described in the previous section, the Digital Twin converts the forecasting workflow into an automated operational system. The pipeline consists of independent, modular Python scripts, each responsible for a specific task. This architecture allows individual components to be updated, maintained, or replaced without disrupting the wider system, thereby improving flexibility, scalability, and long-term sustainability. When executed sequentially, the scripts automate the complete forecasting process, including:

- Acquiring meteorological forecasts and supporting datasets;
- Preprocessing and formatting data and conducting quality-control checks;

- Running the HEC-HMS hydrological model;
- Automatically transferring discharge hydrographs to the HEC-RAS hydrodynamic model;
- Generating flood-extent, depth, and velocity maps with HEC-RAS;
- Extracting key forecast indicators and evaluating warning thresholds;
- Generating standardized Flood Early Warning Bulletins; and
- Preparing outputs for visualization, dissemination, and decision support.

By eliminating repetitive manual processing, automation substantially reduces forecast production time while improving consistency, transparency, reproducibility, and operational reliability. The pipeline also presents forecasts and potential impacts in the Flood Early Warning Bulletin through clear, decision-ready visualizations, enabling technical staff and disaster risk managers to focus on coordinating preparedness and response actions.

6. Key features of the Flood Early Warning Bulletin

The Flood Early Warning Bulletin is the Digital Twin's main communication product, turning complex hydrological and hydrodynamic outputs into concise, actionable information for readiness, anticipatory action and flood response. Co-designed with stakeholders through workshops and prototype reviews, it features terminology aligned with existing disaster management practice, accessible colours that clearly distinguish alert levels, and an information hierarchy that puts critical information first for rapid decisions.



Picture of sample flood bulletin co-designed by stakeholders
Photo by Rahel Mesganaw/IWMI

The Digital Twin automatically generates the bulletin as a standardized PDF in English, Amharic and Somali. Each issue is populated directly from the automated forecasting pipeline, so its figures, maps and warning levels trace back to the model run rather than being compiled manually.

The header shows the issue date, bulletin type, validity period, predicted peak date, lead time and an overall severity rating (Low, Moderate, Severe or Extreme). A plain-language “bottom line up front” summary then states the expected peak flow relative to normal conditions and return-period thresholds, the estimated households and people affected, the lead time and the recommended immediate action. Four headline indicators follow: inundated area, people exposed, households flooded and roads cut. The remaining sections (Table 1) cover early warning information, risk and exposure, inundation and evacuation mapping, water supply and sanitation impacts, anticipatory actions and coordination arrangements.

Table 1. Description of the main components of the Flood Early Warning Bulletin.

Bulletin section	What it communicates	Digital Twin source
1. Overview and context	Headline indicators (inundated area, people exposed, households flooded, road network cut) and a short situation narrative.	HEC-RAS 2D inundation; building footprints; road network
2. Flood early-warning information	Basin rainfall forecast against the historical mean; river discharge forecast hydrograph at the forecast node with return-period bands; trigger table linking discharge thresholds to response posture: Stand-up forum, plan; Pre-position, ready relocation; Stage evacuation (vulnerable first); Full emergency posture.	CFSv2 rainfall forecast; HEC-HMS discharge forecast; return-period analysis
3. Risk information	Four-tier risk level by settlement; exposure of communities, infrastructure and livelihoods; vulnerable groups.	HEC-RAS 2D maximum depth × building footprints; road network
4. Inundation and evacuation map	Projected flood depth map with impacted buildings coloured by depth; settlement table of people, houses, livestock, cropland, evacuation routes and relocation sites	HEC-RAS 2D; Buildings footprints, Woreda
5. Water supply and sanitation impact	Water-supply risk and protective actions for water and sanitation services.	Flood extent; WASH infrastructure: pump locations and characteristics from the Woreda
6. Advisory: anticipatory actions	Five staged actions, each with a responsible owner, trigger, time window and readiness status.	Discharge trigger ladder; woreda DRM roles
7. Integrated emergency support and coordination	Coordination structure under the Woreda DRM Coordinator, partner and resource mobilization, communication chain and timing of the next update	Stakeholder input; institutional arrangements (focal points to be assigned)

Linking forecasts to anticipatory action

The bulletin directly links river forecasts to response actions. Projected discharge at the Genale forecast node is compared with return-period thresholds derived from a Log-Pearson Type III fit to 33 years of annual maximum flows. Each threshold sets an operational posture: a 5–10-year flow activates the coordination forum and planning; a 25-year flow prompts pre-positioning and relocation readiness; a 50-year flow triggers staged evacuation, starting with the most vulnerable; and a 100-year flow triggers a full emergency posture. The advisory section lists five staged actions, each with a responsible institution, trigger, implementation window and readiness status. Measures needing weeks of preparation, such as securing budgets and pre-positioning supplies, can begin once an outlook is issued, while evacuation remains tied to observed discharge triggers. Each section ends with a “So what / do what” statement translating the forecast into practical action.

Impact-based, place-specific information

Rather than reporting river conditions alone, the bulletin translates forecast flood depths into expected impacts on people, infrastructure, and services. Maximum flood depths simulated by HEC-RAS are intersected with mapped building footprints to identify flooded households and classify them by depth:

Low (0.1–0.5 m), Moderate (0.5–1 m), High (1–2 m), and Very high (above 2 m). The number of people exposed is then estimated using the woreda average household size of seven. The flood map is also intersected with the road network to identify road sections expected to be cut by flooding.

7. Lessons learned and recommendations

Effective flood early warning needs more than robust models. Co-creation showed that institutional collaboration, operational capacity and user-centred design matter just as much as the technical foundation.

Local knowledge fills validation gaps: In data-scarce floodplains, stakeholders checked model outputs against their experience of past floods, including the extreme 2023 event, and the annual river-flow cycle. This pinpointed where further calibration was needed and built confidence in the Digital Twin.

Co-creation turns data gaps into shared action: Together, stakeholders diagnosed key monitoring gaps: rainfall stations thin out downstream, and streamflow stations exist only upstream and no longer report. They proposed rehabilitating stations and installing new gauges on the Genale and Dawa rivers just upstream of Dolo woreda, which MoWE and IWMI are now implementing to improve calibration and enable real-time forecast correction.

Diverse participation builds a shared forecast-to-action understanding: Bringing decision-makers, practitioners, humanitarian specialists and researchers from local to national levels together helped everyone see how rainfall forecasts become decision-ready information, and deepened the project team's grasp of local needs.

Design with users, not for them: Because stakeholders shaped the bulletin's content, visuals and structure, it gives DRM offices and humanitarian organizations the information they need in a form they can quickly find, interpret and act on.

8. Way forward

The co-created Digital Twin and Flood Early Warning Bulletin provide a strong foundation for a routine flood early warning service. Subject to budget availability, the transition beyond the project period will focus on five priorities:

Institutional ownership: Confirm the issuing institution, with MoWE as a strong candidate, define MoWE and IWMI roles during a structured handover, and integrate the system into existing EMI, MoWE and DRM early warning structures.

Monitoring and validation: Rehabilitate gauges and install new river and rainfall stations on the Genale and Dawa rivers to recalibrate models and enable real-time bias correction, and evaluate forecast performance over several flood seasons from October–December 2026.

Warning to action: Formalize the trigger ladder through pre-agreed contingency plans and, where possible, pre-arranged financing, so each warning level activates defined actions and resources.

Dissemination and capacity: Agree on channels, including the DRM forum, web, print, radio, SMS and kebele networks, review the bulletin after each flood season, and continue training forecasters, DRM staff and humanitarian partners.

Sustainability and scaling: Secure dedicated funding for operations and maintenance, track whether bulletins are received, understood and acted on, and extend the approach to other flood-prone basins.

Together, these steps can turn the Dolo Ado pilot into a model for climate services and disaster risk management across the region.

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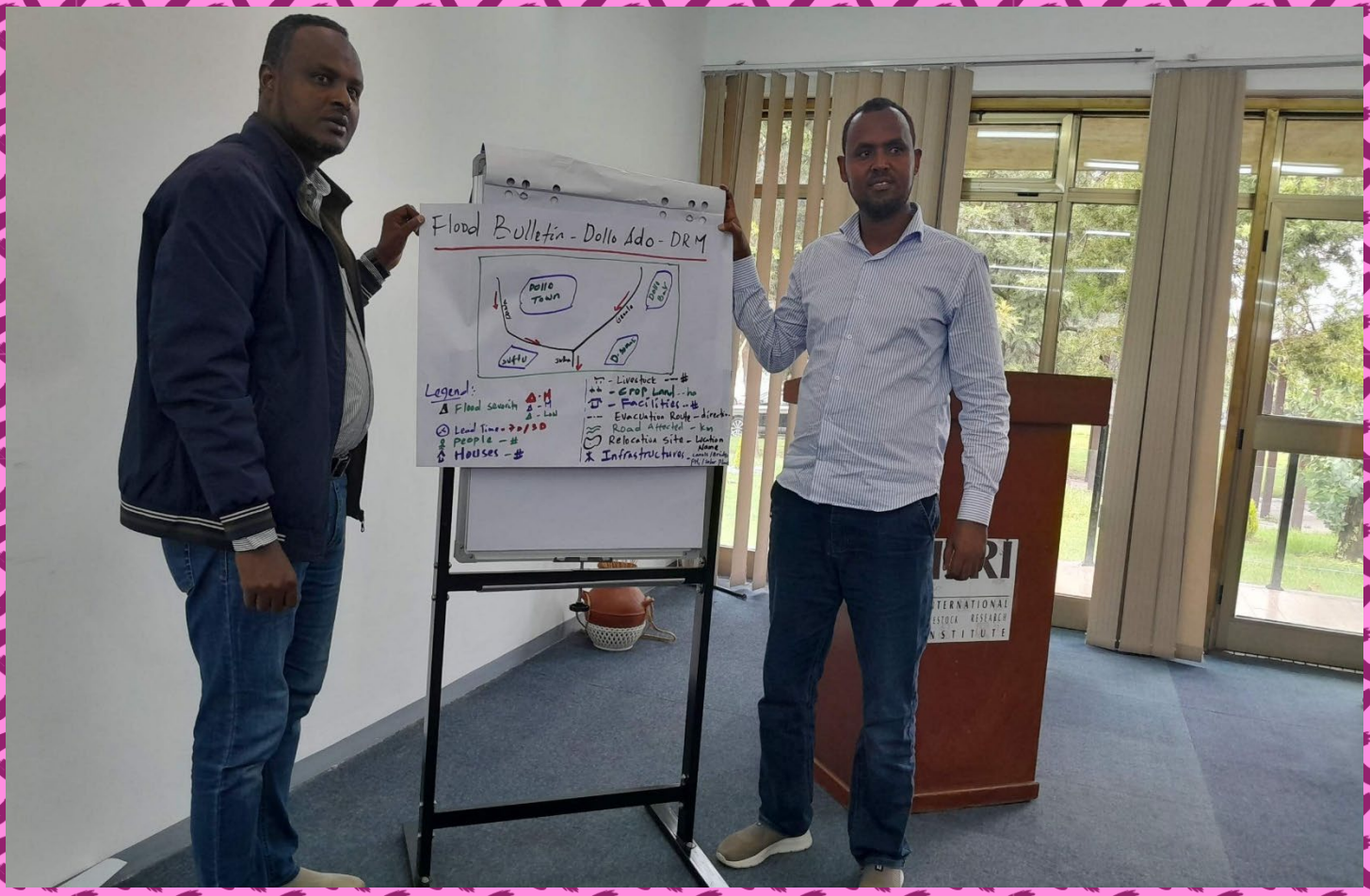
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