CGIAR
SCIENCE FOR A FOOD-SECURE FUTURE

Workshop Report

Hydrological Modelling for a Resilient Future: Innovations at the Water-Climate Nexus

October 5, 2025 | Indian Institute of Technology Roorkee, Uttarakhand, India

Alok Sikka, Shweta Yadav, Mohammad Faiz Alam, Surajit Ghosh,
Dhyey Bhatpuria, Suman Padhee, Sahana V., Shivam Pandey and Dipaka Sena

December 2025

Authors

Alok Sikka, Country Representative, India and Bangladesh; Senior Fellow, International Water Management Institute (IWMI), New Delhi, India
Shweta Yadav, National Researcher, IWMI, New Delhi, India
Mohammad Faiz Alam, Senior Regional Researcher, IWMI, New Delhi, India
Surajit Ghosh, Regional Researcher, IWMI, Colombo, Sri Lanka
Dhyey Bhatpuria, National Researcher, IWMI, New Delhi, India
Suman Padhee, National Researcher, IWMI, New Delhi, India
Sahana V., National Researcher, IWMI, New Delhi, India
Shivam Pandey, Consultant, IWMI, New Delhi, India
Dipaka Sena, Researcher, IWMI, New Delhi, India

Acknowledgements

This work was conducted under the CGIAR Climate Action Program, the CGIAR Policy Innovations Program, the CGIAR Scaling for Impact Program, and the CGIAR Sustainable Animal and Aquatic Foods Program. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund (www.cgiar.org/funders/).

We would also like to acknowledge the support provided by the Indian Council of Agricultural Research (ICAR).

Citation

Sikka, A.; Yadav, S.; Alam, M. F.; Ghosh, S.; Bhatpuria, D.; Padhee, S.; Sahana, V.; Pandey, S.; Sena, D. 2025. *Hydrological modelling for a resilient future: innovations at the water-climate nexus.* Report of the side event at the XIIth Scientific Assembly of the International Association of Hydrological Sciences (IAHS 2025), Uttarakhand, India, 5 October 2025. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Climate Action Program; CGIAR Policy Innovations Program; CGIAR Scaling for Impact Program; CGIAR Sustainable Animal and Aquatic Foods Program. 9p.

Front and back cover photos: IWMI India

Disclaimer

Contents

Background

The International Water Management Institute (IWMI) organised a side event at the XIIth Scientific Assembly of International Association of Hydrological Sciences (IAHS 2025) on “Hydrological Modelling for a Resilient Future: Innovations at the Water-Climate Nexus” on 05 October 2025 at Indian Institute of Technology Roorkee, Uttarakhand, India.

Climate extremes and competing demands are intensifying water challenges, where hydrological modelling offers critical insights for sustainable solutions across sectors and scales. This session highlighted the cutting-edge application of hydrological modelling approaches for various domains designed to address complex water challenges in a changing climate. Featuring contributions from CGIAR Science Programs and Accelerator i.e. Nexus Policy, Climate Action and Digital Accelerator along global partners, the session demonstrated how advanced tools and models are informing decision-making for sustainable and equitable development.

Topics included integrated hydrological modelling for managing water, energy, and food (WEF) nexus, drought and flood early warning system, salinity forecasting in coastal systems, and groundwater modelling for sustainable aquifer management. Emerging areas like socio-hydrology and the integration of hydrology with public health through antimicrobial resistance modelling was also featured.

Objective

The session aimed at delivering the participants on the insights from water risk assessment in vulnerable regions, and frameworks like Water Accounting Plus (WA+), AWARE Platform, Digital Twin, that leverage data for integrated land and water resource management. The session concluded with moderated panel discussion on how hydrological modelling can support resilience, equity, and sustainability across scales and sectors.

Event sessions

Inaugural session

Dr. Alok Sikka, Country Representative, India & Bangladesh/Senior Fellow, IWMI, welcomed the participants and provided an overview of the IWMI and CGIAR. He briefly discussed the projects and initiatives IWMI is carrying out for ensuring water and food security at the national and international levels.

Presentation by Dr. Alok Sikka, Country Representative, India & Bangladesh/Senior Fellow, IWMI, on “Integrated Hydrological Modelling for Managing Water-Energy-Food nexus”

The presentation “Integrated Hydrological Modelling for Managing the WEF Nexus” emphasized the interdependence of water, energy, and food systems and the need for integrated approaches to enhance sustainability and resource efficiency. It introduced the Agricultural Water–Energy–Food Sustainable Management (AWEFSM) framework and integrated hydrological models (SWAT+ and GWFlow) to simulate key hydrological and agricultural processes. Using diverse datasets, namely, the Digital Elevation Model, Land Use Land Cover , soil, groundwater, and meteorological inputs, the model evaluated irrigation modernization scenarios and their effects on water, energy, and food productivity. A composite WEF Nexus Index quantified the trade-offs and synergies under different management interventions such as improved irrigation efficiency, groundwater recharge, and crop diversification. The presentation highlighted on how the resulting WEF Decision Support System aligns with relevant SDG targets (2, 6 and 7) and supports policy decisions promoting sustainable agriculture and water management. The study underscores that managing water holistically within the WEF framework maximizes “nexus gains” and enhances climate resilience.

Presentation by Dr. Shweta Yadav, National Researcher, IWMI on "Role of Urbanization on Physicochemical properties and Antibiogram of a mixed-use Indian watershed under CGIAR One-Health initiative"

The presentation "Role of Urbanization on Physicochemical Properties and Antibiogram of a Mixed-Use Indian Watershed under the CGIAR One Health Initiative" investigated the impacts of urbanization on microbial contamination and antibiotic resistance in the Song River Basin, Uttarakhand. Within the One Health framework, it integrated hydrological modeling (SWAT and BFTM) with metagenomic and physicochemical analyses across urban and peri-urban sites. Results revealed that urban river system (Rispana, Bindal, Suswa) exhibit up to four times higher bacterial loads and greater antibiotic resistance, particularly during the summer. Dominant genera include *Pseudomonas* and *Staphylococcus*, with strong correlations observed between antibiotic residues, antibiotic resistance genes (ARGs), and heavy metals. The SWAT model demonstrated reliable hydrological calibration (Nash Sutcliffe fficiency = 0.70), while bacterial load modeling showed moderate accuracy. Overall, findings highlight urbanization and seasonal variability as key factors driving antibiotic resistance in riverine systems, underscoring the need for integrated pollution management under the One Health approach.

Presentation by Dr. Mohammad Faiz Alam, Regional Researcher, IWMI on "Resilient Aquifers: The Role of Managed Aquifer Recharge (MAR) in Climate Change Adaptation"

The presentation "Resilient Aquifers: The Role of Managed Aquifer Recharge (MAR) in Climate Change Adaptation" highlighted the increasing dependence on groundwater for irrigation in India, leading to widespread depletion. MAR is presented as a sustainable strategy to bridge the supply-demand gap and mitigate impacts on agriculture, food security, and ecosystems. In the Ramganga Basin, over 11,800 MAR structures have been built since 2017, contributing ~255 MCM of recharge (2.5–7.5% of rainfall recharge). There is significant potential to strengthen the management, monitoring, and evaluation of recharge structures. The results on the hydrologic performance of MAR from field-based assessments of representative recharge sites within the Ganges basin—particularly in the Ramganga basin, where groundwater stress is most pronounced— was presented. The findings aim to inform future design, management, and investment decisions under government programs, contributing to more sustainable groundwater recharge and enhanced water security in the Ganges basin and beyond

Presentation by Dr. Alok Sikka, Country Representative, India & Bangladesh/Senior Fellow, IWMI, on "Water Productivity Assessment for Climate Resilient Agriculture"

The presentation "Water Productivity Assessment and Prioritization of Agricultural Water Management for Climate Resilient Agriculture" emphasized improving water productivity (WP) to enhance food and climate security. Agriculture, which consumes over 70% of global freshwater, faces growing water scarcity projected to affect 3.2 billion people by 2050. The study introduced three WP dimensions: physical (yield per water unit), economic (value per water unit), and nutritional (nutrition per water unit). Using the Water Productivity Atlas (WP Atlas), district-level assessments across India reveal large regional variations, highlighting the need for location-specific interventions. In the Ganga Basin, groundwater overexploitation links to high energy use, while crop diversification (e.g., from rice to maize and vegetables) significantly improves WP and reduces groundwater and energy footprints. Tools like Water Productivity Decision Support System (WPDSS) and WP Atlas support scenario modeling and spatial planning, offering practical guidance for climate-resilient, water-efficient agricultural strategies.

Presentation by Dr. Surajit Ghosh; Regional Researcher, IWMI on "Digital Twin for River Basin Management"

The presentation titled "Digital Twin for River Basin Management: The Limpopo Use Case" focused on the integrated digital framework developed to strengthen water resource management and decision-making. It highlighted a co-design approach that engages stakeholders across sectors, integrating open data cubes, hydrological and forecasting models, and AI-based decision interfaces to enhance transparency and accessibility. A key innovation, WaterCopilot, jointly developed by IWMI, Microsoft Research, and The Limpopo Watercourse Commission (LIMCOM) supported by Helmsley Foundation, serves as an intelligent virtual assistant that provides real-time, multilingual, and user-friendly insights through maps, charts, and analytical narratives. The system connects various data services such as evapotranspiration, land use, and water availability using secure APIs and advanced AI methods. Designed for interoperability, scalability, and responsible AI deployment, the LIMPOPO Digital Twin

framework demonstrates strong potential for replication across other basins, integrating citizen science, capacity building, and inclusive data-driven decision support for sustainable river basin governance.

Presentation by Mr. Dhyey Bhatpuria; Dr. Suman Padhee; Dr. Sahana V., National Researchers, IWMI on "Flood and Drought Forecasting and Early Warning to Early Action"

The presentation "Flood and Drought Early Warning to Early Action" focused on advancing climate resilience through data-driven hydrological modelling, risk assessments and early warning systems. Dhyey Bhatpuria highlighted the IWMI Climate Resilience Tools such as the Drought Management System (DMS), AWARE platform, SukhaRakshak-AI, and HydroSecure Dashboard. These projects and products that strengthen disaster preparedness and adaptation planning are led by Dr. Giriraj Amarnath, Principal Researcher, IWMI. A key innovation discussed is the Next Generation Monitoring of Surface water fRom spACE (TRACE) tool, a satellite-based methodology for mapping and monitoring surface water storage in small waterbodies using Sentinel and Landsat data. This enables precise assessment of water availability, surplus, and deficit at basin and administrative levels. Validation against Reservoir data from IndiaWRIS demonstrated strong accuracy. TRACE offers insights into groundwater storages and Terrestrial Water Storages by utilising data from the Central Ground Water Board and GRACE, thereby contributing to integrated storage assessment and monitoring strategies. Suman Padhee spoke on the Hydrological modeling that integrates satellite and climate datasets to power drought and flood prediction modules, supporting anticipatory actions in South Asia and Africa. The DMS provides short- and long-term drought forecasts for platforms like SukhaRakshak-AI, while HydroSecure Flood Early Warning System (FEWS) delivers near real-time flood forecasts using Global Ensemble Forecast System (GEFS) data, improving early response across basins like the Zambezi and Bagmati. Sahana V. introduced the Catchment Risk–Resilience Index (CRI) developed for the Godavari River Basin, integrating 45+ physical, ecological, social, and infrastructure indicators. This helps identify catchments with high risk and low resilience, guiding investments, policy prioritization, and nature-based solutions for adaptive water management. Overall, the work demonstrated a holistic, multi-scale approach linking satellite observation, hydrological modeling, and risk–resilience frameworks to transform early warning into early action—strengthening water security, disaster resilience, and sustainable adaptation planning under changing climatic conditions.

Presentation by Mr. Shivam Pandey, Consultant, IWMI on "Rapid-assessment of Water Accounts for Effective Resource-use Planning in Data-scarce Regions"

The presentation "Rapid Assessment of Water Accounts for Effective Resource-use Planning in Data-scarce Regions" highlighted the importance of water accounting (WA) for sustainable water management. WA systematically quantifies water supply, demand, and usage to support equitable and efficient resource planning. The Water Accounting Plus (WA+) framework integrates satellite-based data to estimate blue (Irrigation water usage) and green (rainwater) water consumption that is crucial for areas with limited data. Applications of WA+ at Global level showed its effectiveness in irrigation management and basin-level planning. The recently developed, Scale-Invariant Water Accounting Plus (SIWA+) model allows faster, multi-scale, and cost-efficient assessments compared to traditional basin-scale approaches. Additionally, PaddyWA+, designed for rice-growing regions, links paddy field water dynamics with regional water balances, extends the applicability of WA+ for effective resource-use planning, these frameworks empower policymakers and water agencies with evidence-based tools for integrated water resources management (IWRM) and climate-resilient planning.

Presentation by Dr. Dipaka Ranjan Sena, Researcher, IWMI on "Salinity Forecasting to Support Irrigation Management and Decision-making in a Polder of Coastal Bangladesh"

The presentation "Salinity Forecasting to Support Irrigation Management and Decision-Making in a Polder of Coastal Bangladesh" addressed water and salinity challenges in Asian mega deltas, focusing on Bangladesh's coastal polders. These low-lying, embanked areas face severe issues like saltwater intrusion, flooding, and poor drainage, threatening agriculture and livelihoods. To improve water management, the study developed an AI/ML-based salinity forecasting system for Polder 34/2p near Khulna in the Ganges Delta. Using river discharge and salinity data (2011–2024) from IWM, GloFAS, and Hardinge stations, multiple machine learning models such as Long Short-Term Memory, Gated Recurrent Unit, Gated Recurrent Unit, Convolutional Neural Network, and Convolutional Neural Network - Long Short-Term Memory were tested. The models achieved high accuracy, with GRU and CNN showing strong performance (R^2 up to 0.96). The system forecasts discharge 30 days ahead

and predict salinity to inform irrigation scheduling and gate operation decisions. Once operational, it will serve as an advisory tool for farmers, supporting sustainable water use and climate-resilient agriculture.

Panel Discussion

The panel discussion brought together distinguished experts: Dr. C.S.P. Ojha (Professor, Indian Institute of Technology, Roorkee) Dr. Puneet Srivastava (Professor, University of Maryland), and Dr. Sunil Gurrapu (Scientist, National Institute of Hydrology, India), who provided reflections on the technical presentations delivered during the session. The discussion focused on the integration of scientific fundamentals, data quality, uncertainty analysis, and sustainable water management practices in advancing climate-resilient hydrology.

Dr. Puneet Srivastava commended the high quality of the presentations and the scientific rigor evident in the work. He emphasized the importance of grounding technological advancements in the fundamental principles of hydrology, cautioning against overreliance on tools without understanding their physical basis and data limitations. Using the example of flow measurements, he explained that both high and low flow conditions pose significant challenges where flood events are difficult to measure safely, while low flows yield unreliable discharge data. As most water resource and quality decisions hinge on extreme hydrological events, he urged researchers to prioritize accurate data collection during these periods.

Dr. Srivastava further stressed the need to incorporate uncertainty analysis in hydrological modeling, especially when integrating multiple datasets and models. He noted that understanding the propagation of uncertainty from climate to water and then to water quality models is essential for credible forecasts. He encouraged researchers to identify the simplest yet most reliable system representation and to continuously question assumptions through iterative analyses to deepen understanding and produce meaningful, sustainable solutions. Drawing on MAR examples, he also advised conducting long-term experimental monitoring before scaling up designs, emphasizing sustainable and clog-resistant system development.

Dr. Sunil Gurrapu expressed appreciation for the breadth of work presented, especially the innovative tools such as Water Accounting Plus (WA+), Scale-Invariant WA+, and the Water Copilot systems developed by IWMI. He shared insights from his own research on climate change impact assessment and hydrological extremes, highlighting the significance of dynamic downscaling of global climate model data for local applications. Dr. Gurrapu raised relevant technical queries about the temporal scales of forecast data used in drought and flood early warning systems, and the spatial resolution of the VIC model used for soil moisture indices, reinforcing the need for model validation and consistency across scales.

Dr. C.S.P. Ojha echoed the earlier comments and praised the scientific diversity of all the presentations. He elaborated on key technical observations, such as improving MAR efficiency through dual-pond systems and settling basins to minimize sediment clogging, insights drawn from his experience with infiltration basin design in the Sabarmati River. He also reflected on the broader applications of digital twin technologies in water resources, noting their origins and growing use in infrastructure modeling. Prof. Ojha appreciated the work on rapid water accounting, salinity forecasting in Bangladesh's polders, and the digital integration of hydrological models, emphasizing that the measurement and validation of discharge data remain persistent challenges in India. He illustrated this with real-world examples from projects in Gorakhpur and along the Indo-Pak and Indo-Nepal borders, where sedimentation, embankment breaches, and changing river courses have significant hydrological and agricultural impacts. Prof. Ojha also highlighted the importance of IWMI's work on AMR modelling at basin scale which is an emerging concern for India.

In conclusion, the panel collectively highlighted the importance of data reliability, uncertainty assessment, field validation, and interdisciplinary thinking in hydrological research. The experts commended IWMI and collaborating institutions for advancing scientific innovation at par with global standards and urged continued emphasis on combining advanced tools with strong physical understanding to deliver meaningful, resilient water management solutions.

Audience Interaction

Mr. Bharat Mahadevan from Climate Ventures inquired about the flow direction in the Bangladesh salinity forecasting study. Dr. Dipaka Ranjan Sena clarified that while river discharge flows north to south, tidal ingress moves south to north. The AI/ML model incorporates both discharge and tidal influences to improve salinity prediction accuracy.

Closing Remarks

Dr. Alok Sikka concluded the session by expressing gratitude to all presenters, panelists, and participants for their valuable contributions. He emphasized the continued importance of field-based measurements, calibration, and validation alongside modern modeling and remote sensing techniques. Reflecting on practical challenges in large-scale implementation, he highlighted successful examples like Mission Kakatiya for desilting and water conservation and recharge enhancement by Government programs. Dr. Sikka appreciated the insightful discussions led by the panelists reaffirming the need to balance theory with field situation. He warmly invited participants to engage further with IWMI's ongoing research and publications and enhanced partnerships.

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

To learn more about CGIAR Science Programs, please visit:
https://www.cgiar.org/cgiar-research-porfolio-2025-2030/climate-action/

Contact
Alok Sikka, Country Representative, India and Bangladesh; Senior Fellow, IWMI, New Delhi, India (a.sikka@cgiar.org)

CGIAR | POLICY INNOVATIONS | CLIMATE ACTION | SCALING FOR IMPACT | SUSTAINABLE ANIMAL AND AQUATIC FOODS

IAHS AISH | ICAR | IWMI International Water Management Institute