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Expanding and mainstreaming sociohydrology toward transdisciplinary praxis

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Since its development in the early 2010s, sociohydrology has deepened our understanding of the long-term coevolution of humans and water by integrating insights from both the natural and social sciences, while also fostering an interdisciplinary community. Its modus operandi to date has been to focus on emergent phenomena, manifesting as unintended consequences, in a variety of contexts. The compound disaster that struck Japan's Noto Peninsula in 2024, and similar experiences in other parts of the world, underscore the urgent need for systemic approaches that are co-developed by academia and practitioners and focus on context-specific solutions. This perspective piece thus calls for expanding and mainstreaming sociohydrology toward transdisciplinary praxis—transforming it into a dynamic and solution-oriented field that is more inclusive at all levels. Sociohydrology must become a driving force for innovation—promoting sustainable solutions that engage and empower local actors through transformative-transdisciplinary actions—involving real people in real places. Only through such transformative praxis can we co-create equitable, sustainable, and context-sensitive responses to the world's most pressing water challenges.

KEYWORDS

stakeholder engagement, interdisciplinary, compound disaster, decentralize, context-specific solution, coevolution, human-water feedbacks

1 Complex human-water feedbacks: insights from the 2024 Noto peninsula earthquake and heavy rain disasters

At 4:10 PM on January 1, 2024, an earthquake with a magnitude of 7.6 struck Japan's Noto Peninsula, causing extensive damage across the region and claiming 549 lives including 321 disaster-related (indirect) cases (Cabinet Office, 2025). One of the most severely affected infrastructures was the water supply system, which suffered catastrophic failures and resulted in widespread water shortages. Yet, some local communities demonstrated robust resilience by restoring traditional wells, thereby securing access to essential drinking water. This adaptive response underscored both the vulnerability of modern water systems and the enduring value of local water knowledge and practices and the need to preserve the wisdom behind traditional and situated adaptive practices.

In September of the same year, the region—still recovering from the earthquake—was hit by an unprecedented heavy rain event, leading to a compound disaster. Wajima City in Ishikawa Prefecture experienced a total rainfall of 546.0 mm over three days, marking the historical record of the Wajima raingauge station since 1976 (Japan Meteorological Agency, 2024). The heavy rainfall affected slopes already destabilized by the earthquake, and triggered over 1,900 landslides. There were nearly as many landslides as the 2,200 landslides caused by the earthquake itself (National Research Institute for Earth Science and Disaster Prevention, 2024). The September rains resulted in 16 fatalities and damaged 1,567 residential buildings. Flooding also affected evacuation shelters for earthquake survivors, which had been placed in floodplains due to the limited available flat land in the mountainous region. Notably, 806 of the approximately 5,000 evacuation shelters (16%) suffered inundation, further exacerbating the hardship faced by evacuees (Hokuriku Shinbun, 2024). Moreover, the delayed restoration of levees and riverbank protection structures, damaged by the earthquake, allowed floodwaters to spread in some areas, intensifying the impact (Umitsu, 2024).

This sequence of one compound event comprising earthquake, torrential rain, and landslides demonstrates the complex feedback mechanisms between natural hazards and human responses. It illustrates how the constraints of the mountainous terrain and the urgency of post-disaster recovery influenced settlement decisions, while the delayed infrastructure restoration amplified the other risk like flood, revealing the intertwined nature of human–water system feedbacks. And the intertwined impacts of seismic activity and extreme precipitation highlight the fragility of modern water infrastructure and the need to contextualize coevolution between nature and broader socio-political systems which can lead to unforeseen consequences. To build resilience, it is essential to understand how resilience has been shaped and continues to evolve through the long-term coevolution between modern centralized infrastructure and local, decentralized systems with the perspective on human-water feedbacks.

Since its development in the early 2010s, sociohydrology has advanced our understanding of human–water feedbacks (Sivapalan et al., 2012; Nüsser et al., 2012; Di Baldassarre et al., 2019; Kreibich et al., 2025). By integrating insights from natural and social sciences, sociohydrology has exposed the complex interdependencies that traditional disciplinary approaches often overlook. As the Noto Peninsula case reveals, contemporary water challenges are increasingly complex, requiring more holistic approaches. Compound disasters can affect entire social systems, and their underlying causes often involve intricate, long-term socio-political and cultural dynamics that exceed the analytical reach of conventional disciplinary frameworks.

To effectively respond to these challenges, we must expand sociohydrology beyond mere understanding of the causes of unintended consequences after the fact, but collaboratively co-create solutions by integrating scientific knowledge with place-based practical adaptation strategies and tactics. This entails not only fostering interdisciplinary collaboration but also actively integrating theory with practice, engaging stakeholders in a mutually beneficial manner, and collectively developing, testing, and scaling 'real-world' solutions that are adaptive and context-specific (Augenstein et al., 2024; Mukherjee et al., 2025). The Noto Peninsula case calls for adaptive management concepts considering long-term coevolution of water and society and participatory governance to avoid unintended consequences of management decisions, such as 'fixes that fail' (Di Baldassarre et al., 2019).

In this perspective, we define praxis as the active process of translating co-produced knowledge into anticipatory, context-specific, and actionable solutions that address real-world water challenges. While transdisciplinary research focuses on co-creating understanding across disciplines and societal actors, praxis goes a step further—aiming to integrate this knowledge into decision-making, governance, and adaptive management. It emphasizes not only learning about the world but also acting within it, in ways that are reflexive, participatory, and grounded in local realities. Our perspective primarily addresses researchers in sociohydrology, while also offering insights for practitioners and policymakers, arguing that sociohydrology must evolve from being an academic field of study into a science of praxis—a mode of inquiry and action that actively engages with complex human–water feedbacks to inform and enable transformative change.

2 Sociohydrology: an interdisciplinary-integrative science in understanding water-society dynamics

Sociohydrology was initially proposed as a scientific field aiming at understanding the dynamics of human–water feedbacks. In its early stages, the field proposed approaches to identify patterns of social behavior and development related to water, focusing on the "regularities" or "recurrences" of these processes through case studies and comparative research (Sivapalan et al., 2012). The methodologies were largely based on natural science traditions, which emphasized deriving generalizable rules and principles to explain observed phenomena and developing data sets that allowed for comparison and verification via modeling and simulation (Pande and Sivapalan, 2017; Di Baldassarre et al., 2018).

Consequently, early sociohydrology was characterized by a more reductionist orientation (Di Baldassarre et al., 2019), with a preference for quantitative methods over qualitative approaches (Seidl and Barthel, 2017). These early efforts provided important methodologies and insights for investigating complex human–water feedbacks and understanding how human activities influence hydrological systems.

As the field gained traction with social scientists, it opened the way for a more complex and holistic treatment of the social component of coupled human-water systems (Wesselink et al., 2017; Melsen et al., 2018; Xu et al., 2018; Ridolfi et al., 2020; Thaler, 2021). The formalization and quantification of social processes through positivist or reductionist approaches were complemented with social science approaches that allowed for the capturing the full complexity of human societies, thus avoiding the over-simplification of critical peripheral elements and interactions (Gober and Wheater, 2015). Perceiving challenges of interdisciplinary integration, Muller et al. (2024) identified specific combinations of disciplines, along a common set of topical, philosophical, and methodological dimensions, that might be easier to integrate (compatible), or to uncover previously unobtainable insights (complementary).

Consequently, the sociohydrological community now uses comparative empirical studies and sociohydrological modelling to test hypotheses regarding the dynamics of diverse socio-hydrological systems and explore future possibility spaces (Troy et al., 2015; Di Baldassarre et al., 2015; Schoppa et al., 2024) and uses a spectrum of human organizational complexity to assess heterogeneities within human systems across different scales (Yu et al., 2022; Van Oel et al., 2024). The rich diversity of interdisciplinary approaches and the development of diverse sociohydrologic communities have fostered the creation of genuinely novel approaches to understand various phenomena and archetypes of human–water feedbacks, as well as their regional diversity (Di Baldassarre et al., 2019; Mijic et al., 2024).

With these advances as the backdrop, focusing on appropriate amalgamations between hydrological and hydrosocial research frameworks, the 1st International Sociohydrology Conference was held in Delft, the Netherlands, in 2021. Under the theme "Engaging Social Scientists and Water Professionals to Address the SDGs," the conference accelerated interdisciplinary collaboration, reinforcing the importance of integrating diverse perspectives within sociohydrology (Pande et al., 2022). While interdisciplinary approaches have broadened sociohydrology's scope, a critical gap remains in translating understanding into actions (De Angeli et al., 2024). Praxis offers a necessary extension to transdisciplinarity: it is not enough to understand and co-create knowledge; we must embed this knowledge into real-world practices, policies, and adaptive management strategies. In this perspective, we argue for a praxis-oriented sociohydrology—one that bridges the gap between theory and action, between knowledge and its practical application.

3 From inter to transdisciplinary Sociohydrology

Will current sociohydrology be sufficient to fully understand and manage the complex human–water feedbacks that emerge, such as what happened during the 2024 Noto Peninsula disaster? It is clear that we must not only expand and mainstream sociohydrology but also make concerted efforts to involve diverse stakeholders and translate our understanding into practical actions to address real-world water issues, turning sociohydrology into more of an activist science.

Over the past decade, sociohydrology has sought to elucidate human–water feedbacks in contexts such as floods, droughts, agriculture, mountainous regions, and Earth system dynamics (Kreibich et al., 2025). However, to fully comprehend complex phenomena such as those observed in the Noto Peninsula, it is necessary to move beyond studying individual human–water feedbacks in isolation and instead understand their interconnected and integrated nature. This requires deeper insights into local community vulnerabilities, the spatial heterogeneity of crises, risks, and opportunities experienced by different social groups and sectors, and the resulting imbalances in the costs and benefits of water infrastructure (both traditional and modern, centralized and decentralized).

The Noto Peninsula serves as a vivid example of how sociohydrology can capture the complex, evolving relationship between communities and water systems. When the earthquake struck, some of the region's residents restored traditional wells for water—a local practice that re-emerged as a lifeline in the face of disrupted centralized water supply. Yet, the subsequent flooding of evacuation shelters revealed the limitations of relying solely on modern and centralized solutions. These contrasting experiences demonstrate the importance of integrating both mainstream scientific solutions with traditional and locally-informed knowledge systems. However, it is rare to find successful examples of such integration in global water management practices.

Transdisciplinarity in sociohydrology is an emerging discussion with only a handful of scholars establishing the need for a 'transdisciplinary turn' in this domain through 'knowledge co-creation' (De Angeli et al., 2024: Preprint), but also at the same time placing concerns about the limits of transdisciplinary research including hierarchical positionalities, different priorities and vested interests among actors, etc. (Krueger et al., 2016).

Latest theorizations on transdisciplinary research in sustainability sciences have tried to tackle some of these challenges. 'Transdisciplinary co-production' (Polk, 2015) and 'transformative transdisciplinarity' (Augenstein et al., 2024) have shown ways in overcoming research-practice barriers, ensuring inclusive and viable results. Thus, transdisciplinary praxis entails transformative action pathways where practitioners and researchers participate in "…the entire knowledge production process including joint problem formulation, knowledge generation, application in both scientific and real world contexts, and mutual quality control of scientific rigor, social robustness and effectiveness" (Polk, 2015: 11).

4 Envisioning transdisciplinary Sociohydrology: pedagogies and praxis

The Noto Peninsula case is not unique to Japan. Similar examples include endeavours in the Philippines, where local communities adapted to flooding during normal high tides after an earthquake induced land subsidence with stilted housing (Laurice Jamero et al., 2017), or in Asia and Sub-Saharan Africa, where drought-affected regions leverage Indigenous water management practices to build resilience (Lombe et al., 2024; Wickramasinghe and Nakamura, 2025). These diverse global examples highlight that the complexity and richness of human–water feedbacks are not isolated to any single region but are a fundamental characteristic of how societies engage with their water related issues.

To advance transdisciplinary sociohydrology, it is crucial to utilize approaches such as computational social science (Shelton et al., 2018; Koutiva et al., 2020), the use of novel and non-traditional data sources, data sharing initiatives, and the integration of quantitative and qualitative methods (Kreibich et al., 2023; Madruga de Brito et al., 2025; Veigel et al., 2025). Standardized methods for capturing and analyzing data on human perceptions, awareness, and water-related behaviors remain lacking. Historical data and information on local and Indigenous water systems are extremely scarce (Nakamura et al., 2024). These call for more concerted efforts by sociohydrologists (social scientists and hydrologists together) to overcome these methodological and conceptual deficiencies that limit advances in sociohydrological science and practice.

Building on such data, efforts must focus on developing sociohydrological models that support exploratory scenario development and the design, implementation, and evaluation of interventions. These models are essential for understanding how human–water coevolution can lead to unforeseen consequences and for developing strategies to mitigate such effects. Deeper insights into real-world human–water feedbacks must inform the creation of effective interventions aimed at promoting the sustainable management of water. However, 'solutions' often have limited capacities to solve problems that are 'wicked' – multi-dimensional, dynamic, and recurring (Mukherjee et al., 2023). The application of sociohydrological models to 'solutions' faces several challenges, including the limited capacity of models to fully represent stakeholder systems and associated uncertainties, the difficulty of defining system boundaries relevant to policy needs, the challenge of integrating individual and community-level behaviors into policy design, and the management of complex feedback loops, such as the levee effect. Furthermore, ontological differences in water governance frameworks, as well as unequal power relations in participatory processes, have been identified as additional barriers to fair and effective decision-making (Razavi et al., 2025; Ghoreishi et al., 2025).

Generating transformative solutions and knowledge capable of challenging entrenched, modern water governance policies, it is essential to pursue a transdisciplinary approach. This requires not only interdisciplinary collaboration between natural and social scientists but also the active involvement of multi-stakeholders, such as policymakers, practitioners, and local communities, directly affected by water challenges and development issues. Critically, this approach must ensure clear pathways from knowledge to action (K2A), where insights move beyond theoretical understanding and become practical solutions for sustainable water management and water governance, respect the unique characteristics of each place in their specific moment in time, incorporate the diverse lived experiences and intergenerational knowledge (De Angeli et al., 2024), and integrate and benefit the best of multiple traditions.

Methods such as participatory action research (PAR) and citizen science offer opportunities to bridge science and communities (Espinoza Cisneros and Blanco Ramírez, 2020; Nardi et al., 2022). For example, a citizen science project in Ethiopia's Upper Blue Nile region helped farmers better understand irrigation water availability and fairness, showing how social and economic factors, rather than hydrological ones, often shape agricultural decisions (Plakandaras et al., 2024). However, conventional approaches often overlook the knowledge and experiences of historically marginalized groups in water management and research (Haeffner et al., 2024). Innovative and inclusive pedagogies can craft meaningful collaborations between academia and user groups, based on mutual trust and recognition, democratizing decision-making processes and actions in solving water challenges.

By adopting these approaches, sociohydrology can transform itself into a dynamic field that goes beyond understanding the long-term coevolution of humans and water—grounded instead in local practices and contextual realities. Free from the constraints of modern technocratic water management and rigid policies, sociohydrology must become a driving force for innovation—advancing decentralized, resilient solutions that draw strength from local knowledge and activate community agency and resilience.

This is no longer a mere academic pursuit; it is a call to praxis—an imperative to move from collaborative understanding to collective actions. We must break away from conventional paradigms and boldly reimagine sustainable solutions rooted in the complex interactions between humans and water: real people in real places. Only through this transformative praxis can we build sustainable, equitable, and context-sensitive solutions for the world's most pressing water challenges.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

SN: Writing – review & editing, Writing – original draft, Conceptualization. HK: Writing – review & editing, Conceptualization. MH: Conceptualization, Writing – review & editing. JM: Writing – review & editing, Conceptualization. GD: Conceptualization, Writing – review & editing. MaS: Writing – review & editing. MiS: Writing – review & editing. GB: Writing – review & editing. TO: Writing – review & editing. MuS: Writing – review & editing, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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