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Innovative solutions for global water quality challenges: insights from a collaborative hackathon event

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Addressing the global water quality challenges requires collaborative efforts, multidisciplinary approaches, and innovative solutions. Here we report on the success of a special collective intelligence "hackathon event," organized by five United Nations agencies and the European Commission, with the aim of reinventing engagement with diverse experts and stakeholders to tackle real-world challenges in water quality monitoring and assessment. Participants from diverse backgrounds and regions convened to devise inventive solutions in four key challenge areas, including (1) transformation of water quality data into water stewardship action, (2) empowering citizen scientists to improve water quality, (3) incorporation of Indigenous communities and their water quality knowledge in global information systems, and (4) routine monitoring of antimicrobial resistance in water. The hackathon approach fosters collective intelligence in a safe, creative and collaborative environment, enabling participants to harness their collective knowledge, expertise and skills. Key outcomes were conceptualizing practical frameworks and tailored toolboxes for diverse water quality innovations to improve monitoring, empower communities, and support policy-making. Emphasis was placed on the purpose and value of interdisciplinary collaborations to address complex global challenges, showcasing synergies between technology, environmental science, and social engagement. Hackathons are catalysts for collaborative innovation which unlock future endeavors in harnessing collective intelligence to safeguard our most precious resource – water.

KEYWORDS

innovative solutions, water quality, collective intelligence, hackathons, international organizations, workshop design, collaboration, sustainable development

1 Introduction

Global ambient freshwaters are in crisis (Albert et al., 2021; Salehi, 2022). Limited data available indicate that human activities are resulting in a decline in freshwater quality globally. Increasing nutrient inputs, contaminants from urbanization and industrial activities, and hydrological and morphological alteration are affecting the health and resilience of freshwater ecosystems and, directly or indirectly, the quantity and quality of water resources available for human use (Chapman and Sullivan, 2022).

The importance of protecting and restoring freshwater systems has been recognized in supranational ambitions, such as those encompassed by Sustainable Development Goal 6 (Herrera, 2019) and by the United Nations Environment Assembly (UNEA) at its third session in December 2017 when it adopted Resolution 3/10 "Addressing water pollution to protect and restore water-related ecosystems" (UNEP/EA.3/Res.10). These ambitions seek to reverse negative trends by improving the global coverage of freshwater monitored, and provide an impetus to fund increased monitoring, reporting and preserving, improving or restoring ambient water quality. In many cases, technical solutions to reverse declines in water quality are available, such as wastewater treatment infrastructures. Similarly, in Europe, policy instruments to improve water quality have been in place for some decades already (Carvalho et al., 2019). However, water quality can be regarded as a "wicked problem," where the pathway to drive real change does not easily emerge from the complex mix of factors that influence outcomes. In several European countries, for example, targets for water quality have still not been satisfactorily achieved, and, declines in water quality have not necessarily been mitigated (Markert et al., 2024), or known factors for poor water quality fully addressed (Harrison et al., 2019). In the face of immensely growing stakes for humanity (Richardson et al., 2023), people and organizations facing environmental challenges, such as those in water quality monitoring, have realized the limits of solely relying on experts, especially in the multilateral system. Indeed, while experts have unprecedented skills to analyze problems in great details, their capacity to develop radical solutions is uncertain (Jansson and Smith, 1991; Bilalić et al., 2008).

There have been increasingly vocal calls to accelerate innovation toward developing radical solutions to safeguard or restore the environment (Pahl-Wostl, 2008) in addressing water quality issues across many factors influencing outcomes. This approach appears especially relevant in monitoring and assessment of water bodies (Jiang et al., 2020), in water governance, policy schemes (Berthet et al., 2021), enforcement, citizen engagement (Song, 2023), driving tangible action based on available data, integration of different data sources, or efficient and effective decision making. Innovations that make tangible progress toward addressing water quality must consider the multifaceted, cross-disciplinary nature of the issues involved, and present solutions that are sustainable, locally applicable, viable, and scalable. These solutions often leverage integration of new or improved components of existing modular systems, without disrupting organizations and institutions (Henderson, 2021). Identifying concrete solutions for the most promising innovations requires multiple perspectives (Hong and Page, 2004), which is the hallmark of collective intelligence (Malone and Bernstein, 2022).

Collective intelligence is the synergy of shared knowledge and skills among a group collaborating toward a common objective or problem-solving. By combining diverse perspectives, stemming from expertise, experiences and cultural backgrounds, groups can innovate and make better decisions compared to isolated individuals. Collective intelligence has been widely used in business, technology, and social sciences to leverage the benefits of teamwork and collective decision-making processes (Malone, 2018). Harnessing the power of collective intelligence not only enhances problem-solving capabilities but fosters creativity and a sense of unity among team members, leading to more effective outcomes and solutions. Importantly, collective intelligence works largely because people resort to non-verbal social interaction cues (Woolley et al., 2010) as a form of mind theory (Leslie et al., 2004). This is enhanced when participants gather in special spaces where unconventional ideas can flourish (Lifshitz-Assaf et al., 2021), when a safe "play-and-work" environment is provided, when participants have equal standing regardless of their role, and their intrinsic motivation is propelled by a clear sense of purpose (Miendlarzewska et al., 2021). The time-bound nature of a hackathon fosters a sense of urgency (Orlikowski and Yates, 2002), compelling participants to quickly sift through and refine ideas. This method ensures that solutions are grounded in local realities and can be implemented effectively at the community level (Trainer et al., 2014).

This approach is particularly conducive to citizen-led initiatives, as it encourages the participation of non-expert individuals with first-hand experience and knowledge of local water management issues (Gray et al., 2020).

Here, we consider how collective intelligence was implemented in the form of a hackathon workshop to renew the problem-solving processes, by fostering bi-directional interactions between International Organizations (IOs) and diverse experts and stakeholders ("collaborators" in this paper) through *grassroots* action groups active in water quality monitoring and assessment around the world. Building on insights learned from the Water Quality Monitoring and Assessment hackathon workshop organized by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the International Atomic Energy Agency (IAEA), the United Nations Institute for Training and Research (UNITAR), and the European Commission's Joint Research Center (EC-JRC), in September 2023, with a novel approach to science policy through collective intelligence. Our approach carefully reconciles the *top-down* and *bottom-up* constraints and advantages of science policy for concrete radical solutions. Solutions are implemented smoothly, while enhancing trust between IOs and "collaborators," as recommended by United Nations High-Level Advisory Board on Effective Multilateralism (HLAB), specifically regarding rebuilding trust in multilateralism (HLAB, 2024). This suggests IO's re-think how people shape their collective sustainable future. We describe how five IOs fundamentally challenged the usual multilateral processes involved in supporting "collaborators." By providing a novel framework, these "collaborators" co-created concrete solutions in a short period of time. This perspective article describes the paradigm shift in hackathons with potential to bring trust and unforeseen efficiency gains for IOs in delivering impact to beneficiaries.

2 Event conceptualization and organization

In March 2022, WMO, UNEP, UNESCO, the WHO and the Open Geospatial Consortium (OGC) jointly launched a *Workshop Series on Water Quality Monitoring* hosted under the banner of the World Water Quality Alliance (WWQA). This workshop series was designed to support countries in implementing global water quality guidance, foster innovative solutions for water quality monitoring and assessment, improve water quality data interoperability, and develop a common roadmap for strengthened cooperation on water quality across various institutions and data streams.

The *Innovation Workshop on Water Quality Monitoring and Assessment*, i.e. the hackathon, was part of this series with objectives to better understand operational challenges in water quality monitoring and assessment, and innovative solutions to address them.

Initially conceived by WMO and UNEP, the hackathon concept added UNESCO, EC-JRC and IAEA as collaborators in workshop planning and organization. Finally, the organizers engaged UNITAR to shape the innovative workshop format and facilitate.

3 Developing targets and event objectives

3.1 Call for challenges

As a first step, an *Open Call for Challenges* (c.f. Appendix 1) was launched to identify outstanding concrete challenges in water quality monitoring and assessment. Using a Challenge Proposal Template designed based on Spradlin (2012), applicants had to complete three key tasks: (1) *establish the need for a solution and justify this need* (articulating the basic need and the desired outcomes), (2) *contextualize the problem* (incl. examining past efforts, successes and failures to solve the problem), and (3) *write the challenge statement* (drilling the problem down to root causes and describing requirements and stakeholders required to solve it).

The emphasis of the *open call* was identifying an organizer responsible for gathering a multidisciplinary team to develop and submit the challenge proposal. 62 proposals were received and evaluated using the following six criteria: (1) relevance to the workshop focus areas, (2) concreteness of the challenge, (3) potential for impact, (4) comprehensiveness and design of the challenge, (5) consortium of submitters, and (6) evidence-based challenge.

Following rigorous evaluation using the evaluation criteria matrix (c.f. Appendix 2), the organizing committee selected four challenges that covered various aspects of water quality monitoring and assessment, and represented groups from four continents:

- Data to Action: Transforming data into actionable insights for water stewardship (North America)
- Empowering citizen scientists to improve water quality, from monitoring to action (Africa)
- Melding AquaWatch and Global Indigenous Knowledge (MAGIK) (Australia)
- Routine Monitoring of Antimicrobial Resistance in Water (Europe)

The proposal submissions for the selected challenges are reported in Appendix 3.

3.2 Call for participation and selection of participants

Experts and stakeholders from various backgrounds were identified to aid solution development for selected challenges, and a *Call for Participation* (c.f. Appendix 4) was initiated. The call featured the intended audience and the following participant selection criteria: (1) relevance of the candidate's expertise and experience to a specific challenge, (2) demonstrated motivation, (3) expected contribution, (4) geographic balance, and (5) gender balance. Geographic and gender representations were taken into consideration: to ensure diversity and inclusion across diverse regions and demographics, the organizers allocated resources to fully or partially fund up to 25 participants from developing nations, Indigenous groups, and marginalized communities.

With 293 applications received, a meticulous selection process resulted in 65 participants chosen for the workshop, of 58 who actually attended the workshop. Figure 1 below provides statistics on the 58 actual workshop participants.

3.3 Workshop design and preparation

This hackathon aimed to leverage collective expertise and innovative approaches to the selected challenges to drive solution implementation. It was planned to last 3 days: *Day 1* focused on learning and refining challenges; *Day 2* involved collaborative ideation and pitching solutions; and *Day 3* centered on strategies to implement identified solutions.

Participants received no specific guidance before the workshop. A dedicated workshop platform was provided, allowing participants to create profiles, access challenge-related spaces, and engage with organizers and others before, during, and after the workshop. Challenge owners underwent three briefing sessions with the organizers in advance of the hackathon to (i) articulate their specific problems, (ii) understand their roles and (iii) prepare presentations.

4 Activities on site (the "hackathon journey")

The hackathon took place in a face-to-face format on 27–29th September 2023 at the EC-JRC site in Petten, the Netherlands.

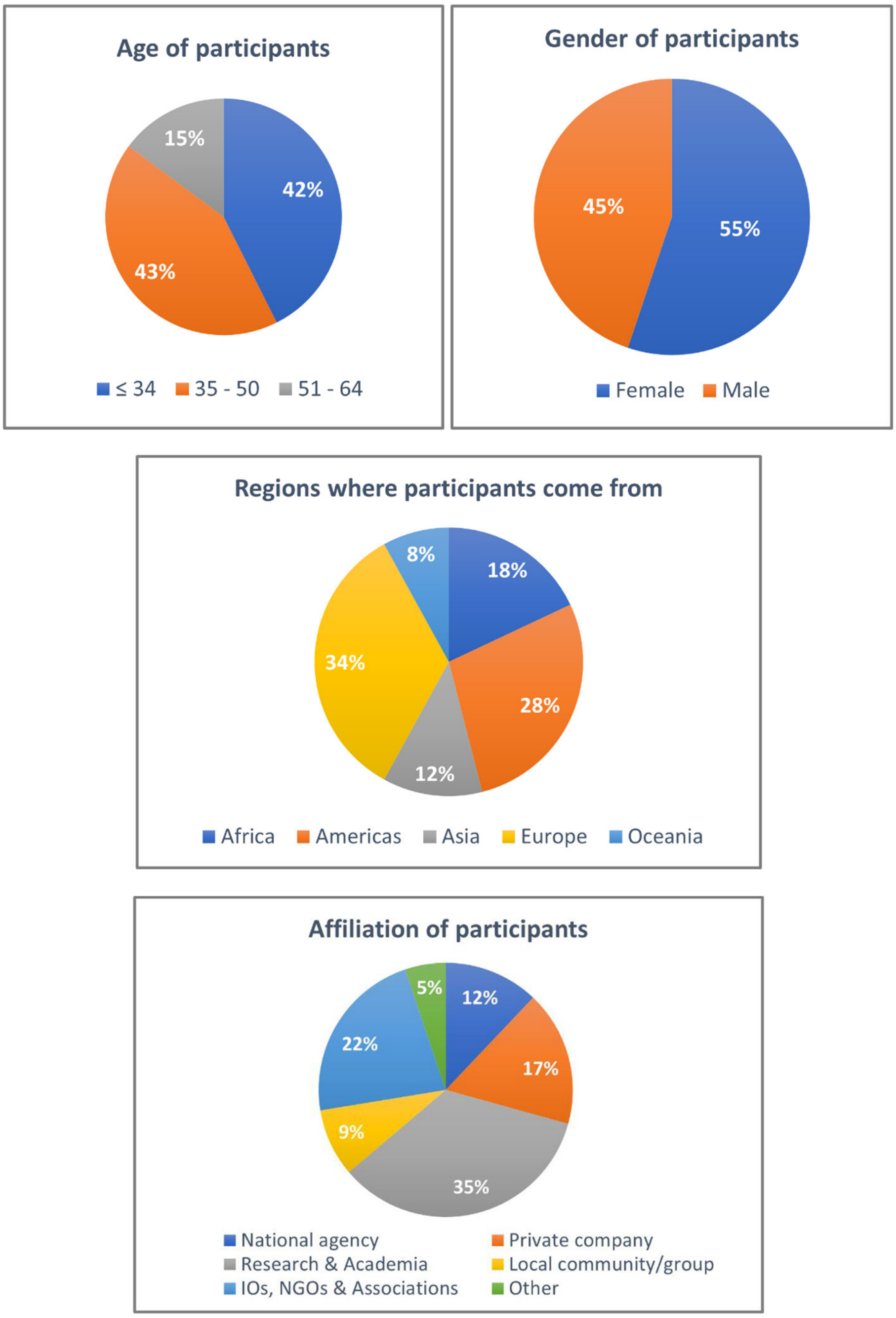

FIGURE 1
Summary statistics of participant age, regional representation, gender and affiliations.

On-the-ground scheduling and organization took place in the following manner:

4.1 Day 1

Challenge organizers pitched their challenges to inspire participants. Facilitators introduced techniques and practical tools for challenge shaping, peer-review and community building for better collective innovation. It was emphasized that expertise or experience should not be the first driver for contribution, but rather intrinsic motivation and shared sense of purpose. Then, participants divided into groups, one per challenge, to build a collective vision around the now-shared challenge. A few relevant sub-challenges were discussed and outcomes from this first exercise were shared with all participants, ensuring an inclusive reflection space.

The "hackathon" and "pitch" concepts were explained to participants. Each challenge group, comprising proponents of the

TABLE 1 Summary of challenge outcomes.

Data to action: transforming data into actionable insights for water stewardship	Participants developed a conceptual framework designed to assist water practitioners and advocate in translating raw data into actionable insights for decision-makers. Affectionately called the "Data Persuader," the framework leads users through a series of questions, helping them identify their data synthesis, interpretation, and communication needs. Working step by step through the whole framework culminates in a customized toolbox with practical resources for effectively communicating data to the practitioner's intended audience. The draft framework is available on GitHub (https://github.com/psaile/data-persuader).
Empowering citizen scientists to improve water quality, from monitoring to action	This challenge highlighted the breadth and scope of citizen science activities globally. Yet it recognized that the potential of these activities for positive impact can remain unrealized for numerous reasons. The challenge team proposed that impact could be improved by developing a two-way communication gateway that allows data and information transferal. This would include linking citizen data to national, regional and global reporting processes such as the SDGs, whilst simultaneously ensuring that information generated from citizen data is contextualized and made available at the local level. The details and perspectives of these outcomes are discussed in Warner et al. (2024) (published) by workshop participants to the same collection.
Melding AquaWatch and Global Indigenous Knowledge (MAGIK)	Participants formed a nascent global network of indigenous and non-indigenous water quality professionals dedicated to broadening perspectives and overcoming challenges to inclusion of indigenous user needs and knowledge into earth observation products and policy (Thompson et al., 2020). Sub-challenges discussed were (i) trust and capacity-building to enable beneficial engagement, (ii) technical data security concerns surrounding storage, (iii) sharing and sovereignty preventing misappropriation of indigenous knowledge. Promising practices and recommendations for both were outcomes of the work during the workshop. The details and perspectives of these outcomes are discussed in Lopez-Maldonado et al. (2024) published by workshop participants in the same collection.
Routine monitoring of antimicrobial resistance in water	Participants proposed to develop an adaptable global framework for routine monitoring of AMR in water to contribute to the achievement of SDG6 (targets 6.3.1, 6.3.2 and 6.a). The recommendation is to monitor wastewaters and natural waters for surveillance of AMR in the human population and for the reduction of AMR pollution in water systems, by setting up centralized regional laboratories. Participants also proposed an implementation plan to address the challenges posed by lack of funding, coordination and awareness. The details and perspectives of these outcomes are discussed in Cutrupi et al. (2024) published by workshop participants in the same collection.

respective challenge and the selected participants, formed sub-groups (maximum of 8 people each) to tackle the identified sub-challenges. Team size matters. Indeed, it has been found in social psychology that the optimal team size is around six people. A smaller size does not bring enough perspectives on problems, while larger groups get overwhelmed by coordination costs and relational loss (Mueller, 2012).

4.2 Day 2

The participants continued to work in small groups on identified sub-challenges in a self-organized and collective way, i.e. with no formal or structured coaching, and lean facilitation as needed. Outcomes of working sessions were pitched to all participants in a plenary setting to gain feedback and answer questions. After the second working session, the participants gathered for a social dinner, where challenge groups presented their final pitches in creative ways.

4.3 Day 3

The challenge groups strategized next steps to implement their ideas and solutions, and again pitched the results to all participants in a plenary setting. The workshop concluded with a panel discussion of challenge and workshop organizers on outcomes and the way forward. This panel discussion was conducted interactively with all participants of the workshop.

5 Follow-up

Sustained interaction amongst the challenge groups post-hackathon was essential, and feedback from participants to organizers was vital to the events success. Additionally, various outreach materials were produced and disseminated to publicize the workshop efforts and achievements via internet and social media, including a news release (WMO HydroHub, 2024).

To document the hackathon outcomes for posterity, some participants along with the workshop organizers decided collectively to produce manuscripts reporting results and reflecting on the unique hackathon approach, and one perspective article to report on how collective intelligence was used to advance innovative solutions to water quality challenges.

6 Results

This workshop catalyzed co-creation of innovative and collaborative solutions in the field of water quality monitoring and assessment by driving cross-sectoral and interdisciplinary reflection among participants.

The primary expectations of the workshop organizers were to:

- connect diverse experts and stakeholders in water quality monitoring and assessment, and enable collaborative concrete solutions to well-defined challenges,

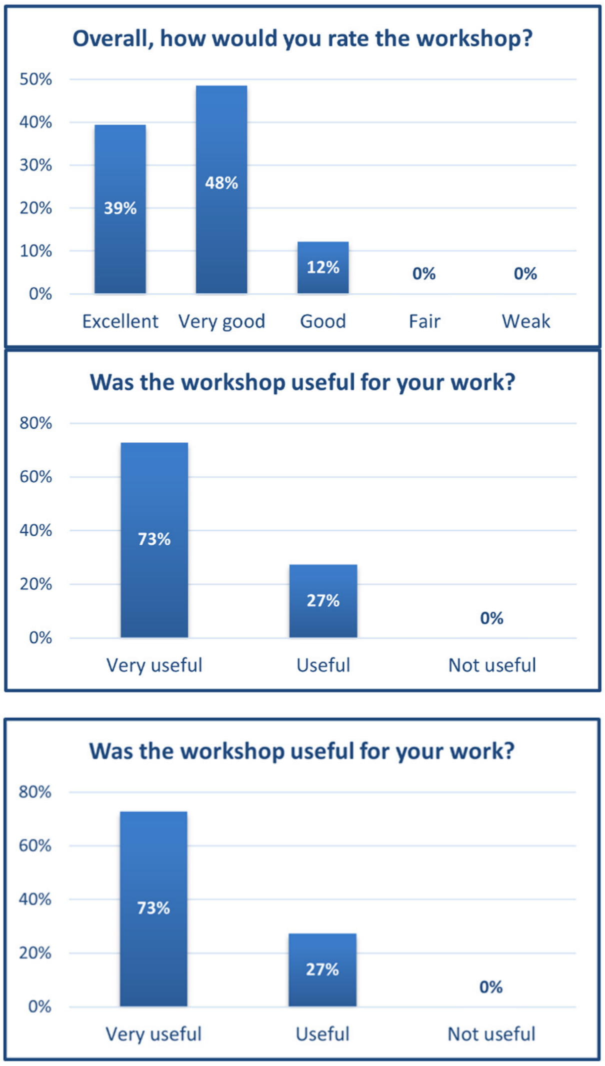

FIGURE 2
The results of the workshop survey.

- plan for implementing the identified solutions, and
- foster new relationship networks among experts and synergize their respective future work.

These expectations were fully achieved for most challenges, and it is important to highlight these achievements were the result of the hackathon approach described above, in which every step played an essential role toward delivering objectives.

The main technical outcomes of each workshop challenge are summarized in Table 1.

7 Lessons learned and recommendations

After the workshop, all the participants were invited to complete an anonymous survey. Figure 2 below shows survey results ($n = 33$).

Also, these three open-ended questions were answered by the workshop participants:

- What did you like the most about the workshop?
- What did you like less about the workshop?
- Is there something you would change for similar workshops in the future?

The elaborate and informative participant responses were analyzed in two steps. First, leveraging the analytical Python programming capabilities of ChatGPT, an initial aggregation of qualitative responses was performed, followed by a careful review and corrections by the authors of this article.

Our results show that diversity, collaboration, hands-on activities, networking, and cross-cultural learning had positive impact on fostering innovation and problem-solving. A diverse pool of participants, with diverse backgrounds and expertise, increased creativity and led to comprehensive solutions. Emphasis on equal participation created an inclusive environment which encouraged free idea sharing and collaboration. Hands-on activities, such as the hackathon format, effectively promoted active learning and rapid problem-solving. Networking among participants from different parts of the world enhanced connections and facilitated future collaboration. Further, low usage of electronic devices during the hackathon benefited participants' immersive and focused experience, and a cross-cultural focus enriched participants' understanding of global challenges. Collective intelligence, harnessed through teamwork and small group discussions, was crucial for brainstorming and identifying sustainable solutions.

Participants noted an overly packed schedule left little time for informal mingling. Also, the absence of interaction during Day 1 briefing sessions delayed relationship building within groups. It was also reported that the workshop duration was too short for deep discussions. Participants expressed a desire for more structured facilitation and guidance to help navigate sessions and tasks effectively using the novel hackathon approach. Overall, the workshop's success in driving innovation and learning highlighted the importance of diversity, active participation, and structured engagement, while also pointing out areas for improvement such as scheduling, activity variety, workshop duration, and facilitation. The results of this analysis coupled with the observations made during the workshop are summarized in the lessons learned and recommendations below (see Table 2).

8 Implications and importance

The workshop aimed to address global water quality challenges through an integrated, collaborative approach. Its primary goal was to efficiently tackle specific water-related issues while incorporating diverse stakeholder perspectives. This approach entailed finding a balance between efficiency, inclusivity, interdisciplinarity, and holistic solutions. The success of the workshop was largely due to its meticulously planned design, preparation, and follow-up, highlighting the significance of every detail in the organization process, to set up a safe space for co-creation in an environment that fostered commitment and innovation (Lifshitz-Assaf

TABLE 2 Summary of lessons learned and recommendations from the workshop.

Diversity fosters innovation	The workshop demonstrated that a diverse pool of participants, encompassing various backgrounds, cultures, and expertise, sparks creativity and innovation. It encourages unique problem-solving approaches and yields more comprehensive solutions.
Equal participation enhances collaboration	The workshop's emphasis on leaving job titles behind allowed for a more open and inclusive environment. This approach empowered everyone to freely contribute ideas, fostering a collaborative atmosphere where all voices were valued equally.
Hands-on activities foster learning	Engaging in hands-on activities, such as the hackathon format, enabled participants to learn actively, apply collective intelligence, and generate viable solutions quickly. This approach showcased the potential for rapid and effective problem-solving.
Networking strengthens connections	Opportunities for networking among a geographically diverse group, focused on shared causes or interests, proved invaluable. The connections forged during the workshop can lead to continued collaboration and knowledge exchange beyond the event.
Embracing unplugged environments	Very low usage of laptops and mobile phones encouraged a more focused and immersive experience, fostering deeper interactions and preventing distractions, which enhanced the quality of discussions and engagements.
Appreciation for cross-cultural learning	The cross-cultural focus provided a platform for understanding diverse perspectives on global issues. This exposure was seen as enriching, broadening participants' outlook and understanding of various global challenges.
Collective intelligence drives solutions	Leveraging collective intelligence through teamwork and small group discussions (maximum eight people) allowed for the effective brainstorming and formulation of recommendations. This collaborative approach was instrumental in tackling concrete problems and identifying sustainable solutions.
Balanced schedule and rest time	The schedule was overly packed with long working hours, late evenings, and early starts, leaving little time for rest, personal reflection and informal exchange moments. Ensuring a balanced schedule with sufficient breaks is crucial for participants to contribute effectively.
Diverse activities and interaction	Lack of interactive sessions such as icebreakers hindered participants from getting to know each other better, impacting group dynamics and trust. Incorporating diverse activities and structured interactions aids in building rapport and comfort among participants, fostering better collaboration.
Workshop duration	The duration of the workshop was deemed insufficient by some, limiting the depth of discussions and group work. Considering a longer duration thus providing additional time for consolidation, interaction, and knowledge exchange among groups could be beneficial.
Facilitation and guidance	Participants desired more structured facilitation and guidance during sessions, especially for newcomers in certain domains or for specific tasks like pitching ideas. Having facilitators with expertise to guide discussions and help resolve emerging barriers can help participants stay on track and maximize their contributions.

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et al., 2021; Miendlarzewska et al., 2021). This was achieved through a comprehensive application process for both challenge organizers and participants, ensuring that those involved were dedicated and motivated. This preparatory stage was crucial in setting the tone for the workshop by enhancing engagement, optimizing learning, creating a sense of purpose and relevance for every participant.

One aim of the workshop was to build a sense of community between people from all corners of the world who would not know each other, yet are committed to water quality in their own way. This sense of community allowed three out of four concrete technical outcomes to be swiftly reported in manuscripts published in this special issue of *Frontiers in Water*. Further, several participants and organizers of the workshop expressed their keen interest in replicating and adapting the structure of the hackathon workshop for their own purpose: the workshop participants from the National Water and Sanitation Agency of Brazil (ANA) have applied the same workshop concept and format in their own agency by organizing a Water Bodies Classification Marathon in March 2024. This hackathon, which was attended by water quality management technicians from several Brazilian states, produced concrete and actionable outcomes.

The broader implications of this Innovation Workshop extend to stakeholders and IOs involved in water quality monitoring and assessment. It presents a novel model for addressing water quality challenges with bottom-up generated solutions, prompting interest from various organizations in adapting this hackathon design for their initiatives. The process demonstrated in the workshop holds potential for application in other areas of water resource management, suggesting a versatile and effective approach to collaborative problem-solving in environmental contexts.

In conclusion, our study underscores the effectiveness of hackathons as a strategic mechanism for fostering collaboration and leveraging collective intelligence to tackle real-world challenges such as water quality monitoring and assessment.

In sharing our perspectives and detailing our experiences, outcomes and lessons learned, we aim to provide guidance on how radical solutions for water quality can be generated through collective intelligence and inspire future initiatives which capitalize on collective intelligence to address societal issues.

By advocating for principles of creativity, collaboration, and cross-disciplinary cooperation, we anticipate carefully planned and curated hackathons will assume a pivotal role in driving forward progress and advocating for sustainable practices. This influence is anticipated to extend beyond the water sector and encompass a broader spectrum of environmental challenges confronting humanity.

In light of these conclusions, our aspiration is to promote wider adoption of collective intelligence methodologies, particularly within the sphere of sustainable development. Specifically, we suggest wider integration of hackathons into IO activities. We anticipate such inclusive events hold significant potential to enhance trust, mutual understanding, visibility, and operational efficiency of IOs which are increasingly compelled to innovate radically (Ambos and Tatarinov, 2022) to remain relevant in a rapidly changing world.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

Author contributions

IC: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Formal analysis, Funding acquisition, Investigation, Project administration, Supervision. ME: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. TM: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. CC: Writing – review & editing. ST: Writing – review & editing. BG: Writing – review & editing. YV: Writing – review & editing. AA: Writing – review & editing. CD: Writing – review & editing. SW: Writing – review & editing. MN: Writing – review & editing. WM: Writing – review & editing. KC: Writing – review & editing. TA: Writing – review & editing. AS: Writing – review & editing. TS: Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

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CD was employed by DataStream. MN was employed by Global Science and Technology. WM was employed by Resistomap.

The remaining 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.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2024.1363116/full#supplementary-material

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