


Nota Tecnica - Technical Note

not peer reviewed



Community perspective on open issues to be tackled in Italian hydrogeology: review from an open discussion

Una prospettiva comunitaria sulle criticità nell'idrogeologia italiana: revisione di un dibattito partecipato

Paolo Colombo^{1,7} , Maria Chiara Porru^{2,7}, Ernesto Pugliese^{3,7}, Daniele Lepore^{4,7}, Alessia Di Giovanni^{5,7}, Davide Fronzi^{6,7}1 Politecnico di Milano, Milan, Italy - email  : paolo1.colombo@polimi.it; ecbn.italy@gmail.com

2 University of Cagliari, Cagliari, Italy

3 University of Bologna, Bologna, Italy

4 University of Naples Federico II, Naples, Italy

5 University "G. d'Annunzio" of Chieti, Pescara, Pescara, Italy

6 Marche Polytechnic University, Ancona, Italy

7 ECHN Italy, IAH

Introduction

Hydrogeology is a complex field that requires an understanding of both hydrology and geology, and it is interlinked with many other disciplines, from health science to agriculture and social sciences. It is also a growing subject, since climate change and anthropic pressures on the water cycle and aquifers worldwide have become more and more evident (Abbott et al., 2019; Berghuijs et al., 2024; de Graaf et al., 2019; Jasechko et al., 2024; Smerdon, 2017; Van Loon et al., 2016) and need to be addressed with adequate knowledge and tools.

Identifying open issues inside a discipline can help address them and improve the discipline itself. The hydrological community launched several activities in this direction. In 2019, the "twenty-three unsolved problems in hydrology" were published (Blöschl et al., 2019), highlighting areas of research, methodologies, and communication which the community agreed on needing answers. The goals of that work were to increase the coherence of the scientific progress in hydrology by having common research subjects, but also to spread awareness of the fact that many hydrological processes were (and still are) not fully understood. From 2013 to 2022, the International Association of Hydrological Sciences (IAHS) organized the scientific decade "Panta Rhei - Everything Flows: Change in hydrology and society", pushing a community-coordinated effort to better understand the increasing human impact on the water cycle (Kreibich et al., 2025), after the identification of a lack of research and action in this aspect (Brondizio et al., 2016; Montanari et al., 2013).

At the 7th National Meeting on Hydrogeology (Flowpath), organized by the Italian Chapter of the International Association of Hydrogeologists (IAH) in June 2025, the Italian hydrogeological community was asked to answer a generic but crucial question: "What are the problems and open issues to be addressed in hydrogeology in Italy?". The discussion was led by ECHN-Italy members (Early Career Hydrogeologists Network), structured to have a 5-minutes intervention from

5 inter-generational and crossing-background speakers, and then leave the next hour and a half to 2-minutes interventions from the event's participants. From the collection of the speeches, 6 clusters of topics were identified, highlighting the most pressing areas that would need intervention to improve hydrogeology in the country.

This article thus delineates the first community-led recognition of open issues in Italian hydrogeology, and aims to be a small cornerstone for future and broader discussions within the community, fostering collective actions on the identified problems and potentially extending the debate to the global IAH community.

Results

During the discussion, 24 interventions were collected. The full list of intervening people's names is reported in the Acknowledgment section. From these, a total of 46 topics were obtained by identifying the main points of each speech. The topics were then grouped into 6 clusters based on their affinity. The clusters are presented and briefly described in the section below, and the topics that led to their definition are further discussed in the subsequent section.

Topic clusters

The following paragraphs summarize the discussion by grouping the community contributions into clusters. The clusters' titles summarize the open issues identified. In Table 1, the number and percentage of topics grouped into clusters are shown.

1. Teaching and education

The current academic education in Italy is thought not to be fit for an up-to-date training of a hydrogeologist able to address the complexity of the topic and to confront with other disciplines.

2. Lack of interdisciplinarity

A paradox was found: the hydrogeologist inherently needs to be a figure able to manage multiple disciplines, but there is a prevalent sentiment that current people working and researching on hydrogeology in Italy lack the ability to confront with other disciplines and professionals. There is a

Copyright: © 2026 by the authors.

License Associazione Acque Sotterranee.

This is an open access article under the CC BY-NC-ND license:

<http://creativecommons.org/licenses/by-nc-nd/4.0/>

tendency towards having a figure able to do everything itself rather than being able to talk with people with different knowledge.

3. Data: availability, knowledge, homogeneity

Hydrogeological data in Italy has been deemed as generally hard to access, scarce, and not uniform among different entities and regions. A lack of understanding of how to manage and utilize the data was also identified.

4. Approach to complexity

The trade-off between the need for simplification and the complexity of the hydrogeological systems has been identified as a main reason for concern, particularly if simplification is used to avoid dealing with complex systems with more care, rather than a way to make them more understandable.

5. AI tools rise

On the verge of the rise of Artificial Intelligence (AI) tools such as Large Language Models (LLMs) and Deep Learning (DL) models applied to hydrogeology, the need for their conscious utilization has been evidenced as a relevant issue to address.

6. Out of clusters

Outside of the identified topic clusters, a case was made about the need to address contaminants of emerging concerns and the Italian policies and regulations fragmentation across regions and administrations.

Tab. 1 - Identified topic clusters, numbers, and percentages of topics grouped into each cluster.

Tab. 1 - Definizione dei cluster per numero e percentuale di argomenti.

Cluster number	Cluster title	Number of topics in cluster [-]	Percentage of topics in cluster [%]
1	Teaching and education	16	34.8
2	Lack of interdisciplinarity	9	19.6
3	Data: availability, knowledge, homogeneity	8	17.4
4	Approach to complexity	6	13.0
5	AI tools rise	5	10.9
6	Out of clusters	2	4.3
	All	46	100

Discussion on the topic clusters

Teaching and education

The most prominent topics were teaching and education, covering 35% of all the topics mentioned (Table 1). The discussion sparked from assessing a general lack of new enrollments in geology university programs. From there, interventions hypothesised the reasons that may be behind this. The education offered at the moment was described as static, with difficulties in evolving to teach multidisciplinary knowledge suitable to the new requests of society and human challenges, such as climate change, alongside a lack of developing critical thinking in students. An insufficient awareness among young students and general society about the role and the job of both geologists and hydrogeologists

was also noted: geologists are seen as “mere describers of the world” and not as professionals capable of providing reliable data and solutions to concrete problems. This is reflected in the educational offerings, with a lack of courses that integrate multidisciplinary knowledge, particularly important for hydrogeologists, as they need to be able to comprehend and manage the complexity of the discipline and the linkages with others.

This topic has also been identified on a global scale. IAH's vice president released a newsletter to the global community (IAH, 2025), recognising a general crisis in the academic field of Earth Sciences, launching the idea and intent on “reframing geology and hydrogeology as disciplines of opportunity and tools toward a safer, more sustainable future”. From 2015, IHE Delft and partners have been organizing the “International Master's programme on groundwater and global change”, named GroundwatCH (groundwatermaster.eu), specifically aimed at addressing gaps in higher education regarding groundwater understanding and its interaction with surface water and changes at global scale.

Lack of interdisciplinarity

The second cluster (20% of interventions, Table 1) is closely linked to the first, but the discussion around it went further in not only deeming the lack of interdisciplinarity as only due to the current Italian hydrogeologists' education, but also in recognising a compartmentalisation between geologists and other figures, underlining a lack of multidisciplinary teams and collaboration often due to lack of comprehension of each other needs, limits and opportunities. Some interventions also noticed a missing link between academia and professionals in the hydrogeological field, with the latter being usually delayed compared to the advances made in the field by the first. The current societal and research contexts need a figure able to understand other disciplines, but not necessarily able to do everything themselves, rather than being able to collaborate and cooperate with other experts and professionals.

Data: availability, knowledge, homogeneity

17% of the speeches addressed data availability, knowledge, and homogeneity as an open issue in the Italian hydrogeological context (Table 1). Data has been described as generally hard to access and usually scarce, and not homogeneously collected and stored. At the same time, when large datasets are available, there is a lack of skills in being able to manage them. These factors both lead and generate from what has been identified as a lack of understanding of the importance of openly available data and how to transform it into crucial information.

Approach to complexity

Embracing complexity is an increasingly important matter in current hydrogeology as well as in the current and future research and social context (Basel et al., 2022; Huang et al., 2025; Pande & Sivapalan, 2017; Sivapalan et al., 2012). 13% of the topics unveiled (Table 1) a well-known trade-off between

the inherent complexity of the systems considered and the need to simplify to provide insights and solutions, especially when modelling is involved (Hugman & Doherty, 2022). Simplification has been however described as usually the winner in this trade-off, since there is a lack in the community to be able to collectively address and represent systemic and complex conditions. The lack of vision and the fear of complexity can thus lead to oversimplified shortcuts, which have been deemed as a topic of concern in the discussion.

AI tools rise

All the interventions regarding AI tools, such as LLMs and DL models, revolved around the need to utilize them knowing both their perks and their limits (11% of the total topics, Table 1). The rise of these tools has been relevant in many fields of research (Elali & Rachid, 2023; Volpi et al., 2023), and hydrogeology is no exception (Alagha et al., 2017; Jung et al., 2024). The discussion agreed on their relevance and potential, but also warned that their use has to be backed up by real knowledge. The need is to avoid reliance on a “black-box” approach (i.e. without knowledge on the underlying processes in models), and instead retain control over algorithms through an appropriate choice of parameters, grounded in the user’s fundamental understanding of the physical setting and involved processes.

Conclusion

Identifying problems and issues is the first step to being able to solve them. Often, problems are “known” by everyone in a community, but until they are discussed, there is no way to address them. The Italian hydrogeological community made this first step by reflecting on issues in hydrogeology in Italy. This was done by dialoguing among peers at the 7th Edition of Flowpath, the National Meeting on Hydrogeology, organized by the Italian Chapter of the International Association of Hydrogeologists (IAH), in an open discussion held by ECHN-Italy.

By analysing the outcomes of the discussion, with more than 20 interventions, six main clusters of open issues were identified. They address relevant concerns linked with hydrogeologists’ reality in the country: teaching and education of hydrogeology in Italy, the lack of interdisciplinarity both taught and practiced, a general lack of data knowledge and availability, a short-sighted approach to complexity, and the need to consider the rise of AI tools.

The list presented in this article can now be a starting point to collectively recognize them and work towards their solutions. No solution can be found for problems not known.

Acknowledgements:

The discussion was organized by ECHN Italy in the context of the 7th Edition of Flowpath, the National Meeting on Hydrogeology organized by the Italian Chapter of the International Association of Hydrogeologists (IAH). The debate was made possible thanks to the interventions from (in order of speech): D. Di Curzio*, M. Meggiorin*, V. Vincenzi*, A. Gargini*, F. Lotti*, D. Lepore, S. Rusi, M. Petitta, P. Fabbri, P. De Vita, L. Di Taranto, S. Da Pelo, E. Cavana, E. Egidio, P. Mazzon, F. De Filippi, L. Alberti, A. Rovelli, P. Colombo. Special thanks are given to the people marked with an asterisk, who accepted to participate as invited speakers.

Author contributions:

Colombo, P.: Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing; Porru, M. C.: Conceptualization, Investigation, Data curation, Writing - review & editing; Pugliese, E.: Conceptualization, Writing - review & editing; Lepore, D.: Writing - review & editing; Di Giovanni, A.: Conceptualization, Writing - review & editing; Fronzi, D.: Writing - review & editing.

REFERENCES

- Arthington, A.H., Bhaduri, A., Bunn, S. E., Jackson, S.E., Tharme, Abbott, B. W., Bishop, K., Zarnetske, J. P., Hannah, D. M., Frei, R. J., Minaudo, C., Chapin, F. S., Krause, S., Conner, L., Ellison, D., Godsey, S. E., Plont, S., Marçais, J., Kolbe, T., Huebner, A., Hampton, T., Gu, S., Buhman, M., Sayedi, S. S., ... Pinay, G. (2019). A water cycle for the Anthropocene. *Hydrological Processes*, 33(23), 3046–3052. <https://doi.org/10.1002/hyp.13544>
- Alagha, J. S., Seyam, M., Md Said, M. A., & Mogheir, Y. (2017). Integrating an artificial intelligence approach with k-means clustering to model groundwater salinity: The case of Gaza coastal aquifer (Palestine). *Hydrogeology Journal*, 25(8), 2347–2361. <https://doi.org/10.1007/s10040-017-1658-1>
- Basel, B., Hoogesteger, J., & Hellegers, P. (2022). Promise and paradox: A critical sociohydrological perspective on small-scale managed aquifer recharge. *Frontiers in Water*, 4. <https://doi.org/10.3389/frwa.2022.1002721>
- Berghuijs, W., Collenteur, R., Jasechko, S., Jaramillo, F., Luijendijk, E., Moeck, C., Van der Velde, Y., & Allen, S. (2024). Groundwater recharge is sensitive to changing long-term aridity. *Nature Climate Change*, 14. <https://doi.org/10.1038/s41558-024-01953-z>
- Blöschl, G., Bierkens, M. F. P., Chambel, A., Cudennec, C., Destouni, G., Fiori, A., Kirchner, J. W., McDonnell, J. J., Savenije, H. H. G., Sivapalan, M., Stumpp, C., Toth, E., Volpi, E., Carr, G., Lupton, C., Salinas, J., Széles, B., Viglione, A., Aksoy, H., ... Zhang, Y. (2019). Twenty-three unsolved problems in hydrology (UPH)—a community perspective. *Hydrological Sciences Journal*, 64(10), 1141–1158. <https://doi.org/10.1080/02626667.2019.1620507>
- Brondizio, E. S., O'Brien, K., Bai, X., Biermann, F., Steffen, W., Berkhout, F., Cudennec, C., Lemos, M. C., Wolfe, A., Palma-Oliveira, J., & Chen, C.-T. A. (2016). Re-conceptualizing the Anthropocene: A call for collaboration. *Global Environmental Change*, 39, 318–327. <https://doi.org/10.1016/j.gloenvcha.2016.02.006>
- de Graaf, I. E. M., Gleeson, T., (Rens) van Beek, L. P. H., Sutanudjaja, E. H., & Bierkens, M. F. P. (2019). Environmental flow limits to global groundwater pumping. *Nature*, 574(7776), Article 7776. <https://doi.org/10.1038/s41586-019-1594-4>
- Elali, F. R., & Rachid, L. N. (2023). AI-generated research paper fabrication and plagiarism in the scientific community. *Patterns*, 4(3), 100706. <https://doi.org/10.1016/j.patter.2023.100706>

- Huang, J., Sangiorgio, M., Wu, W., Maier, H. R., Wang, Q. J., Hughes, J., & Castelletti, A. (2025). Solving the robustness puzzle: The joint impact of optimization approach, robustness metrics, and scenarios on water resources management under deep uncertainty. *Journal of Environmental Management*, 373, 123540. <https://doi.org/10.1016/j.jenvman.2024.123540>
- Hugman, R., & Doherty, J. (2022). Complex or Simple-Does a Model Have to be One or the Other? *Frontiers in Earth Science*, 10. <https://www.frontiersin.org/articles/10.3389/feart.2022.867379>
- IAH. (2025). News & information-August 2025 (IAH News & Information) [Newsletter]. <https://iah.org/wp-content/uploads/2025/08/IAH-Newsletter-Summer-2025.pdf>
- Jasechko, S., Seybold, H., Perrone, D., Fan, Y., Shamsudduha, M., Taylor, R. G., Fallatah, O., & Kirchner, J. W. (2024). Rapid groundwater decline and some cases of recovery in aquifers globally. *Nature*, 625(7996), Article 7996. <https://doi.org/10.1038/s41586-023-06879-8>
- Jung, H., Saynisch-Wagner, J., & Schulz, S. (2024). Can eXplainable AI Offer a New Perspective for Groundwater Recharge Estimation?-Global-Scale Modeling Using Neural Network. *Water Resources Research*, 60(4), e2023WR036360. <https://doi.org/10.1029/2023WR036360>
- Kreibich, H., Sivapalan, Murugesu, AghaKouchak, Amir, Addor, Nans, Aksoy, Hafzullah, Arheimer, Berit, Arnbjerg-Nielsen, Karsten, Vail-Castro, Cynthia, Cudennec, Christophe, Madruga de Brito, Mariana, Di Baldassarre, Giuliano, Finger, David C., Fowler, Keirnan, Knoben, Wouter, Krueger, Tobias, Liu, Junguo, Macdonald, Elena, McMillan, Hilary, Mendiondo, E. Mario, ... and Blöschl, G. (2025). Panta Rhei: A decade of progress in research on change in hydrology and society. *Hydrological Sciences Journal*, 0(0), 1–27. <https://doi.org/10.1080/02626667.2025.2469762>
- Montanari, A., Young, G., Savenije, H. H. G., Hughes, D., Wagener, T., Ren, L. L., Koutsoyiannis, D., Cudennec, C., Torh, E., Grimaldi, S., Blöschl, G., Sivapalan, M., Beven, K., Gupta, H., Hipsey, M., Schaeffli, B., Arheimer, B., Boegh, E., Schymanski, S. J., ... Belyaev, V. (2013). "Panta Rhei-Everything Flows": Change in hydrology and society-The IAHS Scientific Decade 2013–2022. *Hydrological Sciences Journal*, 58(6), 1256–1275. <https://doi.org/10.1080/02626667.2013.809088>
- Pande, S., & Sivapalan, M. (2017). Progress in socio-hydrology: A meta-analysis of challenges and opportunities. *WIREs Water*, 4(4), e1193. <https://doi.org/10.1002/wat2.1193>
- Sivapalan, M., Savenije, H. H. G., & Blöschl, G. (2012). Socio-hydrology: A new science of people and water. *Hydrological Processes*, 26(8), 1270–1276. <https://doi.org/10.1002/hyp.8426>
- Smerdon, B. D. (2017). A synopsis of climate change effects on groundwater recharge. *Journal of Hydrology*, 555, 125–128. <https://doi.org/10.1016/j.jhydrol.2017.09.047>
- Van Loon, A. F., Stahl, K., Di Baldassarre, G., Clark, J., Rangescroft, S., Wanders, N., Gleeson, T., Van Dijk, A. I. J. M., Tallaksen, L. M., Hannaford, J., Uijlenhoet, R., Teuling, A. J., Hannah, D. M., Sheffield, J., Svoboda, M., Verbeiren, B., Wagener, T., & Van Lanen, H. A. J. (2016). Drought in a human-modified world: Reframing drought definitions, understanding, and analysis approaches. *Hydrology and Earth System Sciences*, 20(9), 3631–3650. <https://doi.org/10.5194/HESS-20-3631-2016>
- Volpi, E., KIM, J. S., Jain, S., & Shrestha, S. (2023). Editorial: Artificial intelligence in hydrology. *Hydrology Research*, 54(6), iii–iv. <https://doi.org/10.2166/nh.2023.102>