



Water resources management for a sustainable nexus of hydrogeoethics and societal well-being

Manuel Abrunhosa^{1,2} · António Chambel³ · Silvia Peppoloni^{2,4} · Patrícia Ferraz de Matos⁵ · Alexandra Aragão⁶ · Marco Petitta⁷ · Helder I. Chaminé^{8,9} 

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Editorial

Groundwater is a vital resource for humans, non-human species, and ecosystems. It has allowed the development of human evolution and civilizations throughout history (e.g., Wittfogel 1956, Tempelhoff et al. 2009, Cuthbert and Ashley 2014, Roberts 2014). However, it faces multiple potential threats that make it vulnerable and fragile. Climate change and human activities are the primary causes that have led to water cycle disruptions, particularly a decline in groundwater quality and quantity (e.g., Gleeson et al. 2020, Chaminé et al. 2022, Richardson et al. 2023). Climate variability has induced droughts, floods, and other extreme weather conditions, significantly impacting groundwater in

many regions. Meanwhile, human activities such as over-abstraction, ground contamination, deforestation, land-use change, and other anthropogenic pressures have further compromised groundwater status. Nonetheless, groundwater continues to fulfill water demands in many regions or during specific periods. Therefore, concerted efforts are imperative to ensure its sustainability. So, conservation practices and nature-based solutions must be adopted to efficiently manage groundwater and shield it from additional potential hazards or risks (e.g., contamination, pollution, or over-abstraction). Failure to act quickly can result in the loss of this critical resource, with severe consequences for the economy, society, and ecosystems. From this perspective, it is imperative to prioritize actions underscored by technical-scientific integrity, environmental responsibility, societal sensitivity, and ethical practices.

Hydrogeology is a firmly established scientific discipline that studies groundwater systems, encompassing the chemistry behavior and the intricate dynamics of water flow within pores, fractures, and cavities (e.g., Freeze and Cherry 1979). This technical-scientific field delves into this vital resource's occurrence, flow, and quality status while also addressing the management and planning of different and diverse environmental and human interactions with groundwater systems. In addition, the role of groundwater science and engineering shall be pursued through a keen education of practitioners, students, and educators, or in the bold words of Cherry (2023): "We desperately need educated groundwater professionals to manage and protect freshwater resources. The job market for groundwater professionals is buoyant. Over the past decade, many young people have become motivated to work toward a sustainable planet, and groundwater science will resonate with them. Offering groundwater education in a multidisciplinary framework that interfaces hydrogeology with agriculture, ecology, economics, law, forestry and sociology will not only appeal to students, but is the only way to address groundwater in a

✉ Helder I. Chaminé
hic@isep.ipp.pt

¹ Centre for Earth and Space Research (CITEUC), University of Coimbra, Coimbra, Portugal

² International Association for Promoting Geoethics (IAPG), Rome, Italy

³ Institute of Earth Sciences (ICT), Department of Geosciences, University of Évora, Évora, Portugal

⁴ Istituto Nazionale Di Geofisica e Vulcanologia (INGV), Rome, Italy

⁵ Instituto de Ciências Sociais (ICS), Universidade de Lisboa, Lisbon, Portugal

⁶ Institute for Legal Research, Faculty of Law, University of Coimbra, Coimbra, Portugal

⁷ Department of Earth Sciences, La Sapienza University of Rome, Rome, Italy

⁸ Laboratory of Cartography and Applied Geology (LABCARGA), Department of Geotechnical Engineering, School of Engineering (ISEP), Polytechnic of Porto, Porto, Portugal

⁹ Centre GeoBioTec|UA, Aveiro, Portugal

rigorous manner". Nevertheless, geoscientists and geoprofessionals can play a critical role in engaging with the Earth's systems, which encompasses groundwater: it is unavoidable for them to navigate this interaction with a steadfast commitment to ethical, environmental, and social responsibility.

Geoethics is a sound transdisciplinary field that empowers the conscientious consideration of the moral and societal implications inherent in the research, practice, education, and communication of geosciences to society (e.g., Gundersen 2018, Bohle 2019, Aragão 2019, Bohle and Marone 2021, Di Capua et al. 2021, Peppoloni and Di Capua 2022, Gerbaudo and Tonon 2023, Peppoloni et al. 2023). It is vital to continue and deepen education on the geoethical responsibility for professionals, educators, and students at all levels of education and society (e.g., Peppoloni and Di Capua 2022, Handl et al. 2022, Canseco and Bellaubi 2022).

Considering the specifics of groundwater among freshwater resources, hydrogeoethics is crucial in ensuring ethical research practices and fostering the adoption of best practices in groundwater science and engineering for sustainable water management and planning (Abrunhosa et al. 2021). Central to this endeavor is recognizing societal needs and maintaining environmental equilibrium to achieve balanced and sustainable resource management and planning. This approach must be underpinned by the principle of responsibility, guiding actions towards establishing a harmonious balance between humans and the natural dynamic world (e.g., Jonas 1984, Peppoloni and Di Capua 2022, Peppoloni 2023).

The right to access fresh and clean water stands as one of the fundamental human rights, crucial for the survival and well-being of all ecosystems that rely upon it (e.g., Gleick 1996, 1998, Falkenmark 2003, Llamas et al. 2009, Tortajada and Biswas 2017). The intricate relationship between human activities and groundwater often creates many complex and conflicting interests. This dynamic involves a diverse array of stakeholders, including scientists, professionals, policymakers, managers, organizations, and citizens. Therefore, it becomes imperative to prioritize ethical and responsible groundwater resource management to ensure their sustainable use for the benefit of today's and future generations (e.g., Leopold 1990, Custodio 2000, 2021, Llamas 2003, 2004, Datta 2005, Llamas et al. 2009, Ziegler and Groenfeldt 2017, Groenfeldt 2019, 2021, Abrunhosa et al. 2021, Aragão 2021, Chaminé et al. 2021, Peppoloni 2023). However, insufficient knowledge often leads to inadequate and irresponsible actions. In addition, it is time to acknowledge the pivotal role of groundwater in dialogues surrounding water-related issues. Biswas and Tortajada (2024) depict groundwater as "an unseen, overused, and unappreciated resource" within discussions and decision-making

processes. This recognition serves as a constructive step towards highlighting the significance of groundwater in both societal and environmental contexts, fostering a more sustainable, equitable, and responsible approach to managing water resources.

The Topical Collection (TC) titled "Management for a Sustainable Nexus of Water Resources, Hydrogeoethics and Society" encompasses a range of articles spanning groundwater science and engineering, water resources management, and geoethics. These works explore the latest advancements in groundwater while also addressing ethical considerations, emphasizing the influence of climate change and societal demands on groundwater systems. Most of the contributions are inspired by the insights and discussions issued from the congress "Geoethics and Groundwater Management: Theory and Practice for a Sustainable Development" (Abrunhosa et al. 2021).

The articles within this collection delve into hydrological systems grappling with the challenges posed by climate variability and environmental and societal pressures. They highlight the pressing need for principles and values that promote lasting environmental sustainability, socio-responsibility, and eco-responsibility. Embracing a geoethical approach to existence is utmost in addressing these challenges effectively. Furthermore, the collection offers comprehensive analyses based on extensive research that aligns with various Sustainable Development Goals (SDGs) and interlinkages targets outlined in the UN's "2030 Agenda" and beyond (Guppy et al. 2018). Nowadays, there is a growing awareness among individuals who increasingly expect more from the environmental approaches grounded in the concept of design with nature (McHarg 1992; Chaminé et al. 2022) and societal resilience facing management and planning challenges and potential hazards (Peppoloni 2023).

The TC comprises 15 studies focusing on geoethics and sustainable water management, showcasing research from model regions across the globe. These regions include South America (Brazil), Africa (Morocco, South Africa), Europe (Portugal, Spain, United Kingdom), Asia (Afghanistan) and the Middle East (Iran). The articles highlight critical studies and practical applications addressing groundwater issues within these model regions. They offer a comprehensive and insightful look at topical studies and reflections on hydrogeoethics, geoenvironment, and sustainable water resources management. Among the key topics covered are:

- i) the increasing influence of ethical reasoning in shaping public awareness and the critical role of social geosciences, environmental law, and hydrogeoethical concerns. Three research essays outline the significance of ethical reasoning in highlighting the effects of groundwater-contaminated regions (e.g., ethical reflections

- on groundwater in contaminated areas, hydrogeoethical concerns on groundwater salinity derived from the impact of lockdown owed to the COVID-19 pandemic; geoethical logic for citizens and geoscientists);
- ii) geoethical issues for water security, groundwater protection, and geoenvironmental issues (e.g., geoethical conflicts among groundwater vulnerability and land use; geoethical consequences in the scope of groundwater governance due to expansion of biofuel cash-crops; learning experiences in southern African urban area about geoethical issues related to water security and groundwater resilience in uncertain circumstances; hydrogeoethical assessment for sustainable groundwater resources management in Afghanistan; policy reflections for sustainable groundwater resources management in Iran; some reflections about sustainability and protection of mineral waters);
 - iii) the improvement of the status of groundwater quality by incorporating studies in hydrogeology and hydrological engineering with some geoethical concerns, inputs, and thoughts (e.g., the importance of environmental isotopic hydrology in groundwater studies; groundwater resource management during construction dewatering; the carbon footprint and groundwater issues in Balearic islands; water and wastewater optimization in a food processing industry using water pinch technology; evaluation of nitrate sources and quality of groundwater in the Essaouira basin).

Groundwater management is critical to ensuring the sustainability of Earth's systems. This approach underlines the importance of sustainable planning, monitoring, and managing groundwater resources supported by basic research. The articles within the collection emphasize the significance of incorporating hydrogeoethics considerations, environmental protection measures, and addressing climate change impacts into groundwater management practices. This integrated approach offers a unique opportunity to gain deeper insights into effective groundwater management strategies. The paths outlined in the articles will contribute to choosing balanced and sustainable approaches to managing groundwater, an invisible but essential and too often underestimated natural resource.

Lastly, hydrogeoethics encourages hydrogeoscientists to consider the technical-scientific dimensions of groundwater management and planning as well as the ethical, social, and cultural dimensions. By integrating these perspectives into decision-making processes, they can improve social resilience and design holistic and sustainable solutions that address the complex challenges facing groundwater management and planning.

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Declarations

Conflict of interest The authors declare that they have no competing interests.

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