

Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development

Manuel Abrunhosa · António Chambel · Silvia Peppoloni · Helder I. Chaminé Editors

Advances in Geoethics and Groundwater Management: Theory and Practice for a Sustainable Development

Proceedings of the 1st Congress on Geoethics and Groundwater Management (GEOETH&GWM'20),
Porto, Portugal 2020

This book gathers the peer-reviewed proceedings of the 1st congress on Geoethics & Groundwater Management (GEOETH&GWM'20), held in Porto, Portugal, in an online format on 18-22 May 2020. Hosted in School of Engineering (ISEP), Polytechnic of Porto based on Porto city (a UNESCO World Heritage Site), the international conference focused on what has now been dubbed “hydrogeoethics”, a novel transdisciplinary, scientific field integrating all dimensions of geoethics in groundwater science and practice. Given its scope, the book is of interest to all researchers and practitioners in the geosciences, hydrology, water resources, hydrogeology, natural resources management, environment, engineering, law, sociology, education, philosophy, culture, among others.

This joint congress is the result of a collaborative agreement between the IAH (International Association of Hydrogeologists) and IAPG (International Association for Promoting Geoethics) and reflects the need for concerted actions to achieve sustainable development.

The diversity, scale, significance and increasing magnitude of anthropogenic interactions with aquifers and groundwater, which often involve conflicting values or interests, call for analysis, discussions and decisions on the part of the agents involved, e.g. groundwater scientists, policymakers, managers, organisations, professionals and citizens. This approach calls for a responsible, sustainable and human approach to groundwater use and management.

The groundwater community involved in the exploration and exploitation, use and management of this increasingly vital natural resource is becoming more and more aware that ethical issues pervade all our attitudes from concept to action and need to be addressed. Diverse values and cultures, science and education, law and policies, human and natural environments and the public and the economic sectors view groundwater and its value and/or role differently. The authors believe that in a globalised and interconnected world, common ground must be found in the interest of peace, human development and sustainability.

The main topics covered here include:

1. Fundamentals of hydrogeoethics: cultures, principles and geoethical values on groundwater science and engineering
2. Lessons for a resilient and sustainable future with hydrogeoethics: case studies of geoethics in groundwater science-engineering, profession, and management
3. Scientific and humanistic components of hydrogeoethics in groundwater education and professional training
4. Socio-hydrogeology and ethical groundwater management
5. Geoethics of decision making under uncertainty and ethical issues in neglecting groundwater functioning
6. Groundwater: geological, legal, social, and ethical challenges of a unique natural resource

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The series draws on the best research papers from various IEREK and other international conferences to promote the creation and development of viable solutions for a **sustainable future and a positive societal** transformation with the help of integrated and innovative science-based approaches. Including interdisciplinary contributions, it presents innovative approaches and highlights how they can best support both economic and sustainable development, through better use of data, more effective institutions, and global, local and individual action, for the welfare of all societies.

The series particularly features conceptual and empirical contributions from various interrelated fields of science, technology and innovation, with an emphasis on digital transformation, that focus on providing practical solutions to **ensure food, water and energy security to achieve the SDGs**. It also presents new case studies offering concrete examples of how to resolve sustainable urbanization and environmental issues in different regions of the world.

The series is intended for professionals in research and teaching, consultancies and industry, and government and international organizations. Published in collaboration with IEREK, the Springer ASTI series will acquaint readers with essential new studies in STI for sustainable development.

ASTI series has now been accepted for Scopus (September 2020). All content published in this series will start appearing on the Scopus site in early 2021.

More information about this series at <http://www.springer.com/series/15883>

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In Memoriam

Professor Partha Sarathi Datta (1950–2018), India

“Instead of trying to prove the relevance of excellent fields let us develop excellence in relevant fields.”

Professor Luís Ribeiro (1953–2020), Portugal

“Nature is full of music. Being the elements of nature, and especially water, a source of inspiration in the history of music, there is a sensation in this journey through the musical production of different eras that music can also be an inspiration and a means of reconnecting man with nature.”

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The Conference Logo: Creation, Design and Symbolic

A powerful logo was created by the designer Joel Vilas Boas (GDM|ISEP) for the Congress GEOETH&GWM'20. In its apparent simplicity, it represents a large amount of symbolism underlining the place and aims of the conference. The overall shape and colours are reminiscent of the square ceramic wall tiles in contrasting white and cobalt blue that are a recognized hallmark in Portugal's civilian, religious and military buildings, since the twenty-six century, in the Porto urban area. They were used domestically and exported worldwide, not only as a commodity hand made by the millions, but also as a fortunate association of its technological excellence and usefulness with the expression of new values, ideas and aesthetics proposed to other cultures around the world, not without setting a distinct enduring mark from its origins we, as Portuguese citizens, are proud of.

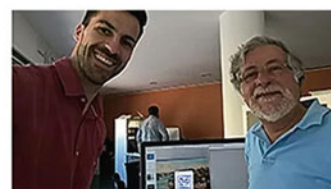
In the composition of the logo, only four simple glyphs in ten arrangements were used, harmoniously distributed inside a line bordered square. An undrawn but distinct central vertical axis of symmetry defines a path for a bottom-up reading of several symbols that set out by



(Logo design: Joel Vilas Boas, 2019)



(Photo: Jaime Neto; Logo: Joel Vilas Boas, 2019)



(Meeting related to the discussion of the logo design; Joel Vilas Botas and Manuel Abrunhosa)

deconstruction and recomposing to define, in quite a few lines what, in our view, Geoethics and Groundwater Management is. A bottom line could represent the strong foundations of Geoethics and Groundwater Science, from which emerge recognized symbols of drawdown curves, and with them the consequences of the exploitation of aquifers underground. Above is what could be a water well head and the processes that may occur on the surface in interaction with the society and the underground. Then, the acronym of the Congress is brought to our minds through face-to-face double-G physiognomies of what might be geoethics and groundwater science/engineering, a wide M for management below. These opposing, often conflicting views, and the need of an informed dialogue, together with the underlying reflections on all values involved and on the consideration of foreseeable consequences of actions and omissions, are the correct supporting paths to foster the emergence of responsible management tools. This could be the readings underlining the perseverance and quality for the construction and maintenance of the sequence of arch bridges connecting the extremes on top of the logo. They evocate the at their times innovative six bridges of Porto over the Douro River, fed in summer by far away aquifers in its vast transboundary catchment in Iberian Peninsula. This supports a safe road to the future of the society and nature in resiliency and sustainability, through the combined efforts of geoscience, engineering, humanities, culture and arts, to cope with the challenges of a changing world.

Side-Event Winning Video: *Before the Last Drop—Viva la Geoethics!*

A Side-Event to the GEOETH&GWM'20 Congress was organized in close cooperation with the section of IAPG–Portugal to run during the academic year 2018/19. It aims to promote geoethics and responsible groundwater management awareness among students and teachers in secondary schools in Portugal. This approach takes advantage of the recent legal framework that allows Secondary School free choice for a part of the syllabus. The outcome is a contest of 3 minute digital videos in free common layout produced by the students under the teacher's supervision. The content of videos may cover scientific, humanistic or artistic issues related to groundwater, in any combination, favouring transdisciplinary thought and emotional involvement on the themes of the GEOETH&GWM'20. Three best videos were selected by an independent jury and side-event chairs.

The 1st prize was awarded to the outstanding video called “*Before the Last Drop—Viva la Geoethics!*”, authored by several students from class 11^oB (2018/19) of the Basic and Secondary School of Fontes Pereira de Melo (Porto, Portugal), and the advisers' teachers were Sandra Eustáquio Ferraz, Marta Paz and Maria de Lurdes Alves. The 2nd prize was given to the Colégio da Rainha Santa Isabel (Coimbra) and the 3rd prize ex-aequo to the schools: Agrupamento de Escolas Anselmo de Andrade (Almada), Colégio de Gaia (Vila Nova de Gaia) and Escola Básica e Secundária Caldas das Taipas (Guimarães).

Water is a vital asset for all terrestrial systems and has always been a determining factor in establishing life in general and human populations in particular. Historically, civilizations have always flourished in settlements with an abundance of water and collapsed when water no longer available. Groundwater, an invisible component of the water and hydrosphere cycle, accounts for more than 97% of all liquid freshwater on the planet and contributes a large percentage to all human uses of it, be it public or domestic supply, agricultural production, livestock or industry, also constituting the main source of supply in regions with water scarcity and acting as a buffer against extreme weather events. In a context marked by increasing environmental challenges imposed by societies that are increasingly overcrowded and marked by excessive consumerism, it is essential to involve the school in order to sensitize young people to these themes.

Currently, the curricular area of earth sciences is crucial for the exercise of responsible citizenship, given the need to understand problems and make informed decisions on issues that affect societies and subsystems on the planet Earth. Society in general, and the school in particular, must embrace the mission of training youth not only scientifically educated, but

also ethically just and balanced, endowing them with the necessary skills to intervene in a well-founded manner in matters of a technical, scientific and ethical nature, in an increasingly challenging world and from the perspective of democratic citizenship.

The GEOETH&GWM'20 offers the unprecedented possibility for students of basic and/or secondary education to participate in a scientific event of this nature, contributing to promote their motivation and enthusiasm regarding science. The work on a project whose theme is of indisputable importance in today's societies also allows for the scientific deepening of the theme and the development of several essential skills and attitudes in modern societies. In addition, the collaborative production of an audio-visual system favours students' motivation, their artistic sensitivity and the use of technology, which young people deal with on a daily basis, can be combined with pedagogy under the specialized guidance of the teacher.

Considering all these assumptions, the winning project *Before the last drop—Viva la Geoethics!* was developed with the class 11^ºB of the Basic and Secondary School of Fontes Pereira de Melo (Porto, Portugal), within the course of biology and geology. The designed audio-visual consists of the adaptation of a lyrics suggesting to the theme of geoethics and sustainability of groundwater, starting from a song well known to the general public, called Viva La Vida, by the band Coldplay.

The class was divided into three groups, one being responsible for choosing the song and adapting the lyrics, another for choosing/drawing the images to be used and finally the third for collecting relevant data/keywords on the topic. Throughout the project, students showed interest and motivation, increasing their autonomy, responsibility and creativeness. Additionally, they all achieved the proposed goals. In addition, to increasing their scientific knowledge about groundwater, they also developed awareness of their importance and the key relationship to a sustainable development and geoethical issues.

Lastly, these types of initiatives, connecting the school community (students, educators and technicians), the scientific community and society, constitute real opportunities to simultaneously promote the building of awareness and knowledge, as well as values, attitudes and competences, from the perspective of active citizenship for a more sustainable and geoethical future.

Winning Video Authors

Students from class 11^ºB (2018/19) of the School of Fontes Pereira de Melo (Porto, Portugal): Alice Pereira; Ana Raquel Costa; Ana Rita Ferreira; António Ferreira; Beatriz Martins; Catarina Ribeiro; Henrique Macieira; Joana Oliveira; Leonor Ferreira; Luís Leite; Margarida Silva; Matheus Bissacot; Nuno Ferreira; Rúben Almeida; Rui Fonseca; Rui Nascimento; and Tiago Reis.

Supervisor Teachers: Sandra Eustáquio Ferraz, Marta Paz and Maria de Lurdes Alves

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Side-Event Chairs

Clara Vasconcelos (IAPG—Portugal, and FCUP), João Oliveira (APPBG and CITEUC), Ana Isabel Andrade (IAH-PC and CITEUC) and Manuel Abrunhosa (IAH-PC, IAPG and CITEUC).

Foreword by Giuseppe Di Capua

Water is life. Water is everywhere on the planet, and humans search for it in the space trying to get indications about possible presence of extraterrestrial life. In future, we might fight for water.

The management of water resources, the access to drinking water and sanitation are issues that involve technical–scientific aspects, and also problems of social equity, intra- and inter-generational justice.

According to the 2019 World Water Development Report of United Nations, “... *the global water demand is expected to continue increasing at the current rate until 2050. Over 2 billion people live in countries experiencing high water stress, and three out of ten people do not have access to drinking water*”. The same report also indicates that stress levels will continue to increase, as demand for water grows, and the effects of climate change intensify.

Water is an unalienable human right, a guarantee of the dignity of each individual. And even if each nation has the right to develop policies to safeguard its interests and priorities, nobody can contravene the fundamental right to access water that vital resource on which life on Earth depends.

Groundwater is considered a renewable resource of freshwater, sustaining human health and activities, and ecosystems. It needs to be managed carefully, and if we want it remains renewable, in a wise and responsible way, while respecting natural dynamics, cultural traditions, other living beings. Pollution, salinization and overexploitation are major threats to its usage, as well as climate change can bring groundwater to be depleted and lost as a resource.

Geoscientists and water-related practitioners have the (geo)ethical duty to support society in defining best ways to manage groundwater, but this implies competence in assuring high level of professionalism, accountability in applying scientific knowledge and providing sustainable solutions, a continuous dialogue with stakeholders and society, integrity in conducting their work.

From 2012, the International Association for Promoting Geoethics works to strengthen the awareness of geoscientists of the need for an ethical approach to georesources and in particular water resources. This means to carefully manage problems related to environmental impacts produced by human interventions on the natural processes that govern surface and groundwater resources, and also to develop strategies in order to harmonize expectations and requests of various stakeholders, including citizens, industry and policy-makers.

The Congress “Geoethics and Groundwater Management” has been a great step to make the hydrogeological community even more aware of its responsibilities and commitments towards society and the planet as a whole and a fundamental moment to bring together experiences, to analyse cases and to propose solutions. As Silvia Peppoloni, Secretary General of the IAPG-International Association for Promoting Geoethics, stated during her introductory speech at the Porto Congress (18–22 May 2020), “*We, as geoscientists and engineers, have ethical and social responsibilities, which arise from the fact of possessing specific knowledge and experience that are able to protect citizens and the environment, and to ensure the sustainable development of human communities. Whatever is our role, researchers, professionals, educators, in each circumstance we have to put our knowledge and experience at disposal of*

society to face and live with the environmental challenges of our times. And in doing this, we have great responsibilities. ... geoethics deals with those responsibilities. Acting geoethically presupposes the awareness of being responsible”.

Since geoethics “...consists of research and reflection on the values which underpin appropriate behaviours and practices, wherever human activities interact with the Earth system (Bobrowsky et al. 2017, p. 5; Peppoloni and Di Capua 2015, pp. 4–5; Peppoloni et al. 2019, p. 30)... (and) deals with the ethical, social and cultural implications of geoscience knowledge, research, practice, education and communication, and with the social role and responsibility of geoscientists in conducting their activities (Di Capua et al. 2017; Peppoloni and Di Capua 2017)”, it is clear the importance to apply the geoethical thinking to groundwater management in order to achieve a more responsible use of water in general and groundwater specifically.

In recent years, many authors have already suggested and developed concepts related to the ethical, social and cultural aspects of hydrogeological knowledge and practice, such as “water ethics” (Groenfeldt 2019), “socio-hydrology” (Sivapalan et al. 2012) or “socio-hydrogeology” (Re 2015).

In addition to them and in line with the definition of geoethics, the concept of “hydro-geoethics” was proposed in 2017 by António Chambel, President of the IAH—International Association of Hydrogeologists, and Manuel Abrunhosa, President of the Portuguese Chapter of IAH and Chair of the Congress “Geoethics and Groundwater Management”. It highlights the peculiarities of hydrogeology and groundwater studies and applications from a geoethical perspective (Abrunhosa et al. 2018). Hydrogeoethics can be considered the field of geoethics focused on ethical research and best practices related to responsible groundwater science and engineering, aimed at creating conditions for sustainable water resources management while respecting human needs and environmental dynamics. Its studying objects are related to transdisciplinary fields in geosciences, anthropological and social sciences, dealing with the relationship between humans and water cycle, cultural, aesthetic and historic traditions linked to water uses, legal frameworks, best practices and governance, groundwater management–society–policy interface.

Just like geoethics, hydrogeoethics is also founded on the principle of responsibility, the ethical criterion that should guide any human action on social–ecological systems. And just like geoethics, it can be defined through the same characteristics (Peppoloni et al. 2019): geoscience knowledge-based, contextualized in time and space, human agent-centric and shaped as virtue ethics.

This book represents a great asset and source of hydrogeological knowledge, professional experiences, case studies, practical solutions, social and cultural insights, inspired by a responsible approach: a valuable legacy authors are leaving to future generations.

Rome, Italy
July 2020

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Foreword by Nabil Khélifi

With the rapid growth in global population, food demand, urbanization and industrialization, the need for water resources has surpassed all expectations. In particular, groundwater resources have become vulnerable to degradation and depletion even though more than 1.2 billion people are excluded from using these resources and remain without access to safe drinking water. Increased groundwater use and associated water pollution levels have crossed sustainable thresholds in many parts of the world. Today, 70% of the world's groundwater withdrawals are used for irrigation purposes as over 40% of global food is produced through irrigation. Moreover, because over 50% of the world's population now lives in urban areas, dependency on groundwater has dramatically increased. This situation has created an imbalance between the demand and the availability of this valuable resource, hence the need for effective, efficient and sustainable management and development of groundwater resources. However, decision-makers and planners face various ethical dilemmas since the importance of this fundamental resource means that there is a complicated relationship between water policies and ethical considerations. The lack of an ethical framework is indeed as big a hindrance as the other major factors causing the water crisis, i.e. increasing demand, zonal disparity in the distribution of water supply, major land-use changes, decline in long-term water level, and increased salinity and pollution. Accordingly, there is a growing consciousness of the need to address the key issues in the ethics of groundwater usage, especially given the paucity of responsible water administration due to limited knowledge of the groundwater situation.

Before we can address groundwater ethics, the main problem is that we still do not have a good understanding of the world's groundwater resources and how to sustainably manage aquifers despite the growing concern of a large number of scientists, practitioners and experts that global groundwater resources are threatened. The lack of information about groundwaters increases the risk of further negligence of the ethics surrounding groundwater extraction and supply. This will have significant repercussions on the sustainable management of water resources, thus will aggravate the tensions surrounding our dependence on groundwater and water and food security across the globe and will hamper the building of resilience to climate change. As concern in this field heightens, a large group of stakeholders are committed to addressing issues related to the ethics of groundwater use from various angles and at different temporal and geographic scales.

For example, UN-Water, at its 30th meeting in Rome, Italy, in January 2019, announced that the theme for World Water Day in 2022 will be *Groundwater—Making the Invisible Visible*. This is an important step in creating awareness of the essential role of global groundwater resources. This initiative has been further endorsed by UN-Water at its 32nd meeting in Rome, Italy, in January 2020 through the announcement of a proposal to hold a Groundwater Summit in 2022. This summit was proposed by the International Groundwater Resources Assessment Centre (IGRAC) along with several UN-Water members and partners, including partners from the Groundwater Solutions Initiative for Policy and Practice (GRIPP), such as the United Nations Educational, Scientific and Cultural Organization—Intergovernmental Hydrological Programme (UNESCO-IHP), International Association of Hydrogeologists (IAH) and the

International Water Management Institute (IWMI). The objective of the Groundwater Summit is to improve the science–policy–practice interface by highlighting the role of groundwater in the broader socio-economic and environmental context and by providing information on groundwater management and governance. The proposed Groundwater Summit and related initiatives and outcomes will be closely aligned with the United Nations 2030 Agenda for Sustainable Development and Sustainable Development Goals (SDGs), the Paris Agreement on Climate Change, Groundwater Governance—A Global Framework for Action, and the Sendai Framework for Disaster Risk Reduction 2015–2030.

In this context, the School of Engineering (ISEP), Polytechnic of Porto in Portugal, made the bold step of organizing the *1st International Congress Geoethics & Groundwater Management: Theory and Practice for a Sustainable Development (GEOETH&GWM'20)* in an online format from Porto in May 2020. It took an unprecedented global approach to the vast subjects of geoethics in groundwater management and to the recognized need for reflection on the correct and prudent actions by discussing theory and practice and by sharing values, knowledge, research, educational projects, best practices and strategies in order to institute responsible integrated management of groundwater resources for a resilient and sustainable future. In a world seeking answers, the aim of GEOETH&GWM'20 was to mobilize a courageous scientific and professional community capable of proposing synergetic scientific, cultural and practical answers to the complex problems affecting society in all its connections with groundwater and the hydrosphere in general. These issues were also raised by Dr. John Cherry, winner of the Stockholm Water Prize 2020, in his influential preamble. To address them, the leading institutions, International Association of Hydrogeologists (IAH) and International Association for Promoting Geoethics (IAPG), have embraced this cause by creating a unique synergy through the GEOETH&GWM'20. Lastly, the conference in Porto produced a landmark book on the new transdisciplinary concept of hydrogeoethics.

It seems clear that groundwater management and development is a topic that calls for the attention of worldwide water experts. In Springer, we share this concern as we have already launched an interdisciplinary publishing programme in the field of water resource management. We offer books, journals and book series on topics such as hydrology and water management; water industry and water technology; and water quality and water pollution. Our publications by international top authors highlight various aspects of the water sciences and advance the latest research results.

This edited volume will complement our Springer Water programme by highlighting case studies on the general topic of *Geoethics in Groundwater Use and Management*. It comprises over one hundred selected proceedings papers from the GEOETH&GWM'20. I would like to thank the editors for constructing a superb volume of work, as well as the reviewers and authors of the chapters for their efforts and confidence in Springer, the leading global publisher of academic books, by sharing their contributions to the new field of hydrogeoethics!

Heidelberg, Germany
July 2020

Nabil Khélifi
Senior Publishing Editor

Preface

Ethics are moral principles and values that govern the actions and decisions of an individual or group. Ethical behaviour comprises of honesty, trust, treating others fairly and loyally. Ethical perception may vary from person to person, among societies and countries. [...] Choices based on the best obtainable detailed scientific information, guided by ethical considerations, offer the best hope to protect groundwater from depletion and pollution (Datta 2005).

Groundwater stored transiently in aquifers is, by far, the most abundant and widespread source of liquid freshwater on the planet (e.g. Shiklomanov 1998, Zektser and Everett 2004, Richts 2011). Its importance to societies is attested by the facts that worldwide about 50% of the public water supply, 40% of irrigation and 35% of industrial uses rely on groundwater. Rivers maintain a baseflow between sparse rainfall events in the basin because groundwater discharges invisibly and continuously to those water bodies that are often incorrectly considered as examples of surface waters originated by overland and run-off flows. Ecosystems dependent on groundwater constitute important repositories of biodiversity, areas of carbon sequestration and food production and have a significant role in local climate. Groundwater plays a determinant role in many engineering interactions with the subsurface, in seawater intrusion and in geothermal energy use, and a sink of energy needed for pumping water from underground. Groundwater is also an important part of climate change adaptation process and is often a solution for people without access to safe water. The quality of groundwater, natural or affected by pollution, has considerable impacts in human and crop health. Natural spring, besides being the most ancient direct access to groundwater, traditionally valued also by the quality of water, normal or mineral with attributes in health treatment, is also a symbol of purity that cultures and religions cherish and protect. However, when freshwater resources come forward, mostly rivers, lakes and artificial reservoirs are mentioned, forgetting groundwater that, by its nature, is a mostly hidden component of the water cycle. Gleeson et al. (2020) state an impressive thought: “holistically understanding, evaluating, and maintaining the water cycle’s role for a resilient Earth System is extremely challenging and urgent in the Anthropocene, as the societal complexities interlock with the complex dynamics of the Earth System”. In general, groundwater keeps being a disregarded subject by citizens, decision-makers and even scientists, other professionals and the citizens in some way related to water resources, ignoring its interlinkage and essential roles in the water cycle, the ecosystems and the functioning of society. Tortajada and Biswas (2017) highlighted a key issue focused on the quality of water as a human right and contributing to the balance of the ecosystems. Insufficient knowledge motivates a lack of proportional and responsible actions. This may be at the source of the threats to groundwater despite the importance of the economic, ecological, health and cultural services it provides. As a consequence, and at their peculiar rhythms, the quantity and the quality of water change due to intensive and inappropriate anthropogenic actions coupled to stresses coming from the natural dynamics of the Earth, climate change, population growth and patterning and health, economic development and also insufficient investment in knowledge, public awareness, proper governance and management at all levels, from global to local. Meanwhile, there are aquifers that remain untapped in regions or periods of water scarcity. To raise global awareness about the roles played by the hidden groundwater, the UN-Water (2015) decided that “Groundwater: making

the invisible visible” would be the theme for the World Water Day 2022. This is a promising step forward, but probably insufficient because nothing really new will be added. This situation configures a case of “the tragedy of the commons” because to “look for solutions in the area of science and technology only, the result will be to worsen the situation” (Hardin 1968), whereby an effective step forward can only be addressed if coupled with a shift in the paradigm of integrated (in substance and values) water resources management in sustainable development.

Hydrogeology is an established geoscience that studies the occurrence, movement and quality of groundwater as a basis for understanding this essential natural resource as a component of the water cycle and in the society, providing the scientific support for the management of its diverse environmental and anthropogenic uses (Freeze and Cherry 1979).

Geoethics is an emerging scientific field that deals with the ethical, social and cultural implications of geosciences knowledge, research, practice, education and communication, and with the relevant social role and responsibility of geo-professionals in conducting their activities while interacting with the Earth systems (e.g. Wyss and Peppoloni 2015, Bohle 2015, Bobrowsky et al. 2017, Peppoloni and Di Capua 2017, 2018, Bohle 2019 and references therein), where groundwater is one of its undisputed important components. In addition, the landmark publications related to the geoethics through the languages of the world and sharing ethical principles through cultural diversity (Peppoloni 2015, 2018) are an inspirational backbone aiming the scientific and technical integrity and culturally diverse approaches.

The ancestral relationship between early human settlements and water includes, among others, pile dwellings on lakes and use of canals associated with rivers, rainwater-harvesting systems, wells, aqueducts, water mines, springs, and underground cisterns (e.g., Wittfogel 1956, Pétrequin 1984, Tempelhoff et al. 2009, Angelakis et al. 2012, Chaminé et al. 2014). The wide diversity, scale, significance and increasing magnitude of the interactions of anthropogenic behaviour with aquifers and groundwater, sets the dilemma of ecocentric versus anthropocentric visions aggravated by lack of explicit consideration of the cultural and religious visions (Ribeiro 2017), involves some degree of conflict of budgets, and also of values or interests, decisions and demands from the all agents involved, call for action for a water ethos grounded in eco-sociocultural responsibility, security concerns, technical-scientific integrity and societal approach to a sustainable groundwater use and management. That needs of a responsible water ethics perspective are highlighted, among others, by Llamas (1975), Leopold (1990), Custodio (2000), Llamas (2004), Datta (2005), Arrojo-Agudo (2010), Braga et al. (2014), Ribeiro (2017) and Abrunhosa et al. (2018). In a recent interview, Dr. John Cherry highlighted some impressive thoughts related to the key role of the water in society: “To make groundwater more visible, we need to get people to ask more questions about water and groundwater in particular”, and also “We need more curiosity about water in the educational system” (SW 2020). In addition, the solutions must be sustainable and designed with nature in an ethical way (e.g. McHarg 1992; Chaminé 2015; Chaminé and Gómez-Gesteira 2019). In fact, that transdisciplinary approach is an amazing opportunity to contribute decisively to a path to sustainability of hydrological cycle that could lead to a better future for all life on Earth (Attenborough 2020).

This Joint Congress emerges from an agreement for cooperation signed on 5 April 2017 about common grounds by the IAH—International Association of Hydrogeologists and IAPG—International Association for Promoting Geoethics. Following its terms, the International Congress “Geoethics and Groundwater Management: Theory and Practice for a Sustainable Development” (GEOETH&GWM’20) aims for the first global approach on the vast subjects of geoethics in groundwater management and its recognized need of reflection for correct and prudent actions. GEOETH&GWM’20 convenes specialists, scholars and professionals of distinct fields of science, engineering, humanities, law and culture as well as educators, students and early career colleagues in some way related to groundwater. They met and interacted online in May 2020 during the most frightening times of COVID-19 and in global lockdown for the first specialized world forum for discussing theory and practice, sharing

values, knowledge, research, educational projects, best practices and strategies aiming at the responsible integrated management of groundwater resources for a resilient and sustainable future. In a world asking for answers, GEOETH&GWM'20 had the goal to stage-manage a courageous scientific and professional community that is capable of proposing synergetic scientific, cultural and practical answers to the complex problems affecting society in all its connections with groundwater.

This Joint IAH and IAPG Congress proposes to the scientific, the cultural community and the society stakeholders a moment of reflection and an opportunity for the foundation, in respect of their own deep roots, of a new logic resulting from the production of new transdisciplinary scientific and cultural added value on geoethics of groundwater. It is considered that there is a real potential of development of a new transdisciplinary geoscience capable to produce its own developments and to feedback positively into the root contributor sciences through its autonomous progress and contributions to a better world in peace, justice and sustainability. This growing concept has been named as hydrogeoethics by António Chambel and Manuel Abrunhosa, since 2017. Its field is soundly grounded in hydrogeology and geoethical principles, including the engineering, socio-economic, legal, environmental, arts and cultural dimensions.

To the former motto of the congress “Leaving No One Behind” (United Nations World Water Day 2019), and given the dramatic times brought by COVID-19 pandemic risking to stall the ongoing efforts of implementing the conference as it was conceived, and mainly the need in groundwater progress in science and protection, we added “The Science Must Go On” (Fig. 1). This was the geoethical commitment for the groundwater community, related water fields and society.

This book comprises the selected proceedings during the 1st Congress “Geoethics and Groundwater Management” (GEOETH&GWM'20), Porto, Portugal, 18–20 May 2020. The groundwater community involved in science, exploration, abstraction, use and management of this evermore essential natural resource is becoming more and more aware that ethical issues pervade all our attitudes from concept to action and need to be addressed coherently. Diverse values and cultures, science and education, law and policies, human and natural environments, the public and the economic sectors foresee groundwater and its values and/or roles differently. We believe that in a globalization intertwined world a common ground must be discussed and agreed for peace, human development and sustainability. A multidisciplinary Scientific Committee from the science, engineering, law, social sciences, natural philosophy, geoethics, environment fields assured the quality of the event and the current publication by earlier proposing themes. That aims for discussion in the conference and assuming the peer review process that addressed scientific, philosophical and legal approaches, analysis of case studies from around the world, management models or proposals, educational views, innovative transdisciplinary knowledge, research or projects on responsible groundwater management, including decision-making under uncertainty and in neglecting groundwater functioning.

In this volume were considered 6 major topics to correspond to the main fields of theory and practice regarding the global combination between groundwater in all possible conceptual dimensions and the geoethical approach (Fig. 2):

1. Fundamentals of hydrogeoethics: cultures, principles and geoethical values on groundwater science and engineering
2. Lessons for a resilient and sustainable future with hydrogeoethics: case studies of geoethics in groundwater science engineering, profession and management
3. Scientific and humanistic components of hydrogeoethics in groundwater education and professional training
4. Socio-hydrogeology and ethical groundwater management

5. Geoethics of decision-making under uncertainty and ethical issues in neglecting ground-water functioning
6. Groundwater: geological, legal, social and ethical challenges of a unique natural resource

The special volume has a core of 95 original proceedings grounded on the scientific sessions and 14 outstanding keynote lectures. The keynote speakers gave interesting insights from the philosophical principles in hydrogeoethics, to hydrological hazards focused on hydrogeomorphology and disasters, geotechnical hazards highlighting the role of groundwater, as well as landslide risks and flooding hazards and hydraulic design and the role of geoethics in groundwater modelling. The volume gathered over 227 authors of academy, research centres, state laboratories or industry from 47 countries of all continents (Europe, Africa, America, Asia and Oceania).

The volume will be of interest to researchers and practitioners in the field of hydrogeology, hydrology, water resources management and groundwater engineering, as well as those engaged in earth sciences, environmental sciences, law, social sciences, natural philosophy, education and culture. Students, geoscientists, engineers, environmental lawyers, social scientists and water-related professionals beyond research in water, earth, environmental and social sciences will also find the book an inspirational and unique asset.

Porto, Portugal
 Évora, Portugal
 Rome, Italy
 Porto, Portugal
 July 2020

Manuel Abrunhosa
 António Chambel
 Silvia Peppoloni
 Helder I. Chaminé

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The present book is dedicated to distinguished hydrogeologists Professor Partha Sarathi Datta (1950–2018) and Professor Luís Ribeiro (1953–2020), both amazing colleagues who promoted high standards and core ethical values in hydrogeology practice for teaching, science, engineering and society.

Preamble by John Cherry

Groundwater makes up 99% of all liquid freshwater, 50% of river flow is groundwater seepage, and many ecological systems are groundwater dependent. Nearly 50% of the global population depends on groundwater for all or part of its drinking water, about 40% of our food comes from irrigation using groundwater, and much of the salinization loss of agricultural soil is due to groundwater. One-third of the major aquifers of the world are depleted beyond recovery, and about 25% of sea level rise is attributable to groundwater depletion. Of the nearly 8 billion people on the planet, two billion do not have access to safe drinking water largely because groundwater is not adequately accessed and this is a worsening problem because the population is ballooning by 2–3 billion in the poor countries by the end of the century. There is now a global water crisis largely due to the combination of groundwater depletion and groundwater pollution. Until recently, humanity solved its major water problems by building more dams for water storage and flood control, but this era is over and solving groundwater problems is now the challenge in most countries. But the growing awareness that groundwater is the essence of the global water crisis is only recent. The importance of groundwater is now recognized by the United Nations in its water theme for 2022: “Groundwater: making the invisible visible”. Although there is now more recognition of groundwater’s importance, there is a broad lack of understanding of the specific nature and magnitude of groundwater problems and how to effectively frame solutions. A root cause of this across the globe is that the knowledge published in the peer review literature is fragmented and specialized and not accessible to serve societal needs in water policy and management. The dialogs of the experts are siloed within many specialty subject domains, and this severely limits the collaborations needed across many expertise fields and the mingling of perspectives required for effective solutions.

The Geoethics and Groundwater Management Congress is an excellent and timely example of the types of multidisciplinary and transdisciplinary engagements needed for progress. This may be the first international conference focused on groundwater that has “geoethics” in the title. The use of this word is an appropriate reminder of how ethically dependent groundwater management and protection should be. A new approach was born as hydrogeoethics. The decisions made by one generation usually do not show up as beneficial or detrimental before many years or decades after they are taken because groundwater “happenings” take place so slowly, over many years or decades. This congress had the engagement of the spectrum of the expertise areas needed within the geoethics umbrella: hydrogeology, engineering, law, economics, sociology, sustainability, management and agriculture with many examples of types of issues and problems and the published proceedings are a service towards informing about many aspects of the spectrum.

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About the Editors



Manuel Abrunhosa born in Porto in 1954 graduated in geology from the University of Porto, Portugal, in 1980. In 1986, he obtained a grade equivalent to a master's degree in the University of Porto after presenting a dissertation and public examination, and in 1988 a master's degree in groundwater hydrology from the Polytechnic University of Catalonia, Barcelona, Spain. He has several post-graduate courses. He began a full-time professional career as Junior Geologist (hydrogeology and engineering geology) in 1977, before graduation, pursuing studies and continuing his first job as contracted helper to the practical classes of disciplines of his geology course in the University of Porto, from 1974 up to 1980. In 1981, he became a partner and director in a small company of Applied Geology and Hydrogeology Services. Since then, he directed and was Author and Co-author of innumerable projects aimed at the private and public sector until 2009. In 1981, after public examinations, he became Lecturer in geology at the Faculty of Sciences of the University of Porto, having taught theoretical and practical classes in hydrogeology, engineering geology, sedimentary petrology, geomorphology, geological cartographic methods, mineralogy, crystallography, structural geology and supervised pedagogic internships in secondary schools. He did research in hydrogeology of fractured media and participated in national and international research projects in this subject aiming water resources and groundwater management in the Minho region (NW Portugal), and in the optimization of groundwater exploitation in complex well field a thin coastal sandy aquifer. Other active interest in science includes natural heritage studies and geoarchaeology with collaborations beginning since as a student with research groups in archaeology, ethnology and history. He was involved in 1990 in the foundation of the first academic course on environmental health and hygiene that included curricula in geology and hydrogeology. He was also involved in a first master's degree in environmental marketing. He is often called as forensic geology expert witness and acts as pro bono scientific advisor to cultural and natural heritage and environmental advocacy associations.

Since 2006, he is an independent Consultant Geologist. He is Member of several national and international scientific and professional associations. At the Portuguese Association for the Study of the Quaternary—APEQ (publisher of the journal

Estudos do Quaternário/Quaternary Studies), he is Secretary of the Board and is President of the AIH-GP—Portuguese Chapter of the International Association of Hydrogeologists (IAH). As an active member of the International Association for Promoting Geoethics (IAPG), he was invited in 2017 to its Board of Experts (Corresponding Citizen Scientists) in Geoethics in Groundwater Management. In 2018, he was jointly designated by IAH and IAPG as chair of the International Congress “Geoethics and Groundwater Management: Theory and Practice for a Sustainable Development” (18–22 May 2020), to be held at ISEP, Porto, Portugal.

The ethics at the profession, in science production and in the applied earth sciences has always been a concern and a guideline for his activities, a challenge for a geologist who, being born from a school oriented to the exploration and exploitation of geological resources in what he calls predatory geology, has gradually changed his priorities to become a geoethics advocate, Environmental and Social Geologist for Sustainability.



António Chambel is a skilled Geologist and Professor of hydrogeology and water resources at the University of Évora, with over 35 years' experience in multidisciplinary groundwater research, consultancy and practice. He graduated in geology from University of Coimbra in 1984 and obtained an MSc in economic and applied geology from University of Lisbon in 1990 and Ph.D. in geology, specializing in hydrogeology, from University of Évora in 1999. His research interests are hydrogeological mapping, environmental hydrogeology, water resources management, groundwater modelling, urban groundwater, groundwater engineering, applied geology, among others. He has been a teacher of hydrogeology in the Department of Geosciences of University of Évora since 1985 and from 2003 to 2005 was President of the department. He has also been Invited Professor in the University of Algarve (Portugal), in the Universities Charles of Prague (Czech Republic), Huelva (Spain) and La Sapienza Rome (Italy), under the ERASMUS Programme, and in the Institute of Transport and Communication (master's degree in environmental impact studies) in Maputo, Mozambique. He supervised several master theses in Portugal, Mozambique and Angola and coordinated and worked in many scientific or applied projects in Portugal and Mozambique.

From 2002 to 2006, he was President of the South Chapter of the Portuguese Water Resources Association (APRH), and from 2004 to 2008 he was President of the Portuguese Chapter of the International Association of Hydrogeologists (AIH-GP). He has been Member of IAH since 1988, and from 2008 to 2012 he was IAH Vice-President for Finance and Membership, 2012–2016 IAH Vice-President for Programme and Science Coordination and President of IAH (2016–2020). In 2007, he was Chair of the 35th IAH Congress in Lisbon. Nowadays, he is past-President of IAH—International Association of

Hydrogeologists. His international experience has been with UNESCO-IHP, with the World Water Council (WWC), having participated in the last World Water Fora (WWF) in South Korea in 2015 and Brasilia in 2018 and, through the role of member of the Executive Committee of IAH in the last 12 years, he has organized and attended IAH congresses and other IAH regional or national meetings, as well as representing IAH in many other events around the world.

He has co-authored numerous publications in journals, conference proceedings/full papers, chapters, technical and professional papers, as well as co-edited several international special issues. In addition, he belongs to some editorial journal boards (e.g. Sustainable Water Resources Management, IAH +Springer, Journal of Groundwater Science and Engineering). He was on many scientific and organizing committees of national and international conferences.



Silvia Peppoloni is a skilled Ph.D. Geologist and Researcher at Italian Institute of Geophysics and Volcanology (INVG) in Rome, Italy, with over 20 years' experience in multidisciplinary applied geosciences research, consultancy and practice. Her professional activity covers the fields of engineering geology, geological hazards and risks, as well as geomorphology, geo-education and geoscience dissemination and communication. In addition, she is fully involved in the base research on geoethics, focusing on ethical, social and cultural issues related to geosciences and promoting sustainability, prevention and geo-education as key concepts of the relationship between geoscientists and society. Since 1999, she is engaged in some international projects on geological hazard and risks and recently in three H2020 European projects dealing with ethical issues: the Project ENVRI PLUS—Environmental Research Infrastructures Providing shared solutions for Science and Society, the Project GOAL: Geoethics Outcomes and Awareness Learning, and the Project EPOS SP: European Plate Observing System Sustainability Phase. She was Adjunct Professor in geology and applied geology at the Universities of Rome “La Sapienza” and Viterbo “Tuscia”; Member of the Experts Committee of the Ph.D. course: “Landscape and Environment”, at the La Sapienza Rome University; Collaborator of some Italian universities and research institutes; and Teacher in courses on Disaster Risk Reduction (École Polytechnique Fédérale de Lausanne) and seismic damage on cultural heritage (European Project Interreg III C NOÈ).

She is Secretary General and Founder Member of the IAPG—International Association for Promoting Geoethics, Councillor of the Executive Committee of the IUGS—International Union of Geological Sciences, Founder and Director of the School on Geoethics and Natural Issues, and Editor in Chief of the series SpringerBriefs in Geoethics. Moreover, she is Member of the Executive Committee of the ICPHS—International Council for Philosophy and Human Sciences, Member of the Executive Council of the Italian Section of the IAEG—

International Association for Engineering Geology and the Environment, Member of the Executive Council of the Italian Geological Society and Coordinator of its Section on Geoethics and Geological Culture. She is Author and Co-author of several publications in indexed journals, conference proceedings/full papers and chapters, as well as Co-editor of several international special issues and books (e.g. Elsevier, Springer, Geological Society of London, *Annals of Geophysics*), and she is among the authors of the *Geoethical Promise* (the “Hippocratic-like Oath” for geoscientists) and the *Cape Town Statement on Geoethics*. In addition, she is Science Writer, Contributor of Italian newspapers/magazines and Author of books on earth sciences intended for the general public. In Italy, she has been awarded with prizes for science communication and natural literature.



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