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Editorial

Integrated Geophysical Methods for Shallow Aquifers Characterization and Modelling

Francisco Javier Alcalá [1,*], Maria Catarina Paz [2], Pedro Martínez-Pagán [3] and Fernando Monteiro Santos [4]

[1] Experimental Station of Arid Zones, Spanish National Research Council (EEZA-CSIC), 04120 Almería, Spain
[2] CIQuiBio, Barreiro School of Technology, Polytechnic Institute of Setúbal, 2839-001 Lavradio, Portugal; catarina.paz@estbarreiro.ips.pt
[3] Department of Mining and Civil Engineering, Universidad Politécnica de Cartagena, 30203 Cartagena, Spain; p.martinez@upct.es
[4] Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal; fasantos@fc.ul.pt
* Correspondence: fjalcala@eeza.csic.es; Tel.: +34-950-281-045

1. Introduction

Aquifers stock about 31.4% of the freshwater on the Earth, provide about 50% of current potable water supply, constitute the sole water source in many areas, support groundwater-dependent ecosystems, and present more resilience than surface watercourses to the negative effects of climate change and anthropogenic activities. However, groundwater use is growing, and signs of degradation are increasingly reported.

Groundwater research is increasingly using geophysical prospecting surveys for aquifer characterization in different hydrogeological environments. They have become a part of the holistic strategy to define aquifer geometry and some transient groundwater features, which are necessary data to implement numerical tools for the modelling of groundwater quantity (flow) and quality (salinity, pollution) dynamics. Geophysical prospecting techniques are non-invasive, usually inexpensive to apply, and useful for providing the accurate and fast subsurface information required for detailed groundwater research over multiple observation scales.

Electrical, electromagnetic, and seismic geophysical techniques are widely used for aquifer characterization. The first two are typically used to deduce aquifer geometry and certain transient groundwater features such as piezometric level, freshwater–saltwater interface, and pore water conductivity, whereas the latter are mostly used to deduce aquifer geometry and certain steady aquifer hydraulic parameters. The integrated use of different techniques reduces the ambiguity of interpretations, especially when the conductive structures and pore-filling fluids (natural and human-induced) are subjected to the temporal dynamics of water content and dissolved ions. Integration can also be referred to using external data (e.g., geotechnical soundings logs, geochemical tracers, physical parameters) to improve and/or validate the geophysical models. Different scientific software platforms with friendly interfaces, robust algorithms for data inversion, and tools for uncertainty analysis are available.

In this broad hydro-geophysical framework, this Special Issue aimed to attract specialized researchers in applied geophysical prospecting techniques for groundwater research, with a special focus on near-surface geophysical prospecting applications for shallow groundwater research. The accepted papers included (i) geophysical prospecting surveys as a part of the holistic strategy for aquifer conceptualization and modelling, (ii) integrated near-surface geophysical prospecting techniques and time-lapse approaches to reduce the ambiguity of hydrogeological interpretations, (iii) experimental field operational designs, and (iv) case studies surveying saturated and unsaturated media for methodological and conceptual purposes. Other papers contributed to the state of the art of the geophysical

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techniques through specific study cases covering (i) hydrogeological environments such as groundwater-dependent ecosystems (GWEs) and urbanized areas in different countries; (ii) aquifer typologies in coastal and inland areas such as weathered Paleozoic crystalline bedrocks, Mesozoic to Neogene carbonated terrains, Neogene and Quaternary volcanic formations, and Neogene and Quaternary detrital sediments; and (iii) climates including humid, sub-humid and semiarid. The used techniques were (i) electrical, such as electrical resistivity tomography (ERT), floating electrical resistivity (FER), and vertical electrical sounding (VES); (ii) electromagnetic such as ground penetrating radar (GPR), time-domain electromagnetic (TDEM), and frequency-domain electromagnetic (FDEM), including low-frequency magnetotelluric sounding (L-MTS); and (iii) seismic, such as multichannel analysis of surface waves (MASW), refraction microtremor (REMI), and vertical seismic refraction (VSR).

2. Contributions

Since the call for papers was announced in June 2019, a total of 11 manuscripts were received. After a rigorous review process, eight papers have been accepted for publication [1–8]. To gain a better insight into the essence of the Special Issue, we offer brief highlights of the published papers below.

The paper "Integrated MASW and ERT Imaging for Geological Definition of an Unconfined Alluvial Aquifer Sustaining a Coastal Groundwater-Dependent Ecosystem in Southwest Portugal" [1] integrates MASW and time-lapse ERT to define aquifer geometry and identify transient groundwater features of the Cascalheira Stream Basin Holocene alluvial aquifer. This aquifer contributes to the Santo André Lagoon, which is part of a coastal GDE in southwest Portugal. This paper contributes a way to disambiguate geological structures in low electrical resistivity (ER) environments, such as coastal areas. The methodology serves to improve the design of shallow groundwater research.

The paper "Geophysical Characterization of Aquifers in Southeast Spain Using ERT, TDEM, and Vertical Seismic Reflection" [2] assesses the effectiveness of different geophysical prospecting techniques to study the Loma de Úbeda Jurassic dolomite-confined thick aquifer in southern Spain. The VSR technique identified the high-amplitude seismic reflectors of the confined structure (aquifer) from the low-amplitude seismic reflectors of the clay-rich confining lower and upper structures. The ERT technique identified lateral changes in facies and small faults. The TDEM technique complemented the VSR and ERT techniques to widen the prospecting depth range.

The paper "Characterization of a Shallow Coastal Aquifer in the Framework of a Subsurface Storage and Soil Aquifer Treatment Project Using Electrical Resistivity Tomography (Port de la Selva, Spain)" [3] couples ERT surveys with implicit modelling tools to identify aquifer geometry and characterize the saltwater intrusion in the Port de la Selva shallow alluvial aquifer in northeast Spain. With the aim to monitor the effects of water percolation through infiltration ponds, the proposed approaches can improve the commitment of stakeholders to the benefits of soil–aquifer treatment procedures for water reuse as an additional non-conventional water source.

The paper "Identifying Changes in Sediment Texture along an Ephemeral Gravel-Bed Stream Using Electrical Resistivity Tomography 2D and 3D" [4] combines the ERT technique with datasets from borehole logs to analyze the inner geometry of channel cross-sections in a gravel-bed ephemeral stream in southeast Spain. The ERT models were correlated with sediment texture data, such as grain size distribution, effective grain size, sorting, and particle shape (Zingg's classification), in order to integrate the horizontal and vertical ER distributions into a 3D model, thus facilitating the identification of layers according to differential sediment supply at the basin scale.

The paper "Combining of MASW and GPR Imaging and Hydrogeological Surveys for the Groundwater Resource Evaluation in a Coastal Urban Area in Southern Spain" [5] conceptualizes and evaluates the groundwater resource in Adra town in southern Spain, a coastal urban area hydrologically influenced by peri-urban irrigation agriculture. The study

included a geological, hydrological, and hydrogeological data compilation, and MASW and GPR surveys to define shallow geological structures and some hydrogeological features. The paper also illustrates how urban groundwater reuse can alleviate the pressure on the currently overexploited regional aquifers.

The paper "Temporal and Spatial Groundwater Contamination Assessment Using Geophysical and Hydrochemical Methods: The Industrial Chemical Complex of Estarreja (Portugal) Case Study" [6] presents data from several geophysical and hydrochemical campaigns carried out to monitor groundwater contamination in the industrial chemical complex of Estarreja in northern Portugal over a period of 30 years. With more than a half-century in operation, this complex has left serious environmental liabilities in its influencing area. Findings from geophysical surveys (using the FDEM technique) are part of the research strategy for soil and groundwater remediation.

The paper "Usefulness of Compiled Geophysical Prospecting Surveys in Groundwater Research in the Metropolitan District of Quito in Northern Ecuador" [7] compiles and examines 23 geophysical prospecting surveys of interest in groundwater research in the Metropolitan District of Quito, including 7 ERT, 8 VES, 4 REMI and 1 FDEM surveys for shallow Holocene and late Pleistocene formations, and 3 L-MTS surveys for Holocene to late Pliocene formations. No surveys exploring the complete saturated thickness of the Pliocene aquifers could be compiled. This gap is impeding the assessment of the groundwater fraction of these regional aquifers that can be exploited sustainably.

The paper "Geophysical Characterization in the Shallow Water Estuarine Lakes of the Southern Everglades, Florida" [8] uses FER and TDEM techniques to understand the spatiotemporal variations of surface water and shallow groundwater salinity in the coastal lakes of the Everglades National Park (ENP) in south Florida in southeast USA. Anthropogenic activities have altered freshwater flows through ENP, such that saltwater has intruded inland from the coastline, causing coastal lakes and their ecosystems to be exposed to higher salinity conditions. Geophysical surveys assessed the spatiotemporal distribution of salinity needed to evaluate restoration efforts.

3. Conclusions

The Guest Editors envision that the published papers in this Special Issue would be of interest to researchers and practitioners, and help identify further research initiatives. We also hope that the readers can find the material of this Special Issue both interesting and inspiring when exploring geophysical methods for shallow aquifers characterization and modeling. The findings and techniques presented in this collection of papers contribute to the increasing interest in groundwater research.

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References

1. Paz, M.C.; Alcalá, F.J.; Medeiros, A.; Martínez-Pagán, P.; Pérez-Cuevas, J.; Ribeiro, L. Integrated MASW and ERT imaging for geological definition of an unconfined alluvial aquifer sustaining a coastal groundwater-dependent ecosystem in southwest Portugal. *Appl. Sci.* **2020**, *10*, 5905. [CrossRef]
2. Rey, J.; Martínez, J.; Mendoza, R.; Sandoval, S.; Tarasov, V.; Kaminsky, A.; Hidalgo, M.C.; Morales, K. Geophysical Characterization of Aquifers in Southeast Spain Using ERT, TDEM, and Vertical Seismic Reflection. *Appl. Sci.* **2020**, *10*, 7365. [CrossRef]
3. Sendrós, A.; Urruela, A.; Himi, M.; Alonso, C.; Lovera, R.; Tapias, J.C.; Rivero, L.; Garcia-Artigas, R.; Casas, A. Characterization of a Shallow Coastal Aquifer in the Framework of a Subsurface Storage and Soil Aquifer Treatment Project Using Electrical Resistivity Tomography (Port de la Selva, Spain). *Appl. Sci.* **2021**, *11*, 2448. [CrossRef]
4. Martínez-Segura, M.A.; Conesa-García, C.; Pérez-Cutillas, P.; Martínez-Pagán, P.; Vásconez-Maza, M.D. Identifying Changes in Sediment Texture along an Ephemeral Gravel-Bed Stream Using Electrical Resistivity Tomography 2D and 3D. *Appl. Sci.* **2021**, *11*, 3030. [CrossRef]

5. Alcalá, F.J.; Martínez-Pagán, P.; Paz, M.C.; Navarro, M.; Pérez-Cuevas, J.; Domingo, F. Combining of MASW and GPR Imaging and Hydrogeological Surveys for the Groundwater Resource Evaluation in a Coastal Urban Area in Southern Spain. *Appl. Sci.* **2021**, *11*, 3154. [CrossRef]
6. Marques, T.; Matias, M.S.; Ferreira da Silva, E.; Durães, N.; Patinha, C. Temporal and Spatial Groundwater Contamination Assessment Using Geophysical and Hydrochemical Methods: The Industrial Chemical Complex of Estarreja (Portugal) Case Study. *Appl. Sci.* **2021**, *11*, 6732. [CrossRef]
7. Peñafiel, L.; Alcalá, F.J.; Senent-Aparicio, J. Usefulness of Compiled Geophysical Prospecting Surveys in Groundwater Research in the Metropolitan District of Quito in Northern Ecuador. *Appl. Sci.* **2021**, *11*, 11144. [CrossRef]
8. Kiflai, M.E.; Whitman, D.; Price, R.M.; Frankovich, T.A.; Madden, C.J. Geophysical Characterization in the Shallow Water Estuarine Lakes of the Southern Everglades, Florida. *Appl. Sci.* **2022**, *12*, 1154. [CrossRef]