

Editorial

Advances in Aquifer Systems Analysis: Flows, Interactions, Quality Status, and Remediation

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1. Introduction

The impact of human activities and climate change on water systems is becoming severe. For this reason, the study of aquifer systems is essential for many applications, such as groundwater management, groundwater remediation, and geothermal applications. In recent decades, both experimental and numerical techniques have been developed to estimate hydrogeological parameters, to understand groundwater flow and transport processes, and to manage groundwater bodies. This Special Issue focuses on recent advances and future developments in aquifer system analysis.

The main findings of this research are summarized in this editorial.

2. An Overview of the Contributions to This Special Issue

The papers published within this Special Issue demonstrate the wide range of topics related to aquifer system analyses; these can be grouped into two main areas related to water resources (mainly groundwater): (i) the management of groundwaters (Contribution 1, Contribution 2, Contribution 3) and the management of surface waters (Contribution 4), and (ii) contamination (Contribution 5, Contribution 6, Contribution 7). The proposed approaches were tested in the laboratory and case studies across Europe and Asia.

2.1. Water Resources Management

The work of Baduna Koçyiğit and Akay (Contribution 1) focuses on identifying groundwater potential zones in basins in order to develop a management plan for the resource. The authors adopted two bivariate statistic models (frequency ratio (FR) and weight of evidence (WoE)) and a Multi-Criteria Decision-Making (MCDM) method, TOPSIS, hybridized using the FR and WoE, with two distance measures, the Euclidean and Manhattan, to estimate the spatial variation in groundwater potential. The approaches considered sixteen groundwater conditioning factors (elevation, slope, aspect, CI, rainfall, Dd, distance to river, distance to fault, distance to road, lithology, soil type, LULC, TWI, TPI, and SPI) and was applied on the Burdur Lake catchment located in southwest Türkiye. The bivariate statistical and MCDM methods differ, and this can be seen in the predictions of the models. In general, these models resulted in good predictions. Even though the Manhattan distance measure provided better results than the Euclidean distance measure, it should be noted that it has not received much attention in similar studies. Furthermore, this study confirmed that uncertainties related to the hybridization methods and distance measurements existed in the results.



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Pershin et al. (Contribution 2) investigated issues in the design of a distributed control system for a network of production wells using the example of mineral water deposits in the Caucasus Mineral Waters region, Russia. The objective of the work was to identify a set of parameters of the control system to properly manage the mineral water resource, identifying the number of production wells that maximize the profit and taking into account the regulations and operational costs. For this reason, the authors developed an algorithm for the synthesis of a distributed control system for a deposit, in which the production wells are located in an ellipse, considering both free and confined aquifers with different thicknesses, lengths, lithologies, and hydraulic conductivities. The optimal number and pumping rate of the production wells in the well network were determined for the case study.

The work of Ilyushin and Asadulagi (Contribution 3) deals with the issues of controlling hydrodynamic processes under random impacts (such as damage to equipment, precipitation, changes in porosity, and human factors) in the aquifers of mineral water deposits using mathematical models. These disturbances were considered a systematic (or possible) effect on the flow rate of water in the aquifer and the head in the wells. The purpose of this study was to develop a control system for hydrolithospheric processes experiencing random impacts, aimed at maintaining the quality and reserves of the mineral water of the deposit through controlling the piezometric level in the exploited aquifer. Fluctuations can be intermittent and have various forms. Therefore, a feedback control system that is able to control the process during uncertain changes was applied at the Kislovodsk mineral water deposit located within the Bolshekavkazsky artesian basin (Russia).

The work of Shawaqfah et al. (Contribution 4) deals with surface water management and focuses on identifying potential flash flood zones, looking at a case study in Jordan. The authors developed hydrological models by integrating GIS settings with HEC-HMS software and introduced a flash flood potential index (FFPI) based on four main physiographic parameters (slope, land use, plant cover, and soil texture). This index should support the decision-making process for flash flood warnings. Thanks to the proposed methods, the authors generated a flash flood potential map for the test case. The map depicted varying levels of flash flood potential, with the highest index recorded as 9 and the lowest as 1. The 95th percentile threshold was employed to identify regions with the highest potential for flash floods.

2.2. Groundwater Contamination

Torkashvand et al. (Contribution 5) highlighted the importance of developing groundwater vulnerability maps to properly manage groundwater bodies. In fact, in areas with low and moderate vulnerability, land use monitoring and strict rules to prevent contamination are essential, while in highly vulnerable areas it is crucial to develop actions and policies to protect the groundwater resources from becoming contaminated. The authors extended the well-known DRASTIC approach [1] to prepare aquifer vulnerability maps that include the impact of contamination. The authors proposed five modified vulnerability indices: FR-DRASTIC (FR—frequency ratio), DRASTIC-SPSA (SPSA—single-parameter sensitivity analysis), DRASTIC-Entropy, FR-Entropy, and FR-SPSA. The proposed approaches were tested on a small aquifer in an agricultural area in Iran that is contaminated by nitrates. Validation of the procedures revealed a noticeable improvement in the results when using the hybrid methods. The vulnerability maps indicate the areas that need more attention from decision makers and environmental planners to mitigate the negative impacts of anthropogenic activities.

Feo et al. (Contribution 6) validated a high-resolution shock-capturing numerical code (CactusHydro, [2]) through data collected via laboratory tests [3]. The experiments

consisted of observing the migration of a dense nonaqueous phase liquid (DNAPL) in a saturated porous medium under fully controlled conditions using a digital image analysis procedure. To achieve this aim, two devices were used: a column and a sand tank. Both experimental devices were modeled using CactusHydro and the results of the numerical simulations were compared with the data collected during the experiments. The good agreement between the numerical and experimental data confirmed CactusHydro's ability to reproduce the DNAPL plume development; this can consequently be applied to evaluate the effects and environmental impacts of DNAPL leaks in saturated zones.

After the validation of CactusHydro, Feo et al. (Contribution 6) simulated the effects of an oil pipeline failure on an aquifer under a range of hydrogeological conditions. The test case was based on the hydrogeology of an oil field in central Italy, characterized by an unconfined aquifer. Feo et al. (Contribution 7) analyzed the effects of potential leakage from a pipeline, considering fluids with different densities (gasoline and diesel oil), different groundwater levels, and three degrees of saturation in the unsaturated zone, as well as the influence of the pressure inside the pipeline. The fluids were considered immiscible, and the processes of volatilization and/or dissolution were not considered. The results indicate that the leaking oil's pressure and the saturation of the unsaturated zone are the parameters that most significantly affect the contaminant's arrival at the groundwater table. The CactusHydro Code, when applied to a real case study, can support the design of reclamation activities through identifying the most effective actions to prevent and/or reduce the probability and extent of pollution and damage to environmental receptors in the event of a major accident.

3. Conclusions

The papers published in this Special Issue highlight the importance of water resources management from the point of view of both quantity and quality. The first main result is the importance of generating maps to support decision-making. Maps can be generated to assess where groundwater resources are available (Contribution 1), and to identify the areas that are most vulnerable to flash floods (Contribution 4) and contamination (Contribution 5). Additionally, the management of drinking water resources is crucial (Contribution 1, Contribution 2, Contribution 3); the management must meet the criteria of not overexploiting the aquifer and ensuring the costs are sustainable (pumping, treatment, etc.). A second finding is the importance of numerical modeling (Contribution 6, Contribution 7) to reproduce contamination phenomena and to design actions to prevent or remediate undesired leakage events.

In conclusion, we hope that this collection of papers will help open new frontiers within the hydrogeological community and stimulate interdisciplinary research.

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