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Editorial

Exploration and Sustainable Management of Groundwater Resources in Geologically Complex Terrain

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1. Introduction

Groundwater is a precious and limited resource. Groundwater resources exploited in geologically complex terrain and their sustainable development have played a critical role in combating water scarcity by decreasing supply due to climate change or increasing demand due to worldwide population growth. However, the complexity and heterogeneity of aquifers in such geological environments remain a challenge for the determination of stable, expected, and sustainable groundwater resources. More advanced methods to improve the accuracy of the prediction and investigation of groundwater-resource-related information need to be developed further. The development of advanced techniques includes (1) groundwater investigation, monitoring, and numerical modeling; (2) climate change's impact on groundwater resources; (3) improved understanding of subsurface processes; (4) subsurface characterization and modeling; (5) adaptive sustainable management strategies.

2. Issue Contents

A total of ten research articles (nine research articles and one review article) in various studies of groundwater-related technology are presented in this Special Issue. The following is a summary of the significant contributions of each article.

In [1], the spatiotemporal characteristics of groundwater level variation in the mountainous areas of Taiwan were investigated to evaluate groundwater potential or underpinning aquifer sustainability development. This study explored the dominant influencing factors that control groundwater dynamics and developed the estimation of groundwater level fluctuation (GWFL) potential in complex aquifer systems of mountainous areas. This study significantly contributed to strengthening the input of the dynamic behavior of groundwater into the estimation of groundwater level fluctuation potential. Investigating the spatial and temporal dynamic behavior of groundwater level fluctuation in mountainous areas using the proposed approach can assist in obtaining effective strategies for developing and managing groundwater resources.

In [2], a pseudo-3D resistivity surveying method was proposed to conduct a groundwater detection survey with case studies on dam leakage detection and groundwater explorations. This study contributed to the establishment of a new geophysical method that can enhance the 3D electrical exploration efficiency for locating water zones in a subsurface system. However, the limitation of the pseudo-3D resistivity method is its higher computational expense compared with the 2D resistivity method.

In [3], an optimized groundwater flow calibration method based on the pilot point emplacement technique in a small-scale area was proposed. Small-scale modeling is complicated, and modeling in such an area presents significant heterogeneity in horizontal

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hydraulic conductivity. This improved calibration technique for the groundwater flow modeling task can provide effective and more accurate results. Thus, the proposed technique improves the groundwater flow model calibration process for groundwater resource management.

In [4], integrated analyses of groundwater recharge and groundwater numerical simulations using SWAT-MODFLOW were proposed to deal with threats to groundwater resources' sustainability. The scenario studies indicated that pumping by increasing over fifty percent of the normal pumping rate could cause a prominent groundwater head decline near the outlet of the watershed and substantial river baseflow reduction. Additionally, another scenario study concerning recharge reduction revealed the huge risk of groundwater sustainability in the study area. All scenario studies are beneficial for the preparation of adaptive sustainable management strategies.

In [5], techniques utilized in geochemical modeling for the safety performance assessment of radioactive waste disposal sites in a subsurface system were reviewed. A process for the estimation of Kd using SCM was established. Both deterministic and probabilistic models can be used to analyze the safety evaluation of repositories. This study provided a strong scientific basis for the assessment of the safety of nuclear waste repositories and supported the development of environmental management or remediation schemes for sites with near-surface contamination.

In [6], a cost-effective approach for identifying fracture network density around a borehole using existing hydraulic test data was proposed. First, a total of 262 existing double-packer test data collected in the mountainous region of Taiwan with Baker's generalized radial flow model were analyzed to obtain the flow dimension n of each packer test, which reflected several characteristics of the fracture system, including heterogeneity, fracture density, and fracture network connectivity. Then, five proposed hydrogeological indices were proposed to verify the current approach. Finally, correlations between the hydrogeological indices and flow dimension n values were evaluated using data grouping techniques and regression analysis. Based on the verification results, the proposed approach was proven to be reliable. This study significantly contributed to the literature because the proposed method can serve as a cost-effective option for the identification of fracture network density around a borehole. The interpretation of fracture network properties of rock mass around a borehole using the proposed approach can help engineers establish a hydrogeological site descriptive model, which can facilitate the design and planning of groundwater-related engineering systems.

In [7], a practical procedure was developed to evaluate the seasonal groundwater level by incorporating seasonal weather forecasts and hydrological models. The seasonal prospective issued by the Central Weather Bureau of Taiwan (CWB) was combined with weather generator data to construct seasonal weather forecasts as the input for hydrological models. A rainfall-runoff model (HEC-HMS) and a coupled groundwater and surface water model (WASH123D) were utilized to simulate the seasonal groundwater levels. This study demonstrated the stable and good performance of the modeling results. However, more discrepancies in terms of the groundwater table could be found in the dry season than in the rainy season. Further discrepancies could be attributed to anthropogenic activities, such as pumping. Overall, the groundwater level can be accurately obtained as long as the rainfall inputs are accurate. The established approach can be used to manage groundwater to prevent water scarcity in future.

In [8], a cost-effective approach, which was based on comprehensive remote sensing (RS)- and geographic information system (GIS)-based models, was developed for the assessment of groundwater potential. To improve the accuracy of the interpretation of groundwater potential sites, this study investigated the dominant parameters of groundwater potential in the mountainous area of Taiwan. Six parameters, including HGU (hydrogeological units), LD (lineament density), SD (slope degree), DD (drainage density), TWI (topographic wetness index), and a variation of the SMI (soil moisture index) were selected to compute the newly proposed normalized groundwater potential index (NGPI) to assess groundwater potential. A positive correlation between NGPI and in situ well yield data was found. The proposed model results show that the accuracy of the interpretation of groundwater potential sites improved from 48.6% to 84.7%. Therefore, the comprehensive RS- and GIS-based model appears to be useful for exploring groundwater potential in complex geological and topographic landforms.

In [9], an interdisciplinary approach for investigating the seasonal behavior and similarity of groundwater level fluctuations in a semi-urban district of Wrocław/Poland during 15 hydrological years by combining mathematics, signal processing, hydrogeology, and meteorology was proposed. The agglomerative clustering results and the correlation investigations clearly showed that groups of similar groundwater level–precipitation behavior can be identified. Typical hydrological year patterns can be influenced by non-identified factors resulting in groundwater level fluctuations that significantly differ from the preceding year. In addition, the investigation results concluded that a day-to-day analysis of precipitation and groundwater level fluctuation in a complex system is not possible. Therefore, the cumulative sum of the precipitation shows a better correlation with the groundwater level than by precipitation alone. Finally, positive correlations were shown to prevail in the winter season, and negative ones in the summer season. In conclusion, the data-processing approaches presented in this study can allow for the identification of relationships between precipitation and groundwater level fluctuations and the classification of hydrological years into a set of classes for other regions of different geological settings and observations.

Groundwater can be used as a water resource in the subsurface, and it may also reduce slope stability. For instance, an active landslide (You-Ye-Lin landslide) in the mountainous area of Taiwan has a long history of intermittent large downslope ground movements affected by groundwater during rainfall periods since Typhoon Morakot in 2008. In [10], to prevent the expansion and deterioration of the landslide, an effective remediation method for slope stabilization, which is to lower the groundwater level through a deep subsurface drainage system composed of two drainage wells, was proposed to investigate its feasibility and stabilization efficiency. A three-dimensional finite element method program (Plaxis 3D) was used to perform the groundwater flow and slope stability analyses. The results demonstrated that the designed drainage system is effective in increasing slope stability by accelerating the drainage of the infiltrated rainwater during heavy rainfalls during the typhoon season and can reduce the landslide potential.

These articles have developed several advanced techniques, including in situ hydrogeological techniques, the processing of groundwater data, and groundwater modeling approaches, and demonstrated the complexity and heterogeneity of the subsurface. Although submissions for this Special Issue have been closed, groundwater studies in complex geologic environments remain challenging. More advancements and novelties in the field and modeling approaches in groundwater investigation and management are strongly encouraged to aid this field's continual development.

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References

1. Chen, N.-C.; Wen, H.-Y.; Li, F.-M.; Hsu, S.-M.; Ke, C.-C.; Lin, Y.-T.; Huang, C.-C. Investigation and Estimation of Groundwater Level Fluctuation Potential: A Case Study in the Pei-Kang River Basin and Chou-Shui River Basin of the Taiwan Mountainous Region. *Appl. Sci.* **2022**, *12*, 7060. [CrossRef]
2. Chen, X.; Guo, Z.; Liu, C.; Liu, J.; Wu, Q. Groundwater Detection Using the Pseudo-3D Resistivity Method: A History of Case Studies. *Appl. Sci.* **2022**, *12*, 6788. [CrossRef]
3. Rabemaharitra, T.P.; Zou, Y.; Yi, Z.; He, Y.; Khan, U. Optimized Pilot Point Emplacement Based Groundwater Flow Calibration Method for Heterogeneous Small-Scale Area. *Appl. Sci.* **2022**, *12*, 4648. [CrossRef]

4. Tolera, M.B.; Chung, I.-M. Integrated Hydrological Analysis of Little Akaki Watershed Using SWAT-MODFLOW, Ethiopia. *Appl. Sci.* **2021**, *11*, 6011. [CrossRef]
5. Liang, S.-Y.; Lin, W.-S.; Chen, C.-P.; Liu, C.-W.; Fan, C. A Review of Geochemical Modeling for the Performance Assessment of Radioactive Waste Disposal in a Subsurface System. *Appl. Sci.* **2021**, *11*, 5879. [CrossRef]
6. Hsu, S.-M.; Chiu, C.-M.; Ke, C.-C.; Ku, C.-Y.; Lin, H.-L. Use of Hydraulic Test Data to Recognize Fracture Network Pattern of Rock Mass in Taiwan Mountainous Areas. *Appl. Sci.* **2021**, *11*, 2127. [CrossRef]
7. Huang, J.-Y.; Shih, D.-S. Assessing Groundwater Level with a Unified Seasonal Outlook and Hydrological Modeling Projection. *Appl. Sci.* **2020**, *10*, 8882. [CrossRef]
8. Lin, J.-J.; Liou, Y.-A. Integrating In-Situ Data and RS-GIS Techniques to Identify Groundwater Potential Sites in Mountainous Regions of Taiwan. *Appl. Sci.* **2020**, *10*, 4119. [CrossRef]
9. Worsa-Kozak, M.; Zimroz, R.; Michalak, A.; Wolkersdorfer, C.; Wyłomańska, A.; Kowalczyk, M. Groundwater Level Fluctuation Analysis in a Semi-Urban Area Using Statistical Methods and Data Mining Techniques—A Case Study in Wrocław, Poland. *Appl. Sci.* **2020**, *10*, 3553. [CrossRef]
10. Lin, D.-G.; Chang, K.-C.; Ku, C.-Y.; Chou, J.-C. Three-Dimensional Numerical Investigation on the Efficiency of Subsurface Drainage for Large-Scale Landslides. *Appl. Sci.* **2020**, *10*, 3346. [CrossRef]