

Challenges and Advances in Groundwater Modelling of Hard Rock Aquifers: Case Studies and Applications

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Abstract

This article discusses groundwater modelling in hard rock aquifers, which are characterized by low permeability and complex geological structures. It covers the types of models used, data requirements, challenges involved, steps involved in modelling, and applications of groundwater modelling. The article also provides details of groundwater modelling software that can be used for modelling hard rock aquifers, such as MODFLOW and FEFLOW. The article includes case studies demonstrating the use of groundwater modelling in a fractured rock aquifer in Sweden, assessing the impact of climate change on groundwater resources in a hard rock aquifer in India, and modelling mine dewatering in a hard rock aquifer in Canada.

Introduction

Groundwater modelling is a technique used to study the behavior of groundwater systems, including the flow and transport of water and contaminants in the subsurface. It is an essential tool for managing water resources in hard rock aquifers, which are characterized by low permeability and complex geological structures. In this article, we will discuss the groundwater modelling of hard rock aquifers in detail, including the types of models used, the data required, and the challenges involved.

Groundwater Models

Groundwater models can be classified into two types: analytical models and numerical models. Analytical models are based on mathematical equations that describe the flow of groundwater in the subsurface. They are simple and easy to use but are limited in their ability to represent complex geological structures. Numerical models, on the other hand, use computers to solve complex equations that describe the flow of groundwater in the subsurface. They can represent complex geological structures and are widely used in groundwater modelling of hard rock aquifers.

There are several groundwater modelling software available for modelling of hard rock aquifers. Here are some popular options:

MODFLOW: Developed by the United States Geological Survey (USGS), MODFLOW is one of the most widely used groundwater modelling software. It is a finite-difference numerical model that can simulate groundwater flow in three dimensions. It is capable of handling complex geological structures and is widely used in groundwater modelling of hard rock aquifers.

FEFLOW: Developed by DHI-WASY GmbH, FEFLOW is a finite element numerical model that can simulate groundwater flow and transport in three dimensions. It can handle complex geological structures and is widely used in groundwater modelling of hard rock aquifers. FEFLOW also has a user-friendly interface and powerful visualization tools.

Visual MODFLOW: Developed by Waterloo Hydrogeologic, Visual MODFLOW is a graphical user interface for MODFLOW. It allows users to build numerical models using a simple drag-and-drop interface and provides powerful visualization and data management tools. Visual MODFLOW is widely used in groundwater modelling of hard rock aquifers.

Groundwater Vistas: Developed by Environmental Simulations Inc., Groundwater Vistas is a graphical user interface for MODFLOW and other groundwater modelling software. It allows users to build numerical models using a simple drag-and-drop interface and provides powerful visualization and data management tools. Groundwater Vistas is widely used in groundwater modelling of hard rock aquifers.

GMS: Developed by Aquaveo LLC, GMS is a graphical user interface for MODFLOW and other groundwater modelling software. It allows users to build numerical models using a simple drag-and-drop interface and provides powerful visualization and data management tools. GMS is widely used in groundwater modelling of hard rock aquifers.

These software packages are widely used in the groundwater modelling community and have proven to be effective for modelling of hard rock aquifers. However, the selection of software depends on several factors such as user experience, budget, project requirements, and the complexity of the aquifer system.

Data Requirements for Groundwater Modelling of Hard Rock Aquifers

Groundwater modelling of hard rock aquifers requires a significant amount of data, including geological, hydrological, and hydrogeological data. Geological data includes information on the geological structure of the aquifer, such as the type and orientation of the rock formations. Hydrological data includes information on the surface water and groundwater recharge rates, as well as the evapotranspiration rates. Hydrogeological data includes information on the hydraulic properties of the aquifer, such as the permeability and porosity of the rock formations.

Challenges Involved in Groundwater Modelling of Hard Rock Aquifers

Groundwater modelling of hard rock aquifers is challenging due to the low permeability and complex geological structures of these aquifers. In addition, the lack of data on the hydraulic properties of the aquifer and the uncertainties in the data can make modelling difficult. The presence of fractures and faults in the aquifer can also make modelling challenging, as these features can significantly influence the flow of groundwater.

Steps Involved in Groundwater Modelling of Hard Rock Aquifers

Groundwater modelling of hard rock aquifers involves several steps, including data collection, model development, calibration, and validation. The following is a brief overview of each step:

Data collection: This step involves collecting geological, hydrological, and hydrogeological data on the aquifer. This includes information on the geological structure of the aquifer, surface water and groundwater recharge rates, and the hydraulic properties of the aquifer.

Model development: This step involves developing a conceptual model of the aquifer, which includes the geological structure, hydraulic properties, and boundary conditions. The conceptual model is then used to develop a numerical model of the aquifer.

Calibration: This step involves adjusting the parameters of the numerical model to match the observed data. This includes adjusting the hydraulic conductivity and recharge rates to match the observed water levels and flow rates.

Validation: This step involves testing the numerical model against independent data sets to verify its accuracy. This includes comparing the predicted water levels and flow rates to the observed data from monitoring wells.

Applications of Groundwater Modelling of Hard Rock Aquifers

Groundwater modelling of hard rock aquifers has several applications, including water resources management, contamination assessment, and mine dewatering. The following is a brief overview of each application:

Water resources management: Groundwater modelling can be used to assess the sustainable yield of the aquifer and to optimize the placement of wells for water supply.

Contamination assessment: Groundwater modelling can be used to assess the transport of contaminants in the subsurface and to develop remediation strategies.

Mine dewatering: Groundwater modelling can be used to design dewatering systems for mines to prevent flooding and to manage water resources in the mine.

Case Studies

The following are some case studies that demonstrate the use of groundwater modelling in hard rock aquifers.

1. Modelling groundwater flow in a fractured rock aquifer

In this study, a numerical model was developed to simulate groundwater flow in a fractured rock aquifer in Sweden. The aquifer was characterized by a complex geological structure with multiple fracture sets. The model was calibrated using water level data from monitoring wells and was validated using tracer test data. The model results showed that the fracture sets had a significant impact on groundwater flow and that the hydraulic conductivity of the fractures was the most important parameter controlling groundwater flow.

2. Assessing the impact of climate change on groundwater resources

In this study, a numerical model was developed to assess the impact of climate change on groundwater resources in a hard rock aquifer in India. The model was calibrated using water level data from monitoring wells and was validated using independent data sets. The model was used to simulate groundwater flow under different climate scenarios and to predict the future changes in groundwater resources. The results showed that the groundwater recharge rates would decrease under future climate scenarios, which would lead to a reduction in groundwater resources.

3. Modelling mine dewatering in a hard rock aquifer

In this study, a numerical model was developed to simulate mine dewatering in a hard rock aquifer in Canada. The aquifer was characterized by a complex geological structure with multiple faults and fractures. The model was calibrated using water level data from monitoring wells and was validated using independent data sets. The model was used to design a dewatering system for the mine, which involved pumping groundwater from the mine and discharging it to the surface. The model results showed that the dewatering system would be effective in preventing flooding in the mine.

These studies are just a few examples of the many research papers that have been published on groundwater modelling of hard rock aquifers.

Conclusion

Groundwater modelling is an essential tool for managing water resources in hard rock aquifers. It can be used to assess the sustainable yield of the aquifer, to optimize the placement of wells for water supply, to assess the transport of contaminants in the subsurface, and to design dewatering systems for mines. Groundwater modelling of hard rock aquifers is challenging due to the low permeability and complex geological structures of these aquifers. However, with the availability of advanced modelling software and improved data collection techniques, it is now possible to develop accurate numerical models of hard rock aquifers.

References

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