Numerical simulation and pollution prediction of karst groundwater in water-conducting faults distribution area

Jinglong Chu*, Nannan Liu, Yu Miao, Xingjie Lin, Haiwei Tan, Fang Liu
BGRIMM Technology Group, Beijing, China
*Corresponding author e-mail: 83573325@qq.com

Abstract. In order to explain the role of the water-conducting faults in the groundwater system, this paper conducts a numerical simulation study of the groundwater system in water-conducting faults distribution area, using FEFLOW software. The influence of the fracture zones is considered as a key point in parameter zoning. The established numerical model of groundwater conforms to the actual hydrogeological conditions. At the same time, cyanide is used as the prediction factor to predict the situation of wastewater leakage into the fracture zones. The results show that the fracture zones are the main runoff channels for pollutant migration and diffusion. The pollutant migration and diffusion in the direction of the fracture zones are faster than that in the main runoff direction of groundwater.

1. Introduction

China is one of the countries with the most developed karst in the world, and the karst area accounts for 1/3 of the total land area. However, the karst aquifer has poor anti-pollution ability, and the karst water environment is very fragile and vulnerable to pollution. Therefore, it is of great significance to carry out the groundwater numerical simulation in the karst area and study the dynamic characteristics and pollution characteristics of karst water. Affected by the development of karst, the pores of the underground aqueous medium in the karst area are unevenly distributed. In some areas, pipelines, fissures and pores coexist. The aqueous medium has strong anisotropy and heterogeneity. According to related researches, in some areas where karst is developed, karst fissures are relatively uniformly developed and hydraulic connection is relatively close. Under the condition of large area, karst aquifer can be generalized to equivalent void medium[1-2]. Parameter zoning is very important in the numerical simulation of groundwater. Most of the existing researches carry out parameter zoning in terms of lithology distribution and aquifer water richness, etc., or by means of automatic model parameter estimation[3-5]. This zoning method divides the simulation into several small blocky areas without considering the effect of water-conducting faults in the aquifer. The hydrogeological parameters of the water-conducting faults are quite different from those of the surrounding rock mass. Reasonable consideration of the hydrogeological parameters of the water-conducting faults will make the model more accurate and more practical.

This paper takes a karst region in central China with several water-conducting faults as an example. The numerical model of groundwater in the karst area is established, using FEFLOW groundwater simulation software. In the model, the fracture zones are meshed and given a higher permeability coefficient, and then the pollutant leakage to the water-conducting fault site is predicted to explain the migration rule of the pollutant. This study has guiding significance for the numerical simulation of groundwater in faults distribution area and the prevention and control of groundwater pollution.
2. Overview of the research area

The research area is located in the transition zone between hills and plains. The Cambrian-Ordovician (E-O) carbonate karst aquifer is distributed in the area. The most developed part of karst is dolomitic limestone and limestone of the Cambrian middle and upper series Loushanguan Group - Ordovician lower series Nanjinguan Formation, with a thickness greater than 113m. The more developed part of karst is bioclastic limestone of the Ordovician lower series Fenxiang Formation - Honghuayuan Formation, with a thickness of 63~175m. The weakly developed part of karst is argillaceous neoplastic limestone of the Ordovician lower series Dawan Formation - upper series Linxiang Formation, with a thickness of 59~154m. The karst aquifer as a whole has the characteristics of strong karst in shallow parts, gradually weakening downward and disappearing. The karst aquifer is a moderately water-rich aquifer, and the dissolution fracture is relatively uniform and the hydraulic connection is relatively close. The sand shale of the Lower Silurian Xintan Formation (S1x), with a thickness greater than 100m, is distributed in the north, south and east of the study area, with high argillaceous content, forming a relative water-barrier layer in the area.

The main faults F2 and F3 in the study area are located in the north and south of the study area respectively, and nearly intersect in the west, with clear boundaries and controlling the planar distribution of carbonate rocks. In addition, a series of NE-trending fault zones have been developed in the study area, including faults F1, F6, F8, F9, F22, and F23, which are also locations with strong karst development, as shown in Figure 1. The fault structure is water-conducting in carbonate rock and plays a role in enriching karst groundwater and forming strong runoff zone; it is water-proof in sand shale and acts as a water-blocking barrier. The local sand shale is also distributed on the southwest side of the study area, but it is cut by fault F23, which connects the karst water in the study area with the karst water in the southwest.

The main recharge area of the karst aquifer in the study area is located in the area of bare bedrock in the west and southwest. Groundwater receives atmospheric rainfall replenishment through fissures and karst caves, and flows from west or southwest to east and supplies karst groundwater in the study area, and is discharged by artificial pumping wells in the east of the study area, which constitutes a hydrogeological unit with unified replenishment, runoff and discharge.

Figure 1. Faults distribution map of the study area
3. Groundwater numerical model

(1) Conceptual model

The hydrogeological conditions in the study area are relatively simple. The boundaries between aquifer and water-barrier layer are clear, and a large number of hydrogeological boreholes are distributed in the study area for reference. Therefore, the simulation range and boundary conditions of the groundwater numerical model in the study area are relatively easy to determine. In the horizontal direction, the north and south sides of the model are bounded by the F2 and F3 faults near the sand shale, which are generalized as the water-proof boundaries. The east and west sides of the model are bounded by F22 and F23 water-conducting faults, which are generalized as the specified water-head boundaries. In the vertical direction, karst water is confined by the quaternary strata overlying the karst aquifer. This study ignores the Quaternary strata and only studies the groundwater characteristics of the karst aquifer. The stratigraphic structure is generalized into a fissure karst water confined aquifer. On the whole, the groundwater flow system in the study area is generalized as a heterogeneous, anisotropic, spatial monolayer structure and three-dimensional stable groundwater flow system.

(2) Establishment and identification of numerical model

The FEFLOW software based on finite element method is used to establish the numerical model of groundwater. The study area is discretized by the triangular mesh method, and the grid density of pumping wells and fracture zones is increased. Sources and sinks mainly include atmospheric rainfall infiltration and artificial drainage. The initial groundwater flow field is obtained by inputting the initial value of boundary conditions, source and sink terms and hydrogeological parameters into the model. Through fitting with the actual groundwater flow field, the hydrogeological parameters are identified and the final groundwater flow field is obtained. The most important parameter is the permeability coefficient. According to the stratigraphic lithology, fracture zones distribution, pumping test and other data in the study area, the permeability coefficient of the simulation area is divided and assigned. The zonation and assignment of permeability coefficient of fracture zones in the model are considered as a key point. The partition and identification results of permeability coefficient in the study area are shown in Figure 2 and Table 1. Since F2 and F3 intersect on the west side of the study area, the rock mass is fractured to a large degree and the permeability coefficient is also large, and the partition sequence number of the west fracture zone is 1. The fracture degree of the other fracture zones is lower than that of the west fracture zone, and the permeability coefficient is smaller than that of the west fracture zone, and the partition sequence number of the other fracture zones is 2. The fitted groundwater numerical model has high precision and can be used to predict the pollution in the next step.

Figure 2. The partition result of permeability coefficient in the study area
Table 1. The identification result of permeability coefficient in the study area

| The sequence number | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     |
|--------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Transverse K (m/d) | 6.00  | 2.00  | 9.50  | 2.00  | 6.00  | 1.00  | 6.00  | 0.10  | 1.00  |
| Longitudinal K (m/d)| 4.00  | 1.33  | 6.33  | 1.33  | 4.00  | 0.67  | 4.00  | 0.07  | 0.67  |

| The sequence number | 10    | 11    | 12    | 13    | 14    | 15    | 16    | 17    |
|--------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Transverse K (m/d) | 0.38  | 0.10  | 0.56  | 0.10  | 0.09  | 9.50  | 8.80  | 1.50  |
| Longitudinal K (m/d)| 0.25  | 0.07  | 0.37  | 0.07  | 0.06  | 6.33  | 5.87  | 1.00  |

4. Simulation prediction
There is a wastewater pool on the surface north of the central part of the study area. Under normal condition, the wastewater pool has an artificial anti-seepage system, so that the waste water will not leak. Under abnormal condition, when the artificial anti-seepage system fails, the pollutants will leak into the northeast F6 fracture zone in the karst aquifer and pollute the karst groundwater. For abnormal situation, the surface pollution source is set as a point pollution source, and the pollutants are continuously released in the way of constant concentration. The characteristic pollutant cyanide is selected as the predictive factor. The concentration of cyanide is 46.8mg/L, and the groundwater standard value of cyanide is 0.05mg/L. The determined pollution source is input into the established groundwater numerical model, and then the model is run. The migration range of cyanide in the karst aquifer is obtained at 1, 10, and 30 years after the pollutant leakage, as shown in Figure 3.

![Figure 3. The migration range of cyanide in the karst aquifer](image)

According to the prediction results, as the water conductivity of the F6 fracture zone is greater than that of the surrounding rock mass, a strong runoff zone of groundwater is formed in the F6 fracture zone. After the wastewater leaks into the F6 fracture zone in the karst aquifer, the pollutant cyanide will mainly migrate along the F6 fracture zone to the northeast direction, and the migration and diffusion to the groundwater main runoff direction will be less. Due to the dilution of groundwater and small hydraulic gradient, the migration rate of pollutant cyanide is relatively slow. After 10 years, the pollutant cyanide will migrate only 150m and reach the F2 fracture zone on the north side, and then migrate along the F2 fracture zone to the southeast direction. During the 30-year simulation period, the pollutant cyanide migrates 360m in the fracture zones, but only 90m eastward in the direction of groundwater main runoff. The migration rate of pollutant cyanide in the fracture zones is much faster than that of pollutant cyanide in the surrounding rock mass.
5. Conclusion
(1) In the areas where faults are distributed, the water-conducting function of fracture zones in groundwater system cannot be ignored. In the process of establishing groundwater numerical model, the influence of fracture zones on groundwater should be considered, and the fracture zones should be included into parameter partition. Based on the parameter partition considering the fracture zones, the model is more realistic.

(2) The fracture zones are the strong runoff zones of groundwater. When the conductivity of the fracture zones is greater than that of the surrounding rock mass, the pollutant migration rate in the fracture zones is faster than that in the surrounding rock mass. So the fracture zones are the dominant channels of pollutant migration and diffusion. In the prevention and control of groundwater pollution, the priority should be given to controlling the leakage and migration of pollutants in the fracture zones.

References
[1] Yang Yang, Tang Jiansheng, Su Chuntian, et al. Research advances on multi-medium flow model for karst aquifers[J]. Carsologica Sinica, 2014, 33(4):419-424.
[2] Zhao Weili, Chu Xuewei, Dong Yu, et al. A analysis on leakage pollution dispersion type in karst aquifer—taking the waste residue site pollution for example[J]. Groundwater, 2011, 33(2):6-14.
[3] Zhong Yuanyuan, Zhang Yongbo. Three-dimensional flow model of karst groundwater in Jinci Spring area and reflow scheme[J]. Water Resources and Power, 2017, 35(9):116-118.
[4] Hu Jianqing, Zhang Wentao. Application of Visual MODFLOW in assessment of deep karst groundwater in Jungar Banner[J]. Coal and Chemical Industry, 2018, 41(1):13-19.
[5] Yu Cuicui. Numerical simulation of karst groundwater and dynamic prediction of spring water level in the Mingshui spring area, Jinan City[J]. Carsologica Sinica, 2017, 36(4):533-540.