Analysis of groundwater pollution caused by mine leachate leakage considering natural impermeable layer

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

Abstract. Aiming at the problem of groundwater pollution caused by mine leachate leakage, a numerical model of saturated-unsaturated groundwater is established by using FEFLOW software, and the spatial and temporal distribution of pollutants in vadose zone and aquifer is predicted, in this paper. The results show that the impervious layer of natural clay can slow down the entry of pollutants into the aquifer and reduce the impact of pollutants diffusion on the aquifer. This paper can provide some references for mine groundwater pollution prevention and control.

1. Introduction
In recent years, the problem of groundwater pollution caused by mining has gradually become a research hotspot. The waste rocks and tailings storage yards formed by mining, under the effect of rainfall leaching, produce leachate, which then leaks into the groundwater, and causes a certain degree of pollution to the groundwater. This phenomenon has had a great impact on the ecological environment, human health and social and economic development. To solve such problems, many scholars have conducted researches and discussions. For example, Zhao Weili et al. carried out an analysis on the characteristic of pollutants transport on the wastewater leakage problem of 10 industrial waste dumps in karst areas of Guizhou Province[1]. Aiming at the seepage pollution of a phosphogypsum storage yard in karst area, Zhang Kezheng et al. used GMS software to simulate the groundwater flow field in karst area and the migration of pollutants in karst aquifer, and determined the concentration distribution of pollutants[2]. Most of the existing researches focus on the problem that the pollutants from mine storage yard leak directly into groundwater. However, there are few researches on the pollution leakage of mine storage yard considering the antifouling action of natural impermeable layer.

In the presence of natural impermeable layer, the role of vadose zone in pollutant leakage should be considered in groundwater pollution prediction. The numerical model of groundwater is an effective method to describe such problems. The numerical model of saturated-unsaturated groundwater can be established to analyze the blocking effect of vadose zone on pollutants and the groundwater response process during surface infiltration and recharge. Commonly used software at home and abroad are FEFLOW, TOUGH2, HYDRUS-2D, etc.[3,4] In this paper, taking a gold mine in Hubei Province as an example, a three-dimensional numerical model of saturated-unsaturated groundwater is established using FEFLOW software for the tailings backfill area with a natural clay layer. It simulates and analyzes the groundwater pollution caused by leachate leakage, clarifies the antifouling function of the
natural impermeable layer in the process of leachate leakage, and predicts the concentration distribution of pollutants in the aquifer after they pass through the natural impermeable layer. This work can provide some references for mine groundwater pollution prevention and control.

2. Overview of the research area

A gold deposit in Hubei Province is of the red clay type. Gold deposits exist in the quaternary red clays. The ore-bearing layer is 20~40m thick. Open-pit mining, heap leaching and activated carbon adsorption are adopted in the mining process\textsuperscript{[5]}. At present, the mining has been completed. In the south of the mining area, four open pits have been formed from east to west, which are 1# ~ 4#. Thick silty clay is still distributed at the bottom of mining pits. The enterprise plans to conduct secondary mineral processing of some valuable tailings produced by ore dressing, and backfill the secondary tailings in the four open pits formed.

The mining area is a covered karst area, and the surface is widely covered by a thick quaternary silty clay layer with a thickness of 30-80m, which is a relative water-resisting layer in the region. Beneath the quaternary silty clay layer are the sand shale of the Lower Silurian Xintan Formation (S1x) and the carbonate rock of the Cambrian-Ordovician (Є-О), both of which are 100~170m thick. The sand shale is a relative water-proof layer, distributed in the north, east and south of the mining area. The carbonate rock is karst aquifer, distributed in the mining area and some areas in the south, and the water storage space is mainly karst fractures. The karst aquifer is a weak to medium water-rich aquifer, and the groundwater is confined. The water inflow per unit of borehole in the karst aquifer is 0.018~0.348L/s•m, and the permeability coefficient of aquifer is 0.19~3.59m/d. Mineral separation workshops and legacy tailings piles in the mining area are located in the sand shale distribution area, where is the relative water-proof layer. The secondary tailings backfill area is located in the carbonate distribution area, where is the karst aquifer. There are several faults in the area, which are pervious in carbonate rock and impermeable in sand shale. The distribution of karst aquifer and water-resisting layer beneath the quaternary strata in the mining area is shown in Figure 1. It should be noted that there is locally a relative water-proof layer of sand shale in the southwest of the mining area, but it is cut by No. 23 fault, which connects the karst aquifer in the mining area with the karst aquifer in the southwest.

Figure 1. Distribution of karst aquifer and water-resisting layer beneath the quaternary strata in the mining area
The influence of meteoric precipitation and surface water on the karst aquifer is not significant because the karst aquifer is covered with thick silty clay which is a relative water-resisting layer. The groundwater in the karst aquifer in the mining area mainly receives the lateral runoff recharge of the karst water in the southwest, flows from the southwest to the east, and is discharged in the way of artificial pumping well in the east of the mining area, which constitutes a hydrogeological unit with unified recharge, runoff and discharge.

3. Groundwater numerical model
(1) Conceptual model and parameters
Taking 1# tailings backfill area as the research object, after the leached water from 1# tailings backfill area passes through the natural clay impermeable layer below, the groundwater pollution problem is simulated and predicted by establishing a numerical model of groundwater. The detailed investigation work in the mining area and many hydrogeological boreholes provide a good basis for the determination of simulation range and model boundary conditions. In the horizontal direction, lithologic boundary is used as the water-proof boundary on the north and south sides of the model, and the water-conducting fault combined with groundwater level monitoring value is used as the specified water-head boundary on the east and west sides of the model. In the vertical direction, the stratum structure is generalized into two layers. The upper layer is mainly the quaternary silty clay which is a relative water-resisting layer, and the lower layer is the carbonate karst erosion fissure layer which is the confined karst aquifer, and the groundwater is mainly deposited and transported in the karst aquifer.

In order to reflect the antifouling performance of the upper silty clay layer, the role of the vadose zone in the silty clay layer is considered in this modeling. The silty clay layer is divided into two sub-simulation layers to increase the vertical resolution of the silty clay layer in this modeling. Therefore, the groundwater flow system in the evaluation area is generalized to be a stable groundwater flow system with heterogeneous, anisotropic, three-dimensional saturate-unsaturated multilayer structure.

The model parameters include the parameters of unsaturated zone and saturated zone. The unsaturated zone parameters mainly include the vertical saturation permeability coefficient, residual water content, saturated water content, etc. The saturation zone parameters mainly include the permeability coefficient of aquifer, elastic water release coefficient, specific yield, dispersivity, etc. The parameters are obtained by means of hydrogeological reports, field tests and literature review.

(2) Establishment and identification of numerical model
The FEFLOW software based on finite element method is used to establish the numerical model. The research area is divided into three layers by triangulation grid method, with a total of 86,896 nodes and 124,551 computing units. The first and second layers depict the silty clay layer in the upper part of the study area, and the third layer depicts the karst confined aquifer in the lower part of the study area. At the same time, the density of the computing grid near the pollution source is increased. Sources and sinks include atmospheric rainfall infiltration, surface water infiltration, evaporation and artificial drainage, etc. Each item is converted to the unit intensity of the corresponding partition, and then assigned to the corresponding cell. The initial groundwater flow field is obtained by inputting boundary conditions, sources and sinks, and initial hydrogeological parameters of each simulated layer into the model.

By fitting the water level data of the observation well, the accurate and reasonable hydrogeological parameters, boundary condition values and the intensity of sources and sinks are identified, and the final groundwater flow field is obtained. The established groundwater numerical model can accurately describe the dynamic characteristic of the groundwater system in the study area.

4. Prediction and analysis
(1) Pollution scenario
Assuming that the artificial anti-seepage system of 1# tailings backfill area has failed, the leached water will penetrate directly into the ground, and pass through the quaternary silty clay layer, and then enter the karst aquifer. 1# tailings backfill area is set as surface pollution source, and the pollutants are
continuously released in the way of constant concentration. According to the most unfavorable principle, adsorption, chemical reaction and other factors are not considered in the simulation of pollutant migration, but only convection and dispersion of groundwater are considered. According to the composition analysis of the leached water, the characteristic pollutant arsenic (As) is selected as the prediction factor, which have the largest superstandard multiple. The concentration of As is 0.6 mg/L, and the groundwater standard value of As is 0.01 mg/L.

(2) Prediction result

The designated pollution source is input into the established groundwater numerical model, and then the model is operated to obtain the migration range of As in the vadose zone and the karst aquifer. The predicted time points are 7, 15 and 30 years after the pollutant leakage occurs, as shown in Figure 2.

It can be seen from the prediction result that after the leachate from 1# tailings backfill area infiltrates into the ground due to the failure of the artificial anti-seepage system, it will take 7 years for the pollutant As to penetrate through the silty clay layer to reach the karst aquifer due to the antifouling action of the quaternary silty clay layer. During the 30-year simulation period, due to the small permeability of the silty clay layer, the pollutant As would hardly diffuse in the horizontal direction of the vadose zone and would remain within the backfill area.

The range of the pollutant As outside the standard in the karst aquifer will gradually increase from the 7th year. Due to the antifouling action of the silty clay layer, the amount of pollutants leaking into the karst aquifer is less. Due to the small hydraulic gradient of groundwater and the dilution effect of groundwater, the migration and diffusion of the pollution halo are slow. The overall trend is to migrate and diffuse eastward. The pollution halo will not go beyond the mining area during the 30-year simulation period and will not have obvious adverse effect on the groundwater environment of the regional karst aquifer.

5. Conclusion

(1) In this paper, a numerical model of saturated-unsaturated groundwater in the study area is established by using FEFLOW software. The influence of mine leachate leakage is predicted by using this model and selecting arsenic as the prediction factor. The prediction result shows that the
quaternary silty clay, as a natural impermeable layer, can play a good role in preventing pollution and greatly reduce the pollution impact of pollutants on the underlying karst aquifer.

(2) This paper can provide some references for other mines to prevent pollution from leached water leakage. In the mining areas without the natural clay impervious layer, it can be considered to lay a natural clay impervious layer under the artificial anti-seepage system of the stock dump to reduce or prevent the impact of pollutants on groundwater after the failure of the artificial anti-seepage system.

References

[1] 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.
[2] Zhang Kezheng, Chen Zhou, Chen Changsheng, et al. Numerical simulation of groundwater seepage and pollutant migration in a karst area phosphogypsum dump[J]. Coal Geology of China, 2018, 30 (5):46~52.
[3] Hu Litang, Wang Jinsheng, Zhang Keni. Development of three-dimensional saturated-unsaturated groundwater flow model in Beijing plain[J]. Journal of Beijing Normal University(Natural Science), 2013, 49(2/3):233~238.
[4] Gu Xiaomin, Zhang Ge, Hao Qichen, et al. Application of TOUGH2 in groundwater numerical simulation of Qaidam Basin[J]. Arid Land Geography, 2016, 39(3):548~554.
[5] Liu Fang, Dai Hongwen. Investigation and assessment of water environment around a gold mine area[J]. China Mining Magazine, 2017, 26(S1):154-157.
[6] He Guoping, Shao Jingli, Cui Yali, et al. Application of FEFLOW to groundwater flow simulation[J]. Journal of Chengdu University of Technology (Science & Technology Edition), 2003, 30(4):356~361.