Influence of mine drainage on regional groundwater of Shilou iron mine in Huaibei City, Anhui Province, China

Jie Yang\textsuperscript{a,\*}, Pengqiang Cao\textsuperscript{b}, Yulan Gao\textsuperscript{a}, Rusheng Jia\textsuperscript{a}, Youxiao Tu\textsuperscript{a}, Yuezan Tao\textsuperscript{c}

\textsuperscript{a}Department of Architecture and Civil Engineering, West Anhui University, Lui'an 237012, China, email: yangjie\textunderscore 6363@163.com (J. Yang)
\textsuperscript{b}Anhui & Huai River Institute of Hydraulic Research, Bengbu 233000, China
\textsuperscript{c}School of Civil and Hydraulic Engineering, Hefei University of Technology, Hefei 230009, China

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\textbf{abstract}

When mining in mines, it is inevitable to produce water gushing; the influence of large amount of mine drainage on groundwater is a problem that should be taken seriously. Taking Shilou Iron Mine for example, based on regional hydrogeological concept model, the numerical model of groundwater was established, which was identified by water-level simulation and crossflow rate calculation, and then the additional drawdown hydrograph was analyzed by considering whether there was water bursting. The results showed that the maximum drawdown of water level of karst water aquifer in the mining area was 0.2753 and 0.2662 m when considering two months of water inrush and normal water gushing by the end of the third year. In addition, the area where groundwater drawdown was greater than 0.2 m was within the radius of 1,500 m at the center of the pit mine, and the mine drainage was of some influence on regional karst groundwater. Furthermore, the maximum value of pore water aquifer was 0.0126 and 0.0104 m in the same case, and the drawdown funnel was roughly stable, so it had little influence on regional pore groundwater during the study period.

\textbf{Keywords:} Water gushing; Numerical simulation; Groundwater drawdown; Crossflow rate; Mine drainage; Pore water aquifer

1. Introduction

The water gushing in mine pit refers to groundwater which flows into the mine through various roadways and mining systems during the construction and production of mines [1]. In recent years, there were frequent occurrences of mine accidents due to water inrush which not only brought huge economic losses to the country but also devoured the lives of many miners [2–4]. Therefore, it is necessary to carry out related research on water bursting and drainage in mine pit. Many scholars at home and abroad have done a lot of research on this topic and achieved some results [5–7]. For example, the tectonic mechanism of water inrush in karst area from the perspective of water storage model, and a corresponding prediction method for water inflow was put forward [8]. Some researchers used discrete element method and software PFC3D to establish a 3D numerical model of water burst in the deep tunnel [9]. A group of researchers established Bayesian discrimination model, fuzzy discrimination model, and gray discrimination model based on water chemical information and obtained the optimum model of water inrush by comparing with the actual water samples [10]. Some researchers predicted the inflow and radius of influence of an open pit mine based on the empirical model and analytical model and analyzed the groundwater recovery after mining [11]. Others researchers used SEEP/W finite element software to establish a numerical model for a mine in Iran, predicted the groundwater runoff and compared with the actual observed data; other researchers discussed the effect of certain acid mine drainage in eastern Turkey...
on the surrounding groundwater, and analyzed the possible influence on the soil, sediment, plant and surface water of the mining area [12,13].

Much of the research had focused on the forecast of water gushing, mechanism of water inrush, assessment and prevention of water burst, effect of mine drainage on water quality, but there were few concerns about the influence of drainage on groundwater level in the mining area [14–23]. Based on the above questions, this paper took Shilou Iron Mine as an example, started from the regional hydrogeological concept model, used the Visual Modflow software to establish numerical model, and carried out the water-level simulation and crossflow rate calculation. What's more, the additional drawdown hydrographs of karst water and pore water aquifer were analyzed and then the impact on groundwater in certain area was determined through the changing trend of water level.

2. Materials and methods

2.1. Study area

Shilou Iron Mine is located in Suixi County of Huaibei which is a city in Eastern China, and the geomorphologic type is alluvial plain, and ground elevation is about 28.5–29.9 m. The Paleozoic strata development in the region mainly includes the Middle Ordovician and the loose Quaternary strata; among them, the Ordovician limestone karst fissure water is the main water source in Huaibei city. Additionally, regional water sources in eastern and western are 0–80 and 30–60 m, respectively. According to the lithologic combination of aquifer medium, times, and water-bearing characteristics, the study area can be divided into three aquifers which are Quaternary pore phreatic water, Carboniferous, and Ordovician karst fissure confined aquifer from top to bottom; a relatively stable layer of clay is isolated between pore phreatic water and fissure karst water, which makes the hydraulic connection weak.

2.2. Numerical simulation of groundwater

2.2.1. Hydrogeology conceptual model

In the simulation of groundwater flow system in mining area, first the regional hydrogeological conceptual model needs to be established, and the model is an approximate treatment of the actual complex system, which is connected with the numerical model through reasonable generalization. The simulation range is mainly divided along the boundary between the Carboniferous and Permian strata; the east-west span is about 10.35 km and north-south is about 16.25 km, a total area of approximately 167.5 km². Second, when the boundary of the model is setup, the change in regional stratigraphic lithology ought to be taken into consideration; the northern part is generalized to the boundary of fixed water level, and others are impermeable. Furthermore, according to the distance from Shilou Iron Mine to Suixi Waterworks which is about 7.5 km, it can set four representative points in between which are point 1, point 2, point 3, and point 4; each point distance from the center of the mining area is 1,500, 3,000, 5,000, and 7,500 m, respectively. Therefore, the effect of drainage on the groundwater in the mining area is reflected by the change ofdrawdown of water level in every point. The location distribution of the points is shown in Fig. 1.

2.2.2. Mathematical model

According to the generalized hydrogeological conceptual model, the regional subsurface water is generalized into the non-homogeneous, anisotropic, and unstable groundwater flow system, and the corresponding numerical simulation mathematical model is established as follows:

Fig. 1. The location distribution of the representative points and water-level observation wells of the research area. (a) Distribution of the representative points and (b) distribution of the observation wells.
approximately 914.14 × 10^4 m^3 d^-1, respectively. By the regional water surveying, the annual total excavation volume is approximately 914.14 × 10^4 m^3 d^-1, which is generalized to two mining wells.

2.2.4. Observation wells and mining wells

According to the preliminary exploration and the hydrogeological survey, there are three observation wells of water level in the simulation range for which distribution is shown in Fig. 1(b). The fractured karst water mining wells in this project are mainly located in the urban areas of Suixi and mining, for which the annual production are 2,361.72 × 10^4 m^3 d^-1; the stage hydrograph and crossflow rate before and after mine drainage are shown in Fig. 4(a) and Table 1 [27]. By analysis of hydrograph, it could be seen that mine drainage had a very small influence on pore groundwater; the variation of crossflow rate in the first year was relatively large which was mainly caused by the water bursting [28–30]. As the difference in water level is very small, the stage hydrograph is enlarged in the first six months, as is shown in Fig. 4(b).

3. Results

3.1. Model identification

3.1.1. Simulation of water level

The parameters were adjusted repeatedly through the method of trial and error; finally, an ideal model identification result was obtained which is shown below [24–26]. Fig. 2 shows the comparison of the calculated water level with observation water level at the end of 2009. It could be seen from the diagram that the average error of groundwater was very limited, and the effect on regional groundwater was very limited, and the maximum drawdown in the karst water source of Suixi Waterworks was 0.12 m (about 181 d), so the mine drainage did not affect normal water source during the study period. Furthermore, the maximum drawdown of pore water was 0.0126 m, and all the points except 1 were less than 0.01 m, so the model prediction. Considering the pit water bursting, the drainage for the first two months was 3.0 × 10^4 m^3 d^-1; the stage hydrograph and crossflow rate before and after mine drainage had a very small influence on pore groundwater; the variation of crossflow rate in the first year was relatively large which was mainly caused by the water bursting [28–30]. As the difference in water level is very small, the stage hydrograph is enlarged in the first six months, as is shown in Fig. 4(b).

3.2. Analysis of numerical solution

3.2.1. Analysis on the drawdown of water level during water bursting

For the karst aquifers, it can calculate the additional drawdown of water level of each representative points at different times when the mine drainage continues to the 3, 6, 12, 24, and 36 months [31–34]. For the upper porous aquifer, according to the drawdown of central pit and karst water in the third year (1,095 d), it can also get the value of porous aquifer caused by crossflow. In consideration of water bursting, the iron mine was drained at 30,000 m^3 d^-1 in the first two months and then pumped at 4,000 m^3 d^-1 which was on the basis of actual water drainage; the calculated results are shown in Table 2, Figs. 5(a) and (b).

According to the above chart, under the condition of water inrush in two months, the maximum additional drawdown of water level of karst water was 0.501 m in the center of mining area; about 6 months later, the drawdown of all points had a decreasing trend. In addition, by the end of the third year, the additional drawdown hydrograph of karst water was basically stable, for which the value of all points beyond the radius of 1,500 m was not greater than 0.2 m, and the maximum drawdown in the karst water source of Suixi Waterworks was 0.12 m (about 181 d), so the mine drainage did not affect normal water source during the study period. Furthermore, the maximum drawdown of pore water was 0.0126 m, and all the points except 1 were less than 0.01 m, so the effect on regional groundwater was very limited, and the drawdown funnel was also roughly stable after 3 y [35,36].
When the sudden rushing of water was not taken into account, the actual water flow of Shilou Iron Mine was pumped by the drainage of 4,000 m$^3$ d$^{-1}$; the additional drawdown of water level on the regional karst water and pore water is shown in Table 3 and Figs. 6(a) and (b).

Combining the above diagrams, when considering without water bursting, the initial drawdown of water level of karst water was 0.115 m in the center of the mining area; it reached the maximum of 0.272 m by the 1,095th day, and the value of rest points were simultaneously increasing, but the trend of drawdown hydrograph had leveled off later. Besides, the drawdown of the pore water level was lower at

![Fig. 3. The correlation curve of calculated water level and observed water level in observation wells 1, 2, and 3.](image)

![Fig. 4. The hydrograph of water level before and after mine drainage. (a) The hydrograph in 1,095 d and (b) the hydrograph in 181 d.](image)

<table>
<thead>
<tr>
<th>Year</th>
<th>Pre-drainage value ($\times 10^4$ m$^3$ a$^{-1}$)</th>
<th>Drainage value ($\times 10^4$ m$^3$ a$^{-1}$)</th>
<th>Variation value ($\times 10^4$ m$^3$ a$^{-1}$)</th>
<th>Rate of change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>582.30</td>
<td>594.86</td>
<td>12.56</td>
<td>2.16</td>
</tr>
<tr>
<td>2010</td>
<td>690.96</td>
<td>699.89</td>
<td>8.93</td>
<td>1.29</td>
</tr>
<tr>
<td>2011</td>
<td>580.85</td>
<td>588.97</td>
<td>8.12</td>
<td>1.40</td>
</tr>
</tbody>
</table>

3.2.2. Analysis on the drawdown of water level without water bursting

When the sudden rushing of water was not taken into account, the actual water flow of Shilou Iron Mine was pumped by the drainage of 4,000 m$^3$ d$^{-1}$; the additional drawdown of water level on the regional karst water and pore water is shown in Table 3 and Figs. 6(a) and (b).
Table 2
The drawdown of water level of karst water and pore water at the end of three years. (with water bursting)

<table>
<thead>
<tr>
<th>Representative points</th>
<th>Distance from pit center (m)</th>
<th>Drawdown of karst water (m)</th>
<th>Drawdown of pore water (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of pit</td>
<td>0</td>
<td>0.2753</td>
<td>0.0126</td>
</tr>
<tr>
<td>Point 1</td>
<td>1,500</td>
<td>0.2002</td>
<td>0.0125</td>
</tr>
<tr>
<td>Point 2</td>
<td>3,000</td>
<td>0.1399</td>
<td>0.0096</td>
</tr>
<tr>
<td>Point 3</td>
<td>5,000</td>
<td>0.0772</td>
<td>0.0060</td>
</tr>
<tr>
<td>Point 4</td>
<td>7,500</td>
<td>0.0182</td>
<td>0.0025</td>
</tr>
</tbody>
</table>

Fig. 5. The additional drawdown (a) hydrograph of karst water and (b) pore water with water bursting.

Table 3
The drawdown of water level of karst water and pore water at the end of three years (without water bursting)

<table>
<thead>
<tr>
<th>Representative points</th>
<th>Distance from pit center (m)</th>
<th>Drawdown of karst water (m)</th>
<th>Drawdown of pore water (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of pit</td>
<td>0</td>
<td>0.2662</td>
<td>0.0104</td>
</tr>
<tr>
<td>Point 1</td>
<td>1,500</td>
<td>0.1917</td>
<td>0.0102</td>
</tr>
<tr>
<td>Point 2</td>
<td>3,000</td>
<td>0.1330</td>
<td>0.0076</td>
</tr>
<tr>
<td>Point 3</td>
<td>5,000</td>
<td>0.0735</td>
<td>0.0044</td>
</tr>
<tr>
<td>Point 4</td>
<td>7,500</td>
<td>0.0174</td>
<td>0.0018</td>
</tr>
</tbody>
</table>

Fig. 6. The additional drawdown (a) hydrograph of karst water and (b) pore water without water bursting.
the starting point which was about 0.001 m, and the value of every point had increased significantly over the past 3 y, for which the maximum was approximately 0.01 m. Although the value of pore water had increased a lot, it had a lower base, and due to the stable clay layer isolation between pore water and karst water, the pore water was less affected by the mine drainage.

4. Discussion and conclusions

Through the simulation study on mine drainage of Shilou, the following conclusions can be drawn.

- When numerical method was to analyze mine drainage, the premise of which was simulation of groundwater flow field, based on the generalized regional hydrogeological conceptual model, the corresponding numerical model was established, the time space dispersion and distribution of wells should be considered. Second, by applying Visual Modflow software, the results of model recognition were mainly achieved by comparing calculated value and observed value with the observation wells.

- Distinguishing whether water inrush or not, the drawdown of water level in the aquifer of karst water and pore water was calculated and analyzed the trend of additional drawdown hydrograph of them in the above two cases. By the end of the third year, the karst water drawdown was basically stable, which in pit center was 0.2753 and 0.2662 m, respectively, in the occurrence of water bursting and normal water gushing. What's more, there was a rising trend of drawdown of pore water, which in pit center was 0.0126 m and 0.0104 m, respectively, in the same case, but the late hydrograph is roughly flat, it had a limited impact on regional groundwater during the calculation period.

- There were many “large mining wells” in the study area such as the drainage of Shilou and Liuqiao Mine, the current situation and planning exploration of water source in Suixi Waterworks, and the influence of these well groups on the regional groundwater level was mutual interference, which was not fully considered in the article, so the accuracy of numerical results would be affected. Additionally, in the longer study period, how to combine the surface water ecosystem to analyze the change law of the regional underground flow field will carry out further research in the later work.

Symbols

\( D \) — The simulation area

\( H \) — The groundwater level, m

\( H_0 \) — The initial water level of groundwater, m

\( H_1 \) — The groundwater level at the simulated boundary, m

\( K \) — The aquifer hydraulic conductivity, m d\(^{-1}\)

\( M \) — The thickness of confined aquifer, m

\( t \) — Time, d

\( W \) — The unit volume flow, m\(^3\)

\( \Gamma_0 \) — The first-class boundary of head loss

\( \Gamma_1 \) — The second type of flowrate boundary

\( \mu \) — The elastic storage coefficient

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