Prediction of Groundwater Environmental Impact: A Case Study of the Exploration Project of a Mining Area in Haiyang

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Abstract Based on the exploration project of a mining area in Haiyang, as well as data collection and groundwater monitoring, groundwater environmental impact was predicted, and emergency protection measures were proposed. The results show that after preventive and control measures were adopted under abnormal conditions, the mining activities in the mining area had a relatively small impact on groundwater and were acceptable, which can provide a simple and effective method for groundwater environmental prediction of similar projects.

Key words Mining; Groundwater environment; Impact assessment; Prediction analysis

DOI 10.19547/j. issn2152 - 3940. 2026. 02 - 03. 017

At present, fossil fuels still constitute the main part of China's energy structure. However, in order to implement the green concept, the environmental impact of coal mining has become a hot topic of discussion at present, especially the impact on groundwater will receive active attention in the future[1-2]. Based on the characteristics of a certain exploration project of a mining area in Haiyang, as well as the guidelines, the evaluation type, grade, and scope were determined. Following the corresponding technical requirements in the guidelines, systematic investigations of hydrogeology, environmental geology, and pollution sources were carried out, and the impact on groundwater was predicted. Emergency policies for groundwater protection were proposed accordingly.

1 Project overview

1.1 Regional geological overview The expansion and renovation project of the tailings pond in the evaluation area is based on the existing Shawang Tailings Pond. Shawang Tailings Pond is located in a narrow mountain valley 0.8 km northwest of Shawang Village and 0.5 km east of the Shawang Mining Area. It was put into use in June 2010, and is 0.5 km away from the Dongliujia Mining Area in a straight line, with a road transportation distance of 1.6 km. It is separated by the Dongliujia Reservoir.

The site of the tailings pond is higher in the south and lower in the north, and has an erosional hilly landform. The mountain body is stable and there are no adverse geological phenomena. The gullies develop in a northwest to southeast direction. The bottom elevation of the pond is approximately 140 m, with a relative height difference of 132 m and catchment area of 0.69 km^2. The surface water is mainly seasonal runoff in the gullies. During the investigation period, there was no water, and the pond is about 200 m away from the Dongliujia Reservoir in the northeast.

The ancient Proterozoic Jingshan Group metamorphic rocks are exposed in the cliff section within the area. The Quaternary is distributed in the mountain gully terraces and gullies. The magmatic rock is the fine-grained diorite granite in the late Proterozoic Muoxinshan rock mass, containing biotite schist and marble inclusions, with microlithization and local potassiumization characteristics. The fault structures are mainly developed in two groups, namely the nearly SN direction and the NE direction.

1.2 Hydrogeological overview The boreholes in the pond did not reveal any aquifer. The aquifers are the Quaternary pore aquifer and the bedrock fracture aquifer. The Quaternary strata are mainly composed of gravel-bearing silty clay, with only a small amount of groundwater present in low-lying areas, and there is a vadose zone in other areas. The strata are loose and have good permeability. For indoor tests, the gravel content of the sampled samples was relatively smaller than that in the original site, so two pit water injection tests were conducted, and the permeability coefficient k was 0.39 m/d.

The bedrock in the area is mainly composed of the Jingshan Group cliff group metamorphic rocks and Muniu Mountain diorite granite, which are respectively layered and band-shaped permeable zones; the thickness of the strongly and moderately weathered zones is 3.80 - 20.70 m, and the permeability coefficient is 0.16 - 0.24 m/d. There are fractures in the area, and the F1 and F2 faults in the SN direction are filled with diorite veins; the rock core of the NE-directed inferred fault F3 is fragmented, and the permeability coefficient is 0.46 m/d.

2 Assessment of groundwater

2.1 Evaluation level According to the *Technical Guidelines for Environmental Impact Assessment — Groundwater Environment* (HJ

Received: February 12, 2026 Accepted: March 23, 2026
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610 – 2011)[3], this project is a class III mining and extraction construction project. The evaluation level is determined by classifying it as class I and class II respectively and taking the higher level. The tailings pond mainly affects the quality of groundwater, and is evaluated as a class I project. Based on indicators such as the anti-pollution performance of the vadose zone, the pollution characteristics of the aquifer, the sensitivity of groundwater, the amount of discharged wastewater, and the complexity of water quality, the evaluation level of groundwater in the tailings pond is determined to be class II.

2.2 Survey and evaluation scope The mining area is located at the northeastern edge of the Jiaolai Basin. It has a low mountainous and hilly terrain with weathering and erosion features, with strong terrain cutting. The altitude ranges from 140 to 272 m, and the slope is from 3 to 10°. There are numerous gullies in the area, and the drainage conditions are good. The main surface water is in the Dongliujia Reservoir, and precipitation flows into the Guxian River.

The Quaternary strata in the mining area are relatively thin, under which there is bedrock, and the groundwater is closely linked with surface water. The direction of groundwater flow is basically consistent with the surface runoff. It flows from southeast to northwest in the mining area and from southwest to northeast in the tailings pond. The lowest erosion benchmark surface of the area is the 140-meter elevation of the Dongliujia Reservoir.

According to the topography and hydrogeological conditions, the survey and evaluation scope of groundwater is determined as follows: to the south, it is bounded by the back edge of the tailings pond; to the east, west, and north, it is bounded by the surface watershed; to the northwest, it extends to Doujiutan Village. It forms an independent hydrogeological unit with an area of approximately 16.8 km^2.

3 Evaluation and prediction of groundwater impact

3.1 Sources of groundwater pollution The tailings pond mainly affects the quality of groundwater, and the leachate seepage can easily cause groundwater pollution. Mining activities mainly influence the groundwater level, and the changes in water level and related environmental hydrogeological issues need to be predicted based on the drainage scale[2].

The groundwater impact level of this project is level 2. According to the guidelines, numerical methods or analytical methods can be adopted. To improve the simulation accuracy, a numerical method was used for prediction.

3.2 Prediction factors To predict water quality, based on the quality of groundwater and wastewater in the evaluation area, the contribution of pollution factors and the characteristics of pollution sources, COD (chemical oxygen demand) with significant impact was selected as the prediction factor. For the prediction of water level, the range of changes in the groundwater level was analyzed according to the water inflow of the mine pit.

3.3 Prediction of the impact of tailings pond leakage on groundwater Engineering analysis shows that the wastewater concentration in the backwater pool of the tailings pond is the highest, near which the sensitive point is set. If a local crack occurs at the bottom of the backwater pool to result in a leakage accident, the crack area is 10 m^2, and the leakage rate is 300 m^3/d. The COD concentration of the leaked liquid is 21 mg/L, and it is disposed of within 30 d. The leaked liquid seeps through the vadose zone and all enters the aquifer (not considering adsorption, degradation and time lag), the impact on groundwater is predicted.

3.3.1 Setting of scenario for tailings pond leakage.

3.3.1.1 Analysis of tailings pond leakage. Shawang Tailings Pond is situated in an independent mountain valley 0.8 km northwest of Shawang Village and 0.5 km east of the Shawang Mining Area. It is approximately 1.6 km away from the newly-built beneficiation plant. Currently, it is undergoing expansion and renovation.

After the expansion, the total storage capacity is 3.1 million m^3, and the effective storage capacity is 2.635 million m^3. It adopts the pressure filtration dry stacking process. The initial dam is a non-permeable compacted earth-rock dam, with a height of 13 m. The maximum height of tailings accumulation is 210 m, and the total dam height is 57 m. The dry density of tailings is 1.3 t/m^3, and 200-mesh tailings accounts for 80%. After pressure filtration, moisture content is 22%, and they are transported by trucks to the tailings storage area for dry stacking. In the tailings pond, the main buildings are at grade 4, and the secondary and temporary buildings are at grade 5. A small amount of leakage generated during storage is collected by the drainage system, sedimented, and then reused for production. The service life is approximately 13.5 years.

The Quaternary strata in the site are composed of gravel-bearing silty clay, with loose structure and good permeability, belonging to a medium-permeable layer. The bedrock consists of Jingshan Group metamorphic rocks and Muniu Mountain granite, which are respectively layered and band-shaped permeable zones; the thickness of the strongly and moderately weathered zones is 3.80 – 20.70 m, and the permeability coefficient is 0.058 – 0.242 m/d, so it is a weak-medium permeable layer. There are fractures in the area, and the F1 and F2 faults in the SN direction are filled with rock veins; the NE-directed fault F3 is fragmented, and the permeability coefficient is 0.46 m/d, so it is a medium permeable layer.

The initial dam is located in the northeast of the site. The strata from top to bottom are as follows: gravel-bearing silty clay (thickness 0.30 – 0.80 m), strongly weathered bedrock layer (thickness 5.60 – 8.60 m), moderately weathered layer (thickness 8.30 – 12.00 m), and slightly weathered layer (thickness 2.70 – 5.20 m). The permeability coefficient of the permeable layer is 0.112 m/d, and it is a medium permeable layer.

In summary, the tailings pond needs to be well protected against seepage. The expanded and newly built initial dam is a non-permeable compacted earth-rock dam. A soil mold is laid inside the dam to form an impermeable layer, and geotextile fabric is laid inside the rockfill to form a reverse filtration layer. The inner slope is built with stones, while the outer slope is planted with grass, and the crest of the dam is mortared with stones. Longitudinal and transverse drainage ditches are constructed outside the dam to connect with side ditches along the mountain to form a drainage system.

3.3.1.2 Analysis of the quality of water seeping from the tailings pond. The results of the quality of water seeping from the tailings pond show that COD concentration is 21 mg/L, exceeding the class III limits of COD concentration in surface water (20 mg/L) and groundwater (3 mg/L). All other detected factors meet the class III standard for groundwater quality. Therefore, the main pollutant in this prediction is COD.

3.3.1.3 Setting of leakage scenario for the tailings pond. Based on the analysis of the leakage of the tailings pond, the leakage scenario is designed as follows: a local crack occurs at the bottom of the backwater pool in front of the dam, and the tailings backwater directly enters groundwater for migration.

3.3.2 Generalization of simulation conditions. The migration process of pollutants in groundwater is complex, involving various effects such as volatilization, diffusion, adsorption, and degradation. This prediction follows the principle of maximum risk, only considering the convection and dispersion effects of groundwater, and ignoring adsorption, chemical reactions, and biological degradation. The leakage point near the retaining dam of the tailings pond is generalized as a instantaneous point source. The main aquifer rock group in the site is shallow fully weathered porous groundwater, and the underlying moderately weathered metamorphic rock has weak permeability; the pollutant mainly affects the shallow pore water, so the water quality of shallow porous groundwater is predicted.

3.3.3 Setting of simulation period. According to the development and utilization plan of the project, the service life of this tailings pond is 13.5 years (approximately 4 930 d). After the service period of the tailings pond expires, it will be closed for 1–2 years. After the closure, reclamation is also required. In order to simulate the impact of the pollutant on groundwater during and after the service period of the tailings pond, the simulation for the accident scenario in this prediction is started from the use of the tailings pond's operation until approximately 5 years after the expiration of the service period, approximately 6 750 d.

3.3.4 Simulation, prediction and evaluation of solute transport. Simulation scenario: there is a local crack in the backwater pool in front of the dam, and water seeps directly into groundwater for transport.

The parameters are input into the water quality model to simulate solute transport and evaluate the impact. COD > 3 mg/L is the range of exceeding the standard, and COD > 0.1 mg/L is the influence range. The pollutant concentration reaches its peak after 30 days of leakage, but does not exceed the standard. As time progresses, the pollution plume expands, and the concentration decreases, close to the background value after 1 000 d. 6 750 days later, it is basically diluted to the background level, with a small transport range and slow speed. The project is approximately 12 km away from the nearest drinking water source, and is located downstream of the protected area. Due to the poor permeability of the stratum, the pollutant has been diluted before reaching the source, having a very small impact on the drinking water source and the water used for irrigation in the surrounding areas.

3.3.5 Prediction of the impact of mine pit inflow water on groundwater level in the mining area. According to the development plan, the lowest mining elevation of the mining area is −380 m. The cone of depression formed by mine pit water inflow in the lower confined aquifer at this elevation is simulated, and the impact on the upper aquifer is analyzed. The prediction results show that the second layer has weak permeability. When mining reaches −380 m, only a small-scale cone of depression is formed around the mine body, but the area is relatively small, and the water level of the first layer does not change significantly. The main aquifer supplying water for deep mining in the mine has relatively weak water-bearing capacity, and the ore deposits are in the form of veins. Therefore, mine exploitation will cause local drying of the structural altered rock aquifers, but the possibility of causing a regional drop in groundwater level is relatively small. The shallow fully weathered metamorphic rocks have poor water permeability, and the mine pit inflow water has very little impact on surface water. In summary, the cone of depression formed by mining has no significant impact on the water supply of surrounding residents and surface water.

4 Analysis of the impact of plant selection on groundwater

The wellhead of each pumping well is equipped with living and production facilities, including offices, accommodation, storage, maintenance, air compressor rooms, power distribution rooms, powder storage silos, crushing workshops, main buildings, laboratories, analytical laboratories, *etc.* Based on the distribution of the ore body and the mining conditions, the room-and-pillar mining method and the upward horizontal layered tailings filling method are adopted: for ore bodies with an inclination angle of < 30°, the room-and-pillar method is used; for ore bodies with an inclination angle of > 30°, the filling method is used. The void areas formed by the room-and-pillar mining method are filled with tailings subsequently. The ratio of the room-and-pillar method to the filling method is 85% : 15%.

The mineral processing crushing system adopts a three-stage two-closed circuit process; grinding adopts a one-stage closed circuit process; the separation adopts the flotation process; the fine ore and the tailings are dehydrated using a two-stage mechanized dehydrating process of concentration and filtration.

According to the project feasibility study, the foundation of the mineral processing plant adopts a cement concrete floor. The various process stages are arranged in separate workshops, and strict management is implemented. Moreover, all the mineral processing process wastewater is recycled and not discharged. Therefore, under normal circumstances, the operation of the beneficiation plant will not have adverse effects on the surrounding groundwater.

Even if an accident occurs in the mineral processing plant, the wastewater overflowing from the production facilities and equipment will be collected in the accident tank within the plant, and will be recycled again without being discharged outside the plant. Therefore, in this situation, the operation of the mineral processing plant will not have adverse effects on the surrounding groundwater either. Dongliujia ore block has been mined for many years, and the downstream groundwater has not been contaminated.

5 Conclusions

The discussion on the prediction of groundwater environmental impact is a crucial prerequisite for the construction and mining of mining areas. Based on the evaluation of groundwater impact, hydrogeological parameters are obtained and then rated through geological exploration. Finally, according to the classification criteria for groundwater evaluation work grades of class I construction projects, the evaluation grade of groundwater in the tailings pond area is at grade 2. For the impact and prediction evaluation of groundwater, the first step is to predict the pollution sources of groundwater quality. COD, which has a significant impact on the quality of groundwater environment, is selected as the prediction content. The impact of tailings pond leakage on groundwater is predicted. Through condition simulation, time period simulation, and migration simulation, the prediction is evaluated. Eventually, it is concluded that the proposed project has a very small impact on the water source area.

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