

Simulation and Prediction of Groundwater Pollution from Planned Feed Additive Project in Nanning City Based on GMS Model

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Abstract. In order to predict the pollution of underground aquifers and rivers by the proposed project, Specialized hydrogeological investigation was carried out. After hydrogeological surveying and mapping, drilling, and groundwater level monitoring, the scope of the hydrogeological unit and the regional hydrogeological condition were found out. The permeability coefficients of the aquifers were also obtained by borehole water injection tests. In order to predict the impact on groundwater environment by the project, a GMS software was used in numerical simulation. The simulation results show that when unexpected sewage leakage accident happened, the pollutants will be gradually diluted by groundwater, and the diluted contaminants will slowly spread to southeast with groundwater flow, eventually they are discharged into Gantang River. However, the process of the pollutants discharging into the river is very long, the long-term dilution of the river water will keep Gantang River from being polluted.

Keywords: GMS model; prediction; groundwater; pollution

1. Introduction

To meet the needs of the market, a new feed additive production line was planned to build in Liujing Town in Heng County of Nanning City to produce Magnesium sulfate, Zinc sulfate and Copper sulfate as poultry feed additives. In the project, magnesia powder, zinc oxide and copper oxide powder were used as raw materials. After being leached with concentrated sulfuric acid, impurities removal and purification processes, crystal mixtures of magnesium sulfate, zinc sulfate and copper sulfate were produced. Once it's under abnormal conditions (i.e. sudden leakage of waste water), the project may cause serious inorganic pollution to the underground aquifer. Therefore, it is necessary to predict the degree of groundwater pollution and the direction of pollutant migration.

2. Geological Environment Conditions

The evaluation area is located in an area with low mountain and hilly landforms. Affected by subtropical monsoon climate, the region is blessed with plentiful rain. Its average annual rainfall is 1427 millimeters and the rainfall mainly concentrated in April to September. The ground elevation in the survey area is 65 ~ 120 m. To the west of the project is Yujiang River. To the east of it is Gantang River.

The strata from top to bottom in the study area are mainly as: (1) Quaternary loose layers, including filling soil, topsoil and residual slope soil. They are mainly clay or silty clay. (2) Eogene stratum, mainly sandstone, mudstone or conglomerate. (3) Cretaceous siltstone.



There are two types of water bearing rocks in the study area. One is the unconsolidated pore water stored in loose layers and the other is fractured pore water stored in clastic rocks. They are mainly recharged by atmospheric rainfall. Controlled by terrain, the groundwater flows from a watershed which located in the middle of the river to rivers on both sides of the East and West (i.e. Yujiang River and Gantang River). However, the groundwater located in the project site flows eastward and drain to Gantang River.

There is no well in the evaluation area due to the poor permeability and low water content of the formation. The discharge of groundwater is mainly through the runoff to the river and phreatic evaporation (The phreatic water level is shallow).

3. Water Quality Assessment

Sampling monitoring was carried out in 5 monitoring holes in the project site and its upstream, west and downstream respectively. The monitoring results showed that the quality of the groundwater in 4 holes has exceeded the standard of water quality in different degrees. Especially, the groundwater in the upstream hole (ZK2) was seriously polluted. Its CODMn exceeded 5.15 times and its Nitrite (NO₂) exceeded 299 times. The water quality in the downstream hole (ZK5) was also seriously polluted. Its CODMn exceeded 10.8 times, and nitrite (NO₂) exceeded 29 times. The pollution is considered to be caused by enterprises near the project.

Surface water samples detection in Yujiang River and Gantang River revealed that without considering microbial indicators, water quality of Yujiang River can reach Grade III according to Chinese "surface water environmental quality standard" (GB3838-2002), while the water quality of Gantang River only reaches Grade IV. The pollution in Gantang River is considered to be related to the sewage discharged by nearby enterprises or discharged from fish ponds along the River.

4. Numerical Simulation of Groundwater Flow

4.1. Boundary Conditions

In the north and south of the area, the watershed is taken as simulation boundaries (i.e. the second kind of boundary). In the eastern, Gantang River is taken as the constant head boundary (i.e. the first kind of boundary). In the west, Yujiang River is used for the constant head boundary [1].

In the vertical direction: The top is bounded by phreatic water, their height can be calculated according to measured water level and interpolation [2]. The bottom is bounded by a thick, slightly weathered sandstone top because it is a water tight boundary.

4.2. Mathematical Model

The groundwater flow model of the study area can be established by the following equations [3]:

$$\left\{ \begin{array}{l} \frac{\partial}{\partial x} \left[K_x \frac{\partial h}{\partial x} \right] + \frac{\partial}{\partial y} \left[K_y \frac{\partial h}{\partial y} \right] + \frac{\partial}{\partial z} \left[K_z \frac{\partial h}{\partial z} \right] + W = \mu_s \frac{\partial h}{\partial t} \quad (x, y, z \in \Omega) \\ h(x, y, z, t) = h_0(x, y, z) \quad (x, y, z \in \Omega), t = 0 \\ h|_{B_1} = h_1(x, y, z, t) \quad (x, y, z) \in B_1, t \geq 0 \\ k \frac{\partial h}{\partial n} \Big|_{B_2} = q(x, y, z, t) = 0 \quad (x, y, z) \in B_2, t \geq 0 \end{array} \right. \quad (1)$$

Where h is groundwater head (m); K_x , K_y , K_z are hydraulic conductivities along x , y , z direction respectively (m/d); B_1 is the specified head boundary (the first kind of boundary); B_2 is the barrier boundary (the second boundary); h_1 is the river water level (m); W is the source and sink intensity (d⁻¹); Ω is the simulation area; μ_s is water storage rate (m⁻¹) and its empirical value of 0.0005 is used in the simulation.

4.3. Hydrogeological Parameters

(1) Infiltration coefficient of aeration zone: because the topsoil in the survey area is mainly silty and silty clay and a lot of the ground is covered with factory buildings or cement pavements, the comprehensive rainfall infiltration coefficient is 0.10.

(2) Permeability coefficients of the aquifers: According to the results of borehole water injection tests and empirical values in Chinese "environmental impact assessment technical guidelines - groundwater environment" (HJ 610-2016) appendix B, the permeability coefficients of the aquifers are: The filling and topsoil 0.75 m/d, residual silty clay 0.075m/d, strong weathered sandstone 0.65m/d, middle weathered layer 0.03 m/d.

4.4. Mesh Generation

The simulation area is about 5.5km². The planar grid was divided into 50 rows and 50 columns. The vertical profile was divided into three layers: (1) fill soil, surface soil and residual silty clay; (2) strong weathered sandstone; (3) medium weathered sandstone. The weak weathered sandstone is as an impermeable layer.

4.5. Hydrogeological Parameters Verification

Based on the parameters obtained from water injection tests, the monitoring groundwater levels (10 points) and the river water levels were input into the model. By slightly adjusting the relevant parameters, the calculated groundwater levels would coincide with the measured groundwater level at each observation point. When the simulated water levels were closed to the observed values, it was considered that the adjusted hydrogeological parameters are credible and can be used for the subsequent water quality prediction.

5. Groundwater Pollution Prediction

5.1. The solute transport mathematical model

The mathematical model of three-dimensional hydrodynamic dispersion problem is [3]:

$$\frac{\partial C}{\partial x_i} \left(D_{ij} \frac{\partial C}{\partial x_j} \right) - \frac{\partial}{\partial x_i} (v_i C) + \frac{q_s}{\theta} C_s - \lambda \left(C + \frac{\rho_b}{\theta} \bar{C} \right) = R \frac{\partial C}{\partial t} \quad (2)$$

$$\text{Initial condition: } C(x, y, t) = C_0(x, y) \quad x, y, t=0 \quad (3)$$

The first kind of boundary conditions:

$$C(x, y, t) \Big|_{\Gamma_1} = C(x, y, t) \quad x, y, t \geq 0 \quad (4)$$

The third kind of boundary conditions:

$$\left(\theta D_{ij} \frac{\partial C}{\partial x_j} - qC \right) \Big|_{\Gamma_3} = g_i(x, y, t) \quad x, y \in \Gamma_3, t \geq 0 \quad (5)$$

In (2) to (5) formulas: C is the concentration of pollutants dissolved in water (M/L³); D_{ij} is hydrodynamic dispersion tensor (L²/T); X_i is space coordinate (L); V_i is groundwater seepage velocity (L/T); q_s is the source (positive) or sink (negative) unit flow (L/T); θ is porosity of groundwater bearing medium, dimensionless; C_s is concentration of source or sink (M/L³); λ is reaction rate constant (1/T); p_b is specific gravity of porous medium (M/L³); \bar{C} is the concentration of pollutant adsorbed on the medium (M/M); R is retardation factor, dimensionless; t is time (day).

The hydrodynamic dispersion coefficient: According to the field dispersion tests carried out in the aquifer of Dingbian area, China (2016), The longitudinal dispersion in the mixture of fine sand, silt and silty clay is about 0.0058 ~ 0.0064 m²/d [4]. Therefore, the longitudinal dispersion in the simulation is

0.006 m, and the transverse dispersion is taken as 1/8 of the longitudinal dispersion (consulting the empirical value).

5.2. Method of Prediction

Among all the production equipment in the project, the three reaction tanks located in the workshop are the most likely to leak. They all made by digging holes in the earth's surface, their bottom may crack due to uneven settlement when loaded or crack due to a slight earthquake (magnitude 3 or above) occurrence. What is more, the leak is hidden and cannot be easy to be found immediately. Therefore, the leakages of reaction tanks are regarded as the most important source of groundwater pollution in the prediction.

Estimation of leakage volume in the reaction tanks: Suppose there is a leak in one of the 3 reaction tanks and the effective water stopping measures were taken after the reaction water level in the tank drops 2 meters. Then, according to the diameter of the reaction tank, the leakage volume of the reactive liquid is 19.23m³. So the leakage of 20 m³ is adopted in the prediction.

Water quality of the leakage liquid: Assuming MgSO₄ saturation in the leakage liquid reached 20% when the leak occurs, then the concentrations of Mg²⁺ and SO₄²⁻ in the leakage solution can be calculated out. However, the concentrations of impurities of Al³⁺ and Fe³⁺ are relatively small and can be estimated by experience(showed in Table 1).

Table 1. Quantity and quality of leakage liquid in a hypothetical leak accident

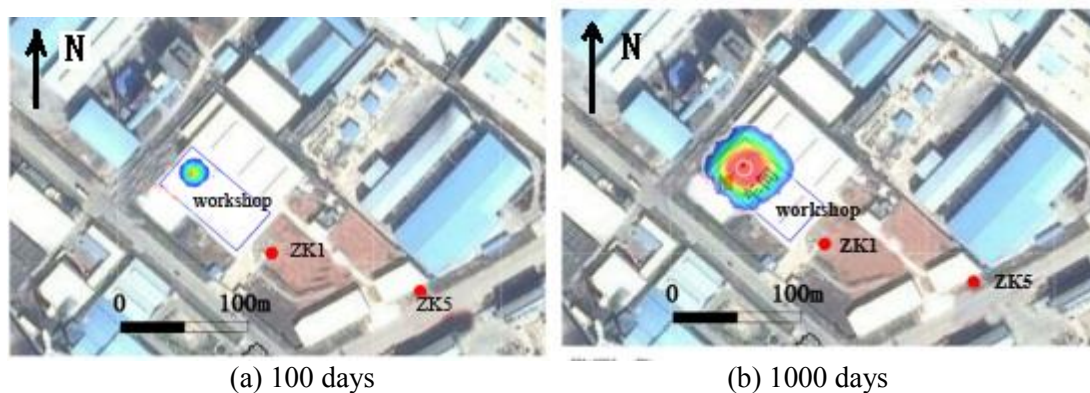
Leakage Volume (m ³)	Pollutant Concentration (mg/L)					
	Mg ²⁺	Cu ²⁺	Zn ²⁺	Al ³⁺	Fe ³⁺	SO ₄ ²⁻
20	2160	2000	2000	100	100	8640

5.3. The Range of Contamination Halos

For SO₄²⁻ halo: the demarcation line is 250 mg/L according to Chinese “Sanitary Standard of Drinking Water” (GB 5749-2006). Considering that the background value is 2.37mg/L (monitoring results in drilling hole of ZK1 at the project site), so 247.6mg/L was used as the demarcation line of SO₄²⁻ halo in prediction. The demarcation line of other indicators were: Fe³⁺ 0.30mg/L, Al³⁺ 0.20mg/L, Zn²⁺ 1.0mg/L, Cu²⁺ 1.0mg/L, Mg²⁺ 113.7mg/L.

5.4. Prediction Results

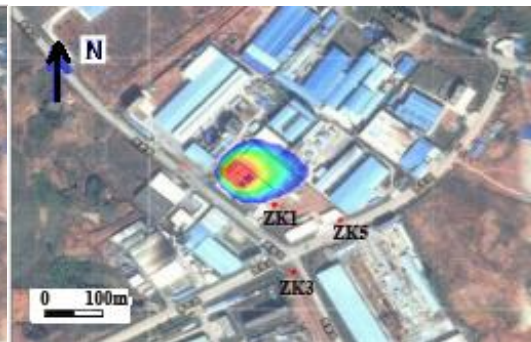
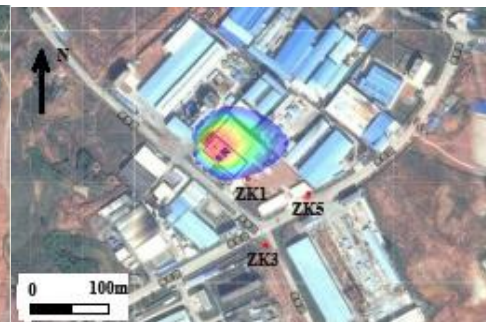
When one of the reaction tanks suddenly leaks, the prediction results of pollution in the aquifer are shown in Fig. 1 to Fig.6.





(c) 10000 days

Figure 1. SO_4^{2-} pollution plume in the aquifer after 1000d, 100d and 10000d of leakage accident. (Note: the concentration of the pollution halo is expressed in different colors; ZK1, ZK3 and ZK5 in the figure denote the drill holes. The same below)

**Figure 2.** Pollution halo of Mg^{2+} after 10000d**Figure 3.** Pollution halo of Cu^{2+} after 10000d**Figure 4.** Pollution halo of Zn^{2+} after 10000d**Figure 5.** Pollution halo of Al^{3+} after 10000d**Figure 6.** Pollution halo of Fe^{3+} after 10000d in the aquifer

The simulation results showed that the forward distances of SO_4^{2-} pollution halos front are 18.8 m, 39.56 m and 114.48 m respectively after 100 days, 1000 days and 10000 days of the leakage accident (refer with Fig.1). Under the dilution of surrounding groundwater and the dispersion of pollutants, the concentration at the central point of SO_4^{2-} pollution halo will be reduced from 8640 mg/L to 4203 mg/L after 10000 days of the leakage accident.

6. Conclusions and Suggestions

(1) Because of poor water storage and low permeability of the formations, there is no well in the study area. So even if the leakage accident occurred, it will not cause any serious consequences to the local residents.

(2) According to numerical simulation results, the aquifer will be heavily polluted after the leakage accident occurred in the project, the pollutants will migrate to the southeast and eventually flow into the Gantang River.

(3) According to simulation results, it will take about 200 years for the frontier pollution halo to reach Gantang River. Because the process of pollutants moving to the river is very long, the long-term dilution of the river water can keep Gantang River from being polluted.

(4) In order to prevent groundwater pollution, the planned enterprises should establish its emergency response system. Only in this way can it timely take measures such as stopping production, plugging leakage point, intercepting sewage, providing rinsing water and treating sewage as soon as heavy leakage accident happened.

7. References

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