Groundwater Environmental Impact Prediction: the Example of Thermal Power Plant

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Abstract—With the rapid development of industry and the increasing population, the balance of groundwater resources has been seriously damaged in China. Quantitative prediction and assessment of the groundwater environment have become necessary for the rational development, use and protection of groundwater resources. Taking the thermal power plant as an example, based on the engineering characteristics and possible pollution of the proposed construction project, the mathematical model of groundwater pollutant migration is established, and the groundwater pollution is predicted by an analytical method. COD, ammonia nitrogen and diesel fuel were selected as predictors to predict the pollutant migration after 100, and 1000 days of pollution occurrence, respectively. The results show that the pollution range will gradually expand with time. After 1000 days, the migration distance of pollutants such as COD and NH₃-N reaches 80m, and the influence distance of pollutants such as diesel oil will gradually weaken with time. If not controlled and managed in time, the leakage of pollutants can cause serious pollution to groundwater during the operation of the electric field.

1 Introduction

Groundwater accounts for approximately 99% of the total liquid freshwater on earth and is the basis for the survival of human society. With the intensification of human activities, over-exploitation has depleted water resources, and problems such as seawater intrusion, ground subsidence, and secondary soil salinization have seriously upset the balance of groundwater resources[1-3]. At the same time, due to rapid economic development, the size and number of power plants in China have increased considerably. During the work of the power plant, ageing and corrosion of the wastewater transport network, the various wastewater treatment structures and damage to diesel storage tanks can cause contaminants to leak into the aquifer and contaminate groundwater. Therefore, solute movement of groundwater contamination in the affected area of the power plant must be predicted and analysed in order to protect the groundwater environment [4-6].

According to the "Technical Guidelines for Environmental Impact Assessment Groundwater Environment" (HJ610-2016) issued by the Chinese Ministry of Ecology and Environment, analyze, predict and evaluate the possible impact of groundwater quality after the expiration of each period of the construction project [7]. In this paper, the second phase of the Liaoyang Aromatic Hydrocarbon Base Thermal Power Plant project was selected, and the groundwater pollution that may be caused by the power plant in normal operation as well as under abnormal working conditions was predicted using the analytical method, as determined by the project engineering characteristics and hydrogeological conditions[8-10].

2 Regional hydrogeological conditions

The geology within the power plant boundary is complex, and the types of groundwater vary from region to region, as does the lithology of the media in the aquifers. The types of groundwater in the power plant area have mainly pored micro-compression water of the Fourth Series loose rock type and Cambrian fracture karst water. The former aquifer lithology is mainly sand and gravel, medium and coarse sand, aquifer thickness is 10~40m, aquifer permeability coefficient is about 20m/d, mineralization degree is 0.3g/L~0.5g/L, groundwater chemical type is HCO₃-Ca type; The latter is mainly found in karst fissures and is unevenly water-rich. The aquifer in the evaluation area is mainly shallow groundwater of the Fourth Series, and the depth of the stable water table is 1.0-1.5 m. The type of groundwater is pore water of the Fourth Series, and the water chemistry type is simple, mainly Cl, HCO₃-Ca type.
3 Groundwater environmental impact prediction

3.1 Prediction Method

The selection of forecasting methods is generally determined according to the engineering characteristics, hydrogeological conditions and data mastery of construction projects. The project power plant belongs to the category of thermal power generation (including thermoelectric power), and there is no ash dump, which is confirmed to be a category IIII project according to the industry classification table of groundwater environmental impact analysis and evaluation. There are decentralized drinking water sources around the project and downstream villages. According to the groundwater environmental sensitivity grading table and groundwater evaluation grade grading table in the guidelines (HJ610-2016), the evaluation grade of the proposed power plant is Grade III, and the analytical method can be used for prediction.

3.2 Groundwater contamination source identification

Under normal working conditions, it is mainly the domestic sewage generated by the staff. Under abnormal working conditions, through the analysis of the construction content of the power station project, the main factors affecting groundwater include [11]: Rupture of the wastewater transport network in the plant, leakage from various wastewater treatment structures due to corrosion, and ageing, leakage from damaged diesel storage tanks, etc. The wastewater and diesel seeped into the ground, affecting groundwater quality.

3.3 Prediction model selection

(1) The leakage of wastewater treatment structures under accidental conditions is a slow, prolonged low-flow leakage. It can be regarded as the continuous injection of pollutants into a uniform flow field through a point source, which produces a two-dimensional pollution region in the x, y plane, where the pollutants are uniformly distributed along the x and y directions by convective action and hydrodynamic diffusion. Under the above conditions, the mathematical model of pollutant migration can be expressed as follows:

$$\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} + D_y \frac{\partial^2 C}{\partial y^2} - \frac{u}{\partial x} \frac{\partial C}{\partial x} - \frac{u}{\partial y} \frac{\partial C}{\partial y}$$

$$-\infty < x, y < +\infty, t > 0$$

Initial conditions: \(C(x, y, t)|_{t=0} = 0 \quad -\infty < x, y < +\infty\). The solution is obtained from the Hankel transformation as

$$C(x, y, t) = \frac{mM}{4\pi n t} \frac{u}{\sqrt{D_L D_T}} e^{-\frac{(x^2 + y^2)}{4D_L D_T}}$$

\(mM\) is the instantaneous mass of the tracer injected by a line source of length M.

(2) Under the accident conditions, the diesel storage tank explosion damage leakage, pollutants through the damaged location into the aquifer. The infiltration is fast and short, can be seen as an instantaneous injection into the aquifer through the point source, the migration range of pollutants is two-dimensional and the following mathematical model can be obtained:

$$\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} + D_y \frac{\partial^2 C}{\partial y^2} - \frac{u}{\partial x} \frac{\partial C}{\partial x} - \frac{u}{\partial y} \frac{\partial C}{\partial y}$$

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3.4 Determination of Predictors and Model Parameters

The selection of prediction factors should include the factors with the largest standard index in each category, the main pollutants identified at the contaminated site, and the pollution required to be controlled by the state or local authorities. According to the groundwater pollution characteristics that may be caused by this power plant project, CODCr and NH3-N, and petroleum are selected as groundwater environmental impact prediction factors. The concentrations at the infiltration point of the prediction factors: industrial effluent COD 300 mg/L, domestic effluent COD 280 mg/L, ammonia nitrogen 25 mg/L, and diesel oil 600 mg/L.

The dispersion factor calculated by the model depends on the hydrogeological conditions of the area and the relevant hydrogeological indicators. Combined with the geological conditions in the area of this power plant, the final determination was 0.1 m²/d for the longitudinal dispersion coefficient, 0.04 m²/d for the transverse dispersion coefficient, 0.30 for the effective porosity, and \(u=0.02\) m/d for the water velocity.

According to the relevant national and local standards [12, 13], pollution factors have corresponding standard limits and detection limits, as shown in Table 1:

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Standard Limit</th>
<th>Detection Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODCr</td>
<td>300 mg/L</td>
<td></td>
</tr>
<tr>
<td>NH3-N</td>
<td>25 mg/L</td>
<td></td>
</tr>
<tr>
<td>Petroleum</td>
<td>600 mg/L</td>
<td></td>
</tr>
</tbody>
</table>
Table 1: Lower detection limits for pollutants and their water quality standard limits

<table>
<thead>
<tr>
<th>Pollution factor</th>
<th>Standard limit value (mg/L)</th>
<th>The detection limit (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>NH3-N</td>
<td>0.2</td>
<td>0.025</td>
</tr>
<tr>
<td>Oil</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

4 Groundwater contamination prediction scenario setting and analysis

4.1 Predictive analysis under normal conditions

The wastewater generated by the project enters the sewage network after treatment in the plant and is discharged after treatment to the standard in the sewage treatment plant. As the wastewater treatment structures and other structures are waterproof, anti-corrosion and impermeable, they can effectively stop leachate and another leachate from seeping into the ground. Under normal circumstances, there will be no groundwater contamination as long as management is in place during the work.

4.2 Predictive analysis under abnormal working conditions

The abnormal working condition refers to the situation when the project production unit is found to have a leakage accident through monitoring and data analysis. According to the engineering characteristics of this power plant project and the guidelines (HJ610-2016), the groundwater environmental impact prediction of pollution factors in the study area was selected for 100d and 1000d.

Figures 1 and 2 show the contours of COD pollutant concentrations for industrial and domestic wastewater in the plant area at 100 and 1000 days after the start of the effluent spill.

From Figure 1 and Figure 2, it can be seen that the migration range of pollutants gradually expands with time from 100 days to 1000 days. On the 100th day, the migration distances of excessive pollutants in industrial wastewater and domestic sewage reached 18 and 15 meters respectively, in the mainstream direction of groundwater; on the 1000th day, the migration distances of excessive pollutants reached 70 and 58 meters respectively.
As can be seen from Figure 3, the extent of pollutant concentration exceedance in the direction of the mainstream groundwater is expanding with the increase of time. At 100 meters downstream of the leakage point, the pollutant concentration of industrial wastewater began to exceed the standard on day 1610 and gradually stabilized at 16.8 g/L after 43 years; the pollutant concentration of domestic wastewater began to exceed the standard on day 2460 and gradually stabilized at 111 mg/L after 32 years. At a distance of 535 meters from the spill site, the pollutant concentration of industrial wastewater began to exceed the standard in the 44th year and gradually stabilized at 7.358 g/L after 109 years; the pollutant concentration of domestic wastewater began to exceed the standard in the 54th year and gradually stabilized at 48.42 mg/L after 104 years.

As can be seen from Figure 4, the migration range of ammonia nitrogen pollutants also expands continuously with time, and the exceedance distance of ammonia nitrogen pollutants in the direction of the mainstream of groundwater reaches 13 m on the 100th day; the exceedance distance of pollutant reaches 50 m on the 1000th day. From Figure 5, it can be seen that the concentration of ammonia nitrogen pollutants began to exceed the standard at 100 m in the direction of the mainstream of groundwater on day 2040 and stabilized at 9.9 mg/L after 38 years. 535 m away from the leakage point, the concentration of pollutants began to exceed the standard on year 50 and stabilized at 4.32 mg/L after 104 years.
It can be seen from Figure 6 that the migration of diesel pollutants tends to expand gradually, but its value decreases significantly at the point of infiltration. Within 100 days, the pollutant concentration at the infiltration point decreases from 600 mg/L to 300 mg/L, the maximum value migrates 5 m along the direction of water flow, and the exceedance distance reaches 21 m. Within 1000 days, the pollutant concentration at the infiltration point decreases to 100 mg/L, the maximum value migrates 20 m along the direction of water flow, and the pollutant exceedance location in the mainstream direction spreads to 76 m.

Figure 7 shows that the concentration values of pollutants at different locations undergo a process of change from rising to falling. The closer the monitoring point is to the source, the larger the peak of pollutant concentration; on the contrary, the farther the detection point is from the source, the smaller the peak of pollutant concentration. At 50 metres from the spill site, the pollutant concentration peaked at 66 mg/l, while at 535 metres, the peak concentration was only 20 mg/l. Therefore, it can be seen that the effect of contaminants on groundwater in the power plant area will gradually disappear with time.

5 Conclusion

This paper uses a two-dimensional analysis scheme of continuous injection and transient injection transport to predict groundwater contamination from power plants under abnormal operating conditions. Both COD and ammonia-nitrogen contaminants that seep into the aquifer can contaminate groundwater under conditions where the waste pipe is ruptured and damaged. Over time, the extent and impact of the contamination will increase, so it is important to deal with leaks as soon as they are discovered to avoid the continued spread of contamination.

The rate of contaminant migration and the magnitude of dispersion depend on the amount and intensity of groundwater pumping, and sufficient hydrogeological information must be available for the analysis to meet the requirements of the groundwater environmental impact assessment. Therefore, when predicting contaminant migration, pumping tests and dispersion tests should be carried out on site to ensure that the parameters meet the calculation requirements.

References


