

Analysis of influence of the power plant ash storage yard on groundwater environment

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Abstract: The fluoride contained in the filter liquor produced by fly ash in the thermal power plant which takes the coal as fuel can lead to groundwater pollution. Therefore, it is of great significance to study the migration characteristics of the pollutants in groundwater, in order to control and prevent the groundwater fluoride pollution. By adopting the numerical modeling method, this paper takes the ash-storage yard of Shahe Power Plant in Xingtai City as an example, to study the characteristics of fluoride migration in phreatic water, and establish a two-dimensional groundwater flow and water quality model on the basis of the hydrogeological condition analysis in this study area. Meanwhile, based on the Vmodflow software, the migration regulation of the fluoride in groundwater has been simulated. Because the phreatic aquifer of this area belonging to the Shahe alluvial-diluvial sediments and with a coarse lithology as well as high permeability, the migration and diffusion ability of the fluoride in this area is relatively strong. It turns out that the longest migration distance in 5 years is 892 m and that within 8 years is 1 515 m.

Keywords: Fluoride; Fly ash; Water quality model

Introduction

Fluorine is an integral element of human body fluid and soft tissue, especially bones and teeth (Issa and Preston, 2003). Researchers realized the intrinsic connection between shortage of fluorine and tooth decay incidence. To relieve some tooth diseases, the fluorine toothpaste and mouthrinse have been widely used now (Wang Bin-bin *et al.* 2010). It's true that fluoride plays an essential role in human life, but the optimal intake can be allowed only within a very narrow range (Ruiz *et al.* 2003; Subhashini and Pant, 2005). In fact, the excessive fluorine intake has been well proved to have some detrimental effects. China witnesses the co-existence of fluorine poisoning and prevalent tooth decay. With large quantities of heavy metal and radioactive elements included, fly ash is the potential source of pollution (YIN Guo-xun and LI

Yan-fen, 2007; YIN Guo-xun *et al.* 2007). So the stacking and treatment of fly ash can pollute environment and especially groundwater (BAI Ji-hong and ZHANG Yong-bo, 2008). The groundwater's slow flow and cycle tend to cause the accumulation of pollution components. In China, the hydrogeological conditions or the fly ash's possible downward penetration in most ash storage yards have not been considered to get involved in the groundwater cycle before these ash storage yards are constructed. In this case, ash storage yards become one of the pollution sources. This paper takes the ash-storage yard of Shahe Power Plant as an example to study the characteristics of pollutants migration and the possible influence on groundwater.

Shahe Power Plant plans to lease the third section of Phase IV ash-storage yard of Xingtai Power Plant on the northern bank of the Shahe River. The third section has a total land area of $27.61 \times 10^4 \text{ m}^2$ and the warehouse capacity of about $109.81 \times 10^4 \text{ m}^3$.

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1 Overview of research area

The study area is situated to the south of Luoyang Village, Lichun Township, Qiaoxi District, Xingtai City, and on the northern bank of Shahe River. The study area includes the arable to the north and the riffle area of the Shahe River. As the part of alluvial-proluvial plain, this area's altitude is higher in the west than that in the east. The Shahe River runs through the research area. However, because a reservoir is built along the upper reach of this river, water is unavailable within the research area due to control of the reservoir.

The study area has two aquifers including phreatic aquifer and deep aquifer. For the phreatic water aquifer, the stratigraphic time is the Upper Pleistocene Series and Holocene Series, and the lithologic nature is the alluvial-proluvial pebble bed and sand layer. To be specific, the main aquifer is found in the pebble bed at the bottom of the Upper Pleistocene Series. Located in the thickly cumulative section of Quaternary System like the flood plain and river terrace of the Shahe River, the baseplate is usually buried as deep as 35-50 m, and the water yield per well is often 30-50 m³/h. The water yield property gradually declines from the west to the east. As the Ordovician System lime rock watery stratum, the deep water aquifer is the main source of water. Between the phreatic aquifer and the deep aquifer are the steady mucky silty clay layer of the Lower Pleistocene Series and the loess-like silty clay layer of the Middle Pleistocene Series with the thickness of about 100 m. This aquitard maintains the weak hydraulic connection between phreatic water and deep cavern water.

Given the hydraulic connection between phreatic water aquifer and deep water aquifer, the pollutants of ash storage yard can only ruin phreatic water. This research is focused on the shallow phreatic water.

Zhuzhuang Reservoir, which lies at 30 km along the upper reach of the research area, provides water for urban use and agricultural irrigation in Xingtai City. This reservoir rarely discharges water unless there are big floods. Therefore, the shallow phreatic water within study area mainly has the sources of water supply like atmospheric precipitation, irrigation water penetra-

tion and lateral runoff of groundwater on the western border. With the additional water supply, groundwater runs in the westward way. The discharge of shallow phreatic water is intended for agricultural irrigation, evaporation and flow to the research area in the eastern area.

2 Simulation of groundwater hydrodynamic field

2.1 Conceptual hydrogeological model

(1) Phreatic structure generalizability

Between shallow phreatic water and deep cavern water are the steady mucky silty clay layer of the Lower Pleistocene Series and the loess-like silty clay layer of the Middle Pleistocene Series with the thickness of about 100 m. The groundwater will be immune to pollution if the clay is as thick as 16.5 m (LIU Chang-li *et al.* 2006). So this research is merely targeted at the phreatic water aquifer. Based on the burial condition and hydrodynamic characteristics of groundwater, the research area can be generalized into the single-layer structure, and the groundwater flow is the phreatic two-dimensional flow in plane.

Since aquifer differs in the geomorphic units, the lithologic nature and combinations are different as well. So the aquifers within different sections of work area have different penetration performances. For the non-homogeneous aquifer, its parameters are subject to the section-based generalization. The average parameter value of each section is used as the initial value for the calculation of number. The experimental parameter system is eventually transformed to the modular parameter system following the model testing and identification. If the aquifer is the porous water-bearing medium, the permeability shows no noticeable change in direction, so the aquifer can be generalized into homogeneous aquifers along different directions.

(2) Boundary condition

When the hydrogeological conditions, groundwater level and peripheral sensitive target distribution are considered, boundary condition can be generalized as boundary of flow in the west and east. Specifically, the inflow boundary lies in the west and the outflow boundary lies in the east. The quantity of inflow and outflow across the

section can be calculated according to the Darcy's law when the aquifer penetration coefficient, sectional hydrodynamic slope and the section area are taken into consideration. The northern and southern boundary are vertical to the groundwater levels and get overlapped with the streamline, so the northern and southern boundary are generalized as the zero-flow boundaries.

(3) Source-sink term

The research area receives the vertical water supply from atmospheric precipitation and irrigation penetration. Discharge mainly takes the form of shallow groundwater exploitation for agricultural irrigation and evaporation. The quantity of infiltration from atmospheric precipitation is calculated based on precipitation, raindrop infiltration coefficient and unit area, and the quantity of irrigation penetration is calculated based on irrigation quantity, irrigation return flow rate and unit area. The exploitation quantity is

$$\begin{cases} \frac{\partial}{\partial x} \left[K(H-z) \frac{\partial H}{\partial x} \right] + \frac{\partial}{\partial y} \left[K(H-z) \frac{\partial H}{\partial y} \right] + \varepsilon + W + \sum_{i=1}^m Q_i \delta(x-x_i, y-y_i) \\ = \mu \frac{\partial H}{\partial t} & (x, y) \in \Omega, \quad t > 0 \\ H(x, y, 0) = H_0(x, y) & (x, y) \in \Omega, \quad t = 0 \\ K(H-z) \frac{\partial H}{\partial n} \Big|_{\Gamma_2} = q(x, y, t) & (x, y) \in \Gamma_2, \quad t > 0 \end{cases} \quad (1)$$

In the formula, H is the groundwater level(L); K is the horizontal penetration coefficient of aquifer (LT^{-1}); μ is the specific yield of phreatic aquifer; z is the baseplate level of phreatic aquifer (L); ε is the rainfall infiltration tension (LT^{-1}); W is the other source-sink terms of groundwater (L^3T^{-1}); Q_i is the yield of production well (L^3T^{-1}); m is the number of production wells; δ is the Dirac Delta function; H_0 is the initial hydraulic head of aquifer (L); Γ_2 is the Neumann boundary; Ω is the seepage calculation area; q is the boundary discharge per unit width of aquifer (L^2T^{-1}); n is the boundary exterior normal direction.

2.3 Numerical simulation of groundwater flow

(1) Model discretization

The whole area adopts the rectangular grid-based dissection. To be specific, the area is divided into 5 775 rectangular grid units which involve 75 rows and 77 columns with the line length of $0.1 \text{ km} \times 0.1 \text{ km}$. With all the valid units, the calculation joint is located in the center of each

calculated based on the water yield data of exploitation wells and the evaporation quantity is calculated based on evaporation from water surface and actual groundwater depth. Following all the calculation processes as stated above, the source-sink quantity is generated for each unit and then added to the joint at the corresponding unit.

To conclude, the hydrogeological conceptual model is the underground water penetration model with the Neumann boundary in the heterogeneous underground pore aquifer of different directions and same nature after the hydrogeological conditions are generalized.

2.2 Mathematical model of groundwater flow

Mathematical model of groundwater flow for the research area is as below:

unit.

The identification period of this simulation extends from July 2012 to March 2013. The groundwater flow field at the outset of July 2012 is used as the initial flow field. With each month as a unit, nine stress periods are involved and each stress period also consists of several time steps.

(2) Simulated identification and verification

In the course of model debugging, it's necessary to sufficiently utilize all the definite conditions the calculators' knowledge about hydrogeological conditions to restrict the model debugging and identification.

This simulation starts with the computation of steady stream when the initial flow field is considered. After the simple steady stream model for input and output is created, the aquifer penetration coefficient is obtained through the model-based reverse production of parameter.

The initial stream field, which is fitted by steady stream, is used as the initial value simulated by the simulation of non-steady stream. Based on the calculation procedure, the hydrogeological parameter, boundary value and other balance items

are identified through the stream field in the same period as the fitting process so that the created model can more closely represent the hydrogeological conditions in the simulated area.

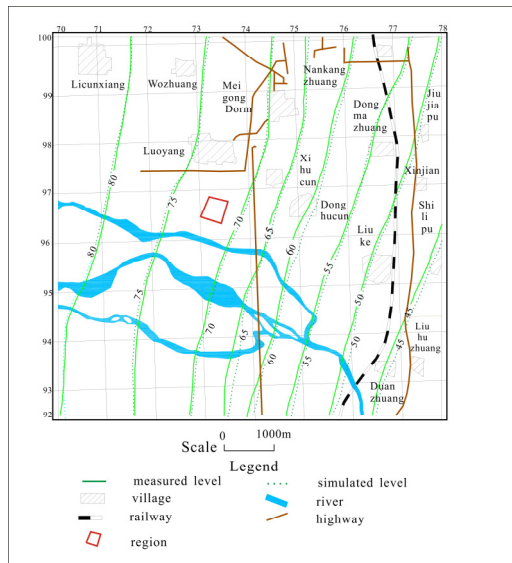


Fig.1 Fitting of phreatic water level contour in December, 2012

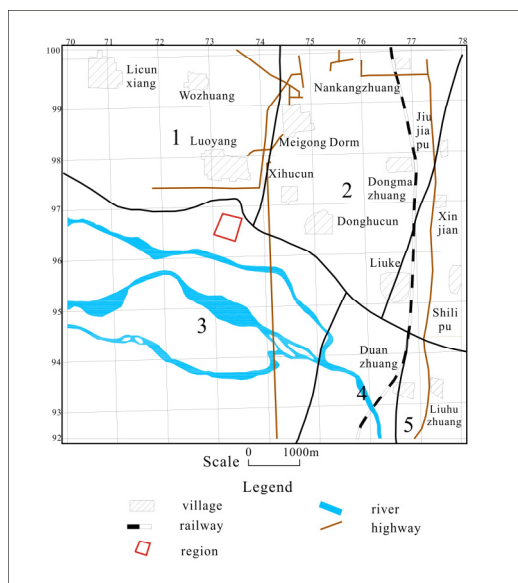


Fig. 2 Partitioning of shallow aquifer parameters

The hydrogeological parameters, which are subject to repeated simulation, identification and verification, can give a satisfactory account of the hydrogeological features in groundwater system, and describe how groundwater changes in differing time and space. The absolute difference of water-level fitting is less than 0.5 m, so the expected result is achieved. Fig. 1 shows the identified and verified two-dimensional stream field, and Fig. 2

indicates the partition of aquifer parameters determined following the optimization and adjustment process. The partitioning parameter value is detailed in Table 1.

Table 1 Aquifer hydrogeological partitioning parameters

Partitioning area No.	Penetration coefficient (m/d)	Specific yield
1	20.16	0.19
2	12.88	0.14
3	22.40	0.21
4	20.50	0.19
5	17.50	0.17

3 Simulation and forecasting of groundwater contamination

3.1 Mathematical model of solute transport

The mathematical model of groundwater solute transport can be expressed as follows:

$$\theta \frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i} (\theta D_{ij} \frac{\partial C}{\partial x_j}) - \frac{\partial}{\partial x_i} (\theta v_i C) - WC_s \quad (2)$$

where, θ -medium porosity, as dimensionless number; C -concentration of component, mg/L; t -time, d; x, y, z -coordinate of spatial position, m; D_{ij} -tensor of hydraulic dispersion coefficient, m^2/d ; V_i -tensor of groundwater penetration velocity, m/d; W -source-sink of groundwater, m^3/d ; C_s -component concentration of source-sink term, mg/L.

3.2 Determination of dispersion

Due to the hydraulic scale-dependent dispersion effect, the accurate dispersion within the range of simulation is almost impossibly available in the outdoor or indoor dispersion tests. So this work is based on the previous research findings (CHEN Cong-xi and LI Guo-min, 1996). Considering the possible migration distance of contaminants within the forecast period, this calculation area adopts the range of 0-100 m. According to Fig. 3, the corresponding vertical dispersion should remain the range of 1-10. The consecutive perspective reveals that this simulation involves the vertical dispersion of 10, and the horizontal dispersion is 1/10 of the vertical

dispersion, that is, 1 in this research.

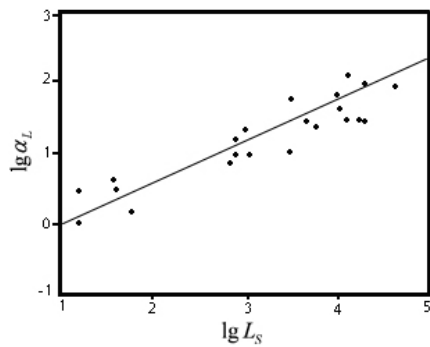


Fig. 3 $\lg \alpha_L$ - $\lg L_S$ of two-dimensional value model of porous medium

3.3 Fluorine migration simulation

When the anti-seepage treatment measures are not taken at the coal cinder yard, the leachate liquid generated by the atmospheric precipitation infiltration will access the aquifer through aeration zone. The local water seepage test results show that the annual precipitation within the evaluation area can result in the bioleaching liquid of 116.05 m³/d when the anti-seepage treatment measure is absent at coal cinder yard. The test results in the power supply industry indicate that low-fluorine and high-fluorine coal cinder's bioleaching liquid has the fluorine concentration ranging from 1.0 to 10.0 mg/L. The fluorine concentration is set as 10.0 mg/L now.

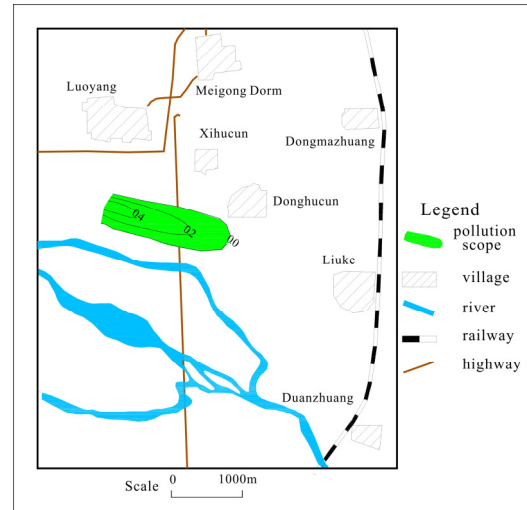


Fig. 4 Influence scope of 8-year fluorine migration

Based on the corrected water flow model and water quality mobility model, the fluorine mobility characteristics are simulated in the phreatic aquifer. The fluorine access to groundwater is set as the continuous source points. For the groundwater Type III water quality standard, fluorine ≤ 1.0 mg/L, and the excess of this value is deemed as the above-standard range. The forecasted result of fluorine migration in aquifer for 5 years and 8 years is detailed in Table 2, and the pollution plume after the 8-year fluorine migration is described in Fig. 4.

Table 2 Simulated Results of Fluorine Migration

Time (a)	Above-standard range (m ²)	Influence range (m ²)	Maximum transport distance (m)
5	0	653 117	892
8	0	1 078 391	1 515

4 Conclusions

(1) The phreatic aquifer of this area belongs to the Shahe alluvial-diluvial sediments. Owing to the relatively high permeability of these coarse-grained sediments, the fluoride migration and diffusion ability is relative good. Within 5 years, the longest migration distance is 892 m and within 8 years, is 1 515 m.

(2) Based on the simulation, due to the penetration and diffusion of leachate liquid, groundwater is polluted to different degrees within the influence scope, but water quality does not

exceed the groundwater Type III standard.

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