CHEMICAL ENGINEERING TRANSACTIONS

VOL. 71, 2018

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216

DOI: 10.3303/CET1871066

Measurement and Control of Chemical Contaminants in Water Conservancy

Zhongxing Shi[a,*], Jinwen Yu[b], Qiang Huang[c]

[a] Xi'an University of Technology, Xi'an 710048, China
[b] KRC Science and Technology(DL)Ltd, Dalian 116033, China
[c] Gansu Jingtaichuan Irrigation Management Bureau, Baiyin 730400, China
bjwuzg@126.com

As groundwater is an important source of drinkable water supplied for human, it concerns human health once chemical pollution occurs. The farmland irrigation and the construction of river conservancy projects all have an adverse impact on groundwater yield and quality. This paper analyzes the hydrogeological conditions of a river, builds a model for surveying chemical contaminants in groundwater. In addition to this, this study also traces the migration and changes of contaminants in underwater. Certain control measures are given against pollution. The findings show that the groundwater in the areas in question has a tendency to increase the concentration of chemical pollutants and deteriorate water quality due to the application of farmland fertilizers; the water quality in most areas has not met the drinking conditions any more.

1. Introduction

Water quality safety is a powerful guarantee that human depends on for survival. As a kind of important water source, the low yield and poor quality of groundwater has a serious impact on human health and social development (Xian, 2010). With the increase in population and the economic and social development, this contradiction has become increasingly prominent (Nandalal et al., 2002). Therefore, the metrology analysis of chemical pollutants in groundwater has important significance for the exploitation and protection of water resources in the area (Shela, 2000).

The metrology analysis of groundwater commonly uses quantitative and qualitative methods, of which, quantitative analysis is more precise, so more frequent has it been applied in recent years. Quantitative analysis includes analytical methods, correlation analysis methods, numerical methods, etc. (Koontanakulvong, 2015; Custodio, 2010), among which, the first two require harsh conditions and a huge mass of long-term data, so that in practices, they are subjected to certain constraints (Samper, 2015); while the numerical method is applicable to a variety of complex groundwater conditions, and widely used thanks to its reliable precision (Raposo, 2012). In recent years, as computer technologies has sprung up, people resort to more and more software for quantitative analysis in the process of numerical simulation of groundwater (Casellas, 2015). Currently, the most commonly used software is Visual Modflow developed by Canada's Waterloo. Users can directly import GIS data or graphics, greatly simplifying data treatment process (Sanford, 2007; Blöschl. 2010). Here we use the software to build a metrology analysis model for groundwater quality, in order to analyze the groundwater quality in some areas of a river.

2. Study background

2.1 Chemical pollution of underwater

Chemical contamination in groundwater contains point, line, and surface sources. Point source refers to the pollution caused by industrial waste water, domestic sewage drainage, etc.; line source refers to the pollution of contaminated river seepage; surface source mainly refers to agricultural pollution, including groundwater contamination caused by sewage irrigation, applied pesticides and chemical fertilizers which infiltrate soil by ways of rainwater (Moore, 2010). As nitrates can frequently enter the groundwater, some events, for example,

Please cite this article as: Shi Z., Yu J., Huang Q., 2018, Measurement and control of chemical contaminants in water conservancy, Chemical Engineering Transactions, 71, 391-396 DOI:10.3303/CET1871066

the growing population, increased rice demand, the application of nitrogen-containing fertilizers, lead to increasingly serious nitrate pollution in agriculture, coupled with farmland drainage and surface runoff, all of which attribute to chemical pollution of groundwater.

Nitrate is ubiquitous in nature. Under the action of microorganisms, Nitrate generates as a strong carcinogen after reduction; additionally, excessive intake of nitrate in the human body will cause methemoglobin. Therefore, China has specified rigid standards for the nitrate content in drinking water.

2.2 River conservancy projects

Study traces the river exploitations as follows: the river basin covers an area of more than 4,600 km^2. Over 100 reservoirs, including large and medium-sized types, have been built in the reach of the river, and the constructed water conservancy projects mainly include rubber dams and diaphragm walls. The former is a pocket type retaining dam built with rubber and canvas, and features simple structure, low cost, strong terrain adaptability, and good aseismic property. However, it is insufficient ruggedness and prone to aging. Rubber dams can improve ground water levels and increase groundwater recharge. Diaphragm wall is a type of continuous wall that plays a role in seepage prevention in the permeable layer or earth-rock dam. Water conservancy facilities can significantly increase surface water storage capacity in river basins.

3. Study coverage

3.1 Study process

Under natural geography and hydrogeological conditions in the area, sampling points are set up; the concentration of chemical contaminants in groundwater are measured and analyzed. Modflow is used to build a mathematical model, testing its precision. When it fits the bill for precision, water quality is measured and analyzed.

The study process is shown below:

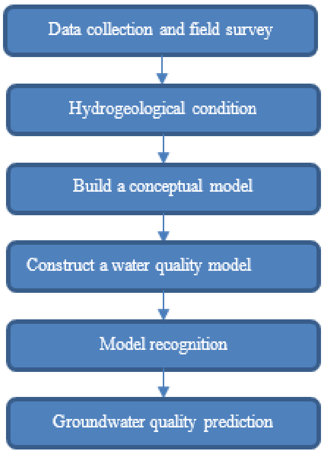

Figure 1: Flow chart of research

3.2 Geographical geography in study area

3.2.1 Hydrogeology

The study area lies in the midstream and downstream of the river, with an elevation of 0-40m, an area of 474km^2. It belongs to a temperate continental monsoon climate, that is, it is drought and little rainfall in spring, hot and rainy in summer, less rainfall and dry in autumn and winter. The average temperature in the study area falls about 13°C. It is hottest and coldest in July and in January respectively. Due to the monsoon, areal precipitation is not distributed uniformly in time and space, presenting the law of decreasing progressively from the coast to the inland.

In study area, the terrain is flat, mostly sandy soil, and dominated as agricultural land. The underground aquifer is distributed along both sides of the river with an average thickness of about 5.2m. The midstream and upstream are dominated by coarse sandstone and conglomerate. The mid- and downstream are fluvial alluvium, containing fine sand, sandy clay, and sub-sand earth. Aquifers are distributed in a shuttle, thick and watery in the middle, thin and poor water richness and water conductivity on both sides.

3.2.2 Water conservancy projects

A dozen of rubber dams have been built in the study area, which play a positive role in flood control and water retainage, and also raise the water table. In addition, due to the perennial exploitation of groundwater in the area, the water level has dropped, causing seawater inwelling to infiltrate into the aquifer. In this case, the local government has constructed diaphragm walls at 1 m depth of underground, as a groundwater reservoir with a water storage capacity of nearly 100 million cubic meters.

3.2.3 Dynamic evolution of underwater

The factors that contribute to the evolution of groundwater runoff mainly include meteorological and hydrological conditions, human intervention. Meteorological conditions include rainfall and evaporation. Human intervention mainly refers to the exploitation of groundwater, including agricultural irrigation, industrial production, and drinking. When the exploitation yield is high, for example, farm irrigation in April will lead to a fall of water table; while in the flood season, agriculture will use more precipitation to irrigate and alleviate the exploitation of groundwater, and the water table will rise up. In recent years, the construction of water conservancy projects has increased the groundwater recharge and impoundment, so that groundwater evolves slowly. The hydrological function means that the river runoff and the peak of groundwater show a certain positive correlation, and the closer the area is to the river, the greater the evolution in the groundwater level and the shorter the response time. In the study area, groundwater recharge mainly comes from atmospheric precipitation and river transfusion, and the main drainage method is artificial exploitation. The changes in water table depend on both recharge and extraction and take on seasonal characteristics.

3.3 Sources of nitrate pollutant

The study area is dominated by agriculture, accounting for nearly half of the total area of the river basin. Agricultural fertilization, livestock excrement, etc., have caused severe contamination from nitrate in the river. After testing, the average content of nitrate pollutants in groundwater in this area reaches 25 mg/L, which exceeds the CAT III standard of groundwater.

According to statistics, in 2009, the application quantity of chemical fertilizer in the area is 300,000 tons, including nearly 70,000 t. nitrogen fertilizer and 190,000 t. nitrogen-containing compound fertilizer. After the application of chemical fertilizers, only a fraction is absorbed as a nutrient by plants. Most of them infiltrate into groundwater or is discharged into rivers in the form of ammonium with rainwater, irrigation water by ways of the soil or surface runoff. Livestock breeding also has serious environmental pollution since there are lots of nitrogen, phosphorus, and pathogenic microorganisms in the livestock manure. Contaminated materials enter groundwater after being leached by rainwater, also causing serious pollution. The application of chemical fertilizers and the livestock farming in the area in 1970 ~ 2001 are shown in Figs. 2 and 3:

4. Study results

4.1 Conceptual model

The hydrodynamic dispersion equation acts as the basis for migration analysis of groundwater pollutants. The pollutant migration model is given as follows:

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial x}(D_{xx}\frac{\partial C}{\partial x}+D_{xx}\frac{\partial C}{\partial y})+\frac{\partial}{\partial y}(D_{yx}\frac{\partial C}{\partial x}+D_{yy}\frac{\partial C}{\partial y})-\frac{\partial}{\partial x}(u_xC)-\frac{\partial}{\partial x}(u_yC)+I \tag{1}$$

$$C(x,y,t)|_{t=0}=f(x,y) \tag{2}$$

When t=0,

$$(D_{xx}\frac{\partial C}{\partial x}+D_{xy}\frac{\partial C}{\partial y})n_x+(D_{yx}\frac{\partial C}{\partial x}+D_{yy}\frac{\partial C}{\partial y})n_y|_{\Gamma 2}=q_2(x,y,t) \tag{3}$$

Where:

D_{xy}, D_{yx}, D_{yy} are the hydrodynamic dispersion coefficients;

C represents the concentration of chemical pollutants in groundwater(mg/L);

I represents the source sink term;

u_x,u_y are actual flow rate of groundwater and fractional velocity in x, y directions(m/d);

$f(x,y)$ is the initial concentration function of chemical pollutants;

Γ_2 represents the second boundary condition of the computation domain;

q_2 represents the flux of chemical pollutants on the second boundary(mg/m^2·d).

The chemical pollutant migration equation and the groundwater flow equation are coupled by the formula (4).

$$u = -\frac{K}{N} gradH \tag{4}$$

Where:

N represents effective porosity;

K represents the permeability coefficient of the aquifer;

gradH represents hydraulic gradient。

4.2 Water quality model

The MT3D program package, which combines the eigenvalues and the improved eigenvalues, is used to calculate the model in order to simulate the migration and diffusion of a type of chemical contaminants in groundwater.

4.2.1 Meshing and time division

The study area is divided into units as shown below, where the white grids are the effective units and 38 grids out of them are chosen for observation well. The distribution of observation wells, mesh generation, and initial nitrate concentrations are shown in Figs. 2 and 3, respectively.

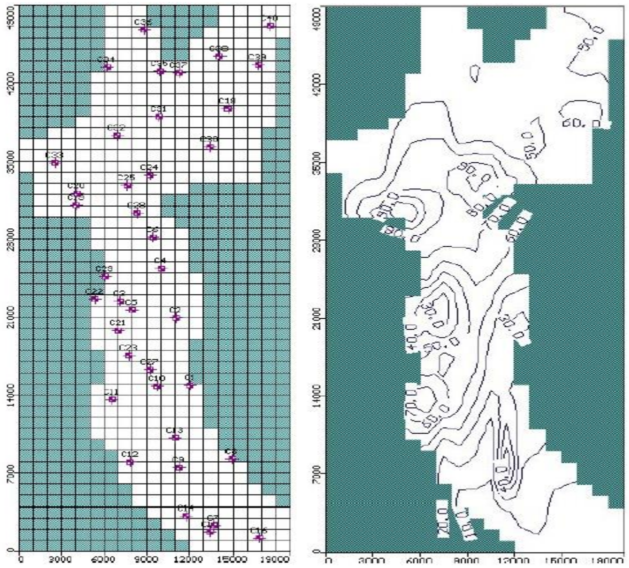

Figure 2, 3: The position of the water quality observation well and the mesh generation chart; Initial nitrate concentration (mg/L)

4.2.2 Model parameters

The lithology seepage coefficient, specific yield and rainfall filtration coefficient determined according to the previous data in this area are shown in Tables 1, 2 and 3, respectively.

Table 1: Permeability coefficient K value of different lithology (m/d)

lithology	Gravel	Sandy gravel	Coarse sand	Midium sand	Fine sand	Silty fine sand	Sand clay	Clay
permeability coefficient K	100-500	40-100	20-50	5-20	0.8-5.2	0.4-1.1	0.09-0.52	<0.1

Table 2: Water supply value table of different lithology

lithology	Clay	Mild clay	Silt	Mild sand	Fine sand	Midium sand	Coarse sand	Gravel
specific yield	0.015-0.052	0.027-0.064	0.045-0.17	0.04-0.073	0.07-0.18	0.09-0.25	0.11-0.26	0.21-0.37

Table 3: Rainfall infiltration coefficient table

lithology	Clay	Sandy clay	Clay sand	Fine sand, fine midium sand
α	0.08-0.17	0.14-0.25	0.22-0.28	0.21-0.35

Regardless of the physical adsorption, chemical reaction and biodegradation of chemical substances in groundwater, the dispersion αL=0.2, transverse dispersion αT=0.015, and effective porosity n=0.2.

4.2.3 Analysis of Nitrate and nitrogen fertilizer application

The correlation between agricultural nitrogen fertilizer application and groundwater nitrate content in the study area in 2010 (see Table 1) is analyzed. The results are shown in Fig. 4.

Table.1 Nitrate nitrogen content and nitrogen application amount of the study area in 2010

As shown in Fig. 6, the nitrate content in groundwater in the study area is positively correlated to the application amount of nitrogen fertilizer. Therefore, the nitrate sink in the groundwater can be measured based on the annual application amount of nitrogen fertilizer.

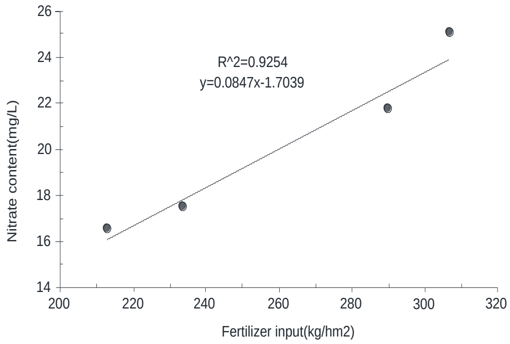

Figure 4: Correlation between nitrogen application amount and nitrate content in groundwater in the study area in 2010

4.3 Model correlation

The groundwater quality monitored on September 1, 2010 is the initial water quality of the aquifer. There are three time frames for identification and correction of the water quality model. The measured concentrations of some observation wells are shown in Figs. 5-8.

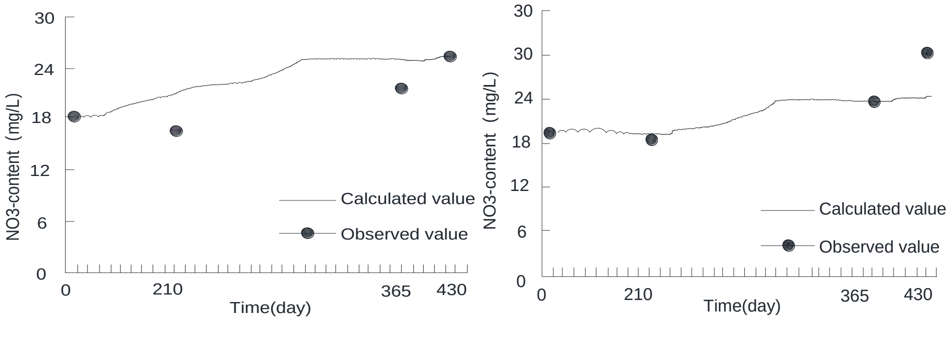

Figure 5,6: Water quality fitting curve of No. 9 observation well; Water quality fitting curve of No. 13 observation well

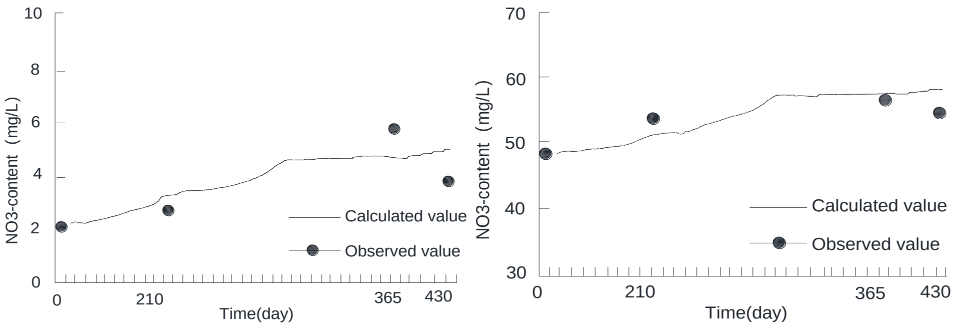

Figure 7,8: Water quality fitting curve of No. 18 observation well; Water quality fitting curve of No. 27 observation well

5. Conclusions

In order to explore what's impact that water conservancy projects and farmland irrigation have on the chemical pollutants of groundwater, this paper uses relevant data, selects 38 monitoring sites for sampling. Visual Modflow is also adopted to measure and analyze the groundwater quality to simulate the migration process of chemical pollutants. The following conclusions are borne out:

1 In the study areas, chemical pollutant nitrate in groundwater is formed due to farmland fertilization;

2 The groundwater quality model gives a quantitative analysis value that can well fit to the measured value, so that it can be used to predict how chemical pollutants in groundwater in the study area migrate and change;

3 Before chemical contaminants enter the groundwater, there is a certain process of biodegradation, chemical and physical purification. However, overhigh concentration of contaminants exceeds the environmental capacity so that the groundwater quality has gradually deteriorated.

References

Blöschl G., Sivapalan M., 2010, Scale Issues in Hydrological Modelling: A Review, Hydrological Processes, 9(3-4), 251-290.

Casellas J., Tomás A., Sánchez A., Alves E., Noguera J.L., Piedrafita J., 2015, Using Haplotype Probabilities in Categorical Survival Analysis: A Case Study with Three Candidate Genes in an Iberian Meishan f2 Population of Newborn Piglets, Journal of Animal Breeding & Genetics, 125(1), 5-12.

Custodio E., 2010, Coastal Aquifers of Europe: An Overview, Hydrogeology Journal, 18(1), 269-280.

Koontanakulvong S., Suthidhummajit C., 2015, The Role of Groundwater to Mitigate the Drought and as an Adaptation to Climate Change in the Phitsanulok Irrigation Project, in the Nan Basin, Thailand, PloS One, 76(15), 89-95.

Moore J.W., Claypool J.E., 2010, Optimizing Remedial Action Implementation at the C & R Battery Company Superfund Site, Environmental Progress & Sustainable Energy, 14(2), 75-79.

Nandalal K., Simonovic D.W., Slobodan P., 2002, State-of-the-art Report on Systems Analysis Methods for Resolution of Conflicts in Water Resources Management, Technical Documents in Hydrology, 13(1), ix–x.

Raposo J.R., Molinero J., Dafonte J., 2012, Parameterization and Quantification of Recharge in Crystalline Fractured Bedrocks in Galicia-costa (NW Spain), Hydrology & Earth System Sciences Discussions, 16(6), 1667-1683.

Samper J., Pisani B., Marques J.E., 2015, Hydrological Models of Interflow in Three Iberian Mountain Basins, Environmental Earth Sciences, 73(6), 2645-2656.

Sanford S.E., Creed I.F., Tague C.L., Beall F.D., Buttle J.M., 2007, Scale‐dependence of Natural Variability of Flow Regimes in a Forested Landscape, AGU Fall Meeting, 43, 1461.

Shela O.N., 2000, Management of Shared River Basins: The Case of the Zambezi River, Water Policy, 2(1), 65-81.

Xian S.D., 2010, A New Fuzzy Comprehensive Evaluation Model Based on the Support Vector Machine, Fuzzy Information & Engineering, 2(1), 75-86.