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STUDY ON THE INFLUENCE OF MULTI-SOURCE RECHARGE ON GROUNDWATER ENVIRONMENT

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Abstract

Groundwater recharge is an effective method to solve the groundwater overexploitation. In this study, the method of numerical simulation is used to discuss the environmental change of groundwater in the process of multi-source recharge. The results of multiple water sources including local regenerated water source, wetland water source and South-to-North water source show that the cumulative loss of groundwater resources in Mihuaishun area in 2007 ~ 2016 reaches -1.784 × 10^9 m^3. The influence of different water sources on the local groundwater environment is different. Nitrate nitrogen concentration of regenerated water source and wetland water source is higher than that of groundwater, and artificial recharge increases the concentration of groundwater in the receiving water area. The nitrate concentration in the water source of South-to-North Water Division is relatively low, which plays a diluting role in the process of groundwater recharge. In addition, the artificial recharge of multiple water sources is also related to local hydrology geological conditions. The influence of multi-source recharge on groundwater quantity and water quality is analyzed comprehensively in this study.

Key words: artificial recharge, groundwater environment, multiple water sources, numerical simulation

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1. Introduction

The essence of artificial recharge of groundwater (also called groundwater recharge) is to artificially inject surface water into underground aquifers by means of some engineering measures to increase underground water (Bouwer, 2002; Elmansour and Elseed, 2018; Greggio et al., 2018; Prabhu and Sivakumar, 2018; Scanlon et al., 2006). Groundwater recharge can achieve various purposes: enriching groundwater resource, regulating surface water, preventing and controlling subsidence, improving groundwater quality, adjusting water temperature to store energy underground, desalting saline groundwater, as well as creating hydraulic barriers to prevent the intrusion of seawater or saline groundwater (Asano and Cotruvo, 2004). For artificial recharge of the aquifer, various sources can be used, which may include rainwater, surface leakage, recovered water, desalinated seawater, but in the knowledge of hydrological details of the aquifer and the quality of the reclaimed water (Marinov et al., 2017; Vandenbohede and Houtte, 2012).

The long-term exploitation has caused the groundwater level in Beijing to fall from 12 m to 24 m at an annual rate of 0.5~1m, forming a huge groundwater funnel (Tian et al., 2011). The falling is particularly rapid in major groundwater sources like Miyun, Huairou and Shunyi. Due to an intensive exploitation of local groundwater, especially in recent years, the groundwater level decreased from 12 m to 45 m, this resulting in a groundwater funnel. Before 2015, reclaimed water recharge is one of the main forms of groundwater recharge in Beijing. However,

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it has been confirmed that reclaimed water recharge may contaminate groundwater (Petruzzelli, 1993). For example, some residuals of trace organic compounds (TrOCs) can be detected in conventional wastewater treatment (Buxton and Kolpin, 2005). Although many of these trace organic compounds are effectively removed by wastewater treatment techniques, some polar and non-biodegradable compound components are still detected in the reclaimed water (Kinney et al., 2006). In addition, in terms of design and engineering, recent studies on reclaimed water have demonstrated a variety of health problems, whose studies are closely related to optimization design (Eusuff and Lasey, 2004), hydrology geochemistry (Goren et al., 2011), denitrifying conditions (Schmidt et al., 2011), saturated and unsaturated and redox conditions (Massmann et al., 2006), contamination factors (Maeng et al., 2011), residence time and blockage (Hoffmann and Gunkel, 2011).
Therefore, it is urgent to assess the water safety risk of groundwater recharge with reclaimed water (Moeck et al., 2017). In general, tracers are also used to study residence time and collect relevant information (Li et al., 2016).

The South–North Water Transfer Project is a strategic project of China. There are three transfer lines of the project, with a total length of 1,230km. The east line starts at Jiangdu Hydro-Junction, Yangzhou, Jiangsu Province (Li et al., 2011), the mid-line, starting from the Danjiangkou Reservoir in the middle and upper reaches of the Hanjiang River, supplies water to Henan, Hebei, Beijing and Tianjin (Wei et al., 2010). After the South-to-North Water Transfer Project diverts water to Beijing, some of the water is used to replenish the Mihuaishun groundwater reservoir and improve the local groundwater environment (Liu, 2003).

This paper explores the variation in local groundwater environment caused by groundwater recharge from multiple water sources, including the South-to-North Water Transfer Project, local reclaimed water source and wetland water source. The results of simulation and prediction can provide theoretical and practical support for underground water recharge from several sources.

2. Material and methods

2.1. Description of the research area

Our research targets the 1,265.8km^2 alluvial fan of the Chaobai River, which covers parts of Miyun, Huairou and Shuny. The underground reservoir in this region was also considered. The study area is surrounded by mountains on the northeast, north and northwest, and crisscrossed by streams in the south. The Chaobai River (Fig. 1) is the largest river in this area. Based on the richness of groundwater, the study area was divided into five regions, where the water output is respectively >5,000, 2,000, 5,000, 1,000~2,000 and <1,000m^3/d for each 3m-drop of single well groundwater level.

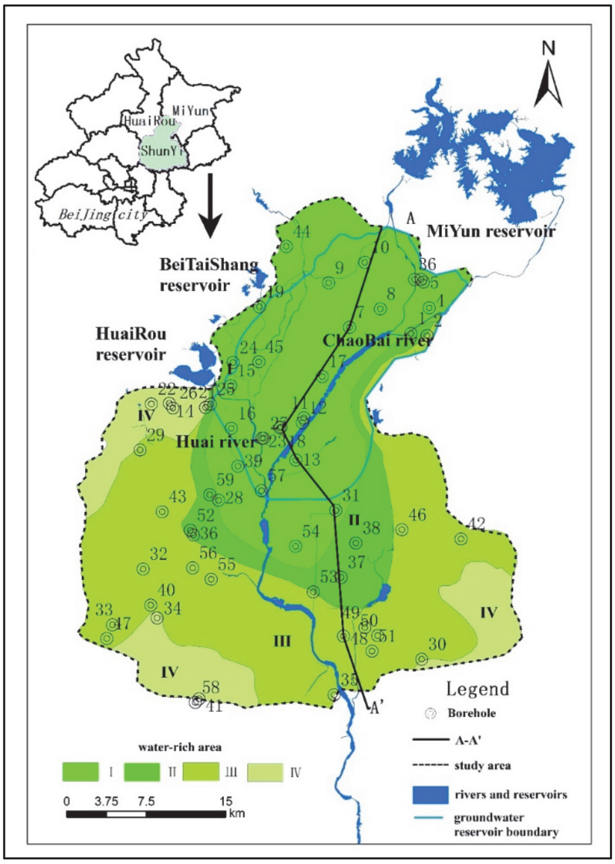

Fig. 1. Scope of the research area

2.2. Hydrogeological condition

The study area belongs to a warm temperate, semi-humid, continental monsoon climate, and has four distinct seasons. The average perennial precipitation stands at 598.34mm. The local water system is called the Chaobai River System, including main streams like the Chaohe River, the Baihe River, the Chaobai River and the Huaihe River. Previously, geological data have been collected from 43 boreholes (Fig. 1).

The data analysis shows that the aquifer medium in the study area mainly consists of sands, pebbles and gravels. From north to south, the particle size gradually decreases, the rock layer becomes thicker, and the single rock layer of the aquifer is replaced with multiple layers (Fig. 2).

2.3. Multiple water sources and groundwater environment

(1) The South-to-North Water Transfer Project

Starting from 2015, the South-to-North Water Transfer Project supplied a total of 44.13 million m^3 of water to the Chaobai River. Excluding the surface evaporation, about 43.63 million m^3 of water permeated to the aquifer. The water quality survey shows the supplied water is rich in ions of bicarbonates, sulfates, calcium and magnesium.

(2) Reclaimed water

The reclaimed water comes from three sources, which respectively lies in Miyun, Huairou and Shunyi. As shown in Table 1, the water from all three sources was on the decline year by year. The reclaimed water testing indicates that the water from all three sources contains lots of ions of bicarbonates, calcium and sodium.

(4) Groundwater

The groundwater in the study area is severely overexploited, forming a huge storage space. According to statistics, since 1999, the groundwater level has fallen from 12m to 45m, and the accumulated loss of groundwater resources has reached 2.1 billion m^3.

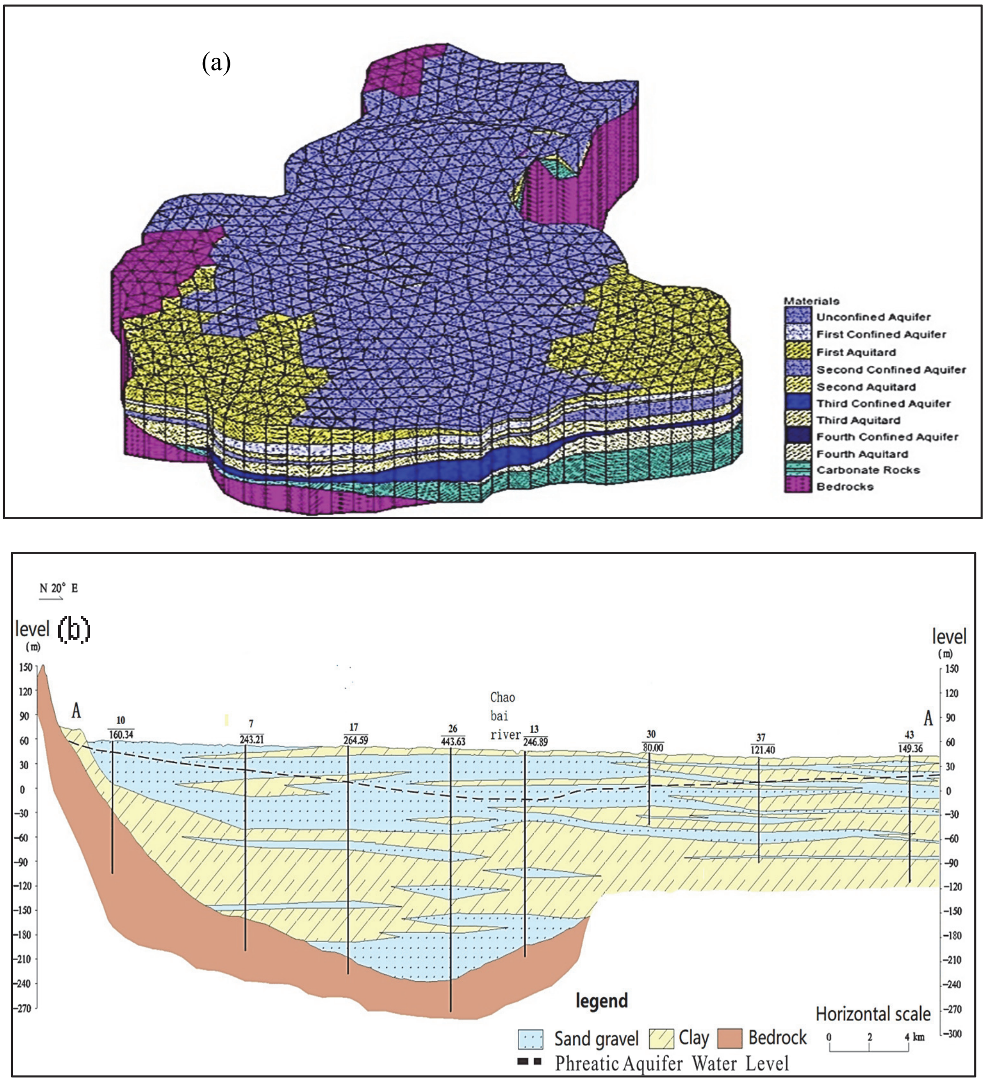

Fig. 2. The hydrogelogical profile of the study area

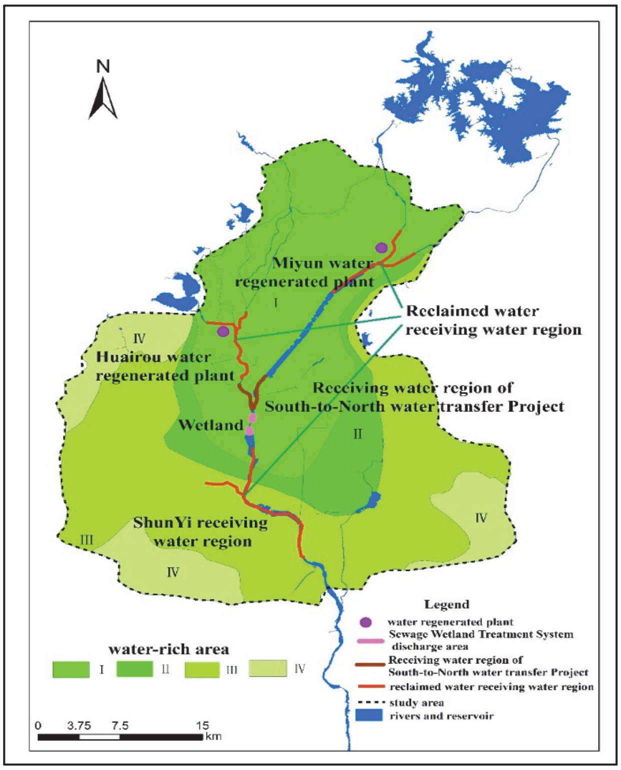

Fig. 3. Locations of the multiple water sources

Table 1. Infiltration of **r**eclaimed water in the Chaobai River from 2007 to 2016

Type	*Cumulative Emission Capacity (million m^3)*	*Cumulative Infiltration Capacity (million m^3)*
Miyun reclaimed water	92	76
Huairou reclaimed water	171	161
Shunyi reclaimed water	179	165
Total	432	402

In order to study the environmental change of groundwater in the process of multi-source recharge., we used the piper three-line diagram of multiple water sources and groundwater to analyze the water quality (Fig. 4). According to the data of water quality test since August 2015, the water quality of the South-to-North Water Diversion Project belongs to bicarbonate -sulfate-calcium-magnesium type water. The pH value of each monitoring section of surface water along the water diversion line is between 6.7 ~ 9.0. The water quality of each reclaimed water belongs to bicarbonate-calcium-sodium type water. Among them, Miyun reclaimed water discharge decreases year by year.

The water quality of wetland water belongs to bicarbonate-calcium-sodium type water. The groundwater quality belongs to bicarbonate-sulfate-calcium-magnesium type water. The cations in the water source of South-to-North Water Division Project, wetland water source and groundwater are mainly Ca^{2+} and Mg^{2+}, while those in Huairou, Shunyi and Miyun reclaimed water sources are mainly Na^+ and K^+, and the anions in each water source are mainly HCO_3^-.

2.4 Mathematical model

(1) Software

In light of the research purpose and the actual hydrogeological conditions, the software FEFLOW was selected to set up a numerical model of groundwater flow. The mathematical formula of the software can be found in the relevant manual. The software provides standard data input interfaces, allowing the user to create finite-element grids using the existing polygons in the GIS space. The user is also enabled to add specific boundary constraints to avoid convergence to unrealistic numerical solutions.

(2) Flow model

Model generalization

The stratum of the study area was divided into seven layers with the bottom at the depth of 250m. The division was carried out considering the following factors: the hydrogeological conditions, groundwater exploitation and utilization, aquifer development and permeability, hydraulic features of groundwater, hydrogeochemical features, and drilling data across the area (Fig. 5).

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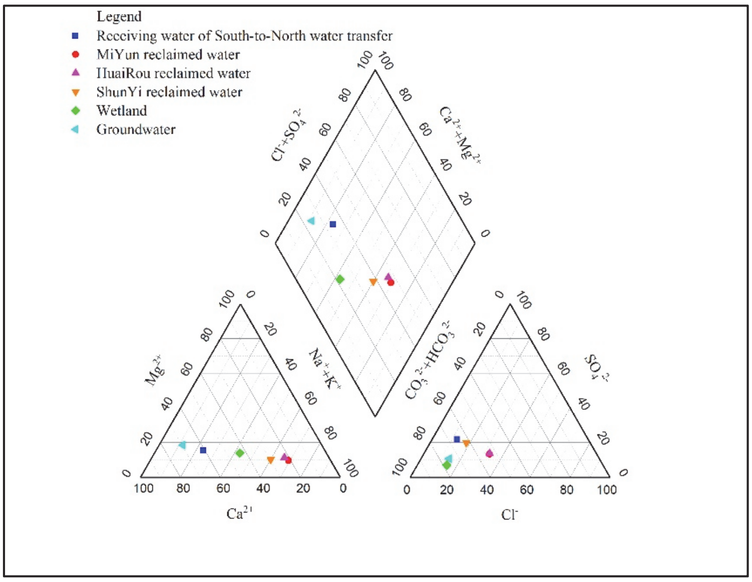
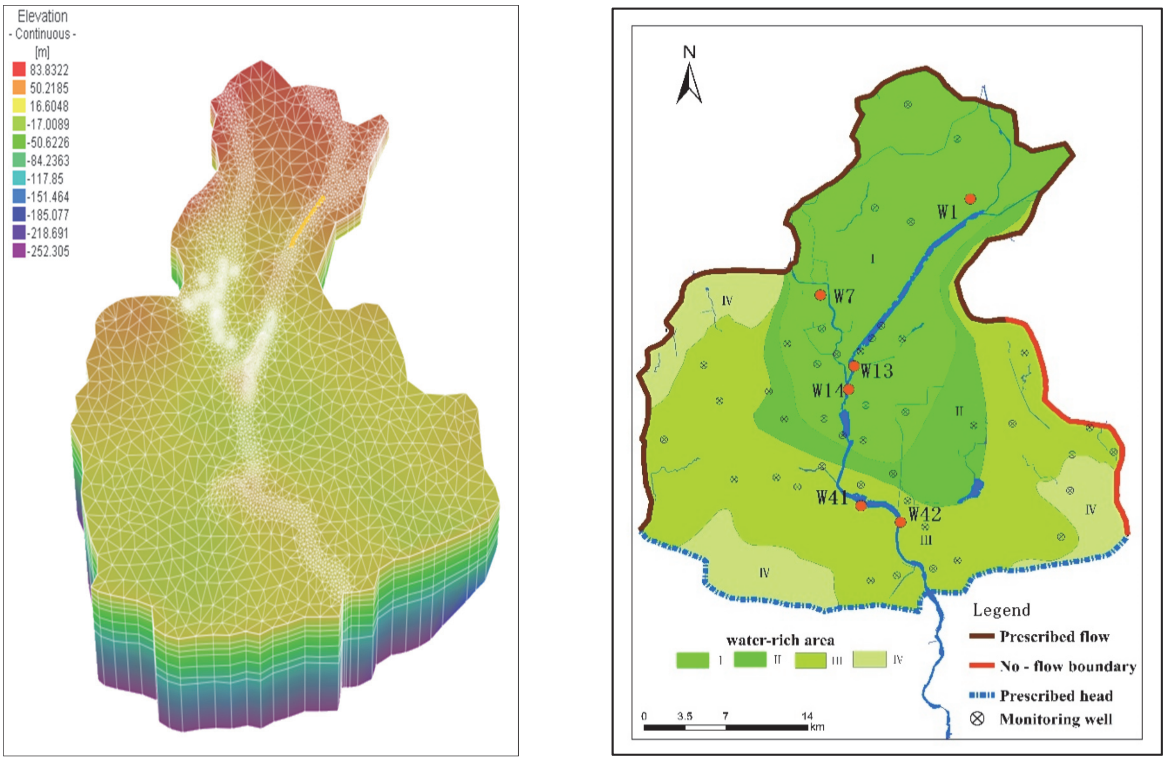


Fig. 4. Piper three-line diagram of the water sources and the groundwater



(a) (b)

Fig. 5. Geological generalization model (a) and boundary conditions (b)

The simulation area was meshed by the FEFLOW into 59,472 triangular units and 34,712 nodes. The grids were denser near main production wells and rivers (Fig. 5(a)). A total of 48 wells were drilled in the study area to monitor the water quality (Fig. 5(b)).

Initial and Boundary Conditions

The groundwater level in 2007 was taken as the initial water level of our model (Fig. 8(a) (b)). In the study area, the northern and western regions mainly receive the lateral runoff in front of the mountains, and were simulated with the second type inflow boundary; the junction between Shunyi and Pinggu was simulated with the second type zero-flow boundary, because the hydraulic connection of the Quaternary groundwater between the two places is cut off by the mountains; the southwest and southeast borders of the study area were simulated with the first type water head boundary, due to the small variation in local groundwater (Fig. 5(b)). The northern and western regions of the investigated area are recharged through lateral spills relative to the mountainside, considered the second entry limit.

The junction between Shunyi and Pinggu is represented by the mountain blocking the hydraulic connection of the groundwater. As the groundwater level varies slightly within this southwest and southeast boundary of the investigated area, the southern limit is considered a first-class limit (Fig. 5 (b)).

Parameters of Flow Model and source/sink term

The study area was partitioned into 42 subareas (Fig. 6) according to hydrogeological conditions. Drawing on borehole data, the hydraulic conductivity (K) was set to 6.5~106.5m/day, and the water supply (μ) to 0.01~0.24. The recharge, runoff and discharge data were extracted from the China Water Resources Statistical Yearbook. On this basis, the water quantities of source/sink terms were computed, with 2007 as the starting year. The computed results are recorded in Table 2.

In Table 2, the rainfall infiltration amount can be calculated by Eq. (1):

$$Q_j = a \times F \times X \tag{1}$$

where: Q_j is rainfall infiltration amount (m^3/a); α is annual rainfall infiltration coefficient; F is calculated area (m^2); and X is annual rainfall amount (m/a).

The agricultural irrigation regression can be calculated by Eq. (2):

$$Q = Q_q \times \beta \tag{2}$$

Q is agricultural irrigation regression, (m^3/a); Q_g is agricultural production, (m^3 / a); and β is irrigation regression coefficient.

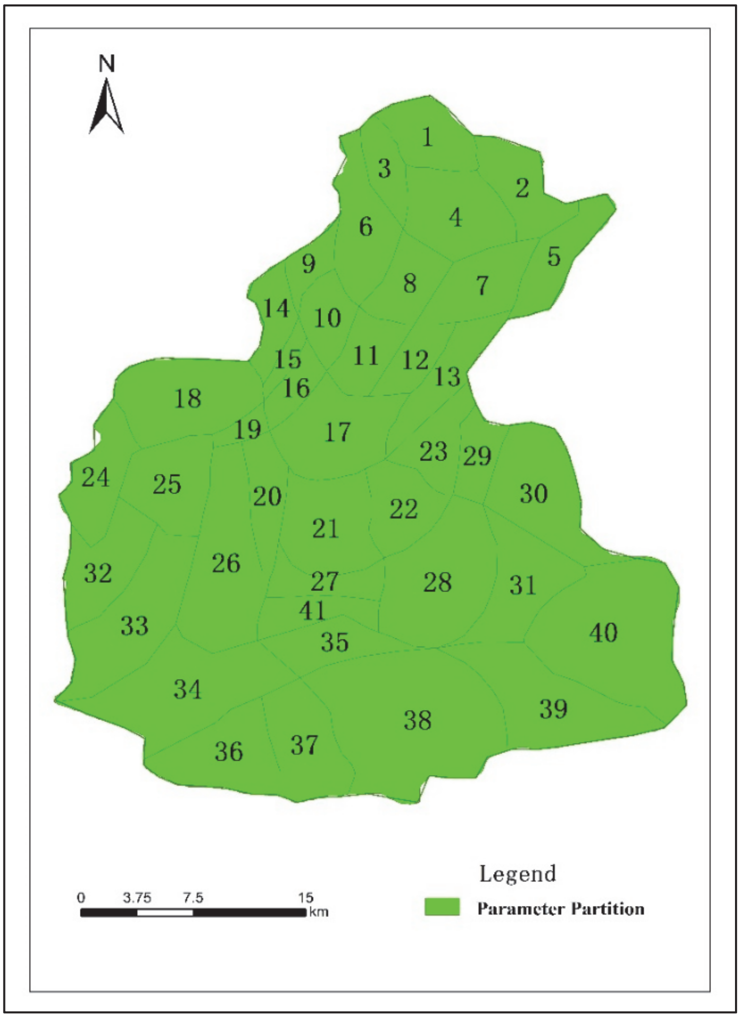


Fig. 6. Parameter partition

Table 2. Water quantities of source/sink terms

Recharge Condition	***Volume (×10^6m^3)***	***Discharge Condition***	***Volume (×10^6m^3)***
Precipitation Infiltration	2159	Evaporation	Negligible
Agricultural Irrigation Infiltration	330	Exploitation	5375
River Leakage	402	Total	5375
Total	2891		

Model calibration and validation

Model calibration aims to determine the hydrogeological conditions of the study area. For this purpose, repeated adjustments were performed on the hydrogeological parameters, individual adjustable recharge items, and hydrogeological structure, and data fitting was conducted over groundwater flow field lines, typical groundwater levels, and measured water qualities. The calibration uses the real-time data monitored by the 48 wells. The model was calibrated from January 2007 to December 2014, and verified from January 2015 to December 2016. The main calibration parameters are the permeability coefficient (K) and the water supply (μ). The time step was set to 30 days. Table 3 presents the calibration results on the water flow model parameters. As shown in Fig. 7, the simulated data agree well with the measured data.

(3) Solute transport model

The solute transport model is established on the basis of the water flow model, and the simulation period is consistent with the water flow model. According to the actual data, nitrate nitrogen is selected as the simulation factor in the solute transport model of the research area, mainly because the nitrate nitrogen concentration in the reclaimed water is higher, and the nitrate nitrogen concentration in the surrounding groundwater is obviously higher due to the infiltration of the reclaimed water.

In the solute transport model, porosity (n), diffusivity (α_L, α_T) and degradation rate parameters (*k*) are selected as model parameters. The adsorption parameters are not taken into account in this model because the adsorption of nitrate nitrogen in aqueous medium is small. Based on the monitoring data, the range of n is set as 0.24 to 0.01, the range ofα_L is set as 0.5 to 8.2 m, the range of α_T is set as 1.0 to 30.5 m, and the range of *k* as $1e^{-10}$ to $1.8e^{-9}s^{-1}$. The concentration of nitrate nitrogen ions in rainfall is relatively low and negligible. In addition, the effect of phreatic water evaporation on nitrate nitrogen concentration in the research area is negligible. The average concentration of nitrate nitrogen ions is shown in Table 4.

Model Calibration and Validation

The solute transport model uses 48 wells in the calibration process. The calibration phase of the model is from January 2007 to December 2014. The parameters of the calibrated model include porosity (n), diffusivity (α_L, α_T) and degradation rate parameters (*k*), with a duration of 30 days. Table 5 shows the calibration results of solute transport model parameters.

Table 3. Calibrated parameters of phreatic aquifer (the bracketed figures are the pre-calibration values.)

Partition Number	*K(m/d)*	*μ*	*Partition Number*	*K(m/d)*	*μ*
1	5.2(5.0)	0.080 (0.010)	22	62.6 (60.0)	0.190 (0.180)
2	105.0 (106.5)	0.250 (0.250)	23	38.0 (40.0)	0.130(0.150)
3	104.3(100.0)	0.240(0.250)	24	28.0 (30.0)	0.120(0.100)
4	102.0(100.0)	0.240(0.250)	25	20.0 (25.0)	0.100(0.100)
5	73.0(80.0)	0.240(0.240)	26	15.2 (20.0)	0.130(0.100)
6	91.3(90.0)	0.230(0.240)	27	20.5(20.0)	0.140 (0.120)
7	88.2 (90.0)	0.220(0.250)	28	13.0(15.0)	0.140(0.120)
8	88.5 (85.0)	0.220(0.250)	29	30.6 (20.0)	0.160(0.120)
9	59.6 (70.0)	0.210(0.200)	30	14.5 (20.0)	0.080(0.080)
10	75.5 (75.0)	0.210(0.200)	31	12.6 (15.0)	0.060(0.080)
11	73.3 (70.0)	0.210(0.200)	32	12.3 (12.0)	0.060(0.080)
12	76.5 (70.0)	0.210(0.200)	33	8.5 (10.0)	0.050(0.050)
13	58.2 (60.0)	0.200(0.200)	34	8.9 (10.0)	0.013(0.010)
14	51.5 (60.0)	0.200(0.200)	35	11.0(10.0)	0.016(0.010)
15	51.2 (50.0)	0.180(0.150)	36	7.6 (10.0)	0.010(0.015)
16	65.5 (60.0)	0.190(0.150)	37	9.5(10.0)	0.010(0.015)
17	60.5(60.0)	0.150(0.150)	38	20.5 (15.0)	0.030(0.040)
18	38.5 (50.0)	0.130(0.150)	39	10.3 (8.0)	0.010(0.010)
19	52.2 (50.0)	0.110(0.150)	40	5.0(5.0)	0.010(0.015)
20	62.6 (55.0)	0.200(0.180)	41	5.0(5.0)	0.040(0.030)
21	62.8 (55.0)	0.200(0.180)	42	61 (60.0)	0.150(0.150)

Table 4. Average concentration of nitrate nitrogen ions in the water sources

Each Source	*Average Concentration (mg/L)*
receiving water of SNWDP	1.12
Miyun reclaimed water	34.5
Huairou reclaimed water	15.4
Shunyi reclaimed water	18.5
wetland effluent	7.7

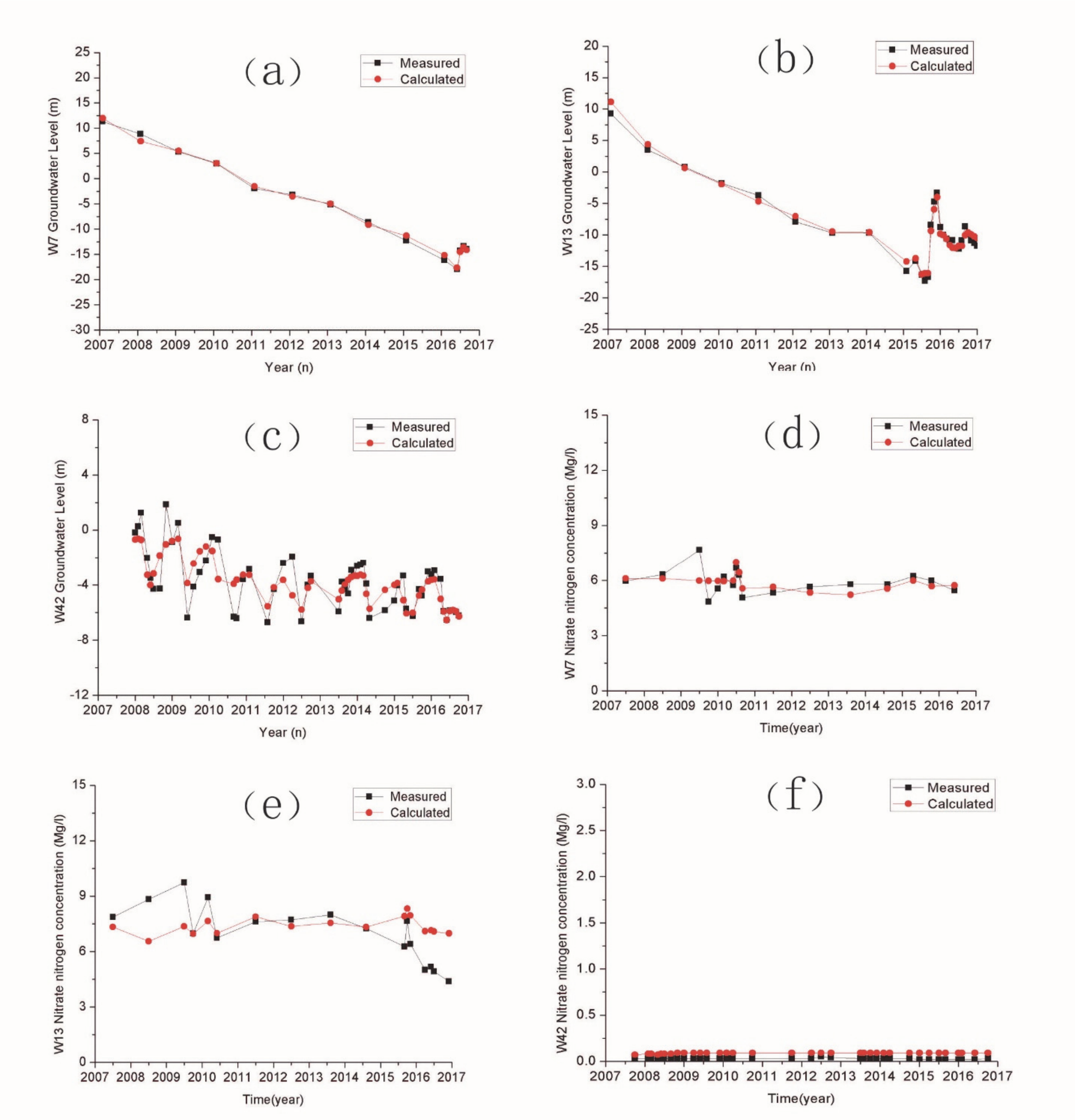


Fig. 7. Comparison of measured and simulated values of groundwater level and nitrate nitrogen ion concentration in a typical monitoring well near the river (Fig. 5 (b))

The validation period of the model is from January 1, 2014 to December 30, 2016. As shown in Fig. 7, the observed and simulated groundwater levels at the end of 2016 are compared via scatter plots. It can be seen that the degree of matching of the observed value and the simulated value is higher. Therefore, the coupling model can reflect the groundwater flow and solute transport conditions in Mihuaishun area.

2.5 Model prediction

Prediction scheme

The forecast period is 2017-2026. The annual infiltration amount of the South-to-North Water Diversion Project is 1.2 billion m^3. The annual rainfall during the forecast period is calculated according to the annual rainfall of 567mm. The rest conditions remain unchanged.

3. Results and discussion

3.1 Prediction results and analysis of flow models

Fig. 8 (e) and (f) respectively show the groundwater level isolines at the end of December 2016 and after ten years of continuous water transfer (the end of 2026). It can be seen that the regional groundwater resource shifts from negative equilibrium to positive equilibrium.

Table 5. Calibration Table for Parameters of Phreatic Aquifer (where the value in "()" is the initial value of parameters before calibration)

Partition Number	***n***	***αL*(m)**	***αT*(m)**	***k* (s-1)**
1	0.080 (0.010)	2.1 (5.0)	10.2 (15.0)	1.0e-10 (1.0e-11)
2	0.250 (0.250)	8.2 (10.0)	30.5(30.0)	1.0e-10 (1.0e-11)
3	0.240(0.250)	8.2 (10.0)	30.5(30.0)	1.0e-10(1.0e-11)
4	0.240(0.250)	8.2 (10.0)	30.5(30.0)	1.0e-10(1.0e-11)
5	0.240(0.240)	7.4 (8.0)	29.5 (25.0)	1.0e-10(1.0e-11)
6	0.230(0.240)	7.4 (8.0)	29.5 (25.0)	1.0e-10(1.0e-11)
7	0.220(0.250)	7.4 (8.0)	29.5 (25.0)	5e-10(5.0e-11)
8	0.220(0.250)	7.4 (8.0)	29.5 (25.0)	5.0e-10(5.0e-11)
9	0.210(0.200)	7.4 (8.0)	25.5(25.0)	5.0e-10(5.0e-11)
10	0.210(0.200)	6.1(8.0)	25.5(25.0)	5.0e-10(5.0e-11)
11	0.210(0.200)	6.1(8.0)	25.5(25.0)	5.0e-10(5.0e-11)
12	0.210(0.200)	6.1(8.0)	25.5(25.0)	5.0e-10(5.0e-11)
13	0.200(0.200)	5.5(5.0)	24.0(20.0)	8.0e-10(5.0e-11)
14	0.200(0.200)	5.5(5.0)	24.0(20.0)	8.0e-10(5.0e-11)
15	0.180(0.150)	5.5(5.0)	24.0(20.0)	8.0e-10(5.0e-11)
16	0.190(0.150)	5.5(5.0)	24.0(20.0)	8.0e-10(5.0e-11)
17	0.150(0.150)	5.5(5.0)	24.0(20.0)	1.2e-9(1.0e-10)
18	0.130(0.150)	2.2(2.0)	17.5 (20.0)	1.2e-9(1.0e-10)
19	0.110(0.150)	2.2(2.0)	18.5 (20.0)	1.2e-9(1.0e-10)
20	0.200(0.180)	4.2(4.0)	20.5(20.0)	1.2e-9(1.0e-10)
21	0.200(0.180)	4.5(4.0)	20.5 (20.0)	1.2e-9(1.0e-10)
22	0.190 (0.180)	4.7(4.0)	20.5 (20.0)	1.2e-9(1.0e-10)
23	0.130(0.150)	3.5(3.0)	18.5 (20.0)	1.2e-9(1.0e-10)
24	0.120(0.100)	2.5(2.5)	15.5 (18.0)	1.2e-9(1.0e-10)
25	0.100(0.100)	1.6 (2.5)	8.5 (15.0)	1.2e-9(1.0e-10)
26	0.130(0.100)	2.0(2.5)	15.5(15.0)	1.2e-9(1.0e-10)
27	0.140 (0.120)	2.0(2.5)	17.5(15.0)	1.2e-9(1.5 e-10)
28	0.140(0.120)	2.0(2.5)	15.5(15.0)	1.2e-9(1.5 e-10)
29	0.160(0.120)	3.5(3.0)	15.5(15.0)	1.2e-9(1.5 e-10)
30	0.080(0.080)	1.9 (2.0)	10.5(10.0)	1.9e-9(1.0e-9)
31	0.060(0.080)	1.5(2.0)	5.5(10.0)	1.6e-9(1.0e-9)
32	0.060(0.080)	1.5(2.0)	5.5(5.0)	1.6e-9(1.0e-9)
33	0.050(0.050)	1.2(2.0)	3.5(5.0)	1.3e-9(1.0e-9)
34	0.013(0.010)	0.5(1.0)	1.5 (5.0)	1.3e-9(1.0e-9)
35	0.016(0.010)	0.8(1.0)	1.5 (5.0)	1.8e-9(1.0e-9)
36	0.010(0.015)	0.5(1.0)	1.5 (5.0)	1.5e-9(1.0e-9)
37	0.010(0.015)	0.5(1.0)	1.5 (5.0)	1.1e-9(1.0e-9)
38	0.030(0.040)	1.0(1.0)	3.5 (5.0)	1.4e-9(1.0e-9)
39	0.010(0.010)	0.5(1.0)	1.0 (5.0)	1.3e-9(1.0e-9)
40	0.010(0.015)	0.5(1.0)	1.0 (5.0)	1.0e-9(1.0e-9)
41	0.040(0.030)	1.5(1.5)	1.5 (5.0)	1.8e-9(1.0e-9)
42	0.150(0.150)	5.5(5.0)	25.0(20.0)	1.2e-9(1.0e-10)

The receiving areas of the South-to-North Water Transfer Project see a rapid increase in groundwater level. The increase rate gradually slows down with the elapse of time. Ten years later, the groundwater level in central funnel can rise by 15m. In the reclaimed water receiving area in Shunyi, the groundwater level rises significantly in the north and remains basically the same in the south, under the influence of the hydrogeological conditions in the north part.

3.2 Prediction results and analysis of the solute transport model

The results show that the influence of water recharge from different water sources on groundwater is different, which is related to the local hydrogeological conditions (Fig. 8 (e,f)). The decrease of nitrate nitrogen concentration in groundwater in the recharge area of South-to-North Water Diversion Project, Huairou reclaimed water plant and wetland area nearby mainly results from the lower nitrate nitrogen concentration of the water from the South-to-North Water Diversion Project area and the dilution of nitrate nitrogen ions in groundwater due to long-term recharge.

The nitrate nitrogen concentration in the reclaimed water of Miyun increases slowly and tends to stabile, and the diffusion rate of contaminant plumes along the river channel decreases. It is due to the increase of nitrate nitrogen ions in local groundwater caused by long- term recharge of reclaimed water. On the other hand, the water level in the funnel area of groundwater rises.

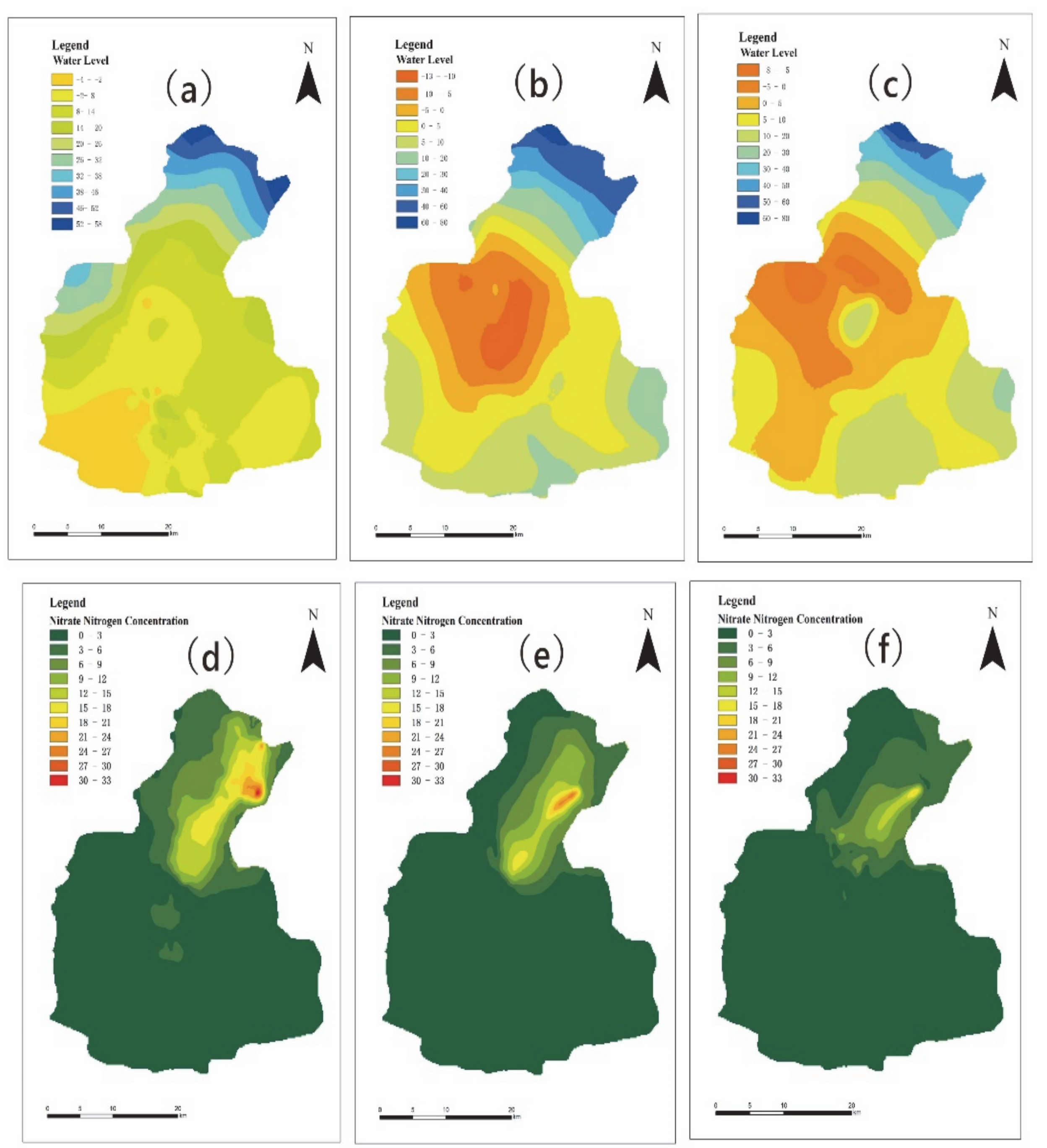


Fig. 8. Isograms of groundwater level and nitrate nitrogen ion concentration. (a)The water level of 50m aquifer in 2007 (b)The water level of 50m aquifer in 2016 (c)The water level of 50m aquifer in 2026 (d)The nitrate nitrogen ion concentration of 50m aquifer in 2007; (e)The nitrate nitrogen ion concentration of 50m aquifer in 2016; (f)The nitrate nitrogen ion concentration of 50m aquifer in 2026

Its difference from the water level near Miyun reclaimed water plant decreases, and the diffusion rate of contaminant plumes decreases due to the long-term recharge. The nitrate nitrogen ions in the south of Shunyi reclaimed water area is basically stable, which is due to the alternation of sandstone layer and clay layer, the relative reduction of aquifer, strong denitrification, and the low nitrate nitrogen concentration in groundwater.

4. Conclusions

In this study, a water flow and solute transport model of artificial recharge groundwater with multiple water sources is established. The model can be used to calculate the change trend of water level and water quality caused by such recharge in the research area. The study shows that multiple water sources contribute to groundwater recharge, raise groundwater level and increase groundwater reserves.

The accumulated loss of groundwater resources in Mihuaishun area reached -1.784 × 10^9 m^3 from 2007 to 2016. The predictions of the model show that after 10 years of water recharge from the water source of South-to-North Water Diversion Project to the aquifer at the rate of 1.2 billion m^3/a, the groundwater balance becomes positive from negative, and the water level in the central funnel area increases by 15m. The influence of multi-source recharge on groundwater environment should be considered at the same time.

The results of the solute transport model show that the nitrate nitrogen concentration of reclaimed water source and wetland water source is higher than that of South-to-North Water Diversion. Artificial recharge increases the concentration of nitrate and nitrogen ions in groundwater in the water-receiving area. Dilution is the main influence factor of water source of South-to-North Water Diversion on groundwater environment.

The aquifers in the south area has the alternation of sandstone layer and clay layer, the relative reduction of aquifer, strong denitrification, and the low nitrate nitrogen concentration in groundwater. To sum up, Multi-Water-Source Artificial Recharge of Groundwater has a great impact on groundwater environment. All the water sources contribute to the recharge of groundwater, raising the groundwater level, increasing the groundwater reserves and Changing the groundwater environment.

The results of this study can guide the reference of multi-source recharge on groundwater quantity and water quality under different hydrogeological conditions. It is suggested to increase the water supply of the South-to-North Water Diversion Project in order to conserve groundwater resources.

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