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THEMATIC ISSUE

Effects of groundwater level variations on the nitrate content of groundwater: a case study in Luoyang area, China

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Abstract Most researchers usually adopt laboratory experimental methods when studying the effects of water level variations on the concentrations of pollutants. In this study, the data from routine monitoring sites in the city of Luoyang, China, are collected and analyzed to verify the results of previous laboratory experiments and to examine whether variations in the water level affect the concentration of pollutants in different locations, particularly that of nitrates. Statistical studies conducted between 2007 and 2011 show a significant variation in the groundwater depth in the Luoyang area. This depth variation clearly affected the groundwater environment in the soil system. This study uses field data to investigate the effects of water table fluctuation on the nitrate content of groundwater. Hydrogeological information and land management data are collected from five monitoring points in Luoyang. The significance of and correlation between the environmental indicators of groundwater depth and soil–water systems are then analyzed using SPSS and Origin software. The results show that the redox potential (E_h) and nitrate nitrogen content are strongly correlated with groundwater depth. Significantly negative correlations were found between nitrate nitrogen and ammonium nitrogen concentration, between E_h and ammonium nitrogen concentration, and between pH and nitrate nitrogen concentration. These results indicate that water table fluctuation affects the soil–water physicochemical properties and further exerts a significant effect on nitrate movement across soil sola.

Keywords Groundwater level variation · Nitrate · Correlation · Movement

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Introduction

The sources of water pollution have recently increased and have become more diverse (Kampbell et al. 2003; Nolan and Stoner 2000; Jacobs 1985), thus exacerbating the underground water pollution problem. Nitrates are typical pollutants in underground water systems and have become the focus of international attention. Nitrates can be both point and non-point sources of pollution because they can originate from agrochemicals (Harter et al. 2002), wastewater irrigation (Reddy 1984), or the intensive feeding of domestic animals (Hallberg 1993). The nitrate content in underground water resources is currently increasing. Agriculture is the main source of nitrate nitrogen pollution in groundwater (Gonzalez-Herrera et al. 2014; Edet 2014; Huang et al. 2013; Klammler et al. 2013). Furthermore, nitrates are highly water soluble, have weak adsorption, and exhibit strong mobility. Nitrates readily leach through vertical migration via atmospheric precipitation or irrigation water. This leaching leads to catchment pollution via lateral recharge and eventually reaches the groundwater–soil medium. If the vadose zone is particularly thin, the pollution of groundwater is likely (Gonzalez-Herrera et al. 2014; Rao et al. 2013). The vertical recharge caused by

Fig. 1 Location map of study area

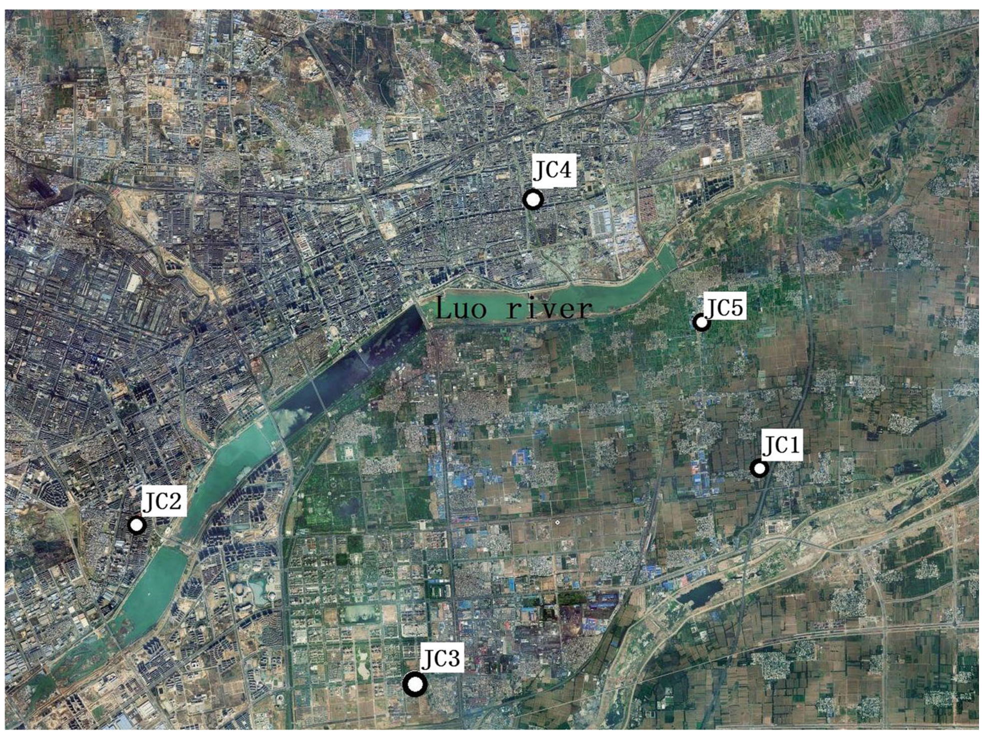


Fig. 2 Map showing the monitoring points in the survey area

atmospheric precipitation and the lateral recharge caused by rivers can both lead to variations in the groundwater level as well as those in soil–water indicators (Ashworth and Shaw 2006; Ashworth et al. 2008). In turn, these fluctuations significantly affect the migration and transformation of underground water pollutants. Hence, a

Fig. 3 Borehole diagrams of the five monitoring points

Soil thickness (m)	Histogram	Petrographic description
1.4		miscellaneous fill soil; plain fill soil; yellowish gray; sallow; composed mainly of construction waste; has loose structure and mixed soil types
2.2		loess-like silt; isabelline; sallow; close-grained; contains brick dust and carbon dust; has pinholes and wormholes; contains silty fine sand and silty clay lenses
2.2		loess-like silty clay; yellowish brown; taupe; dark chocolate-brown; plastic shape
1.8		loess-like silty clay; yellowish gray; sallow; hard plastic shape
2.6		loess-like silty clay; isabelline; sallow; hard plastic shape; has pinholes and wormholes; contains loess doll
3.6		loess-like silty clay; yellowish brown; clay bank; brownish red; plastic shape; contains loess doll and snail shelll
2.9		loess-like silty clay; yellowish gray; sallow; yellowish brown; brownish red; plastic shape; has pinholes and wormholes; contains loess dolll

(a) JC1

Soil thickness (m)	Histogram	Petrographic description
0.5		mool; taupe gray; slightly wet; incompact; well-grown plant roots; main components include silty clay, a small amount of gravel, and household refuse
4.9		loess-like silty clay; brownish yellow; clay bank; solid shape, contains pinholes, wormholes, and nuclear calciums
1.6		loess-like silt; brownish yellow; slightly wet to wet; slightly close-grained; contains pinholes and wormholes
6.5		medium sand; sallow; slightly wet; mineral composition is feldspar, feldspar, and a small amount of mica; homogeneous distribution
7.1		grit; sallow; French gray; skeleton component is quartzite; quartz sandstone; andesite; rhyolite; particle size is 3 cm to 8 cm, with a maximum of 25 cm; filling is mainly medium-coarse sand

(b) JC2

Fig. 3 continued

Soil thickness (m)	Histogram	Petrographic description
4.3		miscellaneous fill soil; black; charcoal gray; black brown; components include silty clay, brick bat, crock, lime, breeze, etc.; loose structure; pocket
2.3		loess-like silty clay; brownish yellow; solid shape; has pinholes and wormholes; contains loess doll with a diameter of 0.5 cm to 2.0 cm
2.7		loess-like silty clay; sepia; tawny; solid shape; has pinholes and wormholes; contains loess doll with a diameter of 0.5 cm to 2.0 cm
5.0		loess soil powder; yellow; pale yellow; yellowish gray; slightly wet to wet; medium dense to dense; has pinholes and wormholes; contains loess doll with a diameter of 1.0 cm to 8.0 cm
6.0		fine sand; yellowish gray; slightly wet; slightly dense to medium dense; components are mainly quartzite and feldspar

(c) JC3

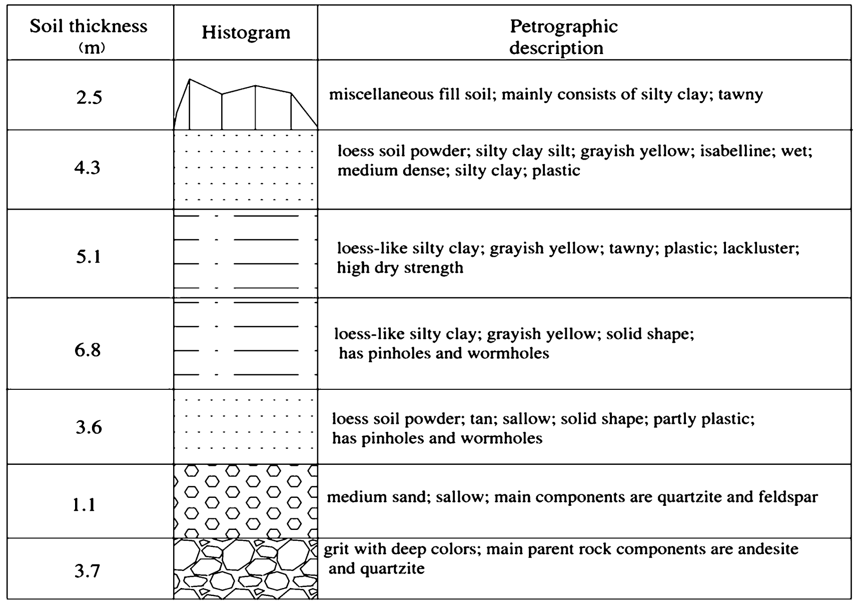
Soil thickness (m)	Histogram	Petrographic description
1.0		loess soil powder; tawny; isabelline; slightly wet to wet; slightly dense to medium dense; has pinholes and wormholes; locality has argillaceous particle composition
3.6		medium sand; yellowish gray; incompact to slightly dense; components are mainly quartzite and feldspar; partly contains gravel and argillaceous particles
3.7		grit with a diameter of 2 cm to 8 cm and content of 50% to 70%; isabelline; cyan; cinereous; components are mainly quartzite, andesite, and basalt
3.3		grit with a diameter of 2 cm to 12 cm and a content of 50% to 80%; filling is mainly medium-coarse sand and argillaceous rock

(d) JC4

systematic understanding of the variations in nitrate content caused by underground water table fluctuation is vital in environmental research.

In recent years, most studies on water table variations have focused on the light non-aqueous phase liquid (LNAPL)/dense non-aqueous phase liquid migration law in porous media, the saturation–capillary pressure hysteresis effect caused by water table fluctuation, and the numerical simulation of variations in the bottom line of unsaturated zones (Steffy et al. 1998; Kampbell et al. 2003). For instance, Tanner et al. (1999) determined that water table fluctuation in a constructed wetland system is conducive to total nitrogen (TN) and NH_4^+–N removal and that the removal efficiency is closely associated with vibration frequency. Indoor-soil column research by Rainwater et al. (1993) showed that water table fluctuation can accelerate diesel degradation in soil. Kamon et al. (2007) determined the transport properties of LNAPL in porous media and conducted LNAPL migration research on the effects of water table fluctuation. However, laboratory simulations can reflect natural processes to a certain extent but cannot demonstrate the complexities present in the actual field.

Fig. 3 continued



(e) JC5

Consideration of impact factors to ensure accuracy can be difficult. Moreover, the various degrees of error inherent in simulations increase the difficulty of translating the results into actual, precise laws. Therefore, specific reports on the effects of water table variations on the variation trend of nitrate content in actual underwater systems are rare.

Thus, this study uses a case study analysis and collects currently available materials to investigate the soil–water physicochemical properties as well as the variation trend of nitrate content under the effects of water table fluctuation in five monitoring points in the Luoyang area, China.

Site context

Physiographic conditions

The research area is located in Luoyang (112°20′ to 112°35′E, 34°35′ to 34°47′N) within Yuxi Luoyang Basin, the location shown in Fig. 1. This area is located north of Mang Mountain, south of Yique, west of Small Qinling Basin, and east of Yanshi Plain. The locality is in the transition area between the southern edge of a warm temperate zone and the northern edge of a subtropical

Table 1 Investigation of the areas surrounding the monitoring points

General situation in the study area		Surrounding conditions			
		Agriculture		Industry	
Identifier	Longitude and latitude	Pumping irrigation	Large-scale pesticide and fertilizer use	Major industry using groundwater	Discharge of sewage
JC1	112°32′13″ East 34°38′29″ North	√	√	√	×
JC2	112°24′12″ East 34°38′4″ North	×	×	×	×
JC3	112°28′26″ East 34°35′58″ North	√	√	√	√
JC4	112°29′16″ East 34°41′20″ North	×	×	×	√
JC5	112°31′12″ East 34°39′47″ North	√	√	×	×

The scope of the survey is centered at the monitoring wells and ranged 1 km around the research centers; "√" and "×" indicate the presence and absence of different wells that correspond to the locations, respectively transition zone. The annual average surface air temperature is approximately 15 °C, with a maximum temperature of 40.4 °C and a minimum temperature of 20.2 °C. The annual average precipitation is approximately 630 mm.

Hydrogeological conditions

Groundwater in the study area is mainly loose rock pore water, and the aquifer thickness is greater than 50 m. The

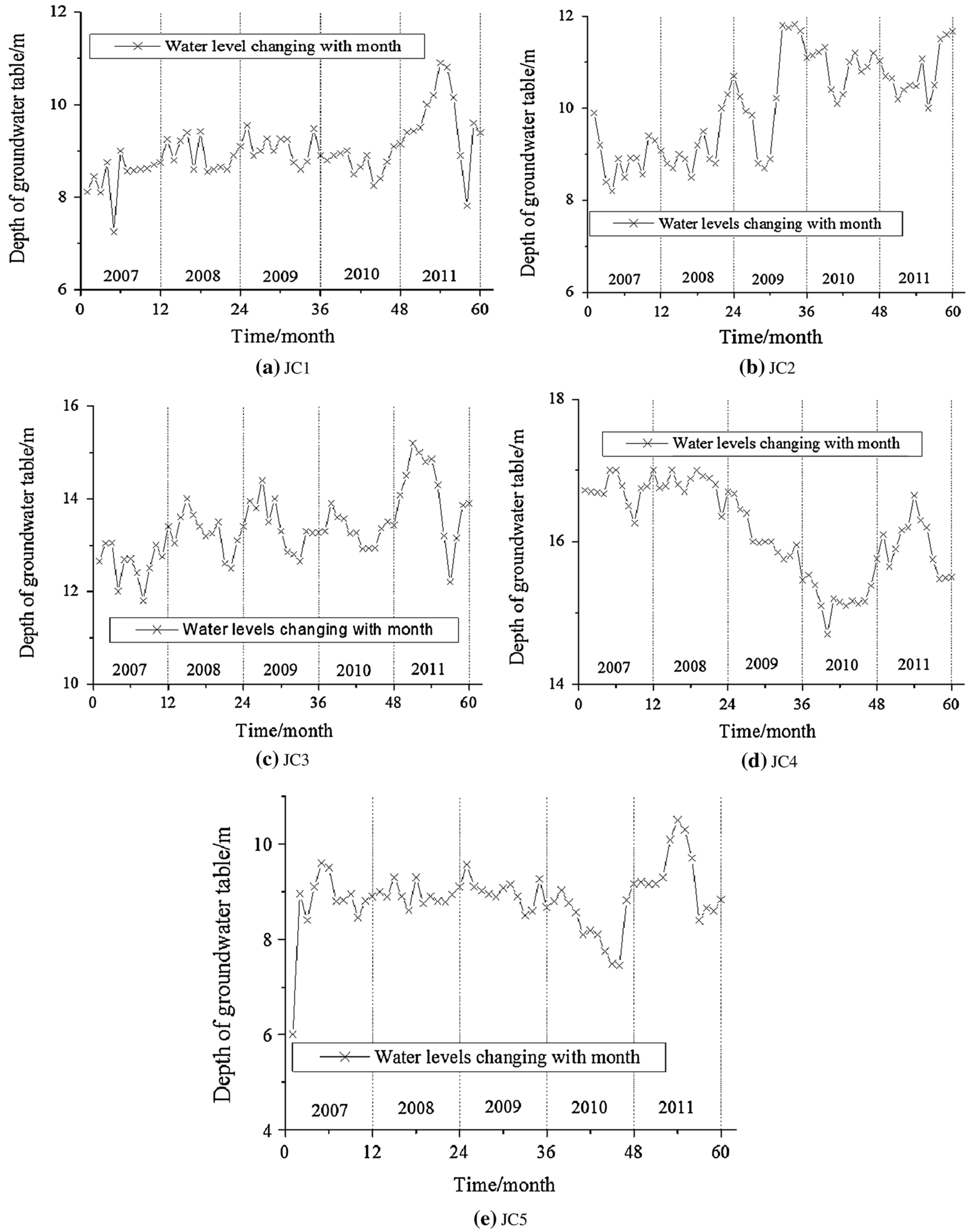


Fig. 4 Dynamic graph of water levels at the five monitoring points from 2007 to 2011

Table 2 Water level characteristics of the monitoring points

Identifier	JC1	JC2	JC3	JC4	JC5
Maximum groundwater depth (m)	10.9	11.83	14.39	17.09	9.6
Minimum groundwater depth (m)	7.14	8.25	11.76	15.04	5.87
Average groundwater depth (m)	8.96	10.01	13.34	16.14	8.89

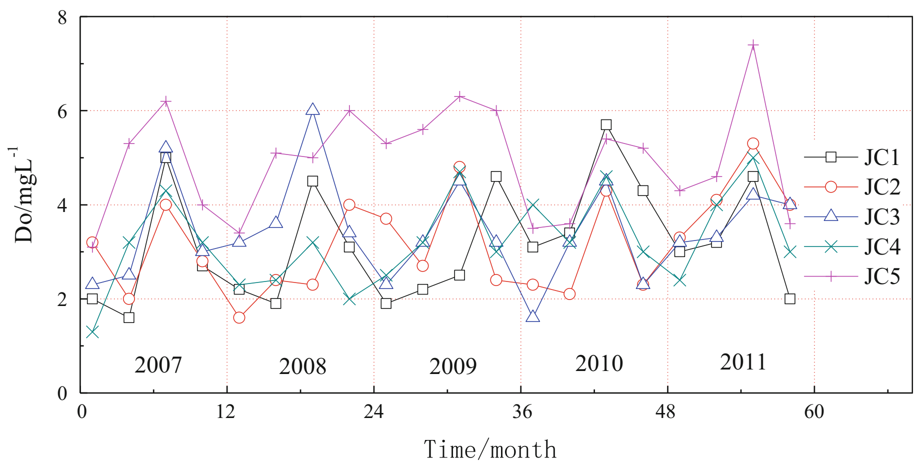


Fig. 5 Variations in the dissolved oxygen (DO) content in groundwater at the five monitoring points

Table 3 Characteristics of groundwater pH at each monitoring point

Identifier	JC1	JC2	JC3	JC4	JC5
Groundwater (m)	7.1–10.9	8.2–11.9	11.8–15.2	14.6–17.1	5.9–10.4
Maximum DO (mg L^{-1})	5.7	5.3	6	5	7.4
Minimum DO (mg L^{-1})	1.6	1.6	1.6	1.3	3.1
Maximum DO (mg L^{-1})	3.21	3.20	3.46	3.21	4.97

Table 4 Characteristics of groundwater pH at each monitoring point

Identifier	JC1	JC2	JC3	JC4	JC5
Depth of groundwater table (m)	7.1–10.9	8.2–11.9	11.8–15.2	14.6–17.1	5.9–10.4
Maximum pH	7.58	7.53	7.7	8.21	7.61
Minimum pH	7.06	6.98	6.9	7	7.09
Average pH	7.28	7.3	7.32	7.29	7.35

Table 5 Characteristics of groundwater redox potential (E_h) at each monitoring point

Identifier	JC1	JC2	JC3	JC4	JC5
Depth of groundwater table (m)	7.1–10.9	8.2–11.9	11.8–15.2	14.6–17.1	5.9–10.4
Maximum E_h(mV)	219	227	185	151	169
Minimum E_h (mV)	142	130	90	91	108
Average E_h (mV)	179	167	150	130	142

groundwater occurs mainly in the plain area of Luoyang and is stored in Cenozoic Quaternary sediments. Overall, the groundwater flows from west to east, and the aquifer permeability coefficient is between 20 and 50 m/d. Important recharge and water sources of the groundwater include rainfall and the Yiluo River. In the study area, the Tertiary unit includes abundant loose sediment, creating favorable conditions for groundwater recharge, runoff, and storage. Thus, shallow groundwater resources are highly abundant.

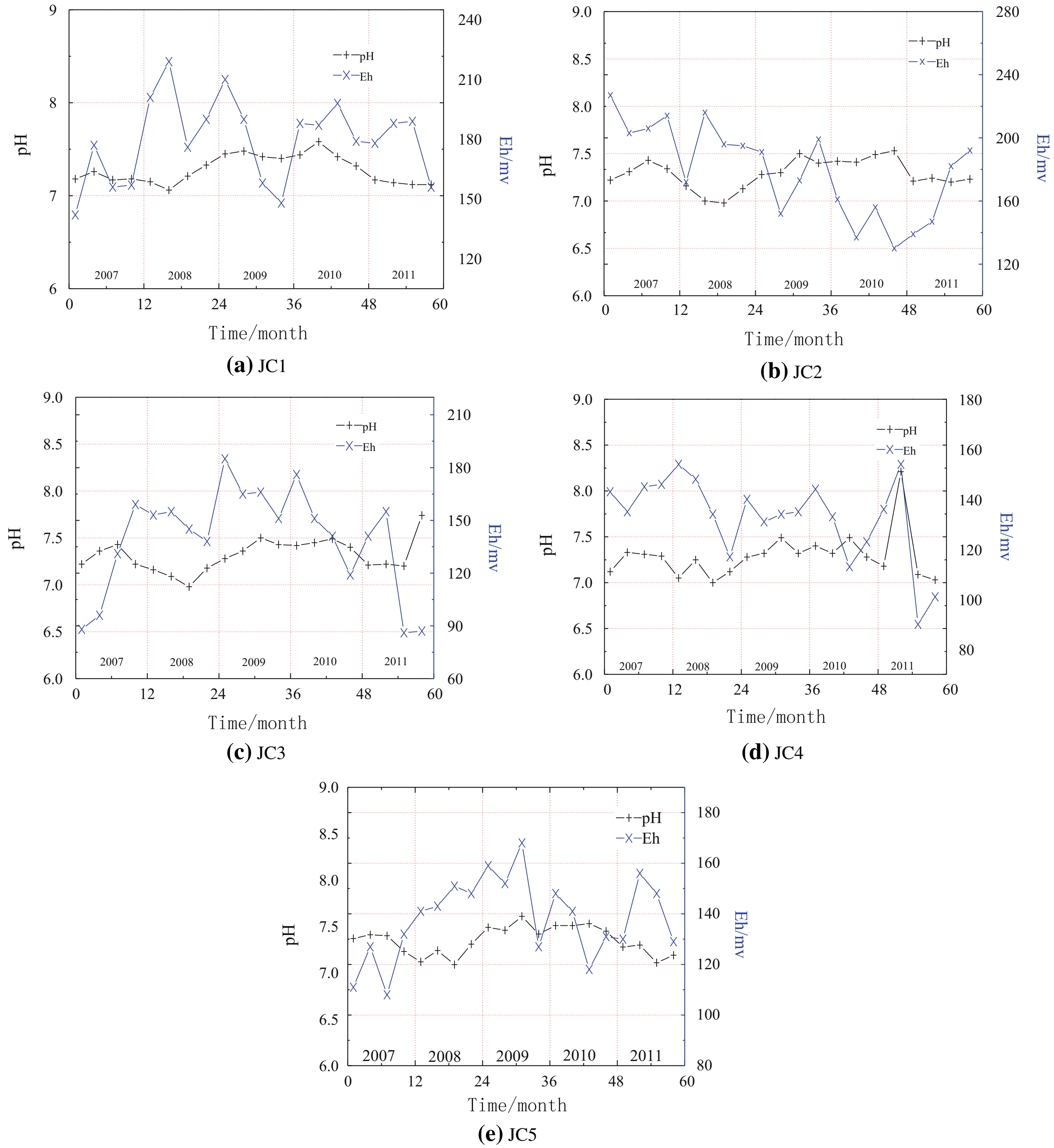


Fig. 6 Variations in groundwater pH and redox potential (E_h) at the various points from 2007 to 2011

Monitoring point information

Basic information

Figure 2 shows the five typical points selected for analysis of the effects of water table fluctuation on nitrate movement based on survey data. Of these, JC1, JC3, and JC5 are wells. JC1 and JC3 are both drinking wells and production wells, JC5 is a drinking well, and JC2 and JC4 are both hydrological observation holes. The depths of JC1, JC2, JC3, JC4, and JC5 monitoring points are 61, 83, 75, 85, and 70 m, respectively. All monitoring points are drilled in drinking water sources.

Geological information

The five monitoring points were selected from various areas. Figure 3 shows significant differences in stratum structures, which indicate large discrepancies in the permeability of the sola and considerable complexity in the soil environment. Groundwater indicators tested at these points between 2007 and 2011 were used to discuss the effects of water table fluctuation on nitrate content.

Human activities in the sites and surrounding areas

In recent years, varying degrees of nitrate nitrogen, ammonium nitrogen, and nitrite nitrogen have been detected and analyzed in the five selected areas. Because agricultural and industrial activities are the main sources of groundwater contamination (Gonzalez-Herrera et al. 2014; Huang et al. 2013; Klammler et al. 2013), we investigated such activities occurring within 1 km of each point. These agricultural and industrial activities include irrigation, chemical fertilizer use, sewage discharge (Wang et al. 2013), and massive use of groundwater. Because such activities can hasten nitrate seepage into the aquiclude across unsaturated zones, we selected them as survey indicators. The investigation results are shown in Table 1.

Methods of sampling and detection

The type of water sampling in which pumps were used was instantaneous. We allowed the water to flow for several minutes to discharge the original water in the pipe; thereafter, the water samples were stored in 200 ml glass containers. We then placed each sample in a portable sample storage box. The samples were sent to the laboratory soon after sampling was completed. Nitrates were detected using the water quality determination method through nitrate–nitrogen ultraviolet spectrophotometry. Ammonia was detected by nitrogen–Nessler's reagent spectrophotometry. Nitrite nitrogen was detected by the nitrogen (nitrite)-spectrophotometric method.

Methodology

In this study, preliminary work focused on the collection of information and data in terms of hydrogeology such as landforms, landscape, and geology and groundwater dynamic indicators such as water temperature, pH, dissolved oxygen (DO), redox potential (E_h), nitrate nitrogen concentration, and ammonium nitrogen concentration. Field data were collected during a five-year period beginning in January 2007. Water table variations consistent with the collected data were analyzed quarterly. In the experiments, water was collected by a Baylor tube, and the water table was monitored by a water level monitoring instrument. Wellhead coordinates and elevation were calculated by a Global Positioning System. Land use within 1 km of the monitoring points was surveyed according to underground water use, nitrogen fertilizer use, factory discharge, and animal husbandry. The survey forms were completed and the data were organized on the basis of local natural geography, geology, and hydrogeologic conditions. The results were then mapped and statistically analyzed by Microsoft Excel 2007, Origin 8.0, and SPSS 17.0.

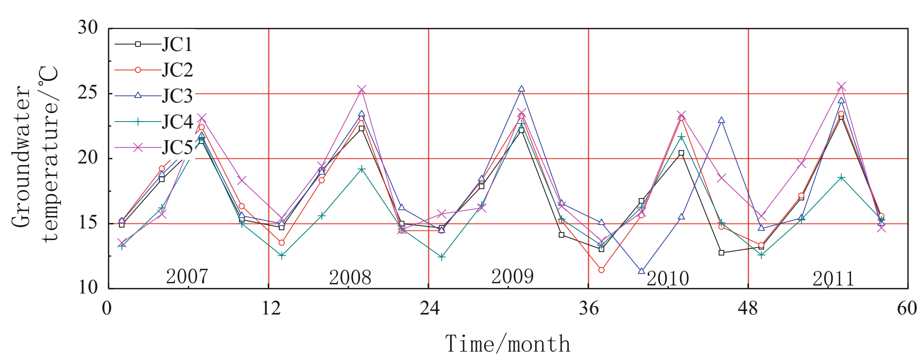


Fig. 7 Variations in groundwater temperature at each monitoring point from 2007 to 2011

Table 6 Groundwater temperature trends at each monitoring point

Identifier	JC1	JC2	JC3	JC4	JC5
Depth of groundwater table (m)	7.1–10.9	8.2–11.9	11.8–15.2	14.6–17.1	5.9–10.4
Maximum temperature (°C)	22.31	23.44	24.43	22.69	25.56
Minimum temperature (°C)	12.75	11.42	11.3	12.43	13.53
Average temperature (°C)	17.08	17.41	17.7	16.15	18.2

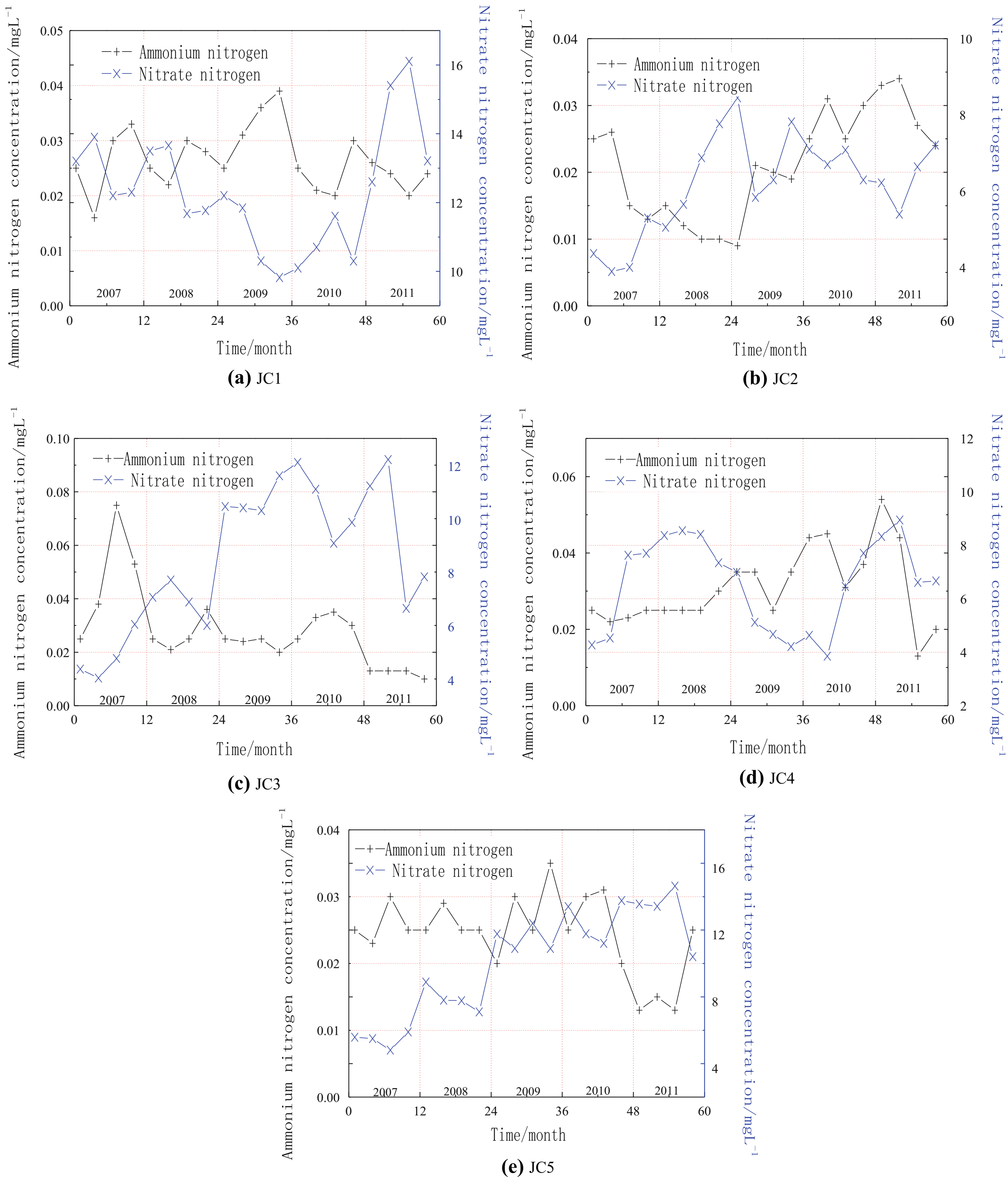


Fig. 8 Variations in nitrate nitrogen and ammonium nitrogen concentrations at the different monitoring points

Results and discussion

Water table mobility

Seasonal precipitation is a major contributor to regional variations in the water table. The rainy season generally occurs from July to September in the study area and accounts for 70 % of the annual precipitation. Moreover, agricultural land in JC1, JC3, and JC5 is pump-irrigated in April, May, and November each year, and the irrigation frequency and pump output are inversely related to local precipitation. Underground water is used as a production material by major industries near JC1 and JC3. Thus, the effects of water table variations in these areas are complicated and are difficult to understand. However, the most important factors affecting water table fluctuation in such areas are precipitation and irrigation water. The variations in groundwater depth at the five monitoring points are shown in Fig. 4. Statistics for the water table are shown in Table 2.

Variations in the dissolved oxygen content

Figure 5 shows variations in the dissolved oxygen (DO) concentration at the monitoring points. A significant variation was observed at each point. The DO concentration peaked in July, with DO values higher than those in other months. The DO concentration in JC5 was higher than those at other points. The dynamic characteristics of underwater DO concentration at each point are given in Table 3.

Variations in pH and E_h

The pH levels at the monitoring points showed periodic variations, although the variations were not significant. The five-year pH-variation statistics are shown in Table 4.

Table 5 shows the five-year statistical characteristics of E_h. Figure 6 shows that E_h is inversely correlated with the variation in the water table. For example, Fig. 4a shows that the data of point JC1 indicate a decrease in groundwater depth from 8.5 to 9.3 m from October 2007 to April 2008, whereas E_h increased from 157 to 219 mV. The groundwater depth increased from 9.3 to 8.55 m during the subsequent 3 months, from April to July 2008, whereas E_h decreased from 219 to 176 mV. In the succeeding season, from July 2008 to January 2009, the groundwater depth decreased from 8.55 m to 9.5 m, whereas E_h increased to 210 mV.

E_h has a higher possibility of showing uniformity with groundwater depth over long-term seasonal variations. Increases in groundwater depth generally cause a decrease in E_h and vice versa.

Table 7 Characteristics of nitrate nitrogen and ammonium nitrogen concentrations at each monitoring point

Identifier	JC1		JC2		JC3		JC4		JC5	
Depth of groundwater table (m)	7.1–10.9		8.2–11.9		11.8–15.2		14.6–17.1		5.9–10.4	
Monitored substance	Ammonium nitrogen	Nitrate nitrogen	Ammonium nitrogen	Nitrate nitrogen	Ammonium nitrogen	Nitrate nitrogen	Ammonium nitrogen	Nitrate nitrogen	Ammonium nitrogen	Nitrate nitrogen
Maximum concentration (mg L^{-1})	0.039	16.1	0.034	8.45	0.075	12.21	0.054	8.95	0.035	14.63
Minimum concentration (mg L^{-1})	0.016	9.82	0.009	3.9	0.01	4.03	0.013	3.85	0.013	4.81
Average concentration (mg L^{-1})	0.0265	12.319	0.0212	6.2	0.0282	8.48	0.0309	6.55	0.0245	10.07

Temperature variations

Figure 7 shows a significant correlation between water temperature and seasonal temperature. For example, the winter temperature of water at JC4 was at minimum between December and February, whereas the peak temperature appeared annually from June to August. Table 6 shows that the difference in temperature at various groundwater depths was not significant and that the average temperature generally ranged from 16.15 to 18.2 °C.

Variations in the nitrate nitrogen and ammonium nitrogen contents

Figure 8 shows the time-dependent variations in groundwater nitrate nitrogen and ammonium nitrogen concentrations in the five monitoring points, whereas Table 7 shows the overall characteristics. The variations in nitrate nitrogen and ammonium nitrogen contents in JC1 were significant and negatively correlated. The five-year statistics of nitrite nitrogen content show that this indicator has an average value of 0.002 ± 0.001 mg L^{-1} and does not follow a significant law. This trend may be attributed to the instability of the nitrification and denitrification intermediates; NO_2^- can be readily oxidized.

Relevance of the groundwater dynamic index and water table fluctuation

From "Monitoring point information", we know the use function and the surrounding environment are relatively similar among JC1, JC3, and JC5. Moreover, these parameters are similar between JC2 and JC4. Therefore, two typical areas, JC1 and JC2, are analyzed in this section. The correlations and significance of groundwater environment indicators and water table fluctuation data were analyzed by SPSS 17.0 on the basis of the hydrogeologic conditions of the sites. The variations in the impact factors such as water temperature, pH, E_h, water table variation and concentrations of nitrate nitrogen, ammonium nitrogen, and nitrite nitrogen at the various points were analytically monitored from 2007 to 2011. The water temperature, pH, and E_h were found to be directly and separately affected by variations in the water table. The effects of water table fluctuation on the contents of nitrate nitrogen, ammonium nitrogen, and nitrite nitrogen were also analyzed by considering the hydrogeologic conditions of the sites.

The correlation and significance of the various parameters, particularly the JC1 and JC2 groundwater indicators, were determined by SPSS 17.0 (Tables 8, 9).

Table 8 shows a significant correlation of groundwater depth and E_h and nitrate nitrogen. The nitrate nitrogen and

Table 8 Correlation of groundwater parameters in JC1

	Depth of groundwater table	pH	E_h	DO	Ammonium nitrogen	Nitrate nitrogen
Depth of groundwater table						
Pearson correlation	1.000	−0.410	0.553[a]	0.096	−0.241	0.469[a]
Bilateral significance		0.865	0.011	0.687	0.306	0.037
pH						
Pearson correlation		1.000	0.098	0.116	0.185	−0.718[b]
Bilateral significance			0.683	0.626	0.435	0.000
E_h						
Pearson correlation			1.000	−0.107	−0.508[a]	0.226
Bilateral significance				0.653	0.022	0.338
DO						
Pearson correlation				1.000	0.170	−0.228
Bilateral significance					0.472	0.334
Ammonium nitrogen						
Pearson correlation					1.000	−0.582[b]
Bilateral significance						0.007
Nitrate nitrogen						
Pearson correlation						1.000
Bilateral significance						

[a] Significantly bilateral at the 0.05 level

[b] Bidirectional correlation at the 0.01 level

ammonium nitrogen concentrations were significantly and negatively correlated. A negative correlation was also observed between E_h and ammonium nitrogen content and between pH and nitrate nitrogen content. In a similar manner, the JC2 data in Table 9 indicate a significant positive correlation between the water-table and nitrate nitrogen content, whereas E_h and ammonium nitrogen content were significantly and negatively correlated. A significant negative correlation was observed between nitrate nitrogen and ammonium nitrogen concentrations.

By JC1 and JC2 as examples in the investigation of water table fluctuation effects on different parameters, the following results were obtained:

Analysis of the relationship between E_h and water table fluctuation

Significantly negative correlations were observed between E_h and water table fluctuation in the two sites. Figure 9a shows the five-year seasonal variations in E_h and water level in JC1 from January 2007 to October 2009 and from January 2011 to October 2011. Figure 9b shows the five-year seasonal variations in E_h and water level in JC1 from January 2007 to April 2008, from January 2009 to January 2011, and from April 2011 to October 2011. Both figures show a negative correlation between E_h and groundwater depth, possibly as a result of the increased water table. The distance between the water level and the ground surface decreased, which in turn increased the DO content E_h. Otherwise, E_h declined when the distance between the water level and the ground surface increased.

Analysis of the relationship between DO and water table fluctuation

Theoretically, the distance between groundwater and the ground surface is small, and air can readily reach the groundwater. However, the current results do not indicate a significant correlation between groundwater DO and groundwater depth in the research areas, possibly because of the complexity of the hydrogeological conditions of the sites and utilization of the surrounding land.

Analysis of the effects of water table fluctuation on nitrate nitrogen and ammonium nitrogen concentrations

According to Tables 8 and 9, a significantly negative correlation exists between water table fluctuation and ammonium nitrogen concentration as well as that between the concentrations of nitrate nitrogen and ammonium nitrogen. According to the analyses discussed in previous sections, the variation in pH with water table fluctuation is not significant when the effects of precipitation on water table fluctuation are ignored. Moreover, the pH varies in the two

Table 9 Correlation of groundwater parameters in JC2

	Depth of groundwater table	pH	E_h	DO	Ammonium nitrogen	Nitrate nitrogen
Depth of groundwater table						
Pearson correlation	1.000	0.318	−0.561[a]	0.326	0.409	0.712[b]
Bilateral significance		0.172	0.038	0.161	0.073	0.000
pH						
Pearson correlation		1.000	−0.404	0.118	0.390	0.017
Bilateral significance			0.077	0.619	0.090	0.945
E_h						
Pearson correlation			1.000	0.300	−0.642[b]	−0.236
Bilateral significance				0.901	0.002	0.317
DO						
Pearson correlation				1.000	0.088	0.199
Bilateral significance					0.711	0.399
Ammonium nitrogen						
Pearson correlation					1.000	−0.504[a]
Bilateral significance						0.024
Nitrate nitrogen						
Pearson correlation						1.000
Bilateral significance						

[a] Significantly bilateral at the 0.05 level

[b] Bidirectional correlation at the 0.01 level

(a) JC1 **(b)** JC2

Fig. 9 Variations in redox potential (E_h) and water level in JC1 and JC2

sites ranged from 6.6 to 8.5 and had negligible effects on microbial activity. Therefore, pH variation is not considered as a major contributor to the variations in nitrate nitrogen and ammonium nitrogen concentrations. The increased water table caused the groundwater DO and E_h to increase, which in turn promoted microbial activity during soil nitrification. Consequently, nitrification was increased but denitrification was inhibited until the nitrate nitrogen concentration increased and the ammonium nitrogen content decreased. Moreover, the high adsorbability and effumability of ammonium nitrogen resulted in its rapid absorption by soil as the water table increased or the groundwater depth decreased. In addition, closer proximity to the surface indicated high volatility, which is among the primary reasons for the decrease in ammonium nitrogen concentration in groundwater. Otherwise, the water table decreased and the groundwater depth increased, which in turn limited the contact between the air and groundwater. Consequently, DO was gradually consumed by microorganisms, and E_h decreased as reducibility increased, which activated denitrifying bacteria. As a result, denitrification increased, whereas nitrification was inhibited. Eventually, the ammonium nitrogen concentration increased, but nitrate nitrogen was deoxidized to a lower state of nitrogenous compounds. These results clearly indicate that the effect of water table fluctuation on groundwater nitrate transformation is significant in field settings.

After several periodic water table fluctuations, the variations in concentrations of nitrate nitrogen, nitrite nitrogen, and ammonium nitrogen became insignificant compared with those under stable water-table conditions. This result may be attributed to the complex utilization of the areas surrounding the sites. Land-use practices such as the intensive use of chemical fertilizers and pesticides and the discharge of industrial wastewater can affect the nitrate content of groundwater.

Conclusion

Water table variations affect soil–water physicochemical properties such as DO and E_h and therefore significantly affecting nitrate migration in soil sola. When the water table decreases, the nitrate nitrogen concentration increases, whereas the ammonium nitrogen concentration decreases because of the variations in physicochemical properties of the soil and underground water. Otherwise, the variations in concentration show opposite tendencies. The instability of nitrite nitrogen, which does not follow a specific law during the entire process, results in its low concentration. After the monitoring points experience several water table variations, the variations in the underwater index as well as those in the concentrations of nitrate nitrogen, ammonium nitrogen, and nitrite nitrogen become insignificant. The complexity of field conditions necessitates the consideration of all possible impact factors and indices. Therefore, water table variations should be considered in practical underwater impact assessments, pollutant migration simulations, and underwater blocking and repair.

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